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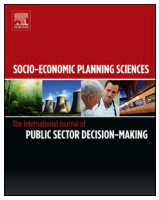

Evaluation of Green Deal compliance performance with a hybrid comparative multi-attribute decision model

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ABSTRACT

The environmental and economic transformation initiated by the European Green Deal is influencing not only EU member states, but also other countries engaged in trade with the EU. This transformation mandates a shift towards sustainable practices in sectors such as agriculture, industry, transportation, energy, and finance. Compliance with the Green Deal is increasingly crucial for countries, particularly those with significant commercial ties to the EU. However, differing levels of development lead to varying degrees of implementation. While studies on the Green Deal compliance of EU member states exist, an evaluation of Türkiye—a candidate EU member with substantial trade relations—would address a significant gap in the literature. This study introduces a novel hybrid comparative multi-attribute decision model that combines subjective (Best Worst Method and its derivatives) and objective (Entropy) weighting to determine the relative importance of 14 sub-criteria under three main criteria: "Reducing" the impacts of climate change, "Protecting" the planet and health, and "Enabling" a green and just transition. Using the Ratio Product Model (RPM), Türkiye's Green Deal compliance from 2017 to 2021 was evaluated. Sensitivity analysis was conducted to validate the robustness of the findings, and comparisons were made using various multi-attribute decision models, including SAW, TOPSIS, and VIKOR, as well as benchmarking against EU countries. The criteria weights, derived from a combination of subjective and objective methods, highlighted the dominant importance of the "Reducing" criterion across all methods. The "Enabling" and "Protecting" criteria showed slight variations in importance depending on the method. The RPM results indicated that 2021 was Türkiye's best-performing year in terms of Green Deal compliance, while 2017 showed the weakest performance. Despite some fluctuations between 2018 and 2019, Türkiye demonstrated significant progress overall. The study not only advances the methodology for evaluating Green Deal compliance but also provides actionable insights for policymakers and industry stakeholders, enabling more informed decision-making. By highlighting Türkiye's trajectory, the findings offer strategic guidance for non-EU countries aiming to align with Green Deal objectives, fostering sustainable development and strengthening economic ties with the EU.

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1. Introduction

In 2019, the European Green Deal (EGD) was signed with the aim of transforming Europe's economy to achieve zero carbon emissions by 2050 [1]. Based on the principles of sustainable development, the EGD provide a comprehensive plan for shifting to a green economy and addressing climate change, as well as social and economic inequalities. This initiation highlights the European Union (EU) commitment to enhancing sustainable practices and encouraging a green economy. The policies of the EGD have been inspired by the European Union's (EU) climate change from the early 1990s and designed to meet ambitious climate goals. Compared to 1990 levels, the Kyoto Protocol's target was a 5 % emission reduction, but it achieved only 1.04 % by 2012 [2]. Moreover, the EGD is expected to reach 40 % by 2030 and 80%–95 % by 2050 ([3]; Quintero & Rueda, 2020). To achieve this, a target for emission reductions has been set to align effectively with the goals of various economic sectors. The ultimate objective of such green economic policies is to achieve zero carbon emissions by 2050, aligning with the goals of the Paris Agreement of limiting global warming [4] and developing a sustainable future for everyone. Similarly, multiple other European reports have been presented to address the adoption of green practices [5,6]. The shift towards green practices across different sectors, i.e. energy, agriculture, transportation, industry and finance, is a global necessity.

To integrate green practices across various sectors, the EGD is required to promote a circular economy that focuses on the optimal utilization of resources while minimizing waste [7,8]. To achieve this, supporting sustainable product design and promoting recycling and reuse processes is crucial. In the energy sector, the EGD focuses on transitioning to renewable energy sources such as solar, wind, and geothermal, rather than using coal and other traditional high-carbon emission processes. Furthermore, in the transportation sector, EGD encourages promoting electric vehicles and seeks to improve the public transportation systems with low carbon emissions. Similarly, in agriculture, a sustainable practice such as diverse crop rotation and reducing tillage can be vital to decrease emissions through soil carbon capture and reduce reliance on synthetic fertilizers. However, adopting green practices requires substantial financial and technological resources. Hence, implementing green practices in different countries encounters various challenges and should be addressed accordingly.

In the context of the EU, it is important to have proper performance monitoring to measure each country's progress according to the EGD policies. These performance monitoring practices will evaluate each country's achievements and identify potential areas for future improvement. Additionally, this will aid in understanding the approaches each country uses to manage the complex challenges of environmental governance. Despite extensive research on the adherence of EU member states to the EGD, there is a significant lack of research concentrating on non-EU countries, especially those with strong commercial ties to the EU. As a potential EU member with strong trade ties to EU countries, Türkiye presents the best example for evaluating the implementation and potential effects of EGD practices in a non-EU country. Therefore, having strong economic ties and candidacy status, the evaluation of EGD performance in the context of Türkiye is a critical research topic for multiple reasons. Firstly, it provides a deep insight into how non-EU member states can address the challenges to attain sustainable economic structure. Secondly, it helps in the comprehensive assessment and global impact of the Green Deal, which can facilitate other nations in similar sustainable economic transitions. Finally, the study will help promote international cooperation by emphasizing the significance of collaboration between countries in achieving sustainability goals.

The study answers the research question: How to evaluate the Green Deal compliance performance in non-EU countries? As a case study, this work investigates Türkiye's Green Deal compliance performance using a hybrid comparative multi-attribute decision model. For this purpose, three main criteria and fourteen sub-criteria associated with the Green Deal were identified. The three primary criteria for evaluating performance are reducing, protecting, and enabling. The reducing criterion aims to minimize the impact of greenhouse gas emissions, the protecting criterion emphasizes safeguarding public health and the environment, and the enabling criterion aims to develop an inclusive framework to facilitate a green transition. For this purpose, a dataset spanning several years from a specified period has been compiled and then analyzed. Multi-Criteria Decision Making (MCDM) was used in the study. MDCM is a branch of operational research that seeks the optimal solution in maximizing/minimizing conflicting objectives within complex situations. MCDM guides the decision maker by quantifying the importance of the criteria in line with the determined goal [9]. The main goal in MCDM is to determine the importance of the criteria, to rank or select the alternatives in line with the goal [10]. Initially, the weights are assigned to each main criteria and sub-criteria using subjective weighting, i.e. Best Worst Method (BWM). BWM has an important place among MCDM methods and was derived to overcome some shortcomings of AHP. Instead of making full pairwise comparisons for decision makers, it allows them to calculate consistent and reliable weights with only 2n-3 pairwise comparisons [11,12]. Then, it also uses objective weighting with the entropy method. The most important advantage of the Entropy method is that it eliminates the human effect in determining the criterion weights. In this case, it ensures that the results obtained are objective [13]. Afterwards, Türkiye's Green Deal compliance performance is examined using the rank-preserving approach called Ratio Product Model (RPM). The RPM proposes to eliminate the limitations of the weighted sum model (WSM) and weighted product model (WPM). It allows to obtain a more reliable ranking by taking into account the proportional importance of the alternatives [10]. Additionally, a sensitivity analysis is performed to validate the accuracy of the results by varying several parameters of the data. Furthermore, for deeper insights, a comparative analysis has also been conducted using other decision techniques—SAW, VIKOR, and TOPSIS—as well as benchmarking against other EU member states. The choice of MCDM methods depends on the characteristics of the problem, the objectives of the research, and the experience of the researcher. Despite the large number of MCDM-based methods in the literature, it is quite difficult to determine which method is most suitable for complex and multidimensional problems [14]. Therefore, more than one method has been used in comparative analysis.

Hence, the objective of this research is threefold.

1. To evaluate the Türkiye's adherence to EGD policies as a non-EU member state, inspect its progress over the years (2017–2021) through three main criteria—Reducing, Protecting, and Enabling—and fourteen sub-criteria.
2. Employing a new approach to evaluate the EGD adherence policies through a hybrid multi-attribute decision model that integrates the BWM and entropy for criteria weighting followed by RPM for ranking. Additionally, a sensitivity analysis is performed to validate the robustness of the proposed methodology.
3. To conduct a comparative analysis of Türkiye's performance using different decision models, including SAW, TOPSIS, and VIKOR, and benchmark it against EU member states.

This research contributes to scholarly work by employing a novel hybrid decision-making model to assess Türkiye's compliance with the Green Deal, followed by a comparative study with other decision models and EU member states. In contrast to existing literature that focuses exclusively on the adherence and progress of EU member states in adopting green practices [15,16], this study extends the scope to investigate the impact on a non-EU country such as Türkiye. Although various research studies have been performed on various economic sectors in Türkiye to align them with EGD policies—such as carbon emissions in the agricultural sector [17], energy transition [18]—it

remains vital to assess Türkiye's performance incorporating green practices over the past few years and conduct a comparative study to identify potential areas for improvement. Recent studies have also revealed that adopting the Green Deal policy in the future may become a crucial requirement for Türkiye to sustain economic relations with EU member states [19,20]. Therefore, this study provides significant implications for policy makers and practitioners. For instance, by highlighting the Türkiye's achievements and challenges in adhering to the EGD policies will facilitate and strengthen the Türkiye's position for EU accession. Additionally, Türkiye's successful adherence of Green Deal policies will assist as a benchmark and motivation for policymakers in other non-EU states to invest in green economy for a better future worldwide.

The rest of the paper is organized as follows. In Section 2, we review the reported literature on the Green Deal Compliance problem and the use of BWM and RPM techniques. In Section 3, we present the research methodology, while in Section 4, we outline the case study. Ultimately, Section 5 concludes the manuscript.

2. Related literature

2.1. Previous studies on green deal compliance performance

The EDG is an extensive set of policies focusing on achieving zero emissions by integrating different green practices to foster sustainable economic growth [21–23]. In the literature, several researchers focused on Green Deal compliance performance to assess the impact of incorporating such environmental standards on the economy [24]. Multiple studies have evaluated different indicators and the impact of Green Deal implementation [25,26]. These indicators provide insights for effectively implementing Green Deal policies across different economic sectors and highlight the possibilities for further improvements. For instance, studies have been performed on energy transition [27], health improvement [28], food industry [29], agriculture [30], and transportation [31] to encourage green practices. The degree to which each EU member state implements and adopts Green Deal compliance differs significantly. For example, a study of 19 EU member states revealed that nations like Bulgaria, Cyprus, and Poland face significant financial and technical challenges that require special consideration to properly align them with the objectives of the Green Deal [32]. Similarly, another study assessed the performance of 27 EU member states using the European Green Deal Index (EGDI), calculated across 18 indicators. The results revealed that Bulgaria and Cyprus had the lowest EGDI scores, marking them as the weakest performers, while Sweden, Denmark, and the Netherlands received the highest EGDI values, ranking as the best-performing states [33]. Furthermore, the study also highlighted that the Old EU-14 member states perform much better in adopting EGD strategies compared to the New EU-13 nations. Moreover, another research study was performed to evaluate the progress of EU member states in achieving energy and climate sustainability strategies outlined in EGD using 14 distinct indicators covering energy, climate, economic and social factors [34]. The findings revealed that Sweden and Denmark were best performers in adopting these EGD strategies, while Bulgaria and Poland faced significant challenges and require greater support to efficiently adopt these sustainable practices. Additionally, a study assessing the performance of different EU member states in reducing carbon emissions and strategic alignment with the 2030 target set by the EGD [35] revealed that Ireland and Greece have made significant progress, while Luxembourg and Lithuania are lagging the target. Similarly, another study evaluated the performance of EU member states in adopting renewable energy, an essential factor in reaching the goals outlined in the EGD, and its economic impacts [36]. The findings revealed that Sweden, Austria, Denmark, and Finland were among the leading countries, with Sweden significantly surpassing its actual target through successful policies promoting hydropower and biomass. In contrast, Spain, Poland, and Belgium underperformed due to their heavy reliance on fossil fuels. These differences highlight the importance of customized policies for each country to achieve sustainable economic growth aligned with the Green Deal.

Moreover, different qualitative studies have been performed that underscore the significance of public participation and stakeholder engagement. These studies revealed that the active involvement of industry stakeholders, government, and civil society is crucial for Green Deal compliance performance [37]. The literature has been significantly improved through various case studies focusing on particular economic sectors. For instance, researchers have widely focused on the energy and transport sectors to examine the transition towards low-carbon emission technologies, such as renewable energy sources [38], electric vehicles [39], etc. Such transformation necessitates technological innovations, financial investments, and supportive policies [40,41]. Similarly, another key area of research involves investigating the economic impacts of Green Deal compliance. For instance, a study using the case of Spain has analyzed its effect on the job market [42]. In light of the reported literature, it is evident how evaluating the Green Deal compliance performance depends on different conflicting aspects, making it a perfect decision problem to be addressed using MCDM tools. Therefore, multiple MCDM approaches have been integrated with other techniques, forming hybrid methods to evaluate complex decisions in the context of the EGD.

For instance, a study was conducted utilizing a hybrid MCDM model that integrates the "satisfaction point" method with a systematic evaluation framework to address the decision problem of sustainable procurement, specifically in selecting iron ore raw materials based on economic, technical, and environmental factors [43]. Similarly, another study was conducted to evaluate EGD implementation in EU-27 member states using a hybrid MCDM method that combines CRITIC for criteria weighting and correlation, the Laplace criterion for balanced evaluation, statistical variance for variability, and the CoCoSo approach for ranking [33]. Moreover, another study integrated the entropy method, which facilitates objective weighting of criteria, followed by the COPRAS ranking approach to assess the sustainability performance of different EU countries [34]. Therefore, these studies demonstrate the effectiveness of hybrid MCDM methods in addressing the complexities of sustainability practices and assessing the implementation and progress of EGD policies. For this purpose, our study employs a hybrid approach that combines the BWM and its derivatives for subjective weighting, alongside the entropy method for objective weighting. This is followed by the Ratio Product Model (RPM) ranking approach to assess the performance of Green Deal policies in the context of Türkiye. Additionally, the study validates the robustness of its results through sensitivity analysis and compares them with other MCDM models, including SAW, TOPSIS, and VIKOR.

2.2. Previous studies on BWM derivatives and RPM

In the past few years, the realm of decision-making, particularly MCDM tools, has attracted noteworthy attention from researchers to deal with complex decision problems [44]. Recently, the Best-Worst Method (BWM), developed by Rezaei [12], stood out as a prominent approach to evaluating decisions using multiple criteria, ensuring the decision provides clear insight and logical reasoning. This method is based on pairwise comparison principles and simplifies the evaluation process compared to AHP by focusing solely on the best and worst criteria. Although paired judgements in BWM have certain consistency issues, studies have been performed to effectively address those issues by utilizing input-based consistency measurements to achieve more coherent results [45]. Due to its effectiveness in addressing intricate decision problems, BWM is widely preferred by researchers across different fields, including healthcare [46], manufacturing [47], construction [48], supplier selection [49,50], humanitarian supply chain management [51], energy [52,53], Micro-Small and Medium Enterprises [54], education [55], logistics [56] and many others.

