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Investigation of barriers for circular economy using Delphi, Best Worst Method, and EDAS: An application study in Turkiye for a manufacturing company

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Abstract

Adopting the principles of a circular economy, which emphasizes reducing waste, reusing resources, and recycling materials to create a closed-loop system, has become imperative for manufacturing firms to maintain their competitiveness in the global market. Examining the adoption of circular practices through the lens of companies' sustainability goals is essential for identifying specific objectives related to circular economy initiatives and overcoming associated barriers. This study presents a case analysis conducted in a manufacturing company to address these barriers. Initially, the company's sustainable development goals were assessed and weighted using the Best Worst method. Subsequently, barriers hindering the transition to a circular economy were identified through a comprehensive literature review, and critical barriers were determined using the Delphi method. Leveraging the weighted sustainable development goals, a prioritized ranking of critical barriers was established using the EDAS method. The findings of the study underscore the significance of addressing key barriers to circular economy adoption. Notably, the top three barriers identified include the high cost of eco-friendly materials, the need for technological and infrastructural advancements, and stakeholder environmental awareness. This study holds practical importance in evaluating circular economy adoption barriers in alignment with sustainable development goals. Furthermore, it provides a practical application within a manufacturing company in Turkiye, a developing country.

1. Introduction

Circular economy (CE) is a comprehensive concept. It operates based on the principle of the 6 Rs: reuse, repair, refurbish, redesign, remanufacture, and recycle, which are applicable to any production and consumption model (Jawahir and Bradley, 2016). The primary benefits of implementing the concept of CE include conserving resources, minimizing energy consumption, and decreasing greenhouse gas emissions, thus reducing the economy's dependence on natural resources (Chhimwal et al., 2022; Tseng et al., 2020). Numerous manufacturing companies have transitioned from the traditional linear economy to adopt the principles of CE in order to ensure sustainability in their operations (Badhotiya et al., 2022; Kumar and Goswami, 2019; Lieder and Rashid, 2016). The shift from a linear to a circular economic model is inherently disruptive, necessitating significant changes and innovative solutions (Chhimwal et al., 2022). This transition entails altering existing operational methodologies and adopting novel ideas and practices to foster more sustainable product development (Chhimwal et al., 2022).

Assessing circular adoption through the perspective of companies' sustainability objectives is vital for them to define their circular economy-related goals and address associated barriers effectively. Notably, within the existing literature, there is a lack of Multi-Criteria Decision-Making (MCDM) studies specifically focusing on barriers to CE adoption within the framework of Sustainable Development Goals (SDGs). Moreover, particularly in developing nations such as Turkiye, there is a demand for more practical studies on the barriers to adopting CE practices. This study presents a case analysis conducted within a manufacturing company. Firstly, the SDGs determined by the company were weighted using the Best Worst Method (BWM). Then, after a detailed analysis in the literature, barriers to transitioning to a CE were identified, and those deemed critically important were determined through the Delphi method. With the weighted SDGs, a ranking was established among the barriers considered critical using the Evaluation Based on Distance from Average Solution (EDAS) method. The contribution of this study to the literature can be summarized in three stages. Firstly, the evaluation of CE adoption barriers in light of the SDGs. Secondly, conducting a practical application in a manufacturing company in a developing country. Thirdly, the integrated use of the Delphi, BWM, and EDAS methods for the evaluation of CE barriers. The Delphi method ensures expert consensus in identifying key barriers, while BWM provides a robust framework for weighting SDGs with reduced pairwise comparisons, overcoming challenges faced by methods like Analytic Hierarchy Process (AHP) in complex criteria sets. EDAS, with its unique focus on proximity to the average solution rather than ideal solutions, offers a practical and efficient approach for ranking barriers, eliminating the need for extensive distance calculations.

The rest of this paper is organized as follows: Section 2 provides a summary of the literature, Section 3 outlines the methodology, Section 4 discusses the case study implementation, and lastly, Section 5 offers the conclusion of the paper.

2. Literature Review

CE is a sustainability strategy that maximizes resource utilization while enabling companies to generate profits from products brought to market (Kumar et al., 2020). The aim of CE is to minimize waste and environmental impacts. This includes reducing carbon and water footprints, as well as air acidification, through the reuse, reprocessing, and recycling of products (Ozkan-Ozen et al., 2020). Industries worldwide are increasingly recognizing the significant financial and environmental advantages associated with sustainable manufacturing practices (Moktadir et al., 2018). The growing awareness within the business community, driven by ongoing and rapid global industrialization, underscores the significance of adopting sustainable manufacturing practices and embracing a CE (Moktadir et al., 2018). The implementation of SDGs aids in enhancing the eco-friendly and circular reputation of manufacturing organizations, thereby improving the performance and efficiency of supply chain operations (Lahane and Kant, 2022).

