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DETERMINANTS OF PROGRESS IN CIRCULAR ECONOMY: A COMPARATIVE MULTI-CRITERIA ANALYSIS OF EU MEMBER STATES AND TÜRKİYE WITH A SPECIAL FOCUS ON PRODUCTION AND CONSUMPTION INDICATORS

DÖNGÜSEL EKONOMİDE İLERLEMENİN BELİRLEYİCİLERİ: AB ÜYE ÜLKELERİ VE TÜRKİYE'NİN ÜRETİM VE TÜKETİM GÖSTERGELERİ ÖZELİNDE KARŞILAŞTIRMALI ÇOK KRİTERLİ ANALİZİ

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ÖZET

As the global population continues to grow, it is reasonable to anticipate a rise in production and consumption levels, leading to increased waste generation. With the aim of achieving sustainable development and transitioning towards a circular economy (CE), nowadays, there has been a paradigm shift away from the traditional linear economic model towards prioritizing waste management practices that emphasize the reintegration of valuable resources into the economic system. In this sense, transitioning to a CE requires substantial changes in production and consumption frameworks, prompting the EU to incorporate eight relevant criteria, including material footprint, resource productivity, waste generation per capita, generation of waste excluding major mineral wastes, generation of municipal waste, food waste, generation of packaging waste and generation of plastic packaging waste to assess countries' progress towards CE from the production and consumption perspective. To ascertain the current status of EU member states and Türkiye, this study conducts a comparative multi-criteria analysis including CRITIC based CoCoSo and WASPAS methods. The results indicate that Croatia consistently ranked at the top in both analyses, followed by Latvia and Slovakia. In certain years, countries like Czechia, the Netherlands, and Spain demonstrated notable performances. On the other hand, Türkiye showed a moderate performance from 2008 to 2020, invariably hovering around the 10th position throughout much of the period.

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ABSTRACT

Küresel nüfus artmaya devam ettikçe, üretim ve tüketim seviyelerinde ve bu bağlamda atık yaratımında bir artışın beklenmesi mümkündür. Günümüzde sürdürülebilir kalkınmayı ve döngüsel ekonomiye geçişi sağlamak amacıyla, geleneksel doğrusal ekonomi modelinden uzaklaşan ve değerli kaynakların ekonomik sistem içine yeniden entegrasyonunu vurgulayarak atık yönetimi uygulamalarına öncelik veren bir paradigma değişimi yaşanmaktadır. Öte yandan bu geçiş, üretim ve tüketim çerçevelerinde önemli değişiklikler gerektirmekte olup, bu bağlamda Avrupa Birliği, materyal ayak izi, kaynak verimliliği, kişi başına atık üretimi, büyük mineral atıkları hariç atık üretimi, belediye atığı üretimi, gıda atığı, ambalaj atığı üretimi ve plastik ambalaj atığı üretimi kriterlerini içeren sekiz gösterge bağlamında ülkelerin üretim ve tüketim açısından döngüsel ekonomi performansını değerlendirmektedir. Bu çalışmada AB ülkeleri ve Türkiye'nin mevcut durumu, CRITIC temelli CoCoSo ve WASPAS karşılaştırmalı çok kriterli karar verme analizi bağlamında ele alınmıştır. Elde edilen sonuçlara göre, Hırvatistan her iki analizde çoğunlukla sırlamanın en üstünde yer almış, ardından Letonya ve Slovakya gelmiştir. Ele alınan dönem dahilindeki bazı yıllarda, Çekya, Hollanda ve İspanya gibi ülkelerin dikkate değer performans gösterdikleri görülmüştür. Diğer yandan, Türkiye'nin çoğunlukla 10. sıraya yakın bir pozisyonda yer alarak orta seviyede bir performans sergilediği görülmüştür.

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The dynamic shifts in the global landscape necessitate the emergence of new paradigms and methodologies concerning the engagement of countries with diverse characteristics in social and economic development. Moreover, considering the finite nature of Earth's resources, there is a growing imperative to optimize their usage in line with sustainability principles, thus driving the development of these new paradigms (Mhatre et al., 2021). Notably, concepts such as the circular economy (CE) can be considered one of them. Since estimates indicate that by 2030, the global population will be 8.55 billion, it is argued that the notion of the CE, particularly significant in countries with substantial environmental footprints, is increasingly acknowledged for its importance among decision-makers and researchers (Martinho and Mourão, 2020; UN, 2022). Various definitions and interpretations of the CE have emerged over time, focusing on economic practices that generate environmentally friendly outcomes at both micro and macro scales, thereby promoting sustainable development (SD) across economic, social, and environmental domains (Mazur-Wierzbicka, 2021a). In this context, it is stated that at odds with the linear economy model, often described as *'take-use-dispose,'* the concept of CE can be traced back to the 1960s, rooted in the *'take-use-reuse'* approach aimed at closing the cycles of product life and valuing waste as reusable materials to mitigate the environmental impact of production cycles (Stahel, 2016; Mazur-Wierzbicka, 2021b). Another definition can be stated as an economic model where businesses transition from the traditional *'end-of-life'* concept, aiming to minimize waste, encourage reuse, and optimize production resource efficiency, distribution, and processes of consumption to drive SD by enhancing environmental quality (Kirchherr et al., 2018).