In addition, BWM has been integrated with various other MCDM methods to improve the decision support system. For instance, it has been combined with AHP to evaluate road safety using case of Budapest [57], fuzzy TOPSIS for supplier selection based on green innovation [58], Fuzzy Interpretive Structural Modelling (FISM) and ANP for cold chain supply performance [59], DEMATEL to investigate the challenges small and medium-sized enterprises [60], PROMETHEE for supplier segmentation [61], VIKOR for green airports [62], SAW for wagons selection [63] among other applications. In most of these combinations, the role of BWM is to determine the relative importance of criteria, while methods such as VIKOR, TOPSIS, DEMATEL, SAW and PROMETHEE facilitate the ranking process. Similarly, our research study utilizes BWM to determine the importance of criteria and sub-criteria, followed by applying a rank-preserving, normalization-agnostic model known as the Ratio Product Model (RPM).

RPM is a recent addition to the field of MCDM that effectively addresses the shortcomings of the Weighted Sum Model (WSM) and the Weighted Product Model (WPM), providing more reliable and precise results [10]. This method is based on ratio estimation. It aims to improve the accuracy of target variables by utilizing auxiliary information [64], in contrast to traditional methodologies that rely merely on direct observations. The RPM method offers several advantages for performing ranking [10]. Firstly, the ranking obtained with RPM remains consistent even with introducing or removing new alternatives. Secondly, the results are robust and stable, even with adding or removing any indiscriminating criteria. Thirdly, the ratios are consistent regardless of the normalization method, such as dividing or multiplication.

2.3. Research gaps and contributions

Firstly, although multiple studies have been analyzing the impact of the European Green Deal on the economic growth of European member states, this study focuses the case on Türkiye, which has strong economic ties with European countries and is a potential candidate to become a permanent member of the EU in the future. Secondly, this study allows non-EU countries to effectively adopt Green Deal policies and develop a sustainable economic structure. Thirdly, this study will strengthen international collaboration between countries to achieve sustainability goals. Fourthly, this study introduces a new approach, i.e. a hybrid multi-attribute decision model that evaluates criteria importance based on the BWM approach, followed by the latest ranking method called RPM. Furthermore, a sensitivity study is performed to obtain additional insights. Finally, to provide a future perspective, a comparison analysis is performed using other multi-attribute decision models like SAW, TOPSIS, and VIKOR, as well as benchmarking with other EU countries.

3. Research methodology

3.1. Brief mathematical backgrounds of the methods used in the research methodology

This study utilizes methods forming a methodological framework, addressing sub-problems related to the main topic. First, multi-criteria decision-making (MCDM) methods determined the importance levels of criteria affecting Türkiye's Green Deal adaptation, focusing on subjective and objective weights. The subjective MCDM method chosen was the Best-Worst Method (BWM), with reasons detailed later. To ensure a comparative research approach, multiple BWM extensions—Fuzzy BWM, interval type-2 fuzzy BWM, and Bayesian BWM—were applied. The entropy method served as the objective weighting technique. Subjective and objective weights were then combined to produce final weight values. For the second sub-problem, the year-based compliance performance with the Green Deal was assessed using Rezaei's RPM [10], allowing comparison with EU countries.

3.1.1. Best-worst methods and its derivatives

The Best-Worst Method (BWM) is employed to determine the relative importance of various selection criteria within a multi-criteria decision-making framework. This subjective method identifies the best and worst criteria, where the best signifies the most important and the worst represents the least important. In this study, BWM is used to calculate local weights for each criterion instead of the Analytic Hierarchy Process (AHP), as it requires fewer pairwise comparisons. While AHP requires $(n\times(n-1))\,/\,2$ comparisons for n criteria, BWM only necessitates $(2\times n)-3$ comparisons, significantly reducing the workload. The process follows several steps as outlined by Rezaei [12].

Step 1: *Determine the selection criteria* $C=\{c_1,c_2,\ldots,c_n\}$. In the first step, the decision criteria regarding the goal of the problem are extracted.

Step 2: *Determine the best and worst candidates in the criteria set.* During this step, it is crucial to identify the most significant and least significant criteria, respectively. Subsequently, a comparison should be conducted between the best criteria and the other criteria, as well as between the other criteria and the worst criteria, using two matrices.

Step 3: *Create the best to others (BO) vector.* A pairwise comparison regarding best and other criteria should be performed using a numerical scale ranging from 1 to 9. The BO vector is expressed in Eq. (1).

$$A_b=(a_{b1},a_{b2},\ldots,a_{bn}) \tag{1}$$

where the value of the best criterion b, which is superior to criterion j, is represented by a_{bj}. By itself, the best criterion pairwise comparison must have a value of 1, or $a_{bb}=1$.

Step 4: *Create the others to worst (OW) vector.* This step involves generating the OW vector utilizing the worst criterion as a reference comparison with worst. The decision-maker assesses the remaining criteria on a scale of 1–9 in relation to the worst criterion. The OW vector, expressed in Eq. (2), is then formulated based on the comparisons between the worst criteria and the remaining criteria.

$$A_w=(a_{1w},a_{2w},\ldots,a_{nw})^T \tag{2}$$

where a_{jw} denotes how much the remaining criterion j is more important than the least important criterion w. By itself, the worse criterion pairwise comparison must have a value of 1, or $a_{ww}=1$.

Step 5: *Determine the ideal weight for each criterion* $\left(w_1^*,w_2^*,\ldots,w_n^*\right)$. During this stage, we construct the nonlinear optimization model of the BWM approach by using Eq. (3).

$$\min\ \xi$$

$$s.t.$$

$$\left|\frac{w_b}{w_j}-a_{bj}\right|\le\xi, \tag{3}$$

$$\left|\frac{w_j}{w_w}-a_{jw}\right|\le\xi,$$

$w_j\ge 0, for\ all\ j$ which in this model $\sum_j w_j=1$. When there are n criteria in total, the model can only compare pairs of $4n$–5 constraints in Eq. (3) solution set. Ultimately, the weight of all criteria combined is equal to 1.

Step 6. *Make the consistency of the decision maker's assessment.* The consistency ratio is calculated following the procedure mentioned in Rezaei [12]. This is the non-linear version of BWM, and the

consistency check is employed considering the formulations in the related reference.

The BWM has been extended to handle uncertainty and subjective judgments. Triangular Fuzzy BWM (TFBWM) uses triangular fuzzy numbers for pairwise comparisons, addressing vagueness in human judgments [65,66]. This is particularly beneficial when precise values are challenging, providing a more flexible decision-making tool [67]. Interval Type-2 Fuzzy BWM (IT2FBWM) further enhances uncertainty modeling by using interval type-2 fuzzy sets, ideal for highly ambiguous environments. It allows for a more thorough representation of uncertainty [68–71]. Bayesian BWM (BBWM): Integrating Bayesian probability theory, BBWM updates its parameters as new data is introduced, translating subjective judgments into probabilistic terms [72]. This approach enables aggregating multiple decision-makers' assessments into a unified model, preserving the full information spectrum without oversimplifying complex judgments [73,74]. BBWM's strengths in probabilistic modeling, dynamic updating, and opinion aggregation make it ideal for group decision-making [75–78].

3.1.2. Entropy method

The entropy weight method, a widely used Multi-Criteria Decision Making (MCDM) technique, determines criteria significance based on their variability. Introduced by Shannon and Weaver in 1947, it is particularly responsive to variation within each criterion, effectively distinguishing between alternatives and assigning weights accordingly. The process involves normalizing the initial data matrix, then calculating entropy and divergence for each criterion. Here, entropy reflects a criterion's uncertainty level and the information it conveys [13,14,79–84]. Key steps in the entropy weight method include:

Step-1: Let us use a set of m alternatives and a set of n criteria in the problem. x_{ij} is the evaluation of alternative i with respect to the criterion j. Based on this notation, the decision matrix is formulated as in Eq. (4).

$$D = (x_{ij}) = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix} \tag{4}$$

Step-2: The decision matrix is then normalized as demonstrated in Eq. (5).

$$\overline{D} = (\eta_{ij}) = \frac{x_{ij}}{\sum_{r=1}^{m} x_{rj}} \tag{5}$$

Step-3: An entropy is calculated in this step as provided in Eq. (6).

$$e_j = -k \sum_{i=1}^{m} \eta_{ij} * \ln(\eta_{ij}) \tag{6}$$

Here, k is a constant number that provides $0 \le e_j \le 1$ and is computed as $k = \frac{1}{\ln(m)}$.

Step-4: The degree of difference is computed via Eq. (7). The higher the d_j values, the higher the significance of the relevant criterion.

$$d_j = 1 - e_j \tag{7}$$

Step-5: The importance weight of a criterion is calculated via Eq. (8).

$$w_r = \frac{d_r}{\sum_{r=1}^{n} d_r}, r \in [1, 2, .., n] \tag{8}$$

3.1.3. Ratio product model

This section introduces the RPM, which ensures accurate rankings, remains neutral to the normalization of the performance matrix, and maintains consistent rankings in various contexts. To apply the RPM, both the criteria weights and the performance matrix need to be converted into ratio forms. Given a performance matrix A for m alternatives and n criteria with corresponding weights w, the RPM follows these steps [10]:

Step-1: Calculate the weight ratio vector $\widehat{w}$ by dividing each criterion weight by the smallest weight value. Let $w_{min} = \min_{1 \le i \le n} w_i$, $\widehat{w}$ is computed as in the following formulae Eq. (9). This approach designates the criterion with the smallest weight as the reference point, against which the importance of other criteria is measured.

$$\widehat{w} = \left[\frac{w_1}{w_{min}}, \frac{w_2}{w_{min}}, \ldots, \frac{w_n}{w_{min}} \right] \tag{9}$$

Step-2: For each criterion, construct a matrix by calculating all possible ratios between the performance values of the alternatives for that criterion. This step yields n matrices, denoted as M^k ($k = 1,2, \ldots,n$), which represent the performance ratios of alternatives for each criterion. Since these matrices reflect the preferences of alternatives based solely on each criterion and do not account for the criteria's importance, they are termed local pairwise ratio matrices (PRMs).

Step-3: Create scaled pairwise ratio matrices $\widehat{M}$ by applying the weight ratios to the corresponding local PRM matrices. The weight ratio is directly multiplied by values greater than one in the matrix, the inverse of the weight ratio is applied to values less than one, and values equal to one remain unchanged. Thus, the elements of matrix $\widehat{M}^k$, demonstrated by M_{ij}^k is computed as in Eq. (10).

$$\widehat{M}_{ij} \begin{cases} \widehat{w}_k M_{ij}^k & if\ M_{ij}^k > 1 \\ \dfrac{M_{ij}^k}{\widehat{w}_k} & if\ M_{ij}^k (1 \\ M_{ij}^k & if\ M_{ij}^k = 1 \end{cases} \tag{10}$$

The matrices $\widehat{M}^k$ are comparable and they consider the criteria weights.

Step-4: Finally, determine the global preferences among alternatives by combining the scaled PRMs $\widehat{M}^k$ using the geometric mean. This aggregated matrix, representing the global PRM, is denoted as M^{agg}.

3.1.4. Methods used in the comparison

Since our study's main argument is to propose a comparative framework, it is useful to briefly examine the MCDM methods to be compared here. The choice of MCDM methods is closely related to the characteristics of the method under study, the objectives of the research, and the experience of the research [33]. We aim to test three different MCDM methods on our dataset to observe how their results compare with RPM. *SAW*, introduced by Ref. [85], is a straightforward MCDM technique that involves normalizing the decision matrix and summing weighted values for each criterion. The alternative with the highest score is deemed the best. SAW has been applied across domains, including IoT system selection [86], capital investment [87] and [88]. *VIKOR* is a compromise-based method by Opricovic [89] and it ranks alternatives by balancing closeness to the ideal solution and minimizing "regret" for the worst criterion outcome. Its compromise solution approach makes it valuable in group decision-making. It is widely used in fields like material optimization [90] and healthcare waste technology [91], and so on [92–98]. *TOPSIS* ranks alternatives based on proximity to the ideal and distance from the negative-ideal solution [99].

Popular in scenarios requiring performance evaluation, TOPSIS is applied in fields like supply chain management [100], material selection [101] and some others [102–105]. Comparing RPM to these methods is essential, as RPM addresses limitations in traditional methods like WSM and WPM. By benchmarking against VIKOR, TOPSIS, and SAW, we assess RPM's accuracy, robustness, and its capacity to capture the complexities of Türkiye's Green Deal compliance. This selection ensures a robust comparative analysis, incorporating methods that address compromise, ideal solution proximity, and simplicity. Ultimately, these benchmarks will validate RPM's performance, strengths, and potential areas for improvement in sustainability assessments.

3.2. The proposed methodology

The proposed approach starts by establishing a criteria system focused on three main criteria—reducing, enabling, and protecting—divided into sub-criteria: six for reducing, five for enabling, and three for protecting. Data for each sub-criterion has been gathered from reputable sources and international institutions, with details provided in subsequent sections. The weighting of each criterion combines subjective and objective methods, using the Best Worst Method (BWM) and its derivatives (TFBWM, IT2FBWM, and BBWM) for subjective weighting, while objective weights are determined through the Entropy method. The process begins with criteria and sub-criteria setup, followed by data collection. BWM and its derivatives yield subjective weights, while Entropy provides objective weights. Final weights are achieved by combining these through four variations: Entropy & BWM, Entropy & TFBWM, Entropy & IT2FBWM, and Entropy & BBWM. These weights are then applied to assess Türkiye's Green Deal compliance from 2017 to 2021 b y calculating weight ratio vectors for each criterion and creating scaled pairwise ratio matrices, which are combined via the geometric mean to determine preferences among the years. The final ranking employs four models: Entropy-BWM & RPM, Entropy-TFBWM & RPM, Entropy-IT2FBWM & RPM, and Entropy-BBWM & RPM. The analysis includes a methodological comparison with EU countries and sensitivity analysis to confirm robustness. Additionally, the framework benchmarks against three other MCDM methods (SAW, VIKOR, and TOPSIS). The approach concludes with managerial recommendations, providing insights for Türkiye's alignment with the Green Deal. A detailed flowchart of the framework is shown in Fig. 1.

4. Application case

4.1. Description of data set

In this study, inspired by the work of Ozdemir et al. [106], which evaluates the Green Deal performance of EU member states, the objective is to conduct a Green Deal performance assessment for Türkiye. The

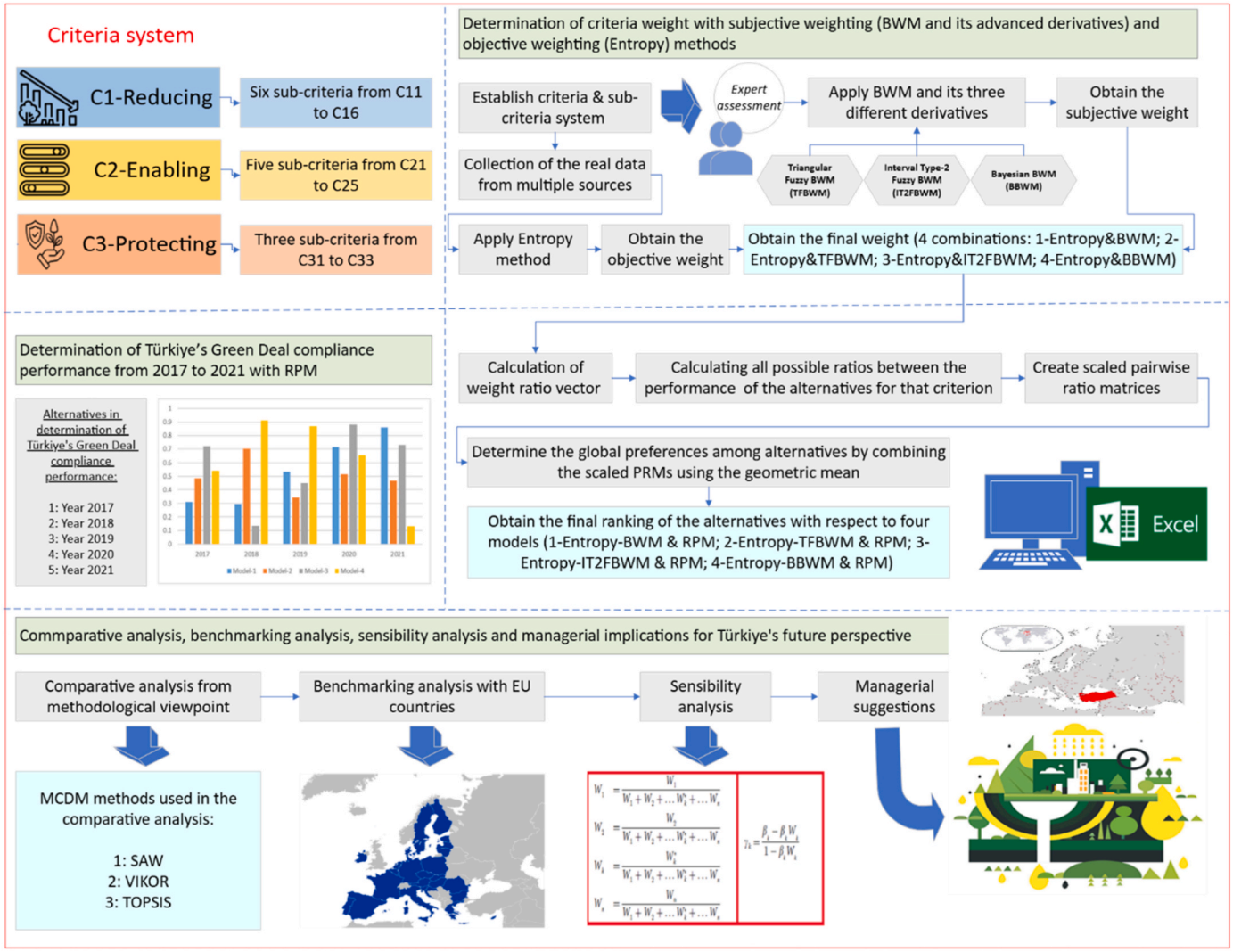


Fig. 1. Flowchart of the hybrid comparative framework.

Green Deal, which aims to improve the impacts of climate change across all areas of life, is of significant importance for EU member states and all countries engaged in commercial cooperation with these states. Türkiye places high importance on Green Deal objectives due to its status as an EU candidate country and its substantial commercial relations with EU member states. Compliance with the Green Deal, which involves a lengthy process and significant policies, is valuable for Türkiye both in the present and future. The criteria mentioned in the study by Özdemir et al. [106] were derived from EuroStat European Green Deal statistics. However, due to the limited availability of data specific to Türkiye for the 2017–2021 period, not all criteria could be utilized. Data were available for a total of 14 sub-criteria across 3 main criteria (reducing, enabling, and protecting). In our study, we have also searched in other databases, but we faced similar limitations. Thus, our analysis is based on the data that were accessible for the 2017–2021 interval, which constrains the scope of our study. The selection of these specific criteria was guided by their direct alignment with the objectives of the European Green Deal and their capacity to provide actionable insights for policymakers. For example, the "Reducing" main criterion emphasizes efforts to mitigate climate change impacts, and its sub-criteria (C_{11}-C_{16}) capture critical aspects such as greenhouse gas emissions, renewable energy use, and sustainable mobility. These indicators reflect Türkiye's efforts to meet global and regional sustainability goals. Similarly, the "Enabling" main criterion highlights structural enablers of a green transition, such as R&D expenditures, environmental tax revenues, and high-capacity internet access, which are vital for fostering sustainable economic growth. Meanwhile, the "Protecting" criterion addresses biodiversity and sustainable agricultural practices, aligning with the Green Deal's commitment to safeguarding the planet and health.

The Green Deal has a significant impact on the efforts to tackle climate change. It will have a direct impact on certain indicators. Robust and multidisciplinary sustainability measurement indicators are needed to assess the impacts of climate change. Climate change is linked not only to environmental but also to social and economic factors. Therefore, it is important to consider these multifaceted interactions [107]. Tutak and Brodny [33], Özdemir et al. [106] and Tutak et al. [34], who conducted similar studies in this direction, created the criteria through the data obtained from EuroStat.

Explanations for these data are provided below and graphed in Fig. 2. The first main criterion, "reducing," can be defined as a set of efforts aimed at mitigating the negative impacts of emerging climate change. The sub-criteria related to this main criterion are as follows: (C_{11}-C_{16}):

C_{11}: The criterion shows the sum of the greenhouse gas emission values in CO2 equivalent. This data, expressed in millions of tons per year, is taken from the Turkish Statistical Institute-TurkStat [108], and includes the sum of CO2 (carbon dioxide), N2O nitrous oxide and F-gases.

C_{12}: Share of renewable energy sources in total energy consumption. It shows the share of self-renewing energy sources such as solar, wind, hydro, geothermal, liquid and gaseous biofuels in households, industry, agriculture and services. It shows the share of renewable energy sources in the total of all energy sources in thousand tons of oil equivalent (TOE). Data for Türkiye are calculated from the National Energy Balance Tables of the Ministry of Energy and Natural Resources [109].

C_{13}: Total energy consumption of a country. Data are taken from EuroStat [110] and are expressed in million tons per year.

C_{14}: Zero emission vehicles are electric and hydrogen powered vehicles that do not directly emit harmful gases (exhaust) into the atmosphere. Data from TurkStat [111], show the share of electric vehicles in total.

C_{15}: Share of railways in passenger transport. Data on the share of railways in total transport modes based on the number of passengers transported per km are taken from EuroStat [112].

C_{16}: This criterion shows the volume of freight transport by road in Türkiye. The data obtained from the road transport statistics of the General Directorate of Highways [113], indicate the share of million

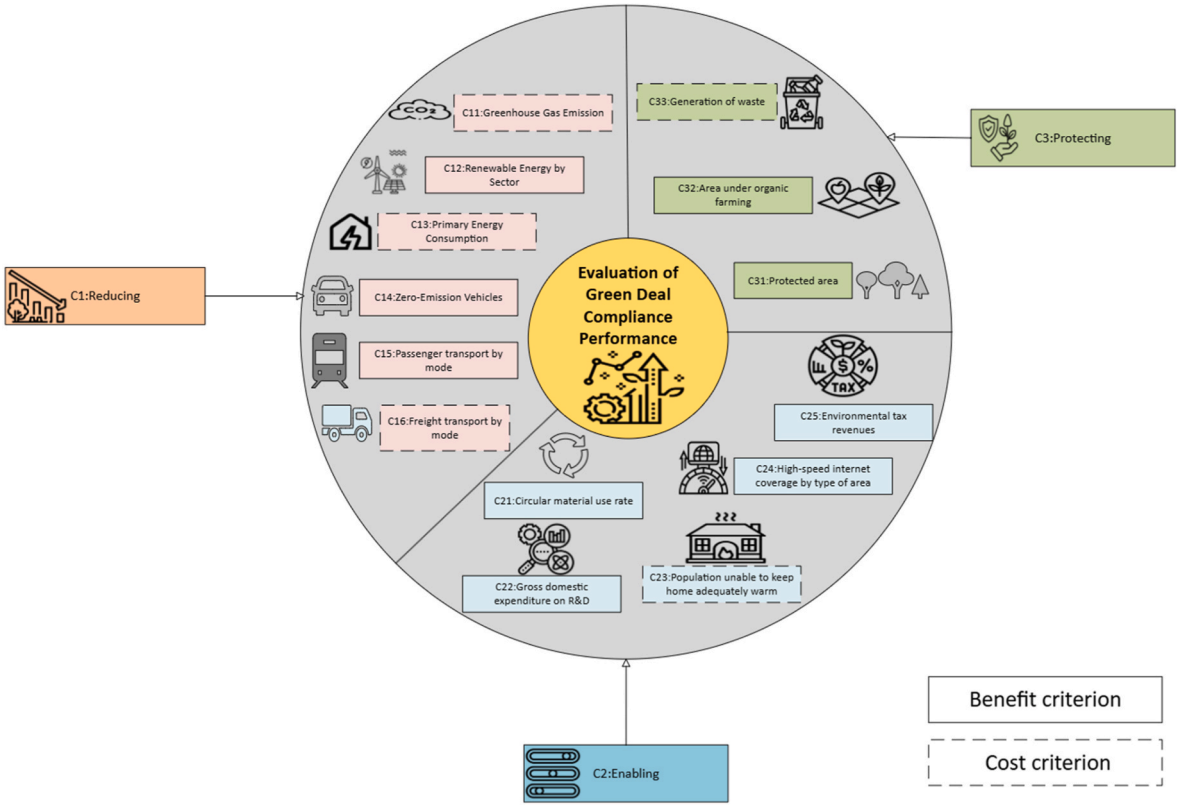


Fig. 2. The criteria system regarding evaluation of Green Deal compliance performance. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

tons of freight transport per km in total.

The main criterion, "enabling," aims to facilitate a fair and environmentally sustainable green transition towards the goals expected to be achieved with stakeholders through the Green Deal. The sub-criteria related to this main criterion are as follows (C_{21}-C_{25}):

C_{21}: Circular material use aims to reduce environmental impacts in total material use by using secondary materials, which are intended to be recycled and reintroduced to the economy, instead of raw materials. The data are taken from the study by Johansson and Korkmaz [114] show the share of recycled materials in the total material utilization rate for Türkiye.

C_{22}: The percentage share of research and development expenditures in gross domestic product. Data on the share of R&D expenditures in total gross domestic product in Türkiye are obtained from EuroStat [115].

C_{23}: It shows the percentage share of the population that cannot afford to heat their homes due to financial reasons within the total population. The data obtained from EuroStat [116] aim to monitor poverty and social conditions.

C_{24}: High-capacity internet network refers to fiber networks or electronic communication networks that provide similar performance. It shows the percentage share of high-capacity internet network usage rate in the total population Data are taken from the Information and Communication Technologies Authority- ICTA [117] of Türkiye.

C_{25}: Environmental tax revenues refer to taxes on energy, environment, transport, pollution and resources that are imposed where there is a proven negative environmental impact. Data from OECD [118] represent the percentage of environmental taxes in total GDP.

Finally, the main criterion "protecting" aims to safeguard our planet and health, including animals, nature, and people. The sub-criteria related to this main criterion are as follows (C_{31}-C_{33}):

C_{31}: It refers to the percentage share of land and water areas protected by the state through various laws and rules in total area. Data are taken from Ministry of Agriculture and Forestry [119].

C_{32}: Indicates the percentage share allocated to organic agriculture within the area used for agriculture. Organic agriculture areas refer to the performance of agricultural activities that are sensitive to the environment and animal health by using all kinds of chemical inputs such as fertilizers, additives, etc. used in production either at all or at the minimum level. Data for Türkiye are obtained from EuroStat [120].

C_{33}: Total waste materials produced per capita in a country. The data obtained from EuroStat [121] expresses the amount of hazardous or non-hazardous waste per capita in kg.

4.2. Determination of criteria weight with subjective and objective weighting

4.2.1. Application of the entropy method

The Entropy method is a mathematical approach used to calculate the objective weights of criteria in a decision-making problem. It evaluates the amount of uncertainty or randomness in the data for each criterion, with the idea that criteria with higher variability provide more information and thus are given more weight. As stated in the methods section, the first two steps involve normalizing the data for each sub-criterion to ensure comparability across different units and scales. Table 1 demonstrates the data set gathered for this research. For each sub-criterion, the entropy value is calculated to determine the degree of dispersion or uncertainty in the data. The degree of diversification is then computed to measure the amount of useful information provided by each sub-criterion. Finally, the objective weights for each sub-criterion are derived by normalizing the degree of diversification values. Fig. 3 presents the final objective weights for each sub-criterion based on the Entropy method.

The computational results indicate that the sub-criterion C21 (Circular material use rate) in the Enabling (C2) category received the highest objective weight (0.1192), highlighting its high variability and

Table 1
Green deal compliance performance criteria.