Embracing CE has become imperative for manufacturing firms to remain competitive in the global market. Nevertheless, these organizations encounter various barriers when it comes to effectively implementing CE practices. To achieve successful integration of CE in the manufacturing sector, it is crucial to conduct a thorough analysis of the barriers hindering its adoption. However, there has been a lack of analysis utilizing a decision-making approach concerning the barriers associated with implementing and adopting CE in the manufacturing sector. While European countries have successfully integrated circular supply chains into their business environments over the past three decades, developing nations continue to encounter challenges in its implementation (Lahane & Kant, 2022). Hence, a thorough examination of the challenges impacting the implementation of CE can help the manufacturing sector in emerging economies transition smoothly from a linear to a circular business model. Evaluation of CE adoption barriers involves a multi-criteria structure, and various MCDM studies have been employed in the literature for this purpose, as represented in Table 1.

Table 1. Evaluation of circular economy adoption barriers using MCDM methods

Study	Methods	Country	Sector
(Erol et al., 2022)	Quality Function Deployment, hesitant fuzzy linguistic term sets	-	-
(Liu et al., 2021)	Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL)	China	Food
(Govindan et al., 2022)	Fuzzy BWM, Fuzzy DEMATEL	Iran	Cable and wire industry
(Cui et al., 2021)	Fuzzy Step-wise Weight Assessment Ratio Analysis (SWARA)- Cost-Effectiveness and Cost-Utility Analysis	-	Manufacturing
(Ayçin and Kayapinar Kaya, 2021)	Fuzzy DEMATEL	Turkiye	Recycling
(Dimitrova et al., 2024)	Fuzzy AHP	Bulgaria	Wine

(Haleem et al., 2022)	Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	Pakistan	Food
(Thinakaran et al., 2023)	DEMATEL, Analytic Network Process (ANP), TOPSIS	Indian	Textile
(Haleem et al., 2021)	Fuzzy Criteria Importance through Intercriteria Correlation	-	Various industries
(Sharma et al., 2021)	SWARA, Weighted Aggregated Sum Product Assessment	Indian	Recycling
(Mahanth et al., 2023)	DEMATEL, ANP	Indian	Recycling
(Khandelwal and Barua, 2024)	Fuzzy AHP	Indian	Plastic

Studies have been conducted on examining barriers to circular adoption in different countries and sectors in the literature. Especially for developing countries like Turkiye, there is a need for more practical studies on CE adoption. When examining studies that explore barriers to the CE using MCDM techniques, it is observed that methods such as AHP, ANP, TOPSIS stand out particularly for selecting and ranking these barriers. However, it is widely recognized that AHP becomes challenging to apply when dealing with a problem that encompasses more than seven criteria or alternatives (Kaviani et al., 2020; Saaty and Ozdemir, 2003). This challenge arises from the potential inconsistency and redundancy that may occur within the matrices used for pairwise comparisons. In this study, the EDAS method has been employed for the ranking and selection of CE barriers. In the realm of alternative selection, several methodologies such as VlseKriterijumska Optimizacija I Kompromisno Rešenje (VIKOR), TOPSIS, Additive Ratio Assessment, Complex Proportional Assessment, and Multi-Objective Optimization By Ratio Analysis have been developed to determine the most suitable alternative by evaluating its closeness to both positive and negative ideal solutions (Kaviani et al., 2020). However, the EDAS approach stands out with a distinct methodology, as it determines the optimal solution based on its proximity to the average solution rather than relying on distances to ideal solutions (Yazdani et al., 2020). This unique feature eliminates the need for calculating positive and negative ideal solution distances, setting EDAS apart from other techniques.