In 2015, the European Union (EU) adopted the *'Closing the loop: An EU action plan for the circular economy,'* urging member states to pledge to implement CE principles. which was followed by the *'European Action for Sustainability'* in 2016, reaffirming the EU's dedication to these objectives (EC, 2015; EC, 2016). In addition, the concept of CE has also been brought to the forefront by the United Nations (UN) in their sustainable Development Goals (SDGs) and their latest scientific publications such as the *"The sustainable development goals report 2023: Special edition"* (UN, 2023). In accordance with above mentioned paradigm, these action plans aim to achieve the optimal environmental outcome by prioritizing waste management (WM) practices that aim to reintegrate valuable resources back into the economic system. Consequently, these led to a shift in WM policies from traditional landfill and/or incinerator (without recover of energy) focused approaches to innovative methods utilizing recycled materials and renewable energy given the evident dangers of landfilling and incineration to both the environment and public health (Voukkali et al., 2023; Agovino et al., 2024). On the other hand, concerns have been raised that current approaches to optimizing WM practices often rely solely on established waste treatment methods like *Reduce, Reuse, Recycle (3Rs)* as it is stated that these methods may not fully extract the maximum potential value from solid waste materials (Romero-Hernández and Romero, 2018). Although, a recent study conducted by Lanzalonga et al. (2024) highlights that Artificial Intelligence (AI) has been implemented in waste management practices. Finally, as an example from a developing country, the inception of WM centered CE initiatives in Türkiye can be traced back to the *'Zero Waste Project'* spearheaded by the Ministry of Environment and Urbanization in 2017 which is followed by the *'Zero Waste Regulation'* in 2019 which expanded the project's scope to encompass municipalities, healthcare institutions, schools, universities, organized industrial zones, private sector entities, and certain manufacturing firms (Görmüş, 2023). Besides that, recent studies, including those by Güllü (2023) and Memiş (2023) highlighted challenges faced by Türkiye's WM practices. However, it is stated that shifting towards a CE necessitates significant transformations in production and consumption frameworks, extending beyond mere resource efficiency and waste recycling (Ivanova and Chipeva, 2019). In this sense, aligned with the principles of the CE and SDGs, sustainable production and consumption practices aims to decrease resource consumption while promoting the production of economically viable, environmentally friendly, and socially beneficial products by minimizing resource usage and waste generation (Witjes and Lozano, 2016; Tseng et al., 2020; Ding, 2021). Furthermore, it can also be stated that sustainable production and consumption are two sides of the same coin; as sustainable production focuses on resource-efficient processes and methods, and sustainable consumption emphasizes finding a balance between consumer choice and environmental responsibility (Markowski et al., 2023). In this context, Arion et al. (2023) and Migała-Warchoł et al. (2023) emphasized the significance of production and consumption indicators -among a set of five categories including waste management, secondary raw materials, competitiveness, etc.- within the EU methodology for evaluating progress towards the CE, as they provide insights into waste generation and resource efficiency, crucial for attaining economic and environmental benefits, which are key factors in adopting CE principles.

On the other hand, Multi-Criteria Decision Making (MCDM), as a subset of operations research, aids in complex decision-making scenarios where multiple goals conflict and/or evaluation of various alternatives based on performance data (scoring criteria) is aimed (D'Adamo et al., 2024). The field of MCDM is characterized by a plethora of methods, and this number continues to grow with the introduction of new developments and extensions. Furthermore, MCDM has a substantial impact across a range of disciplines including economics, business management, engineering, environmental sciences, healthcare, and even politics (Huang and Moh, 2017). Also, at a certain point in the application of MCDM analysis, determining the weight of each criterion becomes necessary, as assigning equal values to all criteria is impractical since they typically vary in importance by considering the goal of the decision-making problem (Md Saad et al., 2014). Moreover, alternatives considered in MCDM problems often exhibit conflicting indicators, making it challenging for any single alternative to fully satisfy all predetermined criteria (Krishnan et al., 2021). Consequently, the MCDM process involves prioritizing criteria, known as the weighting process, which can be conducted subjectively and/or objectively. Subjective methods rely on decision-makers' judgments, whereas objective criteria weights are calculated using quantitative data computation techniques, such as the Criteria Importance Through Intercriteria Correlation (CRITIC) or Shannon Entropy algorithms, excluding the influence of decision-makers' judgments. On the other hand, it is stated that when a set of indicators contains conflicting criteria, which inherently involve goals of both maximization and minimization, the CRITIC method is employed to reconcile this disparity and determine the objective weights (Diakoulaki et al. 1995). Furthermore, by considering the variety of MCDM methods, a recent and innovative addition to the literature is the Combined Compromise Solution (CoCoSo) method. Introduced by Yazdani et al. (2019a), CoCoSo integrates a simple additive weighting and exponentially weighted product model, providing a range of compromise solutions. The CoCoSo method is recognized for its robustness, offering reliable and stable decision-making outcomes, along with a straightforward structure that is widely applicable and easy to comprehend (Lai, et al., 2020). It has also found application across diverse fields including logistic provider selection, supplier selection, sustainability assessments, renewable energy investment selection, and more (Deveci et al., 2021). As another method which is introduced by Zavadskas et al. (2012), the Weighted Aggregated Sum Product Assessment (WASPAS) is one of the earlier techniques in the literature that combines the Weighted Sum Model (WSM) and the Weighted Product Model (WPM). Since it has been established that aggregated methods generally offer greater accuracy compared to individual methods; it can be clearly stated that the WASPAS, combining WSM and WPM, boasts several advantages including computational simplicity, comprehensibility, and logical acceptability (Can, 2018). Additionally, it is asserted that the WASPAS demonstrates robustness against rank reversal among alternatives, contributing to enhanced ranking accuracy (Zavadskas et al., 2014). In accordance with these features, this study employs a methodology integrating the CRITIC approach with the CoCoSo and WASPAS methods.

In this context, the aim of this study can be stated as to conduct a comparative multi-criteria analysis of EU member states and Türkiye, with a particular focus on CE aspects, especially production and consumption indicators, to evaluate their progress and performance. The main contribution of this study is its focused examination of the production and consumption facets of the CE and conducting distinct assessments of Türkiye and EU countries which offers an overview of Türkiye's current status. In addition, by incorporating the most recent data and utilizing robust MCDM methods, this study seeks to provide valuable insights for policymakers and stakeholders to develop more effective strategies and policies. Additionally, the findings aim to contribute to the academic discourse by highlighting the significance of CE practices. In line with this, the paper's structure is outlined as follows: Following section provides a literature review. In the second section, a concise overview of the utilized data and methodologies is given. Section three comprises empirical analyses to establish rankings and present results derived from MCDM methods. The fourth section offers discussion and conclusions.

1. LITERATURE REVIEW

Given the organization of our societies and businesses and the pursuit of sustainable development (SD), it is evident that countries and organizations have numerous avenues to explore. The circular economy (CE) model, in this regard, presents an opportunity for integration and innovation across society, businesses, daily life, natural ecosystems in general; and also waste management in particular (Ghosh, 2020). Hence, it can be asserted that the shift towards the CE demands a fundamentally different approach to conducting business and structuring economic activities. Nevertheless, it is evident that the prevailing global economic model continues to prioritize consumption growth, leading to excessive exploitation of Earth's resources, despite notable shifts in public awareness and political expression (Nazarko et al., 2022). In this sense, at both macro and micro levels, researchers investigate sectoral or spatial dimensions of the CE using diverse methodologies. Furthermore, existing literature also includes studies that solely examine the production and consumption aspects of CE, which aligns with the focus of this current study. Regarding the approach adopted in this study, it's worth noting that numerous studies utilize Multi-Criteria Decision Making (MCDM) methods to analyze the performance of CE objectives across different countries and country groups. In addition to systematic literature reviews, such as Martinho and Mourão (2020), Mhatre et al. (2021), de Melo et al. (2022), dos Santos Gonçalves and Campos (2022), which both focus on the evaluation of the CE in general and also include MCDM methods, relevant selected studies in the context of this study are given below.