Main Criteria	Reducing						Enabling				Protecting			
Sub-criteria	C11	C12	C13	C14	C15	C16	C21	C22	C23	C24	C25	C31	C32	C33
Criterion type	Cost	Benefit	Cost	Benefit	Benefit	Cost	Benefit	Benefit	Cost	Benefit	Benefit	Benefit	Benefit	Cost
Year/ Criteria	Greenhouse gase emission (Million tonnes)	Renewable energy by sector (% of gross final energy consumption | total) BİN TEP	Primary energy consumption (Million tonne)	Zero-emission vehicles (% of newly registered passenger cars)	Passenger transport by mode (% in total inland passenger-km | rail (sum))	Freight transport by mode (% in total inland freight millione tonne-km | road)	Circular material use rate (% of material input for domestic use)	Gross domestic expenditure on R&D (% of GDP | all sectors (total))	Population unable to keep home adequately warm (% of population | total)	High-speed internet coverage by type of area (% of households | total)	Environmental tax revenues (% of total GDP)	Protect area (Protected area | % of total area)	Area under organic farming (% of utilized agricultural area)	Generation of waste (Kilograms per capita | hazardous and non-hazardous (total))
2017	531.1	4.724	145.5	0.00631	1.5	90	3.16	1.18	20.7	14.76	3.09	4.2786	1.49	953
2018	528.1	5.308	143.4	0.00768	1.7	89.2	4.56	1.27	19.1	16.35	2.3	4.4111	1.69	1195
2019	515.6	5.186	144.8	0.00941	3.2	89.2	4.56	1.32	19.2	17.11	2.09	4.5145	1.46	1195
2020	530.2	5.201	141.6	0.02135	2.1	88.3	4.5	1.37	20.3	20.01	2.63	4.6491	1.01	1291
2021	572.0	4.938	156.1	0.04572	2.7	92.5	4.5	1.4	20.5	21.42	1.61	4.6794	0.93	1291

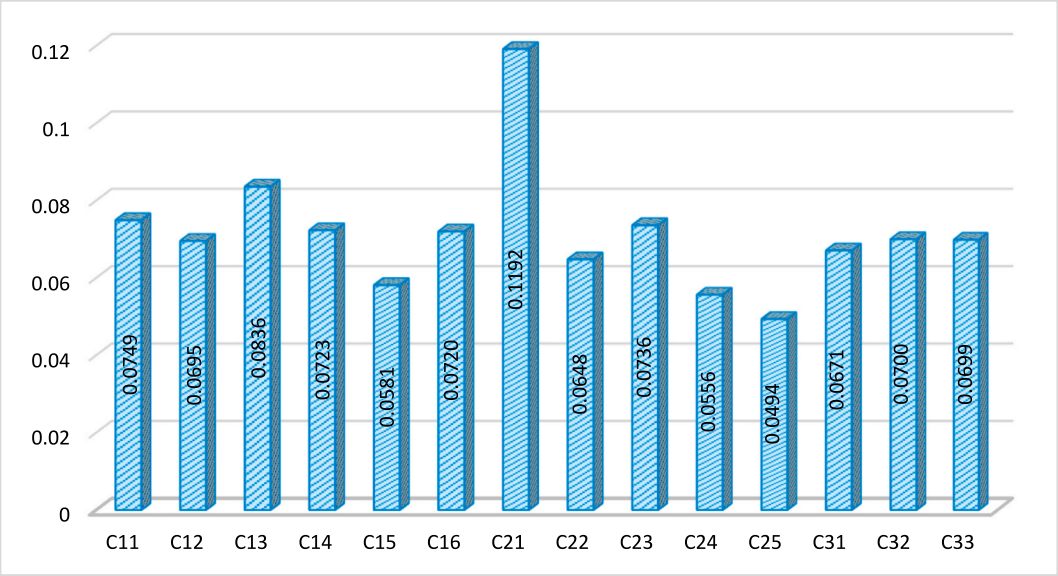


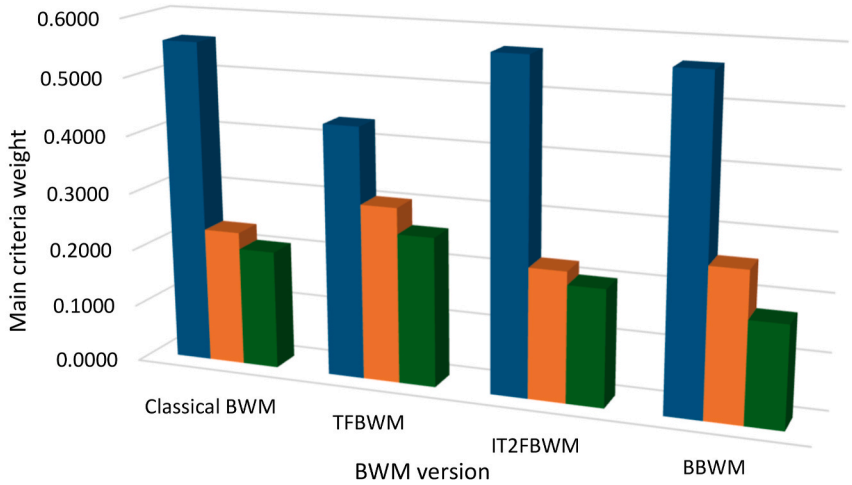
Fig. 3. Results of sub-criteria weights by objective weighting of entropy method.

relevance to Türkiye's Green Deal compliance between 2017 and 2021. This reflects the significance of circular economy practices in sustainable development. Conversely, C25 (Environmental tax revenues) in the same category received the lowest weight (0.0494), suggesting consistent data and possibly less emphasis relative to other criteria. Within the Reducing (C1) category, C13 (Primary energy consumption) has a higher weight (0.0836) than C15 (Passenger transport by mode) (0.0581), indicating more informative energy consumption data for compliance analysis. Overall, weight distribution among sub-criteria suggests a balanced assessment framework, ensuring no single criterion disproportionately impacts the overall evaluation. This balance offers policymakers insight into areas like C21, guiding strategies for improved sustainability practices.

The Entropy method effectively provides objective criterion weights based on data variability. Additionally, the study integrates subjective weighting through the Best Worst Method (BWM) and its advanced versions—Triangular Fuzzy BWM (TFBWM), Interval Type-2 Fuzzy BWM (IT2FBWM), and Bayesian BWM (BBWM). Combining subjective and objective methods enables a comprehensive approach, enhancing the criteria weights' reliability for evaluating Türkiye's compliance with the Green Deal. The following section will discuss the application and results of BWM and its derivatives.

4.2.2. Application of the BWM and its advanced derivatives

This section presents the results of applying four BWM methods to determine the subjective weights of criteria. For this evaluation, five experts contributed: three prominent academics specializing in Green Deal, sustainability, and environmental policy, and two experienced



	Classical BWM	TFBWM	IT2FBWM	BBWM
C1–Reducing	0.5591	0.4360	0.5716	0.5648
C2–Enabling	0.2346	0.3044	0.2255	0.2581
C3–Protecting	0.2063	0.2596	0.2029	0.1771

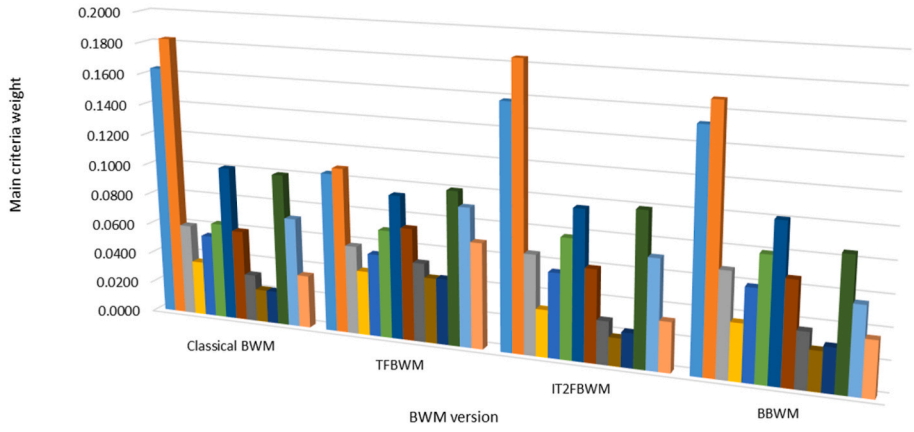
Fig. 4. Results of main-criteria weights by subjective weighting (Four different BWM).

practitioners with hands-on expertise in Türkiye's Green Deal implementation, particularly in energy, transportation, and environmental sectors. This balanced expert panel integrates academic depth with practical insight, ensuring comprehensive and contextually relevant criteria weighting. The main criteria weights—Reducing, Enabling, and Protecting—were assessed using the BWM and its derivatives: Triangular Fuzzy BWM (TFBWM), Interval Type-2 Fuzzy BWM (IT2FBWM), and Bayesian BWM (BBWM). Fig. 4 displays the resulting main criteria weights across these methods.

The four BWM methods employed—Traditional BWM, Triangular Fuzzy BWM (TFBWM), Interval Type-2 Fuzzy BWM (IT2FBWM), and Bayesian BWM (BBWM)—yielded slightly different weights for each main criterion due to their distinct methodological approaches. The Traditional BWM produces a more deterministic outcome, while the fuzzy and Bayesian variants effectively incorporate uncertainty and the variability of expert judgments. In the Traditional BWM, TFBWM, and IT2FBWM, the aggregation of expert evaluations is achieved by averaging each expert's pairwise comparisons. This method captures the collective judgment of the five experts, ensuring that diverse perspectives are reflected in the final weights and mitigating potential biases in individual assessments. In contrast, the BBWM eliminates the need for aggregation, as it incorporates probabilistic models to derive weights directly from expert evaluations. This unique characteristic of BBWM allows it to account for individual opinions without aggregation, providing a robust alternative to traditional methods and enhancing the accuracy of the results.

The "Reducing" criterion consistently ranks highest across all four BWM methods, indicating that experts prioritize it most significantly. The weights assigned by the Classical BWM, IT2FBWM, and BBWM range from approximately 0.55 to 0.57, reflecting a strong consensus on its importance. In contrast, TFBWM assigns a slightly lower weight of 0.4360, likely due to its incorporation of fuzziness, which accommodates variability in expert opinions. The "Enabling" criterion demonstrates notable variability in its assigned weights. TFBWM assigns the highest weight of 0.3044 to "Enabling," suggesting that in contexts involving uncertainty and fuzzy logic, experts may perceive enabling factors as more critical to achieving broader environmental goals. Classical BWM and IT2FBWM provide lower and relatively similar weights of 0.2346 and 0.2255, respectively, indicating a more moderate importance in less flexible settings. BBWM's weight of 0.2581 lies between the Classical and TFBWM results, indicating a balanced perspective that values "Enabling" slightly more than deterministic methods. The "Protecting" criterion generally receives the lowest weights across all methods, suggesting that experts view it as less critical than "Reducing" and "Enabling." TFBWM again assigns a higher weight of 0.2596 for "Protecting," indicating that under fuzzy conditions, it may be regarded as more vital. Classical BWM and IT2FBWM yield similar weights of 0.2063 and 0.2029, respectively, while BBWM assigns the lowest weight of 0.1771, implying that experts perceive protection measures as less significant when accounting for probabilistic variations. This lower weight may reflect a belief that the immediate impact of protection measures is less substantial compared to the other criteria.

The weights reveal that "Reducing" is recognized as the most crucial main criterion for Green Deal compliance, while the significance of "Enabling" and "Protecting" fluctuates based on the specific BWM method applied. This trend underscores a shared expert focus on emission reduction as a key driver of environmental performance. Classical BWM and IT2FBWM generally yield similar weight distributions, indicating a more deterministic interpretation of expert judgments. In contrast, TFBWM assigns higher weights to "Enabling" and "Protecting,"



	Classical BWM	TFBWM	IT2FBWM	BBWM
C11–Greenhouse gas emission	0.1635	0.1037	0.1583	0.1532
C12–Renewable energy by sector	0.1830	0.1078	0.1846	0.1680
C13–Primary energy consumption	0.0597	0.0579	0.0651	0.0679
C14–Zero-emission vehicles	0.0357	0.0421	0.0307	0.0367
C15–Passenger transport by mode	0.0541	0.0540	0.0551	0.0592
C16–Freight transport by mode	0.0631	0.0704	0.0778	0.0800
C21–Circular material use rate	0.1011	0.0937	0.0967	0.1010
C22–Gross domestic expenditure on R&D	0.0596	0.0733	0.0600	0.0667
C23–Population unable to keep home adequately warm	0.0309	0.0517	0.0281	0.0362
C24–High-speed internet coverage by type of area	0.0216	0.0427	0.0183	0.0255
C25–Environmental tax revenues	0.0214	0.0430	0.0224	0.0286
C31–Protect area	0.0999	0.1003	0.0995	0.0850
C32–Area under organic farming	0.0718	0.0906	0.0710	0.0561
C33–Generation of waste	0.0346	0.0688	0.0324	0.0360

Fig. 5. Results of sub-criteria weights by subjective weighting (Four different BWM).

likely due to its incorporation of fuzzy logic, which captures a broader spectrum of expert opinions and the associated uncertainties. BBWM, while offering a balanced perspective, tends to assign lower weights to "Protecting," suggesting a preference for more actionable criteria when using probabilistic approaches. This comprehensive analysis highlights how various BWM versions can provide diverse insights into expert priorities, emphasizing the necessity of integrating multiple perspectives when evaluating Green Deal compliance performance.

Fig. 5 illustrates the weights of sub-criteria determined by the four BWM methods (Classical BWM, TFBWM, IT2FBWM, and BBWM). Overall, the Traditional BWM and IT2FBWM yield similar weights for many sub-criteria, indicating a close alignment in how these approaches capture expert preferences, with IT2FBWM accounting for uncertainties within a limited range. BBWM weights typically fall between those of Classical BWM and IT2FBWM, reflecting a moderate adjustment that acknowledges some variability in expert judgments without extreme fluctuations, unlike the fuzzy methods. The TFBWM method often assigns higher or notably different weights, especially for sub-criteria in the "Enabling" and "Protecting" categories, such as "Circular Material Use Rate," "Population Unable to Keep Home Adequately Warm," and "Generation of Waste." This increased variability can be attributed to the fuzzy nature of TFBWM, which captures a broader range of uncertainty in expert opinions. This suggests that allowing for less precision in assessments may lead to significant shifts in perceived importance among certain criteria.

Across all methods, "Greenhouse Gas Emission" and "Renewable Energy by Sector" received consistently high weights, underscoring their critical role in assessing Green Deal compliance. This agreement among experts highlights the importance of emissions reduction and renewable energy for environmental performance. Sub-criteria like "Protect Area" and "Circular Material Use Rate" also garnered relatively high weights, especially in TFBWM, indicating their recognized significance in promoting environmental sustainability and resource efficiency. In contrast, sub-criteria such as "Zero-Emission Vehicles," "High-Speed Internet Coverage by Type of Area," and "Environmental Tax Revenues" received lower weights across all methods. This suggests that experts do not view these factors as primary drivers of Green Deal compliance, possibly due to their indirect impact on immediate environmental outcomes. The variations in weights assigned by the four methods illustrate how different methodological approaches influence decision-making. Classical BWM offers a clear, deterministic assessment, while TFBWM captures a broader range of expert opinions, introducing higher variability that can be beneficial in uncertain contexts. IT2FBWM strikes a balance between precision and flexibility, incorporating fuzziness within a controlled range. BBWM accommodates probabilistic variations, resulting in weights that reflect a nuanced and balanced perspective. The analysis demonstrates that different Best-Worst Methods (BWM) yield varying results due to their unique methodological characteristics. The Classical BWM and IT2FBWM methods exhibit a strong alignment, indicating stable expert preferences in deterministic and controlled fuzzy scenarios. In contrast, TFBWM captures a broader range of expert uncertainty, highlighting higher variability in the perceived importance of certain criteria. Meanwhile, Bayesian BWM (BBWM) offers a balanced perspective, incorporating probabilistic elements that reflect more nuanced expert judgments.

When the criteria weights are evaluated according to all methods, some clues are provided about which areas countries should focus on. The most important criteria determined are Renewable energy by sector, Area under organic farming, Greenhouse gas emission, Gross domestic expenditure on R&D and Protected area. It has been determined that improving these criteria is very important in reducing carbon emissions. Although improvements in these criteria require high resource usage and relatively long time, they are of critical importance in achieving the determined target.

Overall, the weights assigned to sub-criteria emphasize a clear prioritization of factors directly linked to emissions reduction and energy use, which aligns well with the primary goals of Green Deal compliance. The choice of BWM method significantly affects the emphasis placed on secondary criteria, underscoring the importance of selecting an appropriate methodological approach based on the decision context and the nature of the criteria being evaluated. The final stage of the BWM application involves assessing the consistency of pairwise evaluations from the five experts. The consistency results provide vital insights into the reliability and rationality of expert assessments across various criteria and sub-criteria (as shown in Table 2). The consistency ratio (CR) quantifies the level of agreement in the pairwise comparisons made by the experts. A lower CR indicates higher consistency, suggesting that the experts' judgments are logically sound and align well with one another. In this study, all experts achieved CRs significantly below the threshold values for assessing the main criteria, with CR values ranging from 0.0238 (Expert 4) to 0.0667 (Experts 1 and 2). The threshold values are approximately 0.1294–0.1354, indicating a high level of consistency among all experts in their assessments of the main criteria. Since all CRs are well below the threshold values, this confirms the reliability and consistency of the judgments. Moreover, an evaluation of the consistency of sub-criteria under the main categories (C1, C2, and C3) reveals that all experts have CRs well below the threshold, indicating strong consistency in their assessments of sub-criteria associated with each main criteria category. This strong consistency is crucial for the validity of the BWM model, ensuring that the weights derived from the experts'

Table 2
Consistency check results for BWM application.

Expert ID	Consistency ratio (CR)			
	Main criteria assessment	Sub-criteria under C1 assessment	Sub-criteria under C2 assessment	Sub-criteria under C3 assessment
Expert-1	0.0667	0.0833	0.0000	0.1250
Expert-2	0.0667	0.0972	0.0000	0.2000
Expert-3	0.0500	0.0833	0.0000	0.0714
Expert-4	0.0238	0.1250	0.0000	0.0667
Expert-5	0.0500	0.0139	0.0000	0.1786
Expert ID	Threshold value			
	Main criteria assessment	Sub-criteria under C1 assessment	Sub-criteria under C2 assessment	Sub-criteria under C3 assessment
Expert-1	0.1330	0.3337	0.1330	0.3062
Expert-2	0.1330	0.3337	0.1330	0.2643
Expert-3	0.1354	0.3337	0.1121	0.2819
Expert-4	0.1294	0.3337	0.1121	0.2643
Expert-5	0.1354	0.3337	0.1359	0.2958
Expert ID	Final decision: (CR < Threshold = Consistent; Otherwise = Inconsistent)			
	Main criteria assessment	Sub-criteria under C1 assessment	Sub-criteria under C2 assessment	Sub-criteria under C3 assessment
Expert-1	Consistent	Consistent	Consistent	Consistent
Expert-2	Consistent	Consistent	Consistent	Consistent
Expert-3	Consistent	Consistent	Consistent	Consistent
Expert-4	Consistent	Consistent	Consistent	Consistent
Expert-5	Consistent	Consistent	Consistent	Consistent

judgments are robust and trustworthy. The consistency in expert evaluations reinforces the credibility of the assessments regarding sub-criteria importance, confirming the robustness of the BWM application for multi-attribute decision-making. This reliability is essential for ensuring that the derived weights accurately reflect collective expert opinions. To integrate weights from objective methods, like the Entropy method, and subjective methods such as BWM, a weighted arithmetic mean is commonly used in Eq. (10).

$$w_j = \left(\alpha \times w_j^{objective}\right) + \left(\beta \times w_j^{subjective}\right) \tag{10}$$

where: $w_j^{objective}$ is the objective weight for criterion j (from Entropy), $w_j^{subjective}$ is the subjective weight for criterion j (from BWM and its derivatives), α and β are the weights assigned to the subjective and objective method result. If you assume equal importance for both subjective and objective weights $(\alpha = \beta = 0.5)$, the formulas simplify to:

$$w_j = \frac{w_j^{objective} + w_j^{subjective}}{2} \tag{11}$$

Table 3 gives the merged sub-criteria weighting results both from objective and subjective manner. As the output of the first stage (identified in Fig. 1), four different weight vectors were obtained. They will be further used in the RPM application section.

4.3. Application of the RPM

By applying Rezaei's Ratio Product Model (RPM), Türkiye's compliance performance with the Green Deal from 2017 to 2021 was evaluated. The RPM effectively assesses alternatives based on a set of criteria, integrating both subjective and objective weights while considering performance ratios. Results were obtained for various models: Entropy-BWM & RPM, Entropy-TFBWM & RPM, Entropy-IT2FBWM & RPM, and Entropy-BBWM & RPM. These outputs were interpreted by analyzing (1) the ranking of alternatives (years) and (2) consistency across models. The global preferences were determined using the geometric mean across all models. The matrices for each model are as follows:

$$M^{agg}(\text{Entropy} - \text{BWM \& RPM}) = \begin{pmatrix} 1 & 0.0205 & 0.0422 & 0.0231 & 0.0001 \\ 48.7 & 1 & 3.3050 & 0.3005 & 0.0099 \\ 23.7 & 0.3 & 1 & 0.1157 & 0.0484 \\ 43.2 & 3.3 & 8.6 & 1 & 0.0765 \\ 14431.8 & 101.4 & 20.7 & 13.1 & 1 \end{pmatrix}$$

$$M^{agg}(\text{Entropy} - \text{TFBWM \& RPM}) = \begin{pmatrix} 1 & 0.0475 & 0.0736 & 0.0403 & 0.0009 \\ 21.0 & 1 & 1.9604 & 0.2989 & 0.0263 \\ 13.6 & 0.5 & 1 & 0.2332 & 0.0756 \\ 24.8 & 3.3 & 4.3 & 1 & 0.2108 \\ 1054.5 & 38.0 & 13.2 & 4.7 & 1 \end{pmatrix}$$

$$M^{agg}(\text{Entropy} - \text{IT2FBWM \& RPM}) = \begin{pmatrix} 1 & 0.0272 & 0.0539 & 0.0295 & 0.0001 \\ 36.7 & 1 & 3.7450 & 0.4108 & 0.0108 \\ 18.6 & 0.3 & 1 & 0.1591 & 0.0523 \\ 33.9 & 2.4 & 6.3 & 1 & 0.0778 \\ 13665.0 & 92.9 & 19.1 & 12.9 & 1 \end{pmatrix}$$

$$M^{agg}(\text{Entropy} - \text{BBWM \& RPM}) = \begin{pmatrix} 1 & 0.0439 & 0.0589 & 0.0323 & 0.0001 \\ 22.8 & 1 & 2.7995 & 0.3666 & 0.0125 \\ 17.0 & 0.4 & 1 & 0.1744 & 0.0552 \\ 31.0 & 2.7 & 5.7 & 1 & 0.0821 \\ 7788.7 & 80.1 & 18.1 & 12.2 & 1 \end{pmatrix}$$

The aggregated RPM matrices show Türkiye's compliance performance from 2017 to 2021. A value greater than 1 indicates higher performance for the year in the row compared to the year in the column, while a value less than 1 indicates lower performance. Overall, 2017 has the lowest compliance, with ratios less than 1 when compared to 2018 (0.0205), 2019 (0.0422), 2020 (0.0231), and 2021 (0.0001) in the Entropy-BWM & RPM model. In contrast, 2021 has the highest performance, significantly surpassing all previous years, with 2018 performing well against 2017 (48.7) but lagging behind 2019 (3.3050), 2020 (0.03005), and 2021 (0.0099). The final ranking results are summarized in Table 4.

The analysis suggests that Türkiye's compliance with the Green Deal improved progressively from 2017, with 2021 being the year of peak performance. The year 2017 had the lowest performance, and there was relatively an increase in compliance efforts in the following years, culminating in 2021's strong performance. Each year showed improvements over its predecessor except 2018–2019 term, particularly 2021, which had the highest compliance performance, indicating successful strategies and implementations related to the Green Deal in recent years.

4.4. Discussion of the results

While direct evaluations of Green Deal compliance by countries remain limited, the current study addresses this gap by assessing Türkiye's Green Deal performance across three main criteria—Reducing, Protecting, and Enabling—and 14 sub-criteria. Comparisons with studies by Özdemir et al. [106] and other researchers further highlight Türkiye's progress and position relative to EU member states.

This research evaluates Türkiye's compliance performance from 2017 to 2021, revealing notable progress, particularly in 2021, the country's best-performing year. Comparatively, 2017 marked the weakest performance. This aligns with Özdemir et al. [106], which assessed EU member states using EuroStat data, focusing on indicators such as energy consumption, environmental tax revenues, and transportation metrics. Similarly, studies like Tutak and Brodny [33] used multidimensional approaches, including the European Green Deal Index (EGDI), to analyze Green Deal implementation. These studies share

Table 3
The final weight vectors (merged of objective and subjective weighting).

#	Merging methods		Merged weight value												
	Objective weight	Subjective weight	C11	C12	C13	C14	C15	C16	C21	C22	C23	C24	C25	C31	C32	C33
1	Entropy	BWM	0.1192	0.126	0.072	0.054	0.056	0.068	0.11	0.062	0.052	0.039	0.035	0.083	0.071	0.052
2	Entropy	TFBWM	0.0893	0.089	0.071	0.057	0.056	0.071	0.106	0.069	0.063	0.049	0.046	0.084	0.08	0.069
3	Entropy	IT2FBWM	0.1166	0.127	0.074	0.052	0.057	0.075	0.108	0.062	0.051	0.037	0.036	0.083	0.07	0.051
4	Entropy	BBWM	0.1140	0.119	0.076	0.054	0.059	0.076	0.11	0.066	0.055	0.041	0.039	0.076	0.063	0.053

commonalities in evaluating compliance but differ in scope and methodology. Other works, such as those by Tutak et al. [34] and Doskocil [122], focus on energy and climate sustainability or environmental performance using varied methodologies like Entropy-COPRAS and AHP. The findings from these studies provide valuable benchmarks but often prioritize criteria different from this study, such as renewable energy usage or greenhouse gas emissions. The methodology of this research incorporates a hybrid multi-attribute decision model combining subjective (Best Worst Method) and objective (Entropy) weighting to assess Türkiye's Green Deal performance. This novel approach allows for a nuanced evaluation of the relative importance of criteria. The Ratio Product Model (RPM) was employed for analysis, supported by sensitivity testing to validate robustness.

By contrast, Özdemir et al. [106] utilized the MEREC method to evaluate EU countries, emphasizing criteria such as primary energy consumption and environmental tax revenues. Similarly, Tutak and Brodny [33] developed the EGDI index using methods like CoCoSo and CRITIC to rank countries. Other studies, such as Hoseinzadeh et al. [123] and Wolf et al. [124], adopted simulation models and forecasting methods, focusing on the integration of renewable energy systems or GHG emission trends. These differences highlight the novelty and adaptability of the methods applied in this study. This study underscores the dominant importance of the *Reducing* criterion in Türkiye's compliance, consistent across all weighting methods. The weights of *Enabling* and *Protecting* showed minor variations depending on the applied methods. For instance, the Entropy method identified Circular Material Utilization Rate as the most significant criterion, while Environmental Tax Revenues held the lowest weight.

These results diverge from Özdemir et al. [106], where environmental tax revenues were highly weighted for EU member states but less critical for Türkiye. Tutak and Brodny [33] found Sweden and the Netherlands leading in compliance, with Cyprus performing the weakest. These contrasts illustrate the contextual differences in Green Deal implementation across countries. This study contributes to the Green Deal literature by (1) introducing a hybrid comparative decision model, combining subjective and objective weighting techniques, (2) benchmarking Türkiye's compliance against EU member states, providing actionable insights for policymakers, (3) identifying critical underperforming criteria for targeted improvements. The findings have implications for enhancing Türkiye's compliance strategies, aligning with broader sustainability goals, and informing future research on country-specific Green Deal implementations. While the study offers significant contributions, it is limited to available data from 2017 to 2021 and the specific criteria analyzed. Future research could expand the scope by incorporating more recent data, exploring additional criteria, and applying alternative methodologies for validation.

4.5. Comparative, benchmarking and sensibility analysis

This section presents a comprehensive analysis of Türkiye's Green Deal compliance performance from multiple perspectives. It includes a comparative evaluation using three additional Multi-Criteria Decision-Making (MCDM) methods—Simple Additive Weighting (SAW), VIKOR, and TOPSIS—to validate the robustness and consistency of the ranking results. Additionally, a benchmarking analysis compares Türkiye's performance with that of European Union countries, and a sensitivity analysis assesses the stability of the results under varying conditions and assumptions.

4.5.1. Comparative analysis from methodological viewpoint

In this sub-section, we evaluate Türkiye's Green Deal compliance performance from 2017 to 2021 using various MCDM methods, including SAW, VIKOR, and TOPSIS. Each method integrates different subjective weighting models (BWM, TFBWM, IT2FBWM, BBWM) alongside an objective entropy weighting to assess the robustness of the performance rankings. This comprehensive analysis seeks to identify consistent trends and evaluate the reliability of the results across different methodologies. Table 5 presents the model settings, while Table 6 summarizes Türkiye's Green Deal compliance assessment from 2017 to 2021 using the three MCDM methods with the four subjective weighting models combined with Entropy for objective weighting.

The SAW method results (Models 5 to 8) reveal consistent rankings across all models: 2019 is the best-performing year with the highest weighted averages (0.5719–0.5829), followed by 2021 in second place, 2020 in third, and 2018 in fourth. 2017 ranks last, indicating the least compliance with Green Deal criteria. This uniformity across models highlights a high degree of consistency in the SAW method results, suggesting stable performance assessments regardless of the subjective weighting model used.

The VIKOR method (Models 9 to 12) ranks 2021 as the top-performing year with a VIKOR Q value of 0.0000, indicating clear performance superiority. 2020 ranks second with moderate Q values (0.3909–0.4095), while 2019 is third, and 2018 follows closely in fourth. 2017 ranks last with the highest Q value of 1.0000, reflecting the worst Green Deal compliance. The VIKOR method highlights performance gaps, particularly between 2021 and other years. Similarly, the TOPSIS method (Models 13 to 16) ranks 2021 as the top performer, with closeness coefficient (CC) values ranging from 0.6678 to 0.7008, indicating proximity to the ideal solution. 2020 is second, followed by 2019 in third and 2018 in fourth, while 2017 consistently ranks last with CC

Table 4
Ranking results of the years in performance assessment of Türkiye for Green Deal compliance.

Model ID	Criteria weighting		Performance assessment of the years in terms of Green Deal compliance	Ranking of the years				
	Subjective	Objective		2017	2018	2019	2020	2021
Model 1	BWM	Entropy	Ratio Product Model (RPM)	5th	3rd	4th	2nd	1st
Model 2	TFBWM	Entropy	Ratio Product Model (RPM)	5th	3rd	4th	2nd	1st
Model 3	IT2FBWM	Entropy	Ratio Product Model (RPM)	5th	3rd	4th	2nd	1st
Model 4	BBWM	Entropy	Ratio Product Model (RPM)	5th	3rd	4th	2nd	1st

Table 5
The model setting used in comparative analysis.

Model ID	Criteria weighting		Performance assessment of the years in terms of Green Deal compliance
	Subjective	Objective	
Model 1	BWM	Entropy	Ratio Product Model (RPM)
Model 2	TFBWM	Entropy	Ratio Product Model (RPM)
Model 3	IT2FBWM	Entropy	Ratio Product Model (RPM)
Model 4	BBWM	Entropy	Ratio Product Model (RPM)
Model 5	BWM	Entropy	SAW
Model 6	TFBWM	Entropy	SAW
Model 7	IT2FBWM	Entropy	SAW
Model 8	BBWM	Entropy	SAW
Model 9	BWM	Entropy	VIKOR
Model 10	TFBWM	Entropy	VIKOR
Model 11	IT2FBWM	Entropy	VIKOR
Model 12	BBWM	Entropy	VIKOR
Model 13	BWM	Entropy	TOPSIS
Model 14	TFBWM	Entropy	TOPSIS
Model 15	IT2FBWM	Entropy	TOPSIS
Model 16	BBWM	Entropy	TOPSIS

values between 0.2435 and 0.2767. The steady ranking order in TOPSIS reinforces the robustness of the assessment across different methods.

The consistent rankings across SAW, VIKOR, and TOPSIS methods highlight a strong agreement in assessing Türkiye's Green Deal compliance from 2017 to 2021, with 2021 emerging as the top-performing year and reflecting significant compliance improvements. Conversely, 2017 ranks as the lowest-performing year, indicating the least compliance with the Green Deal criteria. This comparative analysis across multiple MCDM methods and subjective weighting models reinforces the reliability and robustness of the evaluation results, offering a comprehensive view of Türkiye's performance trends regarding Green Deal compliance.

4.5.2. *Benchmarking study with EU countries*

This study compares Türkiye's Green Deal compliance performance with that of EU member states, focusing on Türkiye's current standing, progress, and comparative strengths and weaknesses. Utilizing the MEREC method from Özdemir et al. [106], it identifies key compliance criteria, revealing that "primary energy consumption, freight transport by mode, and environmental tax revenues" are prioritized in the EU, while Türkiye emphasizes the "circular material use rate," which ranks lower in the EU's assessment. For Türkiye, the "Entropy" method highlighted the "circular material use rate" as the most significant criterion, underscoring its critical role in achieving sustainability. Table 7 shows the Green Deal compliance performance of the European Union member states (average of 27 countries) in line with data obtained from EuroStat Green Deal Statistics and the performance data of Türkiye used in this study [22]. From 2017 to 2021, Türkiye's circular material use rate rose by 41.42 %, from 3.16 % to 4.5 %, contrasting with a slight decline in the EU's rate. Despite this improvement, Türkiye still trails behind the EU, indicating a need for enhanced policies to promote circular material use, which can lead to environmental and economic benefits by minimizing waste. Conversely, "environmental tax revenues" were found to have the lowest weight in Türkiye's analysis, reflecting their lesser significance compared to the EU. Both regions saw declines in these revenues, which could indicate high pollution levels or inadequate preventative measures. The EU's higher average environmental tax revenues suggest stronger environmental policies, necessitating that Türkiye and EU member states prioritize robust environmental regulations.

The study also highlights key divergences in performance metrics. For instance, while the EU reduced greenhouse gas emissions by 11.18 % during the study period, Türkiye experienced a 7.70 % increase, necessitating more robust policies. Renewable energy usage grew in both regions, with the EU increasing by 18.90 % and Türkiye by 4.66 %. Although Türkiye's performance is lower, there are positive indicators for future improvements. Primary energy consumption in Türkiye increased, unlike the EU's decline, emphasizing the challenge of meeting energy demands sustainably. The adoption of zero-emission vehicles surged by 650 % in Türkiye, but this is significantly less than the EU's growth of 1217.65 %. Additionally, freight transportation remains dominated by road transport in both regions, which contradicts Green Deal goals promoting sustainable transportation alternatives. Addressing this requires targeted policies to support a shift away from road transport, aligning both Türkiye and the EU with Green Deal objectives.

Between 2017 and 2021, Türkiye saw an 18.64 % increase in R&D

Table 6
Results of comparative analysis.

Year	Model-5		Model-6		Model-7		Model-8	
	Weighted average	Ranking	Weighted average	Ranking	Weighted average	Ranking	Weighted average	Ranking
2017	0.5046	5	0.5037	5	0.5026	5	0.4937	5
2018	0.5624	4	0.5534	4	0.5597	4	0.5493	4
2019	0.5829	1	0.5728	1	0.5802	1	0.5719	1
2020	0.5663	3	0.5569	3	0.5630	3	0.5575	3
2021	0.5698	2	0.5628	2	0.5646	2	0.5610	2
Year	Model-9		Model-10		Model-11		Model-12	
	VIKOR Q value	Ranking	VIKOR Q value	Ranking	VIKOR Q value	Ranking	VIKOR Q value	Ranking
2017	1.0000	5	1.0000	5	1.0000	5	1.0000	5
2018	0.5369	4	0.5872	4	0.5408	4	0.5682	4
2019	0.4967	3	0.5209	3	0.4991	3	0.5170	3
2020	0.3909	2	0.3961	2	0.4024	2	0.4095	2
2021	0.0000	1	0.0000	1	0.0000	1	0.0000	1
Year	Model-13		Model-14		Model-15		Model-16	
	TOPSIS CC value	Ranking	TOPSIS CC value	Ranking	TOPSIS CC value	Ranking	TOPSIS CC value	Ranking
2017	0.2510	5	0.2767	5	0.2576	5	0.2435	5
2018	0.3738	4	0.3749	4	0.3801	4	0.3583	4
2019	0.4236	3	0.4142	3	0.4331	3	0.4213	3
2020	0.4460	2	0.4443	2	0.4468	2	0.4523	2
2021	0.6874	1	0.6678	1	0.6793	1	0.7008	1

Table 7
Green Deal compliance performance of the European Union member states (average of 27 countries).

Main Criteria	Reducing						Enabling					Protecting			
Sub-criteria	C11	C12	C13	C14	C15	C16	C21	C22	C23	C24	C25	C31	C32	C33	
Country	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries	Türkiye/EU Countries
2017	531.1	4.724	145.5	0.00631	1.5	90	3.16	1.18	20.7	14.76	3.09	4.2786	1.49	953	
	78.7	**18.411**	**1384.8**	**0.68**	**7.7**	**75.4**	**11.5**	**2.15**	**8.1**	**10.6**	**6.08**	**25.5**	**7.47**	**5074**	
2018	528.1	5.308	143.4	0.00768	1.7	89.2	4.56	1.27	19.1	16.35	2.3	4.4111	1.69	1195	
	77.0	**19.096**	**1377.8**	**1.028**	**7.8**	**75.7**	**11.6**	**2.18**	**7.6**	**14.8**	**6.01**	**25.7**	**7.99**	**5235**	
2019	515.6	5.186	144.8	0.00941	3.2	89.2	4.56	1.32	19.2	17.11	2.09	4.5145	1.46	1195	
	73.9	**19.887**	**1354.3**	**1.88**	**8.0**	**76.3**	**11.3**	**2.22**	**6.9**	**22.2**	**5.91**	**26.0**	**8.47**	**5235**	
2020	530.2	5.201	141.6	0.02135	2.1	88.3	4.5	1.37	20.3	20.01	2.63	4.6491	1.01	1291	
	66.1	**22.038**	**1235.7**	**5.327**	**5.6**	**77.4**	**11.6**	**2.3**	**7.5**	**28.7**	**5.6**	**26.0**	**9.10**	**4815**	
2021	572.0	4.938	156.1	0.04572	2.7	92.5	4.5	1.4	20.5	21.42	1.61	4.6794	0.93	[a]	1291
	69.9	**21.893**	**1311.2**	**8.967**	**5.9**	**77.3**	**11.4**	**2.27**	**6.9**	**37.0**	**5.58**	**26.0**			**4815**

[a] No data available at EuroStat.

expenditures, exceeding EU growth, indicating a strong commitment to innovation in support of Green Deal goals. However, Türkiye faces significant social challenges, with 20 % of households unable to afford adequate heating, while the EU achieved a 14.81 % reduction in this area, suggesting the need for improved social policies. Although both regions enhanced high-capacity internet coverage, the EU's growth rate surpassed Türkiye's, highlighting a commitment to digital infrastructure. Türkiye also trails the EU in protected land and water areas but made strides with a 9.35 % increase. In contrast, Türkiye's organic farming declined by 37.58 %, while the EU grew by 21.82 %, indicating a need for greater support for sustainable agriculture. Lastly, Türkiye's waste generation rose by 35.47 %, contrasting with the EU's 5.10 % reduction, emphasizing the importance of waste reduction for Green Deal compliance. Addressing these gaps is crucial for Türkiye to align with EU objectives.

Türkiye's Green Deal (GD) compliance performance has been compared with EU member states, highlighting trends in the importance of criteria over time. Using EuroStat data and similar studies, Türkiye's compliance is evaluated in terms of similarities and differences with selected countries. Environmental taxes are the least significant criterion for Türkiye's compliance performance. In 2019, Türkiye's environmental tax revenue accounted for 2.09 % of GDP. With this performance, Türkiye outperformed countries such as Spain, Sweden, Slovakia, Luxembourg, Lithuania, Ireland, Greece, and Germany in environmental tax performance. However, it ranked lower than countries such as Czechia, Denmark, Estonia, Finland, France, Hungary, Italy, the Netherlands, Poland, Portugal, Slovenia, Bulgaria, Croatia, Cyprus, and Romania. Environmental taxes were among the most important criteria in the study conducted by Doskocil [122]. Between 2017 and 2021, Türkiye's primary energy consumption increased by 7.29 %. According to EuroStat (to 2024) data, Belgium showed a slight increase of 0.62 %, while Germany (−8.92 %) and Greece (−12.50 %) recorded significant reductions, and Poland saw a 4.94 % increase. Factors such as Türkiye's growing population, industrialization, and rising consumption underline the importance of adopting exemplary renewable energy policies from countries with declining energy consumption.

Türkiye's circular material use rate improved by 41.42 % between 2017 and 2021. However, it remains below the EU average and lags behind Germany (5.12 % increase) and Greece (112 % increase), according to EuroStat [125]. Although Türkiye performed better than Greece between 2017 and 2020, its overall rate of improvement was slower compared to EU countries such as Spain and Bulgaria. Türkiye's organic farming area decreased by 37.58 % between 2017 and 2021. Meanwhile, Belgium (+19.11 %), Germany (+41.50 %), and Spain (+23.60 %) showed significant increases, while Bulgaria (−37.13 %) also experienced a decline, according to EuroStat [120]. Despite Bulgaria's downward trend, it still outperformed Türkiye in terms of the proportion of organic agricultural land. Türkiye should focus on policies promoting sustainable agricultural practices that benefit the environment, human health, and animal welfare, drawing lessons from better-performing EU nations.

In summary, Türkiye has shown positive progress in GD compliance performance over the years. However, in some areas, it lags behind the EU average and several member states. Raising awareness among the government, producers, and consumers, alongside adapting policies and practices from successful EU countries, will be essential for Türkiye to improve its compliance performance.

Table 8
Scenario design for sensibility analysis.

Scenario design	Weight of major criterion	Weight of minor criteria
1	0.2500	0.0577
2	0.5000	0.0385
3	0.7500	0.0192

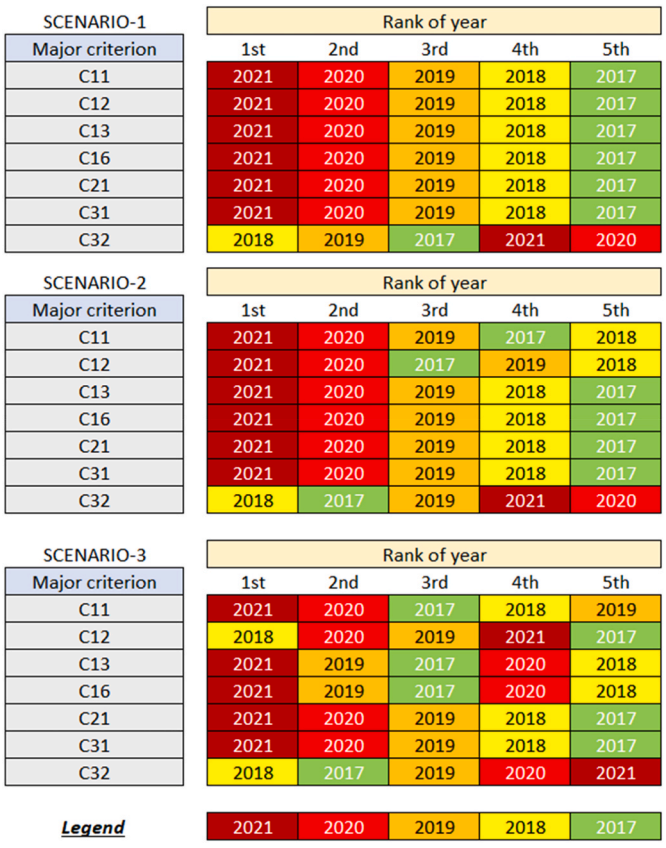


Fig. 6. Sensibility analysis of the results by three scenarios.