The swift expansion of industrial operations leads to challenges such as the generation of waste (both solid and liquid), environmental pollution, resource scarcity, and degradation of environmental conditions (Lahane and Kant, 2022). Therefore, addressing these unsustainable issues necessitates the adoption of sustainable strategies within manufacturing supply chains (Lahane and Kant, 2022). Examining the circular adoption through the lens of companies' sustainability goals is crucial for companies to identify their circular economy-related objectives and overcome associated barriers. In the literature, there is no MCDM study specifically examining CE adoption barriers within the framework of SDGs. In this study, the BWM has been used to weight the SDGs to assist in the selection of barriers. The BWM method involves fewer pairwise comparisons compared to AHP, resulting in increased consistency. With the assistance of the BWM and EDAS methods employed in this study, the ranking among CE barriers has been easily conducted without requiring a heavy computational burden. This integration enables companies to prioritize their actions effectively, allocate resources efficiently, and accelerate their transition towards a circular economy. CE barriers compiled through detailed literature review are as presented in the Table 2.

Table 2. Circular economy barriers

Circular economy adoption barriers	Studies
Lack of information sharing	(Chhimwal et al., 2022; Geng et al., 2012; Jaeger and Upadhyay, 2020)
Environmental awareness among the stakeholders	(Chhimwal et al., 2022; Geng et al., 2012; Moktadir et al., 2018)
Lack of infrastructure and absence of advance tool	(Chhimwal et al., 2022; Geng et al., 2012)
Lack of government support and legislation	(Badhotiya et al., 2022; Kazancoglu et al., 2021; Singh et al., 2020)
Low demand and acceptance of remanufactured materials	(Agrawal et al., 2021; Badhotiya et al., 2022; Khandelwal and Barua, 2024)

Lack of knowledge toward the CE	(Agrawal et al., 2021; Badhotiya et al., 2022; Jaeger and Upadhyay, 2020; Mangla et al., 2018)
Lack of top management commitment	(Badhotiya et al., 2022; Jaeger and Upadhyay, 2020; Khandelwal and Barua, 2024; Mangla et al., 2018)
Lack of technical and qualified personnel on the CE	(Badhotiya et al., 2022; Khandelwal and Barua, 2024; Kumar et al., 2019; Singh et al., 2020)
Need for improvement of technology and facilities	(Badhotiya et al., 2022; V. Kumar et al., 2019; Su et al., 2013)
High cost of eco-friendly material	(Agrawal et al., 2021; Badhotiya et al., 2022; Khandelwal and Barua, 2024)
Lack of incentives to encourage greener activities	(Badhotiya et al., 2022; Kumar et al., 2019; Mangla et al., 2018; Singh et al., 2020)
Informal sector recycling processes	(Badhotiya et al., 2022; Kumar et al., 2019)
High start-up costs	(Jaeger and Upadhyay, 2020; Liu and Bai, 2014)
Innovation diffusion challenge	(Jaeger and Upadhyay, 2020; Preston, 2012)
Lack of information on product design and production	(Jaeger and Upadhyay, 2020)
Hygienic issues	(Berchicci and Bodewes, 2005; Jaeger and Upadhyay, 2020)
Quality compromise	(Jaeger and Upadhyay, 2020)
Limited information exchange systems in logistics	(Jaeger and Upadhyay, 2020)
Lack of industrial symbiosis	(Jaeger and Upadhyay, 2020)

3. Methodology

The stages of this study were conducted using Delphi (Linstone et al., 1975), BWM (Rezaei, 2015), and EDAS (Ghorabaee et al., 2015). Each stage contributed uniquely to defining the methodology and analysis process of the study. In the first stage, a panel of experts was formed to identify the barriers encountered in transitioning to a CE using the Delphi method. Panel members identified significant barriers based on their expertise and reached a consensus. In the second stage, the BWM was employed to determine the weights based on the SDGs identified within the scope of the study. This method facilitated the allocation of weights based on the preferences of experts to determine the importance level of each goal. Finally, the EDAS method, utilizing the weights determined by the BWM, was employed to prioritize the CE barriers. In this stage, the prioritized ranking among barriers was established by considering the relationship of each barrier with the SDGs.

3.1 Delphi Method

The Delphi method is employed to iteratively gather and refine experts' opinions on the issue under examination until a consensus is reached among their viewpoints (Emovon et al., 2018). Delphi facilitates the collection and adjustment of expert judgments through continuous data gathering and additional brainstorming sessions on the topic being studied. The Delphi Method holds considerable significance as a structured approach to decision-making and forecasting, particularly in situations characterized by uncertainty and complexity. Its iterative process, which involves collecting and synthesizing input from a panel of experts through multiple rounds of anonymous feedback and consensus-building, allows for the generation of informed insights and predictions. By harnessing the collective wisