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Assessment of Renewable Energy Performance in Turkey Using a Novel Integrated MSD-CRITIC-RAWEC Model

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Abstract: A novel integrated Multi-Criteria Decision-Making (MCDM) framework was proposed to address the complex challenge of assessing renewable energy performance. The framework incorporates the Modified Standard Deviation (MSD) method and the Criteria Importance Through Intercriteria Correlation (CRITIC) approach to objectively determine the weights of performance indicators, while the Ranking of Alternatives by the Weights of the Criteria (RAWEC) method was applied to derive annual performance rankings. A real-time case study covering Turkey over the period 2015–2023 was conducted to validate the proposed model. A total of ten criteria were identified to comprehensively evaluate the renewable energy performance of Turkey. The empirical findings revealed that the average annual growth rate of installed renewable power capacity, the share of electricity generated from renewables in total electricity generation, and the absolute quantity of electricity produced from renewable sources exerted the greatest influence on performance outcomes. According to the RAWEC-based ranking, the year 2023 emerged as the most successful in terms of renewable energy advancement during the observed period. These findings provide critical insights for policymakers and stakeholders, supporting evidence-based decision-making for enhancing energy security, achieving environmental sustainability, and guiding national energy strategy. The proposed integrated framework demonstrates a robust, data-driven approach that may be adapted to other national contexts or timeframes to support the monitoring, evaluation, and strategic planning of renewable energy systems. Ultimately, the study contributes to the broader discourse on sustainable development and climate change mitigation by offering a replicable and scalable assessment methodology.

Keywords: Renewable energy; Performance analysis; MCDM; MSD; CRITIC; RAWEC

1 Introduction

As the world's population continues to grow, so too does the demand for energy. Because of the increasing consumption of fossil fuels and the serious damage they cause to the environment, countries are quickly turning to renewable energy sources [1]. Given that fossil fuels such as natural gas, oil, hard coal and lignite take thousands of years to form, and that the extraction of existing reserves will become technically more difficult and riskier in the future, this situation will seriously increase the costs that countries have to bear [2]. Dependence of Turkey on fossil fuel causes both environmental pollution and global warming, and it reveals the importance of renewable energy resources for sustainable economic development. The importance of developing renewable energy technologies has increased [3]. Renewable energy utilization plays an essential role in achieving countries' climate change agreement goals, ensuring energy security, improving access to electricity, and reducing the effects of fossil fuel consumption [4]. In order to reduce the pollution of the environment and the emission of greenhouse gases, to overcome the problems of global warming and to prevent the depletion of energy resources, renewable energy resources should be used in a planned and effective manner. This situation demonstrates the essential importance of comprehensive due diligence on energy resources.

As a developing country, Turkey's energy demand growth is above the world average [5]. The fact that Turkey is an energy import dependent country and that its electricity generation is mainly based on fossil fuels has led the country to prioritize the promotion of renewable energy resources and efforts to reduce energy dependency, especially in the last decade [6].

The steady increase in the importance of renewable energy policies in Turkey over the years has contributed to the establishment of an efficient, economical and environmentally friendly energy infrastructure. With the development of Turkey's energy policies, renewable energy sources increased the share of its installed capacity from 43.2% in 2015 to 57.3% in 2023. According to the latest data for 2023, among renewable energy sources, hydroelectricity made the largest contribution to the potential installed capacity with 50.61%. This is followed by solar energy at 24.72%, wind energy at 18.69%, biomass energy at 3.3%, and geothermal energy at 2.68%. In this context, Turkey has maximized the potential of renewable energy resources and increased the share of renewable energy resources in electricity generation to 43.2% in 2023. Among the renewable energy sources, hydropower made the largest contribution to electricity generation with 45.66%. This is followed by wind energy with 24.34%, solar energy with 15.76%, geothermal energy with 7.92% and biomass energy with 6.32% [7]. The planning of such power plant projects, which are among the most important infrastructure investments, taking into account many interactive criteria, is of great strategic importance, considering that such strategic goals require large investments. For countries, analyzing renewable energy performance is very important for reasons such as environmental sustainability, economic development, energy security, etc. In addition, countries need to efficiently achieve their renewable energy policy goals while meeting the requirements of international climate agreements such as the Paris Agreement [8]. Conversely, assessing the performance of renewable energy can enable countries to optimize their energy policies. As a result, there can be an increase in energy security and a reduction in dependency on fossil fuels, which are subject to volatile markets [9].

Different methodologies, covering both qualitative and quantitative assessments, allow decision-makers to analyze the energy performance of countries. In this way, it is possible to identify the effectiveness of renewable energy policies, the contribution of resources to energy security and direct investment in energy infrastructure [10, 11].

There are frequently employed MCDM methodologies for the measurement of renewable energy performance. These methods enable a holistic assessment of countries in terms of different criteria such as economic benefits, environmental effects and social acceptability of renewable energy sources [12]. For countries, measuring renewable energy performance is very important to guide government decisions, support sustainable economic growth and achieve environmental sustainability standards [13].

Therefore, the aim of this study is to propose a new hybrid decision model to evaluate the renewable energy performance of countries. The proposed model includes the combination of MSD, CRITIC and RAWEC methods. In the integrated decision-making tool proposed in the present study, the MSD and CRITIC procedures were used to derive the objective weights of the criteria, and the RAWEC procedure was used for the comparative ranking of alternatives. A case study was conducted in the research to test the applicability of the proposed decision framework. The focus of this study is the analysis of Turkey's renewable energy performance for the period 2015-2023. The aim of this study is to find answers to the following questions with the help of the proposed model:

- RQ1: Why is it important for countries to assess their renewable energy performance?
- RQ2: What criteria should be used to assess countries' renewable energy performance?
- RQ3: Which assessment criterion has the greatest impact on Turkey's renewable energy performance?
- RQ4: Which year is Turkey more successful than other years in terms of renewable energy performance?

The novelty of this research and its contribution to the literature are as follows:

- A new integrated decision-making tool for renewable energy performance analysis was proposed.
- A relatively new objective final weighting procedure was developed to calculate importance weight scores for evaluation criteria.
- MSD, CRITIC, and RAWEC methodology were integrated in this study for the first time in the MCDM literature as a solution tool for solving the renewable energy performance problem.
- The developed decision framework provides a comprehensive decision support system to assist decision makers, investors, government agencies, non-governmental organizations interested in environmental policies and other stakeholders, especially in the renewable energy sector, in measuring and comparing renewable energy performance, thus contributing to more informed and sound decisions.
- The decision framework presented was applied to a case study of renewable energy performance measurement in Turkey. Finally, there is no study in the literature that has used a combination of MSD, CRITIC and RAWEC for the same case study in the past. The creativity of the study stems from the evaluation of renewable energy performance according to ten evaluation criteria rather than comparing them yearly.

The present case study is structured below. Section 2 presents Turkey's development process in terms of renewable energy resources and a comprehensive literature review utilizing previous literature. Section 3 introduces the methodology of the study and the proposed conceptual framework. Sections 4 and 5 contain the empirical findings obtained from the application of the proposed model, and Section 6 gives the findings and policy recommendations.

2 Research Background

This section is organized under two main headings. The initial section provides a detailed investigation of Turkey's development in terms of renewable energy for the period 2015-2023. The second section of the study consists of a comprehensive literature review, which is in line with the objectives of the study.

2.1 Turkey's Development Process in Terms of Renewable Energy Sources

As an energy transit point, Turkey evaluates its geographical location between Europe and Asia, bordering the Mediterranean, Aegean, and Black Seas. In addition, to meet the expected increases in energy demand, it plans to increase the share of renewable energy with high targets annually to expand its energy production capacity.

According to the data obtained from the Turkish Electricity Transmission Company (TEIAS) [7], Turkey's installed capacity based on renewable energy resources has shown a significant increase between 2015 and 2023. While the total renewable energy installed capacity was 31,613 MW in 2015, it increased to 52,206 MW in 2023. With this increase, the share of renewable energy in the total installed capacity of energy resources increased from 43.2% to 57.3%. The highest increase was in solar energy resources. While the installed solar energy capacity was 248.8 MW in 2015, it reached 15,613.4 MW in 2023, increasing its share in the total renewable energy installed capacity from 0.8% to 14.1%. This rapid increase is due to decreased solar energy installation costs and the support of state incentive mechanisms. The second-place wind energy installed capacity increased from 4,503.2 MW in 2015 to 11,806.1 MW in 2023, increasing its share in total renewable energy from 14.2% to 18.5%. The third-place biomass energy installed capacity increased from 370.1 MW in 2015 to 2,446.4 MW in 2023, increasing its share in total renewable energy from 1.2% to 3.8%. The fourth-place geothermal energy installed capacity was 623.9 MW in 2015 and reached 1,691.3 MW in 2023. However, its share in total renewable energy increased from 2% to 2.6%, recording a more limited growth. Finally, hydroelectric energy installed capacity increased from 25,867.8 MW in 2015 to 32,196.4 MW in 2023. However, due to the rapid increase in other renewable energy sources and the efficient evaluation of these potential resources, its share in total renewable energy decreased from 82.8% to 60.9%. This is due to the limited number of new hydroelectric power plant areas and the fact that these projects are quite long-term.

Turkey's electricity production from renewable energy sources, on the other hand, increased from a total of 86,688.7 GWh in 2015 to 137,223.8 GWh in 2023. With this increase, the share of renewable energy sources in total electricity production increased from 32% to 42.3%. Solar energy has been one of the fastest-growing sources of this increase. While electricity production from solar energy was 194.2 GWh in 2015, it reached 23,519.1 GWh in 2023, increasing its share in renewable energy production from 0.2% to 17.1%. Wind energy electricity production, which came in second, increased from 11,856.7 GWh in 2015 to 34,113.2 GWh in 2023, increasing its share in total renewable energy production from 13.7% to 24.9% [7].

Electricity production from biomass energy, which was third, increased its share from 1.9% to 6.3% while it was 1,662.3 GWh in 2015 and reached 8,679.5 GWh in 2023. Electricity production from geothermal energy, which was fourth, increased its share from 3,648.2 GWh in 2015 to 8,854.2 GWh in 2023 and increased its share from 4.2% to 6.5%. Electricity production from hydroelectric energy, which is in last place, has an unstable course. While electricity production from hydroelectric power plants was 69,327.3 GWh in 2015, a decrease of 62,057.7 GWh was observed in 2023 [7]. The reason for this decrease is the variability of water levels over the years, the faster growth of other renewable energy sources and the more efficient use of these potential renewable resources. The share of total renewable energy production has decreased from 80% to 45.2%. However, it still ranks first with the highest share in electricity production from renewable energy sources, with a rate of 45.66% [4].

In general, between 2015 and 2023, solar and wind energy installed capacity and electricity production in Turkey have been the energy sources with the highest increase. Biomass and geothermal energy have also shown a significant increase, while hydroelectric energy remained at a more limited level. The reasons for this limited or low rate are geographical, environmental, economic, and political factors. Until about ten years ago, hydroelectric energy was largely evaluated, and now the areas suitable for new large-scale dam projects are limited.

Hydroelectric power plants have been built on most of the existing rivers, but adding new capacities has become increasingly difficult. In addition, when the construction of these plants requires high-cost engineering studies, long construction periods and large land use, solar and wind energy sources, which can be installed more quickly and in terms of financing, have been preferred. The spread of these large dam projects limits environmental and social impacts such as damaging ecosystems, changing the natural flow of water resources and forcing local people to migrate. In addition, climate change, changes in precipitation patterns and increased drought in recent years have negatively affected the efficiency of hydroelectric power plants. The increase in incentives given to solar and wind energy in energy policies has caused investors to turn to other renewable energy sources.

In conclusion, although Turkey has taken important steps to increase its share in renewable energy, it has entered a long-term transformation process, like many other developing countries, to advance its investments in this field in line with its sustainable development goals. The importance of systematic evaluations is very important for the effective and successful management of this transformation process.

2.2 Literature Review

Energy policy and resource decision-making is a multidimensional, complex process with different parameters and objectives. The analysis of the sustainability of renewable energy performance using MCDM approaches has increasingly attracted attention in recent years. This section reviews studies that empirically examine renewable energy performance using the MCDM procedure. The details of the reviewed studies are summarized and reported in Table 1.

Table 1. Literature review

Author/s	Sample	Method/s	Findings
Mirjat et al. [14]	Pakistan	AHP	Among the four scenario alternatives developed in the energy modeling study, the most suitable electricity generation scenario was determined to be based onenergy efficiency and conservation measures. This was followed by scenarios based on the government'scurrent plans and policies, renewable energytechnologies and maximum clean coal share.
Alizadeh et al. [15]	Iran	BOCR and ANP	As a result of the analysis of the development of Iran'srenewable energy infrastructures, policies and administrative structures using an integrated model, it is concluded that solar energy will be the primary renewable energy source.
Wang et al. [16]	Vietnam	Grey AHP and WASPAS	According to the results of the proposed model for the selection of optimal renewable energy sources, solar energy was found to be the optimal renewable energy source, followed by wind, biomass and solid waste energy.
Değirmenci et al. [17]	Turkey	AHP and GIS	In the study, the GIS model was used for modeling wind energy siting and wind farm siting, while the AHPmodel was used for determining the suitability of wind farm siting and determining the importance of criteria in pairs.
Li et al. [18]	China	ANP	In terms of reducing carbon emissions in China, photovoltaic energy was found to be the best solution in the overall-selection of renewable energy in different regions. It is stated that regions with high carbonemissions are suitable for hydroelectric power plants, while priority should be given to the development of photovoltaic or wind power plants in regions with low carbon emissions.
Sarkodie et al. [19]	Ghana	CRITIC, MOORA, TOPSIS and COPRAS	As a result of the study, which used various decisionmaking techniques, the ranking of energy sources was as follows: hydro > biomass > solar PV >-wind > solar thermal- It also states that the best renewable energy source for Ghana is hydropower.
Lee and Chang [20]	Taiwan	WSM, VIKOR, TOPSIS and ELECTRE	Hydropower was found to be the best renewable energyalternative in Taiwan, followed by-solar, wind, biomass and geothermal. It is also concluded that the mostenvironmentally efficient source is wind energy, while the most socially efficient source is solar PV energy.
Li et al. [21]	China	ANP, WSM, TOPSIS, PROMETHEE, ELECTRE and VIKOR	Among the renewable energy sources in China, hydropower is reported to be the best source. From a regional perspective, it was found that north and northeast China tended to use wind energy, east-and northwest China tended to use photovoltaic energy, and central south and southwest China tended to use hydropower.
Goswami et al. [22]	India	MEREC and PIV	It concludes that among the renewable energy sources in India, hydropower would be the most favourable choice, while biomass energy would be the worst of the five alternatives.
Sánchez-Lozano et al. [23]	Spain	AHP, ELECTRE and TOPSIS	It was found that GIS software can not only support specific problems such as PV farm siting but also create databases that provide an ideal starting point for regional scale analysis. Comparing the ELECTRE-TRI and TOPSIS methods, it is concluded that the rankings obtained from both methods are similar.
Akash et al. [24]	Jordan	AHP	According to cost-benefit ratios, solar, wind, and hydroelectric energy stand out as the best alternatives for electricity generation; nuclear energy wasdetermined as the worst option, followed by fossil fuel electricity generation.

Köne and Büke [25]	Turkey	ANP	The results of the proposed model show that the share of renewable energy sources in installed capacity should be increased to support sustainable development.
Kabir and Shihan [26]	Bangladesh	AHP	As a result of the evaluation according to technical factors, unit costs, location factors, environmentalfactors and social impact criteria for the selection of renewable energies and technologies, it is reported that the most preferred energy option is solar energy, followed by biogas and then wind energy.
Ishfaq et al. [27]	Pakistan	AHP, TOPSIS and VIKOR	The results of the analysis show that the best renewable energy source for Pakistan to invest in is hydropower, followed by wind biomass and solar
Saraswat and Digalwar [28]	India	Fuzzy AHP and Fuzzy TOPSIS	The results of the analysis show that economic factor is the most important criterion, followed by environmental and technical criteria, while solar energy was selected as the most sustainable energy alternative in-India, followed by wind and hydro.

A comprehensive review of the available literature in Table 1 indicates that many studies have assessed the energy performance of countries within the scope of MCDM methodology, e.g., the studies by Mirjat et al. [14], Alizadeh et al. [15], Li et al. [18], Lee and Chang [20], Sánchez-Lozano et al. [23]. The majority of these studies focus on the energy performance of countries other than Turkey. However, it is clear that there are very few studies on Turkey's energy performance, e.g., the studies by Değirmenci et al. [17], Köne and Büke [25]. Moreover, the existing studies are generally based on the comparison of energy resources of countries. Specifically, the majority of these studies have focused on the comparison of various renewable energy sources (wind, solar, hydroelectric, etc.). Therefore, the fact that very few studies have analyzed and assessed the performance of countries or Turkey in terms of renewable energy resources over the years indicates a research gap in the literature. The present study focuses on filling this research gap.

In light of the complexity of assessing countries' renewable energy performance, Wibowo and Grandhi [29] claimed that MCDM methodologies provide highly effective tools for a sustainable and stable assessment process. As demonstrated in Table 1, a range of decision-making models have been employed in the assessment of countries' renewable energy performance. For instance, Wang et al. [16] preferred the approaches of Analytic Hierarchy Process (AHP) and Weighted Aggregated Sum Product Assessment (WASPAS) in their study, while Goswami et al. [22] utilized the Method based on the Removal Effects of Criteria (MEREC) and Proximity Indexed Value(PIV) methodologies in their study. Similarly, Ishfaq et al. [27] applied a decision-making procedure consisting of AHP, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Vise Kriterijumska Optimizacija Ikompromisno Resenje (VIKOR) approaches, while Saraswat and Digalwar [28] employed Fuzzy AHP and Fuzzy TOPSIS model in their study. Consequently, it has been determined that there is an absence of empirical case study in the existing literature that has employed a combination of MSD, CRITIC and RAWEC algorithms. For this reason, in the present case study, MSD and CRITIC algorithms were proposed to objectively weight the selected renewable energy indicators and the RAWEC algorithm was proposed to rank the decision alternatives. In this context, the present study aims to contribute to the existing literature with a new conceptual framework by proposing a relatively new and original research model for decision-makers, the RAWEC model based on MSD and CRITIC.

A review of the available literature shows that the majority of studies conducted by different researchers have assessed the performance of countries in terms of renewable energy based on similar assessment criteria. However, it is noteworthy that the number of studies (e.g., the studies by Akash et al. [24], Köne and Büke [25]) using performance indicators, such as total installed power indicators, renewable power indicators within total installed power, total electricity generation, renewable electric generation ratios within total generation, etc., is quite limited. Therefore, within the framework of this study, in order to overcome this deficiency, a new dataset was created by means of the previous literature and Turkey's renewable energy performance was analyzed from a unique perspective.

3 Methodology

As part of the study, the decision tool proposed to analyze Turkey's renewable energy performance by year includes the MSD, CRITIC and RAWEC processes. Among these procedures, the MSD and CRITIC methods were used to determine the weight coefficients of the evaluation criteria, while the RAWEC procedure was used in the process of ranking the analysis periods that are in the position of decision alternatives. This section provides a theoretical evaluation of these decision support tools. The conceptual framework of the integrated decision-making algorithm presented in this study is displayed in Figure 1.

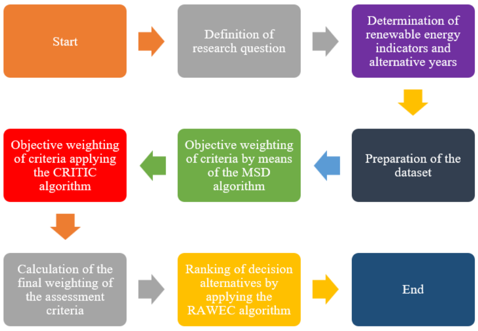

Figure 1. Proposed decision-making algorithm

Note: This figure was prepared by the authors

3.1 MSD Method

The MSD procedure, one of the relatively new objective criterion weighting algorithms, is an improved extension of the Standard Deviation (SD) method introduced in the literature by Puška et al. [30]. Unlike the SD method, this procedure includes the calculation of column sums and the correction of standard deviation values. According to Puška et al. [30], the MSD procedure offers several advantages over other objective criterion weighting algorithms. This method introduces innovative changes to the traditional SD procedure and can produce more precise and effective results, especially for certain data structures. The MSD procedure eliminates some of the shortcomings of classical techniques, e.g., SD, Standard Variance (SV), Entropy, CRITIC, MEREC, etc., and provides more reliable and accurate results. In addition, measuring variation more reliably in small datasets increases the accuracy of statistical evaluations. In cases where the data is not homogeneous, the MSD approach provides a significant advantage by providing more objective and consistent measurement findings in decision-making processes.

In short, the MSD approach overcomes the deficiencies of the classical SD procedure and provides advantages such as reducing the effect of outliers, making more reliable measurements in small datasets, and calculating better risk in financial analyses. The application of the MSD procedure consists of the following steps [31]:

Step 1. In decision-making approaches, the first step is to prepare an initial matrix of alternatives and criteria to solve the problem. In this context, the initial matrix was created according to Eq. (1).

$$Y = [y_{ij}]_{m\times n} = \begin{vmatrix} y_{11} & y_{12} & \cdots & y_{1n} \\ y_{21} & y_{22} & \cdots & y_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ y_{m1} & y_{m2} & \cdots & y_{mn} \end{bmatrix} \tag{1}$$

Step 2. The assessment criteria with different properties in the initial matrix were normalized in the second step. In other words, the initial matrix was made suitable for normal distribution. The normalization process was executed by applying Eq. (2) for the beneficial criteria in the initial matrix and Eq. (3) for the non-beneficial criteria.

$$v_{ij} = \frac{y_{ij}}{\max\{y_{ii} \mid i = 1, 2, \ldots, m\}} \tag{2}$$

$$v_{ij} = \frac{\min\{y_{ij} \mid i = 1, 2, \ldots, m\}}{y_{ij}} \tag{3}$$

Step 3. The values of the standard deviations of the criteria were obtained by Eq. (4).

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m} (v_{ij} - \bar{v}_J)^2}{m}} \tag{4}$$

Step 4. The sums of the columns $\left(\sum_j^n y_{ij}\right)$ of the criteria were calculated.

Step 5. The corrected values for the standard deviation coefficients were obtained by Eq. (5).

$$\sigma' = \frac{\sigma}{\sum_i^n y_{ij}} \tag{5}$$

Step 6. The weights of the importance of the objective criteria were calculated with Eq. (6).

$$w_j = \frac{\sigma'_j}{\sum_{i=1}^n \sigma'_i} \tag{6}$$

3.2 CRITIC Procedure

The CRITIC method, introduced by Diakoulaki et al. [32], is an objective criterion weighting approach that is based on available data in weighting the evaluation criteria. In this procedure, the degree of importance of each criterion in the decision-making process is determined by considering the standard deviations and correlation coefficients of the criteria [33, 34]. Compared to other objective criteria weighting techniques in the decision literature, e.g., Entropy, Grey Entropy, SD, Logarithmic Percentage Change-driven Objective Weighting (LOPCOW), MAXimum of Criterion (MAXC), MEREC, etc., the CRITIC algorithm provides some advantages to decision-makers. One of these advantages is that the CRITIC procedure eliminates the influence of personal judgments and expert opinions by calculating the criteria weights with a completely data-based approach, thus reducing subjectivity. In addition, it considers the amount of information between the performance criteria and the level of conflict between them. In this way, more precise and objective evaluations can be made by considering the standard deviation and correlation levels between the criteria pairs. In particular, considering the correlations between the criteria allows more weight to be given to the criteria with high variability and greater impact on performance. Unlike other weighting approaches, the CRITIC algorithm also draws attention with its easy applicability to datasets with both negative and positive values.

Finally, the CRITIC algorithm can be applied to complex datasets and decision problems with high levels of variation, which is an important advantage for researchers. In addition, the fact that it produces strong and consistent results when applied to decision problems makes it an advantage over other weighting methodologies. The process of applying the method includes the following steps [31, 35, 36]:

Step 1. Decision matrix was prepared according to Eq. (1).

Step 2. The values in the decision matrix were normalized by taking into account the utility attributes. Eq. (7) was used for beneficial criteria and Eq. (8) for non-beneficial criteria.

$$r_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \tag{7}$$

$$r_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \tag{8}$$

Step 3. Eq. (9) was applied to determine the correlation coefficients between the criteria.

$$\rho_{jk} = \frac{\sum_{i=1}^m (r_{ij} - \bar{r}_j)(r_{ik} - \overline{r_k})}{\sqrt{\sum_{i=1}^m (r_{ij} - \bar{r}_j)^2 \sum_{i=1}^m (r_{ik} - \bar{r}_k)^2}} \tag{9}$$

Step 4. After determining the level of relationship between the evaluation criteria, the $\mathrm{C_j}$ value indicating the amount of information for each criterion was calculated using Eq. (10). The standard deviation value σ_{i} for each criterion in Eq. (10) was calculated using Eq. (4).

$$C_j = \sigma_j \sum_{i=1}^n (l - p_{jk}) \tag{10}$$

Step 5. In the last step of the CRITIC procedure, the criteria weightings were calculated with the help of Eq. (11).

$$w_j = \frac{C_j}{\sum_{j=1}^n C_j} \tag{11}$$

3.3 Final Weighting Method

The weight values obtained on the basis of the MSD and CRITIC methods were integrated in Eq. (12) to calculate the final weights for each criterion [37].

$$w_j^{\text{FINAL}} = \frac{w_j^{MSD} \times w_j^{\text{CRITIC}}}{\sum_{i=1}^{n} w_j^{MSD} \times w_j^{\text{CRITIC}}} \tag{12}$$

3.4 RAWEC Procedure

The RAWEC procedure is one of the relatively new ranking methods in the field of MCDM, as developed by Puška et al. [30]. It has been seen that many ranking procedures in the decision-making literature have many application steps, e.g., Compromise Ranking of Alternatives from Distance to Ideal Solution (CRADIS), Evaluation method based on the Distance from the Average Solution in the Minkowski space (EDAS-M), Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS), Alternative Ranking Order Method Accounting for Two-Step Normalization (AROMAN), Alternative Ranking using two-step LOgarithmic Normalization(ARLON), etc. This situation adds complexity to the decision-making process. In order to deal with this problem and to avoid complex calculations, the RAWEC procedure was developed in the decision-making literature. A primary property that distinguishes the RAWEC procedure from other decision-making methods is its two-way normalization. This feature enables the procedure to provide both a more accurate assessment and the integration of ideal and anti-ideal points. The significant advantage of the RAWEC algorithm for decision-makers over other approaches is its simplicity and reliability, with only a few steps to execute and a high degree of confidence in the results. Furthermore, the capacity to be utilized in combination with other decision-making methods offers convenience to researchers. The application of the RAWEC algorithm, which is simple, easy to implement and highly effective compared to other MCDM procedures, consists of four steps [30, 31].

Step 1. The decision matrix shown in Eq. (1) was created.

Step 2. Considering the useful and useless criteria in the decision matrix, a bidirectional normalization was performed in this step. Beneficial criteria were normalized by Eq. (13) and non-beneficial criteria were normalized by Eq. (14).

$$v_{ij} = \frac{y_{ij}}{\max\{y_{ij} \mid i = 1, 2, \ldots, m\}} \text{ and } v'_{ij} = \frac{\min\{y_{ij} \mid i = 1, 2, \ldots, m\}}{y_{ij}} \tag{13}$$

$$v_{ij} = \frac{\min\{y_{ij} \mid i = 1, 2, \ldots, m\}}{y_{ij}} \text{ and } v'_{ij} = \frac{y_{ij}}{\max\{y_{ij} \mid i = 1, 2, \ldots, m\}} \tag{14}$$

Step 3. To calculate the deviation values resulting from the importance weights of the criteria, Eq. (15) and Eq. (16) were applied in this step.

$$n_{ij} = \sum_{i=1}^{m} w_j \cdot (1 - v_{ij}) \tag{15}$$

$$n'_{ij} = \sum_{i=1}^{m} w_j \cdot \left(1 - v'_{ij}\right) \tag{16}$$

Step 4. At the end of the RAWEC procedure, the Ω_i values of the decision alternatives were determined by Eq. (17).

$$\Omega_i = \frac{n'_{ij} - n_{ij}}{n'_{ij} + n_{ij}} \tag{17}$$

Here, the value of Ω_i consists of values between -1 and 1. Accordingly, the alternative with the highest Ω_i value is considered the best.

4 A Real-Case Application of Renewable Energy Performance in Turkey

In this research, a new hybrid decision-making framework was proposed to measure renewable energy performance in Turkey. A case study was conducted to test the applicability of the proposed decision tool. This case study focuses on the measurement of Turkey's renewable energy performance for the period 2015-2023. In order to assess the energy performance, ten performance indicators were identified using previous literature. These indicators were chosen to assess renewable energy performance in a multidimensional framework. The performance indicators selected for the purpose of this case study allow for a more comprehensive assessment of Turkey's renewable energy performance. It is also clear that these indicators have been widely used by researchers in previous studies in the literature to comprehensively assess renewable energy capacity increases and generation performance [15, 19, 38–43]. On the other hand, the analysis period was restricted to 2015-2023. The main reason for this is that the data before 2015 are not reliable enough. Information on these indicators is given in Table 2. In addition, data on these performance criteria were obtained from the database of TEIAS and the International Renewable Energy Agency (IRENA) [7, 44].

Table 2. Selected renewable energy indicators

Code	Optimization	Definition
M1	Non-benefit	Total installed hydraulic power-to-total installed power (%)
M2	Benefit	Total installed power (MW)
M3	Non-benefit	Total installed hydraulic power-to-total installed renewable energy power (%)
M4	Benefit	Total renewable energy installed capacity (MW)
M5	Benefit	Total renewable energy installed capacity-to-total installed capacity (%)
M6	Benefit	Total electricity generation (GWh)
M7	Non-benefit	Total electricity generation from hydroelectric power system-to-total renewable electricity generation (%)
M8	Benefit	Total electricity generation from renewable energy sources (GWh)
M9	Benefit	Total electricity generation from renewable sources-to-total electricity generation (%)
M10	Benefit	Average annual growth rate of installed power (%)

5 Implementation of the MSD-CRITIC-RAWEC Model

This section of the study presents the results of the application of the proposed conceptual framework to assess Turkey's renewable energy performance.

5.1 Results of the MSD Procedure

In the first step of the analysis process, the objective criteria weights of the renewable energy criteria selected in the MSD process were determined. Accordingly, the decision matrix shown in Table 3 was constructed on the basis of Eq. (1).

Table 3. Decision matrix

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
2015	0.3536	73147	0.8207	31521	0.4309	261783	0.8026	83658	0.3196	0.0734
2016	0.3399	78497	0.7745	34450	0.4389	274408	0.7390	90981	0.3316	0.0732
2017	0.3201	85200	0.7038	38751	0.4548	297278	0.6672	87263	0.2935	0.0854
2018	0.3195	88551	0.6694	42264	0.4773	304802	0.6129	97791	0.3208	0.0393
2019	0.3123	91267	0.6420	44395	0.4864	303898	0.6715	132278	0.4353	0.0307
2020	0.3231	95891	0.6297	49202	0.5131	306703	0.6084	128360	0.4185	0.0507
2021	0.3155	99820	0.5916	53234	0.5333	334723	0.4717	118568	0.3542	0.0410
2022	0.3041	103809	0.5637	56005	0.5395	328379	0.4846	137843	0.4198	0.0400
2023	0.2882	110914	0.5061	63161	0.5695	331149	0.4566	140160	0.4233	0.0684

The normalized matrix obtained by applying Eq. (2) for beneficial criteria and Eq. (3) for non-beneficial criteria is shown in Table 4.

Table 4. Normalized matrix

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
2015	0.8149	0.6595	0.6166	0.4991	0.7567	0.7821	0.5689	0.5969	0.7342	0.8594
2016	0.8478	0.7077	0.6534	0.5454	0.7707	0.8198	0.6180	0.6491	0.7617	0.8567
2017	0.9002	0.7682	0.7190	0.6135	0.7987	0.8881	0.6845	0.6226	0.6744	1.0000
2018	0.9020	0.7984	0.7560	0.6692	0.8381	0.9106	0.7450	0.6977	0.7371	0.4606
2019	0.9227	0.8229	0.7882	0.7029	0.8542	0.9079	0.6800	0.9438	1.0000	0.3593
2020	0.8919	0.8645	0.8036	0.7790	0.9010	0.9163	0.7506	0.9158	0.9615	0.5933
2021	0.9134	0.9000	0.8554	0.8428	0.9365	1.0000	0.9681	0.8459	0.8138	0.4799
2022	0.9475	0.9359	0.8977	0.8867	0.9474	0.9810	0.9422	0.9835	0.9644	0.4681
2023	1.0000	1.0000	1.0000	1.0000	1.0000	0.9893	1.0000	1.0000	0.9724	0.8015

In Table 5, firstly, the standard deviation of each normalized criterion was calculated by Eq. (4), then the corrected values for the standard deviation coefficients were determined using Eq. (5). At the end, the objective criterion weights for each assessment criterion were calculated using Eq. (6). The results of the calculations are presented in Table 5.

Table 5. Results of the MSD procedure

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
σ_j	0.0534	0.1090	0.1199	0.1650	0.0846	0.0745	0.1588	0.1641	0.1270	0.2285
Σ	8.1404	7.4571	7.0900	6.5386	7.8034	8.1952	6.9573	7.2553	7.6195	5.8787
σ'	0.0066	0.0146	0.0169	0.0252	0.0108	0.0091	0.0228	0.0226	0.0167	0.0389
w_j	0.0356	0.0794	0.0918	0.1370	0.0588	0.0494	0.1239	0.1228	0.0905	0.2109
Rank	10	7	5	2	8	9	3	4	6	1

5.2 Results of the CRITIC Procedure

In the second part of the analysis process, the objective criteria weights of the renewable energy criteria selected within the scope of the CRITIC procedure were calculated. In this direction, the decision matrix reported in Table 3 was created based on Eq. (1). Then, in the second step of the procedure, by applying Eq. (7) and Eq. (8) to the beneficial and non-beneficial criteria, respectively, the normalized matrix shown in Table 6 was obtained.

Table 6. Normalized matrix

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
2015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1836	0.7806
2016	0.2099	0.1417	0.1467	0.0926	0.0573	0.1731	0.1840	0.1296	0.2682	0.7763
2017	0.5122	0.3191	0.3714	0.2285	0.1725	0.4866	0.3915	0.0638	0.0000	1.0000
2018	0.5216	0.4079	0.4808	0.3395	0.3347	0.5898	0.5483	0.2501	0.1926	0.1582
2019	0.6314	0.4798	0.5678	0.4069	0.4007	0.5774	0.3790	0.8605	1.0000	0.0000
2020	0.4663	0.6022	0.6069	0.5588	0.5932	0.6158	0.5614	0.7912	0.8818	0.3653
2021	0.5827	0.7062	0.7281	0.6863	0.7390	1.0000	0.9565	0.6179	0.4282	0.1883
2022	0.7563	0.8119	0.8167	0.7739	0.7838	0.9130	0.9191	0.9590	0.8906	0.1698
2023	1.0000	1.0000	1.0000	1.0000	1.0000	0.9510	1.0000	1.0000	0.9152	0.6903

The correlation coefficient matrix, which was calculated using Eq. (9) and shows the level of relationship between the assessment criteria, is presented in Table 7.

In the final step of the CRITIC procedure, firstly the C_j values, which express the amount of information related to each criterion, were determined based on Eq. (10). Then, secondly, the objective importance weights w_j for the criteria were obtained using Eq. (12). The empirical results obtained are presented in Table 8.

5.3 Results of Combined Weights

At this step of the analysis process, the importance weight values for the assessment criteria obtained based on the MSD and CRITIC methods were integrated within the scope of Eq. (12), and the final importance weights for each criterion were determined. The final importance weights calculated for each assessment criterion are shown in Table 9.

Table 7. Correlation matrix

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
M1	1	0.9311	0.9538	0.9046	0.8750	0.8943	0.8680	0.8032	0.6215	-0.3516
M2	0.9311	1	0.9942	0.9956	0.9891	0.9493	0.9559	0.8872	0.7052	-0.4109
M3	0.9538	0.9942	1	0.9823	0.9741	0.9607	0.9490	0.8861	0.7009	-0.4592
M4	0.9046	0.9956	0.9823	1	0.9968	0.9326	0.9525	0.8840	0.7071	-0.3890
M5	0.8750	0.9891	0.9741	0.9968	1	0.9322	0.9518	0.8882	0.7141	-0.4265
M6	0.8943	0.9493	0.9607	0.9326	0.9322	1	0.9784	0.7851	0.5484	-0.5077
M7	0.8680	0.9559	0.9490	0.9525	0.9518	0.9784	1	0.7525	0.5086	-0.4111
M8	0.8032	0.8872	0.8861	0.8840	0.8882	0.7851	0.7525	1	0.9478	-0.5863
M9	0.6215	0.7052	0.7009	0.7071	0.7141	0.5484	0.5086	0.9478	1	-0.5537
M10	-0.3516	-0.4109	-0.4592	-0.3890	-0.4265	-0.5077	-0.4111	-0.5863	-0.5537	1

Table 8. Results of the CRITIC procedure

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
C_j	0.7246	0.6415	0.6527	0.6699	0.7320	0.8643	0.8796	1.1204	1.5990	4.6698
w_j	0.0577	0.0511	0.0520	0.0534	0.0583	0.0689	0.0701	0.0892	0.1274	0.3720
Rank	7	10	9	8	6	5	4	3	2	1

Table 9. Final weight values of criteria

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
MSD w_j	0.0356	0.0794	0.0918	0.1370	0.0588	0.0494	0.1239	0.1228	0.0905	0.2109
CRITIC w_j	0.0577	0.0511	0.0520	0.0534	0.0583	0.0689	0.0701	0.0892	0.1274	0.3720
MSD $\times$ CRITIC	0.0021	0.0041	0.0048	0.0073	0.0034	0.0034	0.0087	0.0110	0.0115	0.0785
Final w_j	0.0153	0.0301	0.0354	0.0543	0.0255	0.0252	0.0645	0.0814	0.0856	0.5828
Rank	10	7	6	5	8	9	4	3	2	1

According to the final weight scores and their ranking results reported in Table 3, the three criteria with the highest impact on Turkey's renewable energy performance for the period 2015-2023 are $M10$ (average annual growth rate of installed power), $M9$ (total electricity generation from renewable sources-to-total electricity generation) and $M8$ (total electricity generation from renewable energy sources), respectively. On the other hand, $M1$ (total installed hydraulic power-to-total installed power), $M6$ (total electricity generation) and $M5$ (total renewable energy installed capacity-to-total installed capacity) were found to have the least impact on Turkey's renewable energy performance over the same period.

5.4 Results of the RAWEC Procedure

After obtaining the final weights for the criteria, at this step of the analysis process, the final importance weights were evaluated within the scope of the RAWEC method to determine Turkey's renewable energy performance rankings by year. The scope of the RAWEC method first started with the creation of the decision matrix, which was created according to Eq. (1) and presented in Table 3. Then, in the second step, the decision matrix was normalized based on Eqs. (13)-(14). The results of the normalized values are reported in Table 10 and Table 11.

Table 10. Normalized benefit matrix

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
2015	0.8149	0.6595	0.6166	0.4991	0.7567	0.7821	0.5689	0.5969	0.7342	0.8594
2016	0.8478	0.7077	0.6534	0.5454	0.7707	0.8198	0.6180	0.6491	0.7617	0.8567
2017	0.9002	0.7682	0.7190	0.6135	0.7987	0.8881	0.6845	0.6226	0.6744	1.0000
2018	0.9020	0.7984	0.7560	0.6692	0.8381	0.9106	0.7450	0.6977	0.7371	0.4606
2019	0.9227	0.8229	0.7882	0.7029	0.8542	0.9079	0.6800	0.9438	1.0000	0.3593
2020	0.8919	0.8645	0.8036	0.7790	0.9010	0.9163	0.7506	0.9158	0.9615	0.5933
2021	0.9134	0.9000	0.8554	0.8428	0.9365	1.0000	0.9681	0.8459	0.8138	0.4799
2022	0.9475	0.9359	0.8977	0.8867	0.9474	0.9810	0.9422	0.9835	0.9644	0.4681
2023	1.0000	1.0000	1.0000	1.0000	1.0000	0.9893	1.0000	1.0000	0.9724	0.8015

Table 11. Normalized cost matrix

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
2015	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9186	0.4180
2016	0.9438	0.9318	0.7707	0.9150	0.9819	0.9540	0.7617	0.9195	0.8853	0.4193
2017	0.8576	0.8585	0.7987	0.8134	0.9475	0.8806	0.6744	0.9587	1.0000	0.3593
2018	0.8157	0.8260	0.8381	0.7458	0.9029	0.8589	0.7371	0.8555	0.9149	0.7800
2019	0.7823	0.8015	0.8542	0.7100	0.8859	0.8614	1.0000	0.6324	0.6744	1.0000
2020	0.7673	0.7628	0.9010	0.6406	0.8398	0.8535	0.9615	0.6517	0.7014	0.6055
2021	0.7209	0.7328	0.9365	0.5921	0.8080	0.7821	0.8138	0.7056	0.8287	0.7486
2022	0.6869	0.7046	0.9474	0.5628	0.7987	0.7972	0.9644	0.6069	0.6993	0.7675
2023	0.6166	0.6595	1.0000	0.4991	0.7567	0.7905	0.9724	0.5969	0.6935	0.4482

Based on Eqs. (15)-(16), the results obtained regarding the deviation values originating from the importance weights of the criteria are given in Table 12 and Table 13.

Table 12. Deviation matrix for benefit criteria

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
2015	0.0028	0.0103	0.0136	0.0272	0.0062	0.0055	0.0278	0.0328	0.0227	0.0819
2016	0.0023	0.0088	0.0123	0.0247	0.0058	0.0045	0.0246	0.0286	0.0204	0.0835
2017	0.0015	0.0070	0.0100	0.0210	0.0051	0.0028	0.0203	0.0307	0.0279	0.0000
2018	0.0015	0.0061	0.0086	0.0180	0.0041	0.0023	0.0164	0.0246	0.0225	0.3144
2019	0.0012	0.0053	0.0075	0.0161	0.0037	0.0023	0.0206	0.0046	0.0000	0.3734
2020	0.0017	0.0041	0.0070	0.0120	0.0025	0.0021	0.0161	0.0069	0.0033	0.2370
2021	0.0013	0.0030	0.0051	0.0085	0.0016	0.0000	0.0021	0.0125	0.0159	0.3031
2022	0.0008	0.0019	0.0036	0.0062	0.0013	0.0005	0.0037	0.0013	0.0030	0.3100
2023	0.0000	0.0000	0.0000	0.0000	0.0000	0.0003	0.0000	0.0000	0.0024	0.1157

Table 13. Deviation matrix for non-benefit criteria

	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10
2015	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0070	0.3392
2016	0.0009	0.0021	0.0081	0.0046	0.0005	0.0012	0.0154	0.0066	0.0098	0.3384
2017	0.0022	0.0043	0.0071	0.0101	0.0013	0.0030	0.0210	0.0034	0.0000	0.3734
2018	0.0028	0.0052	0.0057	0.0138	0.0025	0.0036	0.0169	0.0118	0.0073	0.1282
2019	0.0033	0.0060	0.0052	0.0157	0.0029	0.0035	0.0000	0.0299	0.0279	0.0000
2020	0.0036	0.0071	0.0035	0.0195	0.0041	0.0037	0.0025	0.0283	0.0256	0.2299
2021	0.0043	0.0080	0.0023	0.0221	0.0049	0.0055	0.0120	0.0240	0.0147	0.1465
2022	0.0048	0.0089	0.0019	0.0237	0.0051	0.0051	0.0023	0.0320	0.0257	0.1355
2023	0.0059	0.0103	0.0000	0.0272	0.0062	0.0053	0.0018	0.0328	0.0262	0.3216

In the final step of the RAWEC procedure, the Ω_i scores of the decision alternatives and the success rankings of the alternatives based on these scores were obtained by Eq. (17) and the results are reported in Table 14.

Table 14. Results of the RAWEC procedure

	n_{ij}	n'_{ij}	Score (Ω_i)	Rank
2015	0.2308	0.3461	0.1998	4
2016	0.2156	0.3874	0.2850	3
2017	0.1263	0.4258	0.5425	2
2018	0.4184	0.1978	-0.3580	8
2019	0.4348	0.0944	-0.6433	9
2020	0.2926	0.3277	0.0567	5
2021	0.3532	0.2442	-0.1825	7
2022	0.3324	0.2450	-0.1514	6
2023	0.1183	0.4372	0.5741	1

Considering the findings reported in Table 14 based on the RAWEC procedure, 2023 was determined as the most successful year for Turkey regarding renewable energy performance for the period 2015-2023, followed by 2017 > 2016 > 2015 > 2020 > 2020 > 2022 > 2021 > 2018 and 2019, respectively. In light of these findings, Turkey's highest performance in 2023 can be attributed to the large investments in solar and wind energy and the resulting capacity expansion. In addition, the Turkish government implemented renewable energy policies more effectively in 2023 and increased cooperation between the public and private sectors. In 2020 and 2021, the pandemic period, some projects were postponed or canceled due to economic contraction and uncertainty. However, it can be noted that Turkey seized the opportunity to invest more in the renewable energy sector in the post-pandemic period and achieved a high performance with the commissioning of these projects by 2023. Moreover, the exchange rate, which has been on an increasing trend for many years, led to a significant increase in costs in Turkey. As a consequence of the global energy crisis, fossil fuel price increases and energy supply security issues increased the demand for renewable energy in Turkey. The economic downturn in 2020-2021 can be seen as a reason for the lower performance. Conversely, 2023 was a year in which Turkey overcame the aforementioned negative factors in terms of energy efficiency, which contributed to the high performance and acceleration of energy efficiency.

6 Conclusions and Recommendations

Measuring the performance of renewable energy is very important in terms of sustainability, efficiency and environmental impact. These measurements provide practical information for countries to monitor the effectiveness of their energy policies, improve resource use and reduce their carbon footprint. Hence, this study's purpose is to suggest a new integrated MCDM model for analyzing the renewable energy performance of countries. For this goal, a real-time case analysis was conducted in Turkey for the period 2015-2023. In the present study, which focuses on solving the renewable energy performance problem, ten evaluation criteria were identified to analyze the renewable energy performance of Turkey. While the MSD and CRITIC procedures, which are objective criterion weighting methods, were utilized in determining the weight coefficients of the determined performance criteria, the RAWEC procedure was used in the process of deciding Turkey's success rankings by the years.

According to the empirical findings obtained within the scope of the final weighting procedure, it was concluded that the three criteria that have the most impact on Turkey's renewable energy performance are the average annual growth rate of installed capacity, total renewable energy generation-to-total electricity generation, and total renewable energy generation-to-total installed capacity. In contrast, the three criteria with the least effect on performance are the ratio of total hydro installed output to total installed output, the ratio of total electricity generation to total installed output, and the ratio of total renewable energy installed output to total installed output.

These results are of great importance for evaluating Turkey's renewable energy strategies and shaping future energy policies. Particularly for decision-makers in the renewable energy sector, investors, government agencies and non-governmental organizations interested in environmental policies, these findings can help identify which factors should be prioritized more.

On the other hand, the empirical results suggest that more focus should be placed on the metrics that have the most impact on increasing Turkey's renewable energy capacity. This could help investors to identify which projects they should invest more in. It can also provide guidance on which areas should be prioritized for government investment in renewable energy infrastructure. On the other hand, low-impact measures indicate that current policies have not made much progress in these areas or that these factors are less variable. This may lead policymakers to review these metrics and perhaps develop more effective solutions. In addition, considering the 2015-2023 time period, hydroelectric energy had the largest share in terms of renewable energy resource use in Turkey. However, for the same period, solar and wind energy were the renewable energy sources that increased the most over the years. The main reasons for this are the high construction costs of hydroelectric power plants, high engineering costs, long construction times, and the need for large areas of land. Such difficulties led decision-making authorities to solar and wind energy, which have lower financing costs and shorter installation times. In conclusion, these findings provide an important reference point for improving the effectiveness of renewable energy policies, guiding investment decisions and developing electricity generation capacity in a sustainable manner.

The results obtained within the framework of the RAWEC methodology show that the most successful year for Turkey in terms of renewable energy performance in the period 2015-2023 is 2023 and the least successful year is 2019. The fact that 2023 was the most successful year in terms of renewable energy performance in Turkey can be explained as follows: i) for Turkey, 2023 was a year in which renewable energy policy goals were accelerated, YEKA (Renewable Energy Resource Areas-RERA) projects were expanded, and international financial support increased. ii) in Turkey, 2023 was a period when total installed capacity and renewable energy capacity reached record levels. The implementation of these projects resulted in a substantial increase in the production of hydroelectric and solar energy. iii) this was further accelerated by the global energy crisis and Europe's efforts to reduce its dependence on fossil fuels, which contributed to the acceleration of renewable energy investments in Turkey during the period 2022-2023.

Conversely, the 2018-2019 period was the worst in terms of renewable energy performance in Turkey, which can be explained as follows: i) in the 2018-2019 period, energy investments decreased significantly due to economic fluctuations in the Turkish economy and rapid exchange rate movements. ii) specifically, the substantial rise in financing costs for renewable energy projects resulted in an increase in the cost of imported renewable energy equipment, which had a significant impact on investors during this period. iii) the subsequent global pandemic (COVID-19) led to delays in the implementation of renewable energy projects in Turkey, as well as in the rest of the world. The outcomes of the present study provide some practical information for stakeholders such as policymakers, investors, and energy sector professionals as follows:

• In consideration of the study's findings, it is possible to predict the periods of high growth and the policies that will increase investment for individuals and institutions that will invest in the renewable energy industry.

• The assessment of which infrastructure and technologies are more effective in the more successful periods allows renewable energy policies for future periods to be planned accordingly.

• In order to enhance the security of energy supply and decrease the demand for fossil fuels in Turkey, it can contribute to the development of strategies to increase the share of renewable energy sources in total energy production.

• The findings of the research can be utilized as a reference in the process of developing and implementing policies in line with the European Green Consensus and carbon neutrality objectives.

• The findings of the study can guide future investigations on renewable energy policies, energy investments and sustainability performance.

In conclusion, this research provides a year-by-year analysis of Turkey's renewable energy development and reveals which years and which energy policies are more effective. The empirical findings obtained as a result of the research provide guidance for future energy policies, private sector investments and transformations in the energy sector. In this context, the model proposed in the study can be used to test the effectiveness of the energy policies currently implemented in Turkey.

As in other empirical studies, this case study has a number of limitations. The first limitation is that the scope of the current research is limited to Turkey. Therefore, the results of the study cannot be generalized to countries other than Turkey. However, more concrete and comprehensive findings can be obtained by assessing different countries or groups of countries within the scope of analysis in future studies. Second, the MSD and CRITIC objective weighting procedures were employed in the process of weighting the chosen renewable energy indicators. In the literature, there are many objective and subjective weighting approaches for weighting the assessment criteria. Therefore, the fact that only the MSD and CRITIC methods are preferred for calculating the weighting coefficients for the evaluation criteria, considering the importance of the alternatives, can be regarded as another limitation. Therefore, subjective weighting algorithms such as AHP, Analytic Network Process (ANP), Decision-Making Trial and Evaluation Laboratory (DEMATEL), Level Based Weight Assessment (LBWA), Logarithmic Methodology of Additive Weights (LMAW), Simple Weight Calculation (SIWEC), Ranking Comparison (RANCOM), etc. can be implemented in future research. However, by integrating objective and subjective methodologies, more consistent weighting coefficients can be obtained. Conversely, the utilization of solely the RAWEC methodology in the process of ranking decision alternatives in the current case analysis can be considered as a third limitation. In the literature on decision-making, there are many approaches, e.g., AROMAN, MARCOS, Multi-Attribute Ideal-Real Comparative Analysis (MAIRCA), Preference Similarity Index(PSI), PIV, Additive Ratio Assessment (ARAS), Multi-Objective Optimization on the basis of Simple Ratio Analysis(MOOSRA), CRADIS, ARLON, Multi-Attributive Border Approximation Area Comparison (MABAC), Root Assessment Method (RAM), Faire Un Choix Adéquat (in French-FUCA), etc., used in the process of ranking alternatives. Consequently, these methodologies can be employed in subsequent empirical studies and contribute to the extant literature. Furthermore, the ranking results obtained by applying these methodologies together can be combined using combination operators such as Borda Count and Copeland. This approach has the potential to yield more objective and reliable ranking results. Within the scope of the study, the ten renewable energy indicators chosen as assessment criteria and the period 2015-2023 can also be presented as the fourth constraint. Thus, in future studies, the results obtained can be improved by selecting different samples and analysis periods. Finally, in future empirical studies, researchers can contribute to the related field by performing analyses based on the grey system theory and fuzzy decision-making approaches instead of classical decision-making procedures.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there is no conflict of interest in the study.

References

[1] Z. Durmuş, S. Aslan, and V. Esen, "Türkiye'de rüzgâr enerjisinin mevcut durumu ve geleceği," 2022. https://www.kongreuzmani.com/2-uluslararasi-lisansustu-calismalar-kongresi-igscong-2022.html

[2] V. Quaschning, *Understanding Renewable Energy Systems*. Routledge, 2014. http://dx.doi.org/10.4324/9781315800493

[3] F. Evrendilek and C. Ertekin, "Agricultural sustainability in Turkey: Integrating food, environmental and energy securities," *Land Degrad. Dev.*, vol. 13, no. 1, pp. 61–67, 2002. https://doi.org/10.1002/ldr.480

[4] IEA, "World energy outlook 2024 – analysis - IEA," 2025. https://www.iea.org/reports/world-energy-outlook-2024

[5] E. C. ÖZCAN and T. EREN, "Application of TOPSIS method for maintenance planning: Natural gas combined cycle power plant case study," *Uluslar. Muh. Arast. Gelis. Derg.*, vol. 6, no. 2, pp. 26–38, 2014. https://doi.org/10.29137/umagd.346087

[6] Z. Durmuş, S. Aslan, and V. Esen, "Türkiye'de yenilenebilir enerji kaynaklarının elektrik üretiminde kullanımına genel bir bakış," pp. 1088–1099, 2023.

[7] TEIAS, "Türkiye elektrik üretim-iletim istatistikleri," 2025. https://www.teias.gov.tr/turkiye-elektrik-uretim-iletim-istatistikleri

[8] R. Li, H. Wen, X. Huang, and Y. Liu, "Renewable energy: A curse or blessing—International evidence," *Sustainability*, vol. 15, no. 14, p. 11103, 2023. https://doi.org/10.3390/su151411103

[9] V. Kukharets, R. Čingienė, J. Čėsna, and S. Kukharets, "Analysis of renewable energy's impact on energy import dependency in Lithuania," *Rural Dev.*, vol. 2023, no. 1, pp. 78–83, 2024. https://doi.org/10.15544/rd.2023.016

[10] A. Martínez, S. Valero, E. Velasco, and C. Senabre, "Energy intensity of the economy as a variable to measure the energy efficiency of a country: Comparison between European member states," *Renew. Energy Power Qual. J.*, vol. 12, no. 3, pp. 246–250, 2024. https://doi.org/10.24084/repqj12.301

[11] H. Zhao and S. Guo, "External benefit evaluation of renewable energy power in China for sustainability," *Sustainability*, vol. 7, no. 5, pp. 4783–4805, 2015. https://doi.org/10.3390/su7054783

[12] B. Kantoğlu and İ. D. Argun, "Evaulation of renewable energy source alternatives prioritization," *Turk. J. Eng.*, vol. 7, no. 1, pp. 1–8, 2023. https://doi.org/10.31127/tuje.1001488

[13] H. KOÇ, "Assessing the renewable energy efficiency levels of BRICS countries and Turkey using stochastic frontier analysis and information complexity criteria," *Adıyaman Univ. J. Sci.*, vol. 11, no. 1, pp. 136–146, 2021. https://doi.org/10.37094/adyujsci.755048

[14] N. H. Mirjat, M. A. Uqaili, K. Harijan, M. W. Mustafa, and M. W. A. Khan, "Multi-criteria analysis of electricity generation scenarios for sustainable energy planning in Pakistan," *Energies*, vol. 11, no. 4, p. 757, 2018. https://doi.org/10.3390/en11040757

[15] R. Alizadeh, L. Soltanisehat, P. D. Lund, and H. Zamanisabzi, "Improving renewable energy policy planning and decision-making through a hybrid MCDM method," *Energy Policy*, vol. 137, p. 111174, 2020. https://doi.org/10.1016/j.enpol.2019.111174

[16] C. N. Wang, J. C. Kao, Y. H. Wang, V. T. Nguyen, and S. T. Husain, "A multicriteria decision-making model for the selection of suitable renewable energy sources," *Mathematics*, vol. 9, no. 12, p. 1318, 2021. https://doi.org/10.3390/math9121318

[17] S. Değirmenci, F. Bingöl, and S. C. Sofuoglu, "MCDM analysis of wind energy in Turkey: Decision making based on environmental impact," *Environ. Sci. Pollut. Res.*, vol. 25, no. 20, pp. 19 753–19 766, 2018. https://doi.org/10.1007/S11356-018-2004-4/FIGURES/10

[18] T. Li, A. Li, and Y. Song, "Development and utilization of renewable energy based on carbon emission reduction-evaluation of multiple MCDM methods," *Sustainability*, vol. 13, no. 17, p. 9822, 2021. https://doi.org/10.3390/su13179822

[19] W. O. Sarkodie, E. A. Ofosu, and B. C. Ampimah, "Decision optimization techniques for evaluating renewable energy resources for power generation in Ghana: MCDM approach," *Energy Rep.*, vol. 8, pp. 13 504–13 513, 2022. https://doi.org/10.1016/j.egyr.2022.10.120

[20] H. Lee and C. Chang, "Comparative analysis of MCDM methods for ranking renewable energy sources in Taiwan," *Renewable Sustainable Energy Rev.*, vol. 92, pp. 883–896, 2018. https://doi.org/10.1016/j.rser.2018.05.007

[21] T. Li, A. Li, and X. Guo, "The sustainable development-oriented development and utilization of renewable energy industry——A comprehensive analysis of MCDM methods," *Energy*, vol. 212, p. 118694, 2020. https://doi.org/10.1016/j.energy.2020.118694

[22] S. S. Goswami, S. K. Mohanty, and D. K. Behera, "Selection of a green renewable energy source in India with the help of MEREC integrated PIV MCDM tool," *Mater. Today Proc.*, vol. 52, pp. 1153–1160, 2022. https://doi.org/10.1016/j.matpr.2021.11.019

[23] J. M. Sánchez-Lozano, M. S. García-Cascales, and M. T. Lamata, "Comparative TOPSIS-ELECTRE TRI methods for optimal sites for photovoltaic solar farms. Case study in Spain," *J. Cleaner Prod.*, vol. 127, pp. 387–398, 2016. https://doi.org/10.1016/j.jclepro.2016.04.005

[24] B. A. Akash, R. Mamlook, and M. S. Mohsen, “Multi-criteria selection of electric power plants using analytical hierarchy process,” *Electr. Power Syst. Res.*, vol. 52, no. 1, pp. 29–35, 1999. https://doi.org/10.1016/s0378-7796(99)00004-8

[25] A. Ç. Köne and T. Büke, “An Analytical Network Process (ANP) evaluation of alternative fuels for electricity generation in Turkey,” *Energy Policy*, vol. 35, no. 10, pp. 5220–5228, 2007. https://doi.org/10.1016/j.enpol.2007.05.014

[26] A. Kabir and S. Shihan, “Selection of renewable energy sources using analytic hierarchy process,” in *International Symposium on the Analytic Hierarchy Process, Bali*, 2003.

[27] S. Ishfaq, S. Ali, and Y. Ali, “Selection of optimum renewable energy source for energy sector in Pakistan by using MCDM approach,” *Process Integr. Optim. Sustain.*, vol. 2, no. 1, pp. 61–71, 2018. https://doi.org/10.1007/S41660-017-0032-Z/TABLES/20

[28] S. K. Saraswat and A. K. Digalwar, “Evaluation of energy sources based on sustainability factors using integrated fuzzy MCDM approach,” *Int. J. Energy Sect. Manag.*, vol. 15, no. 1, pp. 246–266, 2021. https://doi.org/10.1108/IJESM-07-2020-0001/FULL/PDF

[29] S. Wibowo and S. Grandhi, “Sustainability performance evaluation of renewable energy systems,” in *2014 11th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD)*, 2014. http://doi.org/10.1109/FSKD.2014.6980846

[30] A. Puška, A. Štilić, D. Pamučar, D. Božanić, and M. Nedeljković, “Introducing a novel multi-criteria ranking of alternatives with weights of criterion (RAWEC) model,” *MethodsX*, vol. 12, p. 102628, 2024. https://doi.org/10.1016/j.mex.2024.102628

[31] O. Y. Akbulut and Y. Aydın, “A hybrid multidimensional performance measurement model using the MSD-MPSI-RAWEC model for Turkish banks,” *J. Mehmet Akif Ersoy*, vol. 11, no. 3, pp. 1157–1183, 2024. https://doi.org/10.30798/makuiibf.1464469

[32] D. Diakoulaki, G. Mavrotas, and L. Papayannakis, “Determining objective weights in multiple criteria problems: The critic method,” *Comput. Oper. Res.*, vol. 22, no. 7, pp. 763–770, 1995. https://doi.org/10.1016/0305-0548(94)00059-h

[33] O. Y. Akbulut, “Finansal performans ile pay senedi getirisi arasındaki ilişkinin bütünleşik CRITIC ve MABAC çKKV teknikleriyle ölçülmesi: Borsa istanbul çimento sektörü firmaları üzerine ampirik bir uygulama,” *Pamukkale Univ. J. Soc. Sci. Inst.*, vol. 40, pp. 471–488, 2020. https://doi.org/10.30794/pausbed.683330

[34] Ö. Işık, “AHP , CRITIC VE WEDBA yöntemlerini içeren entegre bir çKKV modeli ile AXA sigorta şirketinin finansal performansının analizi,” *Int. J. Bus. Econ. Manag. Perspect.*, vol. 5, no. 2, pp. 892–908, 2021. https://doi.org/10.29228/ijbemp.55049

[35] O. Y. Akbulut, “Critic ve EDAS yöntemleri ile iş Bankası’nın 2009-2018 yılları arasındaki performansının analizi,” *Ekon. Polit. Finans Araşt. Derg.*, vol. 4, no. 2, pp. 249–263, 2019. https://doi.org/10.30784/epfad.594762

[36] Ö. Işık, “Türkiye’de hayat dışı sigorta sektörünün finansal performansının CRITIC tabanlı TOPSIS ve MULTIMOORA yöntemiyle değerlendirilmesi,” *Bus. Manage. Stud. Int. J.*, vol. 7, no. 1, pp. 542–562, 2019. https://doi.org/10.15295/bmij.v7i1.1090

[37] Ö. Işık, M. Shabir, G. Demir, A. Puska, and D. Pamucar, “A hybrid framework for assessing Pakistani commercial bank performance using multi-criteria decision-making,” *Financ. Innov.*, vol. 11, no. 1, p. 1, 2025.

[38] G. Dos, M. Sodini, and M. E. Virgillito, “Profit-driven and demand-driven investment growth and fluctuations in different accumulation regimes,” *J. Evol. Econ.*, vol. 25, no. 4, pp. 707–728, 2015. https://doi.org/10.1007/S00191-015-0406-8/FIGURES/8

[39] A. George Assaf, A. Josiassen, A. S. Mattila, and L. Kneževic Cvelbar, “Does advertising spending improve sales performance?” *Int. J. Hosp. Manage.*, vol. 48, pp. 161–166, 2015. https://doi.org/10.1016/j.ijhm.2015.04.014

[40] A. C. G. Kısa, “Tr83 bölgesinde yenilenebilir enerji kaynaklarının critic tabanlı gri ilişkisel analiz yaklaşımı ile değerlendirilmesi,” *Pam. Univ. Müh. Bilim. Derg.*, vol. 27, no. 4, pp. 542–548, 2021. https://doi.org/10.5505/pajes.2021.99389

[41] P. K. Samut, “OECD ülkelerinin yeşil lojistik performansı ile enerji, sağlık ekonomisi ve çevre ilişkisinin analizi,” *Verimlilik Dergisi*, pp. 67–82, 2023. https://doi.org/10.51551/verimlilik.1112577

[42] M. Krysiak and A. Kluczek, “A multifaceted challenge to enhance multicriteria decision support for energy policy,” *Energies*, vol. 14, no. 14, p. 4128, 2021. https://doi.org/10.3390/en14144128

[43] H. Hasheminasab, D. Streimikiene, and M. Pishahang, “A novel energy poverty evaluation: Study of the European Union countries,” *Energy*, vol. 264, p. 126157, 2023. https://doi.org/10.1016/j.energy.2022.126157

[44] IRENA, “Country Rankings,” 2025. https://www.irena.org/Data/View-data-by-topic/Capacity-and-Generation/Country-Rankings