4.5.3. Sensibility analysis

The sensibility analysis evaluates sub-criteria by designating each as the major criterion while treating the others as minor. The major criterion is assigned a weight of 0.2500, with thirteen minor criteria uniformly weighted at 0.0577. This setup examines how changes in the major criterion's importance affect overall results (Table 8). Three scenarios are tested, where each of the seven selected sub-criteria (C11, C12, C13, C16, C21, C31, and C32) is treated as the major criterion. These were chosen based on their average weight exceeding 0.07, ensuring a comprehensive understanding of their influence on final rankings.

The sensibility analysis results in Fig. 6 illustrate how year rankings vary based on the selected major sub-criterion. In Scenario 1, the top five years are consistently ranked as 2021, 2020, 2019, 2018, and 2017, indicating stability across criteria. However, when criterion C32 is designated as the major criterion, the ranking shifts to place 2018 at the top, followed by 2019, 2017, 2021, and 2020. Scenario 2 mirrors Scenario 1 closely, with 2021, 2020, and 2019 remaining in the top ranks, while 2018 and 2017 rise slightly when C32 is major. Scenarios 1 and 2 show consistent rankings, but Scenario 3 introduces more variability, particularly with C12 and C32, highlighting the influence of the major criterion on overall rankings. This analysis reveals the robustness of rankings against changes in sub-criteria weight and identifies which sub-criteria significantly impact results.

5. Conclusion and future recommendations

The European Green Deal is an agreement that aims to use Europe's resources efficiently, promote a competitive economy, ensure sustainable development and protect nature. Participating countries aim to improve their current situation by taking the necessary measures under this agreement. This study aims to evaluate Türkiye's performance within the scope of the European Green Deal over the years and determine the importance of certain criteria. Three main criteria and fourteen sub-criteria related to the Green Deal were determined. Multiple conflicting goals required the use of MCDMs to assess the importance of these criteria from both objective and subjective perspectives. BWM derivatives and the entropy method were used to determine the criteria weights, thus determining the important parameters and importance levels of Green Deal compliance. Then, country performance between 2018 and 2021 was ranked and it was revealed that the most positive performance was in 2021 and the weakest performance was in 2017.

This methodology offers valuable management opportunities for decision makers. By determining the weights of the parameters and evaluating the performance, decision makers can make data-based decisions instead of relying on intuition. Concrete data enables decision makers to identify successful strategies and areas requiring change, providing transparent and measurable information about Green Deal compliance. As a result, decision makers can create a roadmap to determine and prioritize strategic goals, take necessary measures, and identify strengths and weaknesses. This study will guide decision makers to maintain and develop strengths while addressing weaknesses by analyzing success criteria and performance.

However, this study has some limitations that should be acknowledged. One key limitation is the availability of comprehensive data, as the analysis relies on five years of data (2017–2021), which includes many missing values for several sub-criteria in earlier years prior to 2017 and restricts a more granular analysis of individual sub-criteria. Another limitation is the generalizability of the findings to other non-EU countries, as the results are specific to Turkiye's context. Future research could address these limitations by expanding the scope to include additional countries with significant trade ties to the EU, allowing for a broader comparative analysis. Additionally, future studies could investigate additional criteria—such as financial incentives for green technologies, regulatory compliance, or public-private partnerships—that could provide a more holistic evaluation of Green Deal performance. The study can be repeated after 5–10 years to compare the changes in the performance of Turkiye or other countries. In addition, raising education and awareness on issues affecting climate change, sustainability or Green Deal compliance will play an important role in the adaptation of individuals or organizations to this change. This will directly/indirectly contribute to country performance.

Further, the methodology could benefit from incorporating advanced predictive tools, such as artificial neural networks or machine learning algorithms, to estimate the future trajectory of Green Deal compliance. These tools can enhance the evaluation system by identifying indirect measurement methods and offering forecasts based on current trends. Such advancements would provide more actionable insights, enabling decision-makers to refine their strategies and revise roadmaps to align with evolving Green Deal objectives.

CRediT authorship contribution statement

Mehmet Karadag: Writing – original draft, Validation, Data curation. **Muhammet Gul:** Writing – original draft, Validation, Supervision, Software, Project administration, Methodology, Data curation, Conceptualization. **Melih Yucesan:** Writing – original draft, Visualization, Software, Methodology. **Miguel Ortiz-Barrios:** Writing – original draft, Conceptualization. **Alessio Ishizaka:** Writing – original draft, Conceptualization. **Jehangir Khan:** Writing – original draft, Conceptualization.

Data availability

Data will be made available on request.

References

[1] EEA. Annual European Union greenhouse gas inventory 1990–2017 and inventory report 2019. Submission under the united nations framework convention on climate change and the Kyoto Protocol. Report. Copenhagen: European Environmental Agency European Union; 2019.

[2] Panth P. Green house gases emission reduction: targets and achievements by annex I parties (1990-2012). Indian Journal of Economics and Development 2016;4(10):1–13.

[3] Rehfeldt M, Worrell E, Eichhammer W, Fleiter T. A review of the emission reduction potential of fuel switch towards biomass and electricity in European basic materials industry until 2030. Renew Sustain Energy Rev 2020;120:109672.

[4] Masson-Delmotte V, et al. Global warming of 1.5 C. Report. Incheon. Intergovernmental Panel on Climate Change Intergovernmental Panel on Climate Change; 2018.

[5] European Commission. A clean planet for all - a European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. 2018. Technical Report COM(2018) 773 final. Report. Brussels: European Commission European Commission.

[6] European Commission. Stepping up Europe's 2030 climate ambition - investing in a climate-neutral future for the benefit of our people. Communication from the commission SWD(2020) 176 final. Report. Brussels: European Commission. European Commission; 2020.

[7] De Pascale A, et al. The circular economy implementation at the European Union level. Past, present and future. J Clean Prod 2023;423:138658.

[8] Mihai FC, Ulman SR. Circular economy in green deal strategies. In: Sustainable and circular management of resources and waste towards a Green Deal; 2023. p. 49–63.

[9] Kumar A, Sah B, Singh AR, Deng Y, He X, Kumar P, Bansal RC. A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renew Sustain Energy Rev 2017;69:596–609.

[10] Mohammadi M, Rezaei J. Ratio product model: a rank-preserving normalization-agnostic multi-criteria decision-making method. J Multi-Criteria Decis Anal 2023;30(5–6):163–72.

[11] Pamučar D, Ecer F, Cirovic G, Arlasheedi MA. Application of improved best worst method (BWM) in real-world problems. Mathematics 2020;8(8):1342.

[12] Rezaei J. Best-worst multi-criteria decision-making method. Omega 2015;53:49–57.

[13] Mete S, Yucesan M, Gul M, Ozceylan E. An integrated hybrid MCDM approach to evaluate countries' COVID-19 risks. Soc Econ Plann Sci 2023;90:101744.

[14] Brodny J, Tutak M. Assessing the level of digital maturity of enterprises in the Central and Eastern European countries using the MCDM and Shannon's entropy methods. PLoS One 2021;16(7):e0253965.

[15] Riepl T, Zavarská Z. Towards a greener visegrád group: progress and challenges in the context of the European green deal. Research report. Vienna: the Vienna Institute for international economic studies (wiiw) the Vienna Institute for international economic studies (wiiw). 2023.

[16] Rybalkin O. Sustainable development goals progress in the European Union: correlation with EEPSE green economy index. Access to science, business, innovation in digital economy 2022;3(2):121–35.

[17] Taneja S, Özen E. Impact of the European Green Deal (EDG) on the agricultural carbon (CO2) emission in Turkey. Int J Sustain Dev Plann 2023;18(3):715–27.

[18] Çağ A, Telci B, Batir O, Haklıdır FST. Evaluation of the impact of the European green deal act on the green energy transition of Turkey by the AHP model. In: International world energy conference. Kayseri; 2022. p. 2022.

[19] Tuğaç Ç. The evolution of europen union's climate change adaptation policies and the importance of current adaptation policies for Turkey. Kent Akademisi Dergisi 2022;15(3):958–82.

[20] Şahin G, Taksim MA, Yitgin B. Effects of the European Green Deal on Turkey's electricity market. İşletme Ekonomi ve Yönetim Araştırmaları Dergisi 2021;4(1):40–58.

[21] Dolge K, Blumberga D. Economic growth in contrast to GHG emission reduction measures in Green Deal context. Ecol Indicat 2021;130:108153. https://doi.org/10.1016/j.ecolind.2021.108153.

[22] EuroStat. Statistics for the green deal. Retrieved from, https://ec.europa.eu/eurostat/cache/egd-statistics/. [Accessed 8 January 2025].

[23] Liu PR, Raftery AE. Country-based rate of emissions reductions should increase by 80% beyond nationally determined contributions to meet the 2 C target. Communications earth & environment 2021;2(1):29.

[24] Adamowicz M. Green deal, green growth and green economy as a means of support for attaining the sustainable development goals. Sustainability 2022;14(10):5901.

[25] Fetting C. The European green deal. Report. Vienna: ESDN ESDN Office; 2020.

[26] Kuci A, Fogarassy C. European green deal policy for the circular economy opportunities and challenges. Hungarian Agricultural Engineering 2021;39:65–73.

[27] Hainsch K, et al. Energy transition scenarios: what policies, societal attitudes, and technology developments will realize the EU Green Deal? Energy 2022;239:122067.

[28] Haines A, Scheelbeek P. European Green Deal: a major opportunity for health improvement. Lancet 2020;395(10233):1327–9.

[29] Hu Y, Tu T, Lei Z. Impact of corporate environmental goals on compliance behaviors in European Union food industry: A cross-country analysis. *Journal of Cleaner Production* 2024;*444*:141212.

[30] Cuadros-Casanova I, et al. Opportunities and challenges for common agricultural policy reform to support the European green deal. Conserv Biol 2023;37(3):14052.

[31] Tsakalidis A, van Balen M, Gkoumas K, Pekar F. Catalyzing sustainable transport innovation through policy support and monitoring: the case of TRIMIS and the European green deal. Sustainability 2020;12(8):3171.

[32] Aszódi A, et al. Comparative analysis of national energy strategies of 19 European countries in light of the green deal's objectives. Energy Convers Manag X 2021;12:100136.

[33] Tutak M, Brodny J. Disparities among EU-27 countries in the implementation of the European Green Deal strategy goals. Smart and Sustainable Built Environment 2024. https://doi.org/10.1108/SASBE-07-2024-0266.

[34] Tutak M, Brodny J, Bindzar P. Assessing the level of energy and climate sustainability in the European Union countries in the context of the European green deal strategy and agenda 2030. Energies 2021;14(6):1767.

[35] Bąk I, et al. Is the European Union making progress on energy decarbonisation while moving towards sustainable development? Energies 2021;14(13):3792.

[36] Simionescu M, Păuna CB, Diaconescu T. Renewable energy and economic performance in the context of the European Green Deal. Energies 2020;13(23):6440.

[37] Kettunen M, et al. An EU Green Deal for trade policy and the environment. Report. Brussels/London: IEEP IEEP; 2020.

[38] Hoicka CE, et al. Implementing a just renewable energy transition: policy advice for transposing the new European rules for renewable energy communities. Energy Pol 2021;156:112435.

[39] Esteban H, Otero BG. Is the transition to E-mobility the silver bullet to achieve climate-neutral transport? An interdisciplinary review in the search for consistency and collateral effects. Eur Bus Law Rev 2023;34(1):81–98.

[40] Köhler J, et al. An agenda for sustainability transitions research: state of the art and future directions. Environ Innov Soc Transit 2019;31:1–32.

[41] Dowson M, Poole A, Harrison D, Susman G. Domestic UK retrofit challenge: barriers, incentives and current performance leading into the Green Deal. Energy Pol 2012;50:294–305.

[42] García Vaquero M, Sánchez-Bayón A, Lomincha J. European green deal and recovery plan: green jobs, skills and wellbeing economics in Spain. Energies 2021;14(14):4145.

[43] Polishchuk V, et al. The hybrid mathematical model for the evaluation and selection of iron ore raw materials in the context of the European Green Deal. Acta Montan Slovaca 2022;27(3).

[44] Ortiz-Barrios M, Cabarcas-Reyes J, Ishizaka A, Barbati M, Jaramillo-Rueda N, de Jesús Carrascal-Zambrano G. A hybrid fuzzy multi-criteria decision making model for selecting a sustainable supplier of forklift filters: a case study from the mining industry. Ann Oper Res 2021;307:443–81.

[45] Liang F, Brunelli M, Rezaei J. Consistency issues in the best worst method: measurements and thresholds. Omega 2020;96:102175.

[46] Talib F, et al. Ranking model of total quality management enablers in healthcare establishments using the best-worst method. The TQM Journal 2019;31(5):790–814.

[47] Malek J, Desai TN. Prioritization of sustainable manufacturing barriers using Best Worst Method. J Clean Prod 2019;226:589–600.

[48] Mojumder A, Singh A, Kumar A, Liu Y. Mitigating the barriers to green procurement adoption: an exploratory study of the Indian construction industry. J Clean Prod 2022;372:133505.

[49] Rezaei J, Nispeling T, Sarkis J, Tavasszy L. A supplier selection life cycle approach integrating traditional and environmental criteria using the best worst method. J Clean Prod 2016;135:577–88.

[50] Lo HW, Liou JJ, Wang HS, Tsai YS. An integrated model for solving problems in green supplier selection and order allocation. J Clean Prod 2018;190:339–52.

[51] Mohaghar A, Sahebi IG, Arab A. Appraisal of humanitarian supply chain risks using best-worst method. International Journal of Industrial and Manufacturing Engineering 2017;11(2):349–54.

[52] Mousavi-Nasab SH, Sotoudeh-Anvari A. An extension of best-worst method with D numbers: application in evaluation of renewable energy resources. Sustain Energy Technol Assessments 2020;40:100771.

[53] Gupta P, Anand S, Gupta H. Developing a roadmap to overcome barriers to energy efficiency in buildings using best worst method. Sustain Cities Soc 2017;31:244–59.

[54] Singh M, Rathi R, Garza-Reyes JA. Analysis and prioritization of Lean Six Sigma enablers with environmental facets using best worst method: a case of Indian MSMEs. J Clean Prod 2021;279:123592.

[55] Petrudi SHH, Ghomi H, Mazaheriasad M. An integrated fuzzy delphi and best worst method (BWM) for performance measurement in higher education. Decision Analytics Journal 2022;4:100121.

[56] Ding JF, Weng JH, Chou CC. Assessment of key risk factors in the cold chain logistics operations of container carriers using best worst method. Int J Refrig 2023;153:116–26.

[57] Moslem S, Farooq D, Ghorbanzadeh O, Blaschke T. Application of the AHP-BWM model for evaluating driver behavior factors related to road safety: a case study for Budapest. Symmetry 2020;12(2):243.