Fura et al. (2020) conducted an analysis to assess the progress of CE adoption across European Union (EU) countries. Utilizing Eurostat data, distinct CE areas including waste management, secondary raw materials, competitiveness and innovation and also production and consumption were examined. Seventeen Eurostat indicators spanning every two years between 2010 and 2016 were selected for comparative analysis and similarity measures. The findings reveal Belgium, Luxembourg, and the Netherlands as leaders in CE progress, while Cyprus, Estonia, Malta, and Greece lag behind in CE implementation. Garcia-Bernabeu et al. (2020) devised a composite indicator for assessing CE performance among EU countries. A multi-criteria approach was employed to construct a CE composite index using the Technique for Order Preferences by Similarity to Ideal Solutions (TOPSIS) methodology. The findings positioned Germany, the United Kingdom, and France at the forefront, while Malta and Estonia were placed near the bottom of the rankings. Mazur-Wierzbicka (2021b) conducted a multidimensional comparative analysis, employing linear ordering to generate a synthetic dependent variable and taxonomic methods to conduct cluster analysis, aimed at evaluating the implementation of the CE by EU countries. The findings indicate that the older EU member states (EU-15) are leading in CE advancement, with countries like Germany, Belgium, the Netherlands, Spain, and France demonstrating notable progress. Conversely, the countries showing the least advancement in adopting CE practices include primarily Malta and Cyprus. Stanković, et al. (2021) conducted a comparative analysis of CE development across EU countries. The dataset included 11 indicators, spanning a seven-year period with biennial data. Utilizing an integrated approach of Principal Component Analysis (PCA) and Preference Ranking Organisation METHod for Enrichment Evaluations (PROMETHEE), the analysis revealed that Germany leads in CE development, followed by the Netherlands, France, and Austria. Furthermore, a positive correlation was observed between the national-level development of circular economies and the socio-economic development of the respective countries. Candan and Cengiz Toklu (2022) examined the CE outlook of EU member states, utilizing the CE monitoring framework. Importance weights of criteria were calculated using the fuzzy Simple Multi-Attribute Rating Technique (SMART) approach. Subsequently, countries were ranked based on their CE performances for the years 2014, 2016, and 2018 using the Combinative Distance-Based Assessment (CODAS) method. The findings identified the top-performing countries as Netherlands, Luxembourg, Belgium, France, and Germany. Nazarko et al. (2022) assessed the progress of EU member states towards a CE using Data Envelopment Analysis (DEA) and factor analysis, incorporating indicators across above mentioned four dimensions. The study revealed a strong correlation between a country's GDP per capita and its position in achieving CE objectives. Additionally, factor analysis indicated significant intercorrelations among various CE indicators. In accordance with this study's context, Croatia, Netherlands, Luxembourg, and Slovenia emerged as leaders among EU countries, particularly in waste generation, recycling rates (including e-waste), circular material utilization, and value added. Kaya et al. (2023) utilized an integrated framework comprising clustering methods and MCDM to investigate the social progress of EU members in the CE. Initially, k-means cluster analysis was employed to categorize the 27 EU member states based on similar levels of social impact. Subsequently, the CRiteria Importance Through Intercriteria Correlation (CRITIC) method and the Method based on the Removal Effects of Criteria (MEREC) were applied to determine the weights of social indicators. To identify the best-performing country in each cluster, a hybrid Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS) method was developed. The findings revealed that the first cluster consists of countries with the lowest unemployment and corruption rates, with the Netherlands exhibiting the best performance. The second cluster comprises countries with the lowest employment rates, with Croatia demonstrating the best social performance in this group. Lastly, countries in the third cluster exhibit the highest income distribution and unemployment rates, with Lithuania emerging as the best-performing country in this category. D'Adamo et al. (2024) investigated the CE performance of the EU27 for the years 2019 and 2020, utilizing 15 CE indicators sourced from Eurostat and applying the

Analytic Hierarchy Process (AHP). The weightings obtained from the analysis highlight the dominance of the competitiveness and innovation category, with the global sustainability and resilience category following closely. Moreover, performance analysis outcomes reveal Belgium's superiority in both baseline and alternative scenarios, surpassing Italy and the Netherlands, respectively.

Building on the aforementioned studies regarding CE evaluations in European countries, works of Edina et al. (2022), Kozma et al. (2022), and Özceylan (2022) can also be taken into consideration. On the other hand, the following studies specifically focus on the production and consumption aspects of the CE, including evaluations of countries: Koska and Erdem (2023) assessed waste management performance within Türkiye's manufacturing industry in the context of the CE, employing the Step-wise Weight Assessment Ratio Analysis (SWARA) and VIseKriterijumsa Optimizacija I Kompromisno Resenje (VIKOR) methods. The model utilized manufacturing waste indicators from the Turkish Statistical Institute, covering biennial data from 2000 to 2020. The findings reveal an upward trend in waste reduction, reuse, and recycling indicators, alongside a downward trend in disposal rates. Consequently, Türkiye is expected to face minimal challenges in aligning with the European Green Deal, with notable positive environmental progress. Marković et al. (2023) devised an index utilizing selected metrics from the database of Eurostat employing multi-criteria analysis techniques. The CRITIC method was employed to obtain weights, while Grey Relational Analysis (GRA) facilitated the computation of the index evaluating perforance of waste management. The model incorporated five indicators sourced from the database of Eurostat for 2018 and 2019, comprising recycling rates of municipal waste, all waste excluding major mineral waste, packaging waste, bio-waste per capita, and rates of recovery in construction and demolition waste. The findings reveal that Austria, Belgium, Luxembourg, the Netherlands, and Slovenia excel in implementing effective waste management practices, whereas Bulgaria, Croatia, Cyprus, Malta, Poland, Romania, and Slovakia demonstrate lower performance scores on the waste management index. In a study akin to the present study but excluding Türkiye from the country grouping and concentrating solely on the year 2020, Seyhan (2023) evaluated indicators of production and consumption and CE outlook of 27 EU countries using the MARCOS method based on the MEREC approach. Through the MEREC application, the most significant criterion emerged as recyclable raw material trade, followed by cyclic material utilization rate, gross value added, private investment. According to the MARCOS findings, top performers in CE indicators of production and consumption include Germany, France, the Netherlands, and Spain; while Luxembourg, Finland, Malta, Cyprus, and Estonia rank as low performers.

Finally, it can be asserted that the Combined Compromise Solution (CoCoSo) and the Weighted Aggregated Sum Product Assessment (WASPAS) methods remain at the forefront of contemporary MCDM research, as evidenced by their continued utilization in recent studies across various applications since these methods, while robust and sophisticated, offer accessible and insightful tools for researchers seeking valuable insights in their studies. Therefore, by taking into account the methodology employed in this study and numerous research endeavors in the literature from various disciplines which have utilized the the CoCoSo and the WASPAS methods, a selection of such studies along with their respective fields of application are presented in the following table:

Table 1: *Examples of CoCoSo and WASPAS oriented studies in selected fields*

	Field	Authors
CoCoSo	Supplier selection	Yazdani et al. (2019b); Ecer and Pamucar (2020); Yazdani et al. (2021); Parsa Rad et al. (2024)
	Location selection	Ulutaş et al. (2020); Kieu et al. (2021); Zhang and Wei (2023); Yan et al. (2024)
	Healthcare	Peng et al. (2021); Torkayesh et al. (2021); Zhang and Tian (2023)
	Finance & Banking	Peng and Huang (2020); Bektaş (2022); Narang et al. (2022); Gülcemal et al. (2023); RouhaniRad et al. (2023)
	Transportation	Ulutaş et al. (2021b); Bouriama et al. (2023); Ecer et al. (2023); Rashidian et al. (2024)
	Industry evaluations	Peng et al. (2020); Choudhary and Mishra (2020); Garg et al. (2023)
	Energy	Ecer (2021); Ulutaş et al. (2021a); Ghoushchi et al. (2021); Dehshiri and Amiri (2023)
WASPAS	**Field**	**Authors**
	Supplier selection	Stojic et al. (2018); Singh and Modgil (2020); Alrasheedi et al. (2022); Liu et al. (2023)
	Location selection	Baušys and Juodagalvienė (2017); Miç and Antmen (2021); Yücenur and Ipeki (2021); Yalcin Kavus et al. (2023)
	Healthcare	Mishra and Rani (2021); Chakraborty and Saha (2022); Komal (2023)
	Finance & Banking	Gezen (2019); Karaca et al. (2020); Nguyen et al. (2022); dos Santos and da Sailva (2023); Jing et al (2023)
	Transportation	Baç (2020); Tumsekcali et al. (2021); Garside et al (2023); Görçün et al. (2024);
	Industry evaluations	Ghorshi Nezhad et al (2015); Keshavarz-Ghorabaee et al (2019);
	Energy	Balezentis et al. (2021); Saraswat et al (2021); Bączkiewicz and Wątróbski (2022) ; Dhumras and Bajaj (2024)

Consequently, building upon previous studies in the literature, it can be stated that this research makes a contribution by applying a robust methodology to conduct a comparative multi-criteria analysis of EU member states and Türkiye and by focusing on CE aspects, particularly production and consumption indicators, utilizing most recent data and empirically validated MCDM methods to evaluate their progress and performance.

2. DATA & METHODOLOGY

2.1. Data

The assessment of progress towards the circular economy (CE), considering production and consumption indicators in both European Union (EU) countries and Türkiye, was carried out by analyzing data from the Eurostat database, including biennial data from 2008 to 2020. The indicator set consists of 8 indicators; however, due to data unavailability for the food waste (FW) indicator until 2020, the analysis covered 7 indicators between 2008 and 2018, and all 8 indicators for 2020. In the first step, dataset has been pre-processed and missing values are handled. In this regard, the Simple Imputer class from the Scikit-learn library along Python was utilized to find and fill these values. These 8 indicators, along with their abbreviations, are listed in Table 2 for reference.

Table 2: *Production and consumption indicators with abbreviations*

No.	Criteria	Abbrv.
1	Material footprint	MF
2	Resource productivity	RP
3	Waste generation per capita	WGP
4	Generation of waste excluding major mineral wastes per GDP unit	GOW
5	Generation of municipal waste per capita	GOM
6	Food waste	FW
7	Generation of packaging waste per capita	GOP
8	Generation of plastic packaging waste per capita	GOPP

Source: Eurostat

As stated above, due to data unavailability the indicator set was adjusted, removing one indicator (FW) for 2008 and onwards until 2020, thereby including only 7 indicators. The next sub-section offers concise summaries of the employed methodologies in this study.

2.2. METHODOLOGY

2.2.1. Criteria Importance Through Intercriteria Correlation (CRITIC) Method

The CRITIC method, a commonly employed objective criteria weighting technique in academic research, calculates objective weights for a given set of criteria using standard deviation and correlation values. It was introduced by Diakoulaki et al. (1995). The procedural steps of the CRITIC method are outlined as follows (Kaya et al., 2023):

Step 1: The decision matrix, comprising *n* criteria and *m* alternatives, is formulated as depicted in Equation (1):

$$X = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

Step 2: The performance measures in matrix X are normalized using Equation 2:

$$r_{ij} = \begin{cases} \frac{x_{ij}-x_j^-}{x_j^+-x_j^-}, x_j^+ = \max_i x_{ij}, x_j^- = \min_i x_{ij} \\ \frac{x_j^- - x_{ij}}{x_j^+-x_j^-}, x_j^+ = \min_i x_{ij}, x_j^- = \max_i x_{ij} \end{cases} \quad (2)$$

where x_{ij}^T denotes the normalized outcome of i^{th} alternative by considering j^{th} criterion.

Step 3: In this step, a correlation coefficient matrix is created to gauge the relationships between the criteria and the correlation coefficient is calculated using Equation 3 to determine the degree of correlation between the criteria:

$$\rho_{jk} = \frac{\sum_{i=1}^{m}(r_{ij}- \overline{r_j}).(r_{ik}- \overline{r_k})}{\sqrt{\sum_{i=1}^{m}(r_{ij}- \overline{r_j})^2 \ \sum_{i=1}^{m}(r_{ik}- \overline{r_k})^2}} \quad j,k = 1,2,\ldots.,n \quad (3)$$

Step 4: The information contained within criterion *j* (C_j) is obtained via below equation:

$$C_j = \sigma_j \sum_{k=1}^{n}(1-\rho_{jk}), j = 1,2,\ldots,n \quad (4)$$

Step 5: To calculate the criteria weights, the total of C_j values (C_k) are computed and the weights (W_j) are acquired using the formula (5):

$$C_k = \sum_{k=1}^{m} C_j$$

$$W_j = \frac{C_j}{\sum_{k=1}^{n} C_k}, j,k = 1,\ldots,n \quad (5)$$

2.2.2. Combined Compromise Solution (CoCoSo) Method

CoCoSo, introduced by Yazdani (2019a), utilizes an integrated model combining simple additive weighting and exponentially weighted product approaches, offering a range of compromise solutions. To address a CoCoSo decision problem, the following steps are typically followed after determining the alternatives and relevant criteria:

Step 1: The decision matrix that includes *n* criteria and *m* alternatives is constructed:

$$X = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (6)$$

Step 2: The normalized values of the matrix X are calculated using the equation below:

$$r_{ij} = \begin{cases} \frac{x_{ij}-x_j^-}{x_j^+-x_j^-}, x_j^+ = \max_i x_{ij}, x_j^- = \min_i x_{ij} \\ \frac{x_j^- - x_{ij}}{x_j^+-x_j^-}, x_j^+ = \min_i x_{ij}, x_j^- = \max_i x_{ij} \end{cases} \tag{7}$$

Step 3: The sum of the weighted comparability sequence and the aggregate power weight of comparability sequences for each alternative is denoted as S_i and Pi, respectively:

$$S_i = \sum_{j=1}^{n}(w_j r_{ij}), \tag{8}$$

S_i is obtained using a method called grey relational generation and below given Pi is obtained by the multiplicative approach:

$$P_i = \sum_{j=1}^{n}(r_{ij})^{w_j}, \tag{9}$$

Step 4: The relative weights of the alternatives are calculated using various aggregation methods. In this phase, three assessment scoring techniques are employed to determine the relative weights of the alternatives, as indicated by the formulas below:

$$k_{ia} = \frac{P_i+S_i}{\sum_{i=1}^{m}(P_i+S_i)} \tag{10}$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \tag{11}$$

$$k_{ic} = \frac{\lambda S_i+(1-\lambda)P_i}{\lambda \max_i S_i+(1-\lambda)\max_i P_i}; \ 0\leq \lambda \leq 1 \tag{12}$$

Equation (10) is understood to represent the average of the total of WPM and WSM scores, while Equation (11) denotes the total of relative scores for WPM and WSM in comparison to the best. Equation (12) presents the compromise value which is balanced between WPM and WSM model scores, and here a typical decision-maker select λ (often equals to 0.5).

Step 5: The ultimate ranking of the alternatives is established according to the values of k_i, which signify greater significance as they increase:

$$k_i = (k_{ia}k_{ib}k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia}+k_{ib}+k_{ic}) \tag{13}$$

2.2.3. Weighted Aggregated Sum Product Assessment (WASPAS) Method

The WASPAS approach, proposed by Zavadskas et al. (2012) integrates the Weighted Product Model (WPM) and Weighted Sum Model (WSM) and stands out as a robust MCDM method, representing a novel utility determination approach, argued to offer higher accuracy compared to WPM and WSM by its proponents. The procedure for applying the WASPAS method is outlined below (Tuş and Aytaç Adalı, 2019):

Step 1: Constructing the decision matrix, which comprises *n* criteria and *m* alternatives.

$$X = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{14}$$

Step 2: Normalizing the decision matrix is accomplished by considering the criteria's characteristics using Equations (15) and (16) accordingly:

$$x_{ij}^* = \frac{x_{ij}}{\max_i(x_{ij})} \quad i = 1,2,\ldots,m \ and \ j = 1,2,\ldots.n \tag{15}$$

$$x_{ij}^* = \frac{\min_i(x_{ij})}{x_{ij}} \quad i = 1,2,\ldots,m \ and \ j = 1,2,\ldots.n \tag{16}$$

Step 3: The overall relative importance of the i^th alternative, utilizing WSM, is computed as follows:

$$Q_i^1 = \sum_{j=1}^{n} x_{ij}^* w_j \tag{17}$$

Step 4: The same value, employing WPM, is obtained as follows:

$$Q_i^2 = \prod_{j=1}^{n}(x_{ij}^*)^{w_j} \tag{18}$$

Step 5: To determine sum of relative importance of an alternative (Q_i) a generalized equation is used. The decision-making process' accuracy and effectiveness are enhanced with the assistance of Equation (19), where λ ranges between 0 and 1:

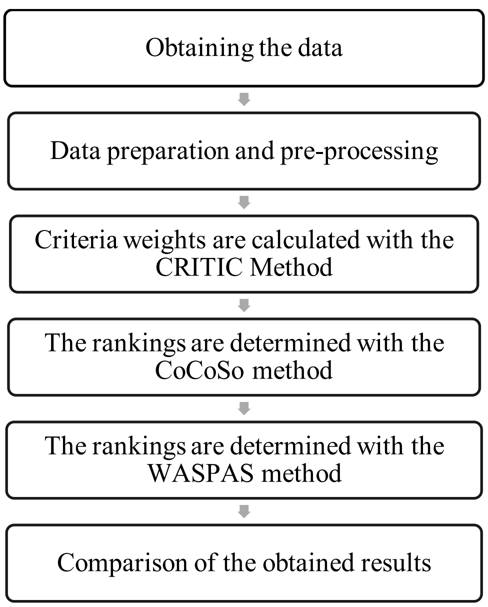
$$Q_i = \lambda Q_i^1 + (1-\lambda)Q_i^2 \tag{19}$$

Step 6: Finally, the ranking of the alternatives are done by taking Q values into account. The top-ranked alternative exhibits Q value which is the highest. If the value of λ equals to 0, the WASPAS method transforms into WPM, and if λ equals to 1, it transitions to WSM.

3. RESULTS & DISCUSSIONS

This research incorporates two distinct Multi-Criteria Decision Making (MCDM) applications designed to evaluate advancements in the circular economy (CE), focusing on production and consumption indicators in both European Union (EU) countries and Türkiye for every two years between 2008 and 2020 using an objective criteria weighting approach. The analysis steps are outlined in Figure 1 below:

Figure 1: *Steps of the comparative MCDM analysis*



Upon concluding the initial two steps outlined in the preceding chapter, the Criteria Importance Through Intercriteria Correlation (CRITIC) method was employed to determine the weights of the criteria. Following this, the countries were ranked based on production and consumption criteria using the Combined Compromise Solution (CoCoSo) and Weighted Aggregated Sum Product Assessment (WASPAS) methods. The final phase included a comparison of the obtained results.

On the other hand, it is stated that minimizing food waste (FW) offers cost savings for consumers and businesses, and the recovery and redistribution of excess food can produce nutrients, animal feed, and secondary raw materials (Amicarelli and Bus, 2020). Additionally, since circular utilization of FW involves recycling, repurposing and reducing, it can also be used for various purposes such as biomass utilization, insect farming, production of biofertilizers and more importantly, energy production (Bigdeloo et al., 2021). In this context, FW is considered as one of the key indicators of CE (Moraga et al., 2019). However, as previously mentioned, the data for this indicator is available only for the final year of the dataset. Therefore, considering its above given importance to the concept of CE, it was initially included in the comparative MCDM application and then excluded to maintain the integrity of the analysis. After both analyses, it was observed that neither the rankings of the indicators in the CRITIC application nor the top and bottom rankings in the two MCDM analyses changed. Despite this, given the above importance of FW for CE as stated in the literature, the results of the analysis that include this indicator are given in this study.

As stated above, after acquiring the data, the criteria weights acquired from the CRITIC application for each year spanning 2008 to 2020 are shown in Table 3 below:

Table 3: *The criteria weights between 2008-2020*

	2008	2010	2012	2014	2016	2018	2020
MF	0.14756	0.13357	0.12450	0.12812	0.13084	0.12760	0.12287
RP	0.13807	0.13221	0.14129	**0.16082***	**0.16401***	**0.16628***	0.14842
WGP	0.14395	**0.16156***	**0.17333***	0.16010	0.15583	0.15151	0.13332
GOW	**0.17261***	0.15764	0.16679	0.15805	0.16030	0.16172	**0.15470***
GOM	0.13732	0.15450	0.13999	0.13468	0.13255	0.13015	0.12426
FW	-	-	-	-	-	-	0.11192
GOP	0.13838	0.14124	0.13997	0.13964	0.14075	0.14196	0.10526
GOPP	0.12212	0.11927	0.11412	0.11857	0.11572	0.12079	0.09925

The findings presented in Table 3 highlight the generation of waste excluding major mineral wastes per GDP unit (GOW) criterion as the most significant factor at the beginning and conclusion of the studied period. During this timeframe, waste generation per capita (WGP) secured the top ranking for 2010 and 2012, whereas resource productivity (RP) criteria claimed the highest position for the subsequent years. Additionally, it is evident that no single criterion presented significant dominance throughout this period, indicating a balanced distribution of weights among production and consumption indicators. The GOW indicator measures the total waste produced within a nation (measured by mass), excluding significant mineral wastes, in relation to the nation's domestic material consumption (Eurostat, 2024a). By considering the relevant literature, it can be stated that this indicator carries significant importance for countries since evaluating waste production relative to material consumption and effectively using resources while considering sustainability is crucial for CE. On the other hand, WGP represents the aggregate waste generated within a nation, encompassing significant mineral waste, divided by the nation's average population (Eurostat, 2024b). WGP tends to increase in densely populated areas and is often influenced by income levels, as indicated in various studies (Dahlen et al., 2009; Masebinu et al., 2017). Furthermore, changes in consumption patterns can alter WGP trends, even when population growth remains consistent, as highlighted by recent research (Ngegba et al., 2020). Thereby, it can be asserted that this indicator holds significant importance for countries as it provides insights into their waste production relative to their population size, aiding in the assessment of resource utilization efficiency and environmental sustainability. Finally, RP is defined as the GDP divided by household material consumption (Eurostat, 2024c). Recognized as a crucial metric within the CE framework, RP signifies the efficiency of resource utilization. It measures the balance between economic growth and the direct consumption of natural resources by households and businesses. A higher RP value indicates that the economy is expanding at a faster pace than the depletion of raw materials (Pollitt and Ajayi, 2023). In essence, in a CE context, RP improves as the economy reduces its reliance on newly extracted resources and prolongs the lifespan of existing resources (Baptista, 2021). In the following phase of the study, the advancement towards achieving a CE, focusing on production and consumption in both EU nations and Türkiye, was assessed utilizing the CoCoSo and WASPAS techniques. The results obtained through the former method are displayed in Table 4:

Table 4: *Rankings of countries obtained with the CoCoSo method*

Countries	2008 Rankings	2010 Rankings	2012 Rankings	2014 Rankings	2016 Rankings	2018 Rankings	2020 Rankings
Austria	18	20	22	21	21	20	25
Belgium	7	11	11	8	9	5	18
Bulgaria	26	25	27	27	25	26	27
Croatia	9	7	**1***	**1***	**1***	**1***	**1***
Cyprus	22	24	15	10	11	9	23
Czechia	**3***	**3***	**3***	4	7	11	8
Denmark	23	9	24	23	24	24	21
Estonia	28	27	28	28	28	28	26
Finland	25	26	26	26	27	27	28
France	15	18	19	16	13	13	7
Germany	16	22	23	22	22	22	22
Greece	10	13	9	9	6	**2***	9
Hungary	4	4	6	11	10	12	14
Ireland	27	23	20	24	23	23	24
Italy	17	19	17	12	12	10	6
Latvia	**1***	**1***	4	6	5	8	11
Lithuania	8	5	8	14	14	17	16
Luxembourg	24	28	25	25	26	25	19
Malta	12	12	12	15	17	15	12
Netherlands	5	15	10	5	4	**3***	**2***
Poland	6	8	16	18	19	19	15
Portugal	21	21	18	19	18	21	17
Romania	20	6	14	13	16	16	20
Slovakia	**2***	**2***	**2***	**2***	**2***	4	5
Slovenia	13	10	5	7	8	7	4
Spain	19	17	7	**3***	**3***	6	**3***
Sweden	14	16	21	20	20	18	13
Türkiye	11	14	13	17	15	14	10

* Indicating top three countries

According to the findings, Latvia demonstrated the strongest performance in the initial two years, followed by Slovakia and Czechia. Meanwhile, Croatia experienced a significant rise and consistently secured a top position from 2012 until the end of the analyzed period. The second and third positions were shared interchangeably by Greece, the Netherlands, Spain, and Slovakia, while Estonia, Finland, and Bulgaria ranked the lowest. Türkiye displayed a relatively consistent performance, securing the 10th position in 2020 and 11th at the outset of the analyzed period in 2008. Furthermore, Croatia and Slovakia exhibited consistent performance by maintaining a position in the top three throughout the period. The obtained rankings from the following MCDM analysis, namely WASPAS, are provided below:

Table 5: *Rankings of countries obtained with the WASPAS method*

Countries	2008 Rankings	2010 Rankings	2012 Rankings	2014 Rankings	2016 Rankings	2018 Rankings	2020 Rankings
Austria	25	21	23	24	23	22	22
Belgium	8	19	17	17	16	13	21
Bulgaria	24	26	26	26	26	26	28
Croatia	5	**2***	**1***	**1***	**1***	**1***	**1***
Cyprus	21	17	6	4	5	4	12
Czechia	4	5	7	8	11	21	15
Denmark	16	7	18	20	17	18	20
Estonia	28	28	28	28	28	28	27
Finland	27	27	27	27	27	27	26
France	10	12	16	12	10	10	8
Germany	12	18	22	23	21	19	18
Greece	22	24	20	18	14	7	14
Hungary	6	**3***	5	11	13	16	10
Ireland	11	22	11	16	9	**3***	**3***
Italy	9	13	12	6	7	8	5
Latvia	**1***	**1***	**2***	5	**2***	**2***	13
Lithuania	15	8	15	19	20	23	23
Luxembourg	17	25	19	14	19	15	11
Malta	14	6	14	13	18	11	17
Netherlands	**2***	10	9	7	4	5	4
Poland	13	23	25	25	25	25	24
Portugal	23	15	13	15	15	17	19
Romania	26	14	21	21	24	24	25
Slovakia	**3***	4	**3***	**3***	6	9	7
Slovenia	19	20	10	10	12	14	6
Spain	20	11	4	**2***	**3***	6	**2***
Sweden	18	16	24	22	22	20	16
Türkiye	7	9	8	9	8	12	9

* Indicating top three countries

Aligned with the initial method's findings, Latvia showcased the strongest performance in the first two years and maintained a commendable performance throughout the analyzed period. Similarly, as per the CoCoSo results, Croatia persistently held a top position between 2012 and 2020. Although Hungary and the Netherlands only attained top-three rankings in 2008 and 2010 respectively, Slovakia demonstrated a more unvarying performance throughout the initial half of the analyzed period. Corresponding to previous analyses, Estonia, Finland, and Bulgaria ranked the lowest. Additionally, Türkiye exhibited relatively better performance throughout the analysis, consistently securing a position in the top ten except for 2018. Overall, Croatia and Latvia demonstrated steady performance, mostly maintaining positions in the top three throughout the period, with Latvia experiencing a notable decline in 2020. The illustration of Türkiye's placement, as derived from the country rankings obtained through both MCDM analyses, is shown in Figure 2 below:

Figure 2: *Türkiye's Performance on production and consumption compared to EU countries*

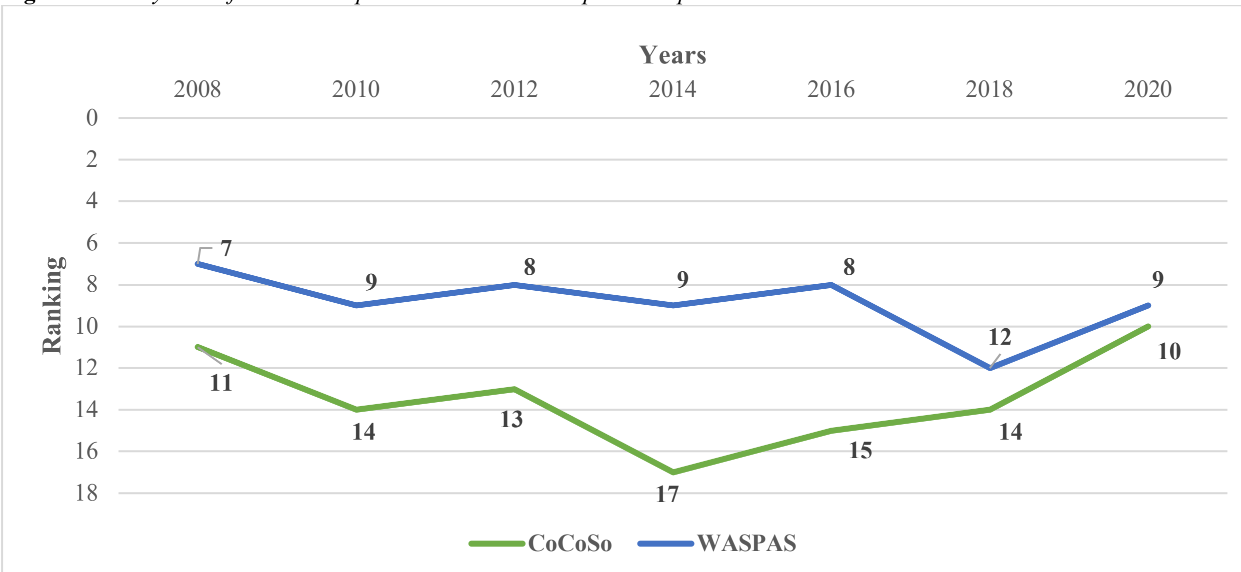


Figure 2 depicts Türkiye's steady and moderate performance from 2008 to 2020 across the designated criteria. However, based on the WASPAS application, Türkiye exhibited notably better performance and consistently ranked within the top ten throughout most of the period. Furthermore, the CoCoSo analysis revealed a significant improvement in performance after 2014, with Türkiye ascending from the 17th ranking in 2014 to the 10th in 2020. Therefore, it can be inferred that Türkiye demonstrated average performance between 2008 and 2020, as assessed by both MCDM analyses in this study, regarding production and consumption performance related to the CE.

4. DISCUSSION & CONCLUSIONS

Over the past decade, there has been a growing global focus on sustainable development (SD) and goals related to this (SDGs), including efforts to tackle resource scarcity, reduce greenhouse gas emissions, and reconsider waste management practices. In 2015, two major action plans emerged: the United Nations (UN)'s *'Transforming Our World: The 2030 Agenda for Sustainable Development,'* which comprises 17 SDGs, and the European Commission (EC)'s action plan for the circular economy (CE) that aim to shift towards a model, wherein resources, materials, and products are retained within the system for longer periods to reduce waste generation (UN, 2015; Rodriguez-Anton et al., 2019). Briefly, the concept of CE is founded on principles aiming to reduce waste and pollution, prolong the lifespan of products and materials, and restore natural systems (Mhatre et al., 2021). In this regard, it is noted that the most significant correlations are observed between CE initiatives and certain SDGs, namely *SDG 6 (Ensuring Access to Clean Water and Sanitation)*, *SDG 7 (Promoting Affordable and Clean Energy)*, *SDG 8 (Fostering Decent Work and Economic Growth)*, *SDG 12 (Encouraging Responsible Consumption and Production)*, and *SDG 15 (Protecting Life on Land)* (Schroeder et al., 2019). Furthermore, it is mentioned that Türkiye also launched the *'Zero Waste Project'* in 2017, with a specific emphasis on CE, and then the *'Zero Waste Regulation'* in 2019 was implemented, which broadened the project's reach to encompass industrial production zones, private sector establishments, and specific manufacturing facilities (Görmüş, 2023). Therefore, it can be stated that, despite the entrenched nature of the linear economic model, characterized by the extraction, processing, and consumption of inputs, there is an increasing interest among countries in transitioning away from this model towards embracing a CE model (Hartley et al., 2020).

Moreover, the outputs of production and consumption serve as crucial indicators reflecting a nation's resource availability, depletion status, generated waste resulting from consumption, and investments in recycling, thus pivotal in gauging a country's self-sufficiency (Seyhan, 2023). Within this framework, sustainable production and consumption reflect a rising consciousness driving alterations in economic policies to account for the environmental costs associated with products and services, while also encouraging the adoption of further sustainable production and consumption practices, also as outlined in UN's SDG 12 (Dantas et al., 2021). Hence, the European Union (EU) incorporated production and consumption metrics within a framework of five categories to assess resource utilization and appraise actions related to the CE (Arion et al., 2023). In this context, this study employed an objective criteria weighting approach within a comparative framework of Multi-Criteria Decision Making (MCDM) methodology to assess CE performance based on production and consumption indicators across EU countries and Türkiye. The dataset, sourced from Eurostat, encompassed biennial data spanning from 2008 to 2020. While the dataset mainly comprised 8 indicators, the analysis focused on 7 indicators from 2008 to 2018, expanding to include all 8 indicators for 2020 due to data constraints. Additionally, data preprocessing was necessary to address a few missing values. Findings from the criteria weighting application revealed that resource productivity (RP) criterion ranked highest for three of the analyzed years, followed by the generation of waste excluding major mineral wastes per GDP unit (GOW) and waste generation per capita (WGP), each topping the list for two years. Importantly, no single criterion exhibited significant dominance over the entire analyzed period. According to the findings of the initial analysis conducted using the Combined Compromise Solution (CoCoSo) method, Croatia maintained a consistently top-ranking position from 2012 until the conclusion of the examined timeframe. Meanwhile, the second and third spots were frequently alternated among countries such as Czechia, Slovakia, and Spain; and Estonia, Finland and Bulgaria emerged as the lowest performers respectively. Based on the findings obtained through the Weighted Aggregated Sum Product Assessment (WASPAS) method, Croatia and Latvia maintained top positions from 2008 to 2020, followed by Slovakia and Spain. It is also found that Ireland demonstrated a notable performance particularly in the last two years. The weakest performers were identified as similar with the previous analysis. Considering the comparative aim of the analysis conducted in this study, it is evident that both multi-criteria analyses yielded results in line with each other, thereby mutually reinforcing the outcomes of each method. Finally, while there is limited research in the literature specifically assessing performance in terms of the production and consumption facets of the CE, it can be inferred that these outcomes partially align with studies such as Nazarko et al. (2022), Marković et al. (2023) and Seyhan (2023).

Regarding its performance as illustrated in Figure 2, Türkiye demonstrated a consistent and moderate trajectory from 2008 to 2020 across the production and consumption criteria. Upon comparing the results of both methods, Türkiye displayed a superior performance in WASPAS compared to the CoCoSo evaluation, consistently maintaining a position within the top ten throughout most of the period. Furthermore, an improvement in performance post-2018 is observed in both analyses. It can be asserted that despite the scarcity of studies in the literature assessing Türkiye's performance, these results align with the conclusions drawn by Koska and Erdem (2023), indicating that Türkiye exhibited an upward trend in waste management indicators, showcasing its strongest performance between 2016 and 2020, which is notably consistent with our findings using the CoCoSo approach. As a conclusion, the primary contribution of this study lies in its specific emphasis on the production and consumption aspect of the CE, an aspect seldom addressed in cross-country evaluations in the literature. Additionally, the study utilized the most recent available data and employed two distinct MCDM approaches to compare the results obtained. Moreover, this research adds to the literature by performing separate assessments of Türkiye and EU countries including official indicators and a criterion weighting approach depending on objective calculations. Through these analyses, it provides a valid overview of Türkiye's current status, which could be seen as a valuable contribution to the redefined relations with the EU. However, it's worth noting that focusing solely on one aspect of the CE can also be considered a limitation of this study. Furthermore, missing values in the dataset led to the absence of evaluation for the year 2022, the most recent year available. Additionally, in this study only two out of many MCDM methods found in the literature are used. Lastly, due to data constraints, the analysis focused on seven production and consumption indicators from 2008 to 2018 instead of eight. In terms of policy implications, the proposed assessment model proves valuable for academics, experts, and officials, as it yields similar results with both methods and aligns closely with findings from other studies. Moreover, the model and methodology offer valuable insights for Turkish policymakers and government officials in gauging the country's position in the production and consumption aspect of the CE relative to EU countries, thereby aiding in the development of new policies and incentives. Future research could explore the utilization of an expanded set of production and consumption indicators, as well as alternative methods that integrate MCDM with emerging approaches such as machine learning methodologies.

AUTHOR DECLARATIONS

Declarations of Research and Publication Ethics: This study has been prepared in accordance with scientific research and publication ethics.

Ethics Committee Approval: Since this research does not include analyzes that require ethics committee approval, it does not require ethics committee approval.

Author Contributions: The author has done all the work alone.

Conflict of Interest: There is no conflict of interest arising from the study for the author or third parties.

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