[58] Gupta H, Barua MK. Supplier selection among SMEs on the basis of their green innovation ability using BWM and fuzzy TOPSIS. J Clean Prod 2017;152:242–58.

[59] Jafarpour M, Shojaei P, Alimohammadlou M. A model for improving cold supply chain performance: an integrated FISM/BWM/ANP approach. Int J Procure Manag 2022;15(5):599–624.

[60] Alimohammadlou M, Sharifian S. Industry 4.0 implementation challenges in small-and medium-sized enterprises: an approach integrating interval type-2 fuzzy BWM and DEMATEL. Soft Comput 2023;27(1):169–86.
[61] Taghipour A, Fooladvand A, Khazaei M, Ramezani M. Criteria clustering and supplier segmentation based on sustainable shared value using BWM and PROMETHEE. Sustainability 2023;15(11):8670.
[62] Kumar A, Aswin A, Gupta H. Evaluating green performance of the airports using hybrid BWM and VIKOR methodology. Tourism Manag 2020;76:103941.
[63] Stević Ž, et al. The selection of wagons for the internal transport of a logistics company: a novel approach based on rough BWM and rough SAW methods. Symmetry 2017;9(11):264.
[64] Danish F, Jan R, Daniyal M, Tawiah K. Optimum stratification using dynamic programming with a mixture of ratio and product estimators under super population model. Math Probl Eng 2023;2023(1):3149912.
[65] Guo S, Zhao H. Fuzzy best-worst multi-criteria decision-making method and its applications. Knowl Base Syst 2017;121:23–31.
[66] Dong J, Wan S, Chen SM. Fuzzy best-worst method based on triangular fuzzy numbers for multi-criteria decision-making. Inf Sci 2021;547:1080–104.
[67] Karimi H, Sadeghi-Dastaki M, Javan M. A fully fuzzy best–worst multi attribute decision making method with triangular fuzzy number: a case study of maintenance assessment in the hospitals. Appl Soft Comput 2020;86:105882.
[68] Wu Q, Zhou L, Chen Y, Chen H. An integrated approach to green supplier selection based on the interval type-2 fuzzy best-worst and extended VIKOR methods. Inf Sci 2019;502:394–417.
[69] Celik E, Yucesan M, Gul M. Green supplier selection for textile industry: a case study using BWM-TODIM integration under interval type-2 fuzzy sets. Environ Sci Pollut Control Ser 2021;28(45):64793–817.
[70] Altay BC, Celik E, Okumus A, Balin A, Gul M. An integrated interval type-2 fuzzy BWM-MARCOS model for location selection of e-scooter sharing stations: the case of a university campus. Eng Appl Artif Intell 2023;122:106095.
[71] Celik E, Gul M. Hazard identification, risk assessment and control for dam construction safety using an integrated BWM and MARCOS approach under interval type-2 fuzzy sets environment. Autom ConStruct 2021;127:103699.
[72] Mohammadi M, Rezaei J. Bayesian best-worst method: a probabilistic group decision making model. Omega 2020;96:102075.
[73] Lo HW, Liou JJ. An integrated Bayesian BWM and classifiable TOPSIS model for risk assessment. Multi-criteria decision analysis for risk assessment and management. 2021. p. 21–51.
[74] Yanilmaz S, Baskak D, Yucesan M, Gul M. Extension of FEMA and SMUG models with Bayesian best-worst method for disaster risk reduction. Int J Disaster Risk Reduc 2021;66:102631.
[75] Liu J, Zhang J, Leng J. Combining permissioned blockchain and Bayesian best-worst method for transparent supplier selection in supply chain management. Sci China Technol Sci 2024:1–15.
[76] Gul M, Yucesan M. Performance evaluation of Turkish Universities by an integrated Bayesian BWM-TOPSIS model. Soc Econ Plann Sci 2022;80:101173.
[77] Saner HS, Yucesan M, Gul M. A Bayesian BWM and VIKOR-based model for assessing hospital preparedness in the face of disasters. Nat Hazards 2022:1–33.
[78] Yalcin Kavus B, Ayyildiz E, Gulum Tas P, Taskin A. A hybrid Bayesian BWM and Pythagorean fuzzy WASPAS-based decision-making framework for parcel locker location selection problem. Environ Sci Pollut Control Ser 2023;30(39):90006–23.
[79] Chodha V, Dubey R, Kumar R, Singh S, Kaur S. Selection of industrial arc welding robot with TOPSIS and Entropy MCDM techniques. Mater Today Proc 2022;50:709–15.
[80] Gök-Kısa AC, Celik P, Peker I. Performance evaluation of privatized ports by entropy based TOPSIS and ARAS approach. Benchmark Int J 2022;29(1):118–35.
[81] Zafar S, Alamgir Z, Rehman MH. An effective blockchain evaluation system based on entropy-CRITIC weight method and MCDM techniques. Peer-to-Peer Networking and Applications 2021;14(5):3110–23.
[82] Brodny J, Tutak M. The analysis of similarities between the European Union countries in terms of the level and structure of the emissions of selected gases and air pollutants into the atmosphere. J Clean Prod 2021;279:123641.
[83] Li H, Wang W, Fan L, Li Q, Chen X. A novel hybrid MCDM model for machine tool selection using fuzzy DEMATEL, entropy weighting and later defuzzification VIKOR. Appl Soft Comput 2020;91:106207.
[84] Yazdani M, Torkayesh AE, Santibanez-Gonzalez ED, Otaghsara SK. Evaluation of renewable energy resources using integrated Shannon Entropy—EDAS model. Sustainable Operations and Computers 2020;1:35–42.
[85] Churchman CW, Ackoff RL. An approximate measure of value. Wiley; 1954.
[86] Radulescu CZ, Radulescu M. A hybrid group multi-criteria approach based on SAW, TOPSIS, VIKOR, and COPRAS methods for complex IoT selection problems. Electronics 2024;13(4):789.
[87] Aliyeva K, Aliyeva A, Aliyev R, Özdeşer M. Application of fuzzy simple additive weighting method in group decision-making for capital investment. Axioms 2023;12(8):797.
[88] Siolemba Patiro SP, Hendarto KA, Parmono VR, Wibowo LR, Suka AP, Abdurakhman A, Yatma TDN. Analyzing residents' preferences to ecotourism impacts using simple additive weighting: the case of Mount Rinjani National Park, Indonesia. For Sci Technol 2024;20(1):25–37.
[89] Opricovic S. Multi-criteria optimization of civil engineering systems. Belgrade: Faculty of Civil Engineering; 1998.
[90] Yadav R, Saini S, Sonwal S, Meena A, Huh YS, Brambilla E, Ionescu AC. Optimization and ranking of dental restorative composites by ENTROPY-VIKOR and VIKOR-MATLAB. Polym Adv Technol 2024;35(7):e6526.
[91] Gao F, Han M, Wang S, Gao J. A novel Fermatean fuzzy BWM-VIKOR based multi-criteria decision-making approach for selecting health care waste treatment technology. Eng Appl Artif Intell 2024;127:107451.
[92] Abdul D, Wenqi J, Tanveer A, Sameeroddin M. Comprehensive analysis of renewable energy technologies adoption in remote areas using the integrated delphi-fuzzy AHP-VIKOR approach. Arabian J Sci Eng 2024;49(5):7585–610.
[93] Ak MF, Yucesan M, Gul M. Occupational health, safety and environmental risk assessment in textile production industry through a Bayesian BWM-VIKOR approach. Stoch Environ Res Risk Assess 2022;36(2):629–42.
[94] Büyüközkan G, Karabulut Y, Göçer F. Spherical fuzzy sets based integrated DEMATEL, ANP, VIKOR approach and its application for renewable energy selection in Turkey. Appl Soft Comput 2024;158:111465.
[95] Gul M. Application of Pythagorean fuzzy AHP and VIKOR methods in occupational health and safety risk assessment: the case of a gun and rifle barrel external surface oxidation and colouring unit. Int J Occup Saf Ergon 2020;26(4):705–18.
[96] Gul M, Ak MF, Guneri AF. Pythagorean fuzzy VIKOR-based approach for safety risk assessment in mine industry. J Saf Res 2019;69:135–53.
[97] Gul M, Celik E, Aydin N, Gumus AT, Guneri AF. A state of the art literature review of VIKOR and its fuzzy extensions on applications. Appl Soft Comput 2016;46:60–89.
[98] Gul M, Yucesan M, Ak MF. Control measure prioritization in Fine− Kinney-based risk assessment: a Bayesian BWM-Fuzzy VIKOR combined approach in an oil station. Environ Sci Pollut Control Ser 2022;29(39):59385–402.
[99] Hwang CL, Yoon K. Multiple attribute decision making: methods and applications. Springer-Verlag; 1981.
[100] Ali I, Charles V, Modibbo UM, Gherman T, Gupta S. Navigating COVID-19: unraveling supply chain disruptions through best-worst method and fuzzy TOPSIS. Benchmark Int J 2024;31(5):1548–89.
[101] Jha MK, Gupta S, Chaudhary V, Gupta P. Material selection for biomedical application in additive manufacturing using TOPSIS approach. Mater Today Proc 2022;62:1452–7.
[102] Çelikbilek Y, Tüysüz F. An in-depth review of theory of the TOPSIS method: an experimental analysis. Journal of Management Analytics 2020;7(2):281–300.
[103] Dhanalakshmi CS, Madhu P, Karthick A, Mathew M, Vignesh Kumar R. A comprehensive MCDM-based approach using TOPSIS and EDAS as an auxiliary tool for pyrolysis material selection and its application. Biomass conversion and biorefinery 2020:1–16.
[104] Nafei A, Azizi SP, Edalatpanah SA, Huang CY. Smart TOPSIS: a neural network-driven TOPSIS with neutrosophic triplets for green supplier selection in sustainable manufacturing. Expert Syst Appl 2024;255:124744.
[105] Salih MM, Zaidan BB, Zaidan AA, Ahmed MA. Survey on fuzzy TOPSIS state-of-the-art between 2007 and 2017. Comput Oper Res 2019;104:207–27.
[106] Ozdemir S, Demirel N, Zaralı F, Çelik T. Multi-criteria assessment framework for evaluation of Green Deal performance. Environ Sci Pollut Control Ser 2023;31(3):4686–704. https://doi.org/10.1007/s11356-023-31370-2.
[107] Barry D, Hoyne S. Sustainable measurement indicators to assess impacts of climate change: implications for the New Green Deal Era. Current Opinion in Environmental Science & Health 2021;22:100259. https://doi.org/10.1016/j.coesh.2021.100259.
[108] TurkStat. Greenhouse gas emissions statistics, (1990-2022). https://data.tuik.gov.tr/Bulten/Index?p=Greenhouse-Gas-Emissions-Statistics-1990-2021-49672&dil=2. [Accessed 7 June 2024].
[109] Ministry of Energy and Natural Resources. National energy balance Tables (1972-2022). Retrieved from, https://enerji.gov.tr/eigm-raporlari. [Accessed 30 July 2024].
[110] EuroStat. Primary energy consumption (2000-2022). Retrieved from, https://ec.europa.eu/eurostat/databrowser/view/sdg_07_10_custom_1302857/default/table. [Accessed 7 June 2024].
[111] TurkStat. Distribution of cars registered to the traffic according to fuel type, (2004 – 2024). https://data.tuik.gov.tr/Bulten/Index?p=Motorlu-Kara-Tasitlari-Ocak-2024-53453. [Accessed 7 June 2024].
[112] EuroStat. Modal split of inland passenger transport. Retrieved from, https://ec.europa.eu/eurostat/databrowser/view/tran_hv_psmod_custom_1301132/default/table. [Accessed 7 June 2024].
[113] General Directorate of Highways. Highway transportation statistics. https://www.kgm.gov.tr/SiteCollectionDocuments/KGMdocuments/Yayinlar/YayinPdf/KarayoluUlasimIstatistikleri2023.pdf. [Accessed 25 June 2024].
[114] Johansson T, Korkmaz M. Measuring the degree of circularity in Turkey: material flow analysis. Retrieved from, http://spectrumhouse.com.tr/turkiyede-donguselllik-derecesinin-olculmesi-materyal-akis-analizi/. [Accessed 25 June 2024].
[115] EuroStat. Gross domestic expenditure on R&D by sector. Retrieved from, https://ec.europa.eu/eurostat/databrowser/view/sdg_09_10_custom_1315739/default/table. [Accessed 7 June 2024].
[116] EuroStat. Population unable to Keep home adequately Warm by poverty status. Retrieved from, https://ec.europa.eu/eurostat/databrowser/view/sdg_07_60_custom_1315834/default/table. [Accessed 7 June 2024].
[117] ICTA. Annual provincial statistics. Reterieved from. https://www.btk.gov.tr/uploads/pages/yillik-il-istatistikleri/2023.pdf. [Accessed 25 June 2024].
[118] OECD. Environmentally related tax revenue. Retrieved from, https://stats-2.oecd.org/index.aspx?DatasetCode=ERTR. [Accessed 25 June 2024].
[119] Ministry of Agriculture and Forestry. Protected areas, (1958 – 2023). Retrieved, https://www.tarimorman.gov.tr/DKMP/Belgeler/dkmp%20resmi%20istatistik/resmiistatistikler/korunanalanistatistikleri/2024/Di%C4%9Fer/Korunan%20Alanlar_2023.xlsx. [Accessed 25 June 2024].

[120] EuroStat. Area under organic farming. Retrieved from, https://ec.europa.eu/eurostat/databrowser/view/sdg_02_40_custom_1308801/default/table. [Accessed 7 June 2024].
[121] EuroStat. Generation of waste by hazardousness. Retrieved from, https://ec.europa.eu/eurostat/databrowser/view/sdg_12_51_custom_6165931/default/table. [Accessed 7 June 2024].
[122] Doskocil R. The multicriteria assessment of the green growth in the context of the European unions green deal. www.amfiteatrueconomic.ro 2022;24(61):739.
[123] Hoseinzadeh S, Nastasi B, Groppi D, Astiaso Garcia D. Socio-techno-economic-environmental investigation of scenarios-based combination sources of green energy system—a case study in Spain. Energy Rep 2024;12:2611–20. https://doi.org/10.1016/j.egyr.2024.08.063.
[124] Wolf S, Teitge J, Mielke J, Schütze F, Jaeger C. The european green deal—more than climate neutrality. Intereconomics 2021;56(2):99–107. https://doi.org/10.1007/s10272-021-0963-z.
[125] EuroStat. Circular material use rate statistics. Retrieved from, https://ec.europa.eu/eurostat/databrowser/view/SDG_12_41_custom_1315713/bookmark/table?lang=en&bookmarkId=e4657bd0-03a1-480b-abe3-d122fa0ac4f2. [Accessed 11 January 2025].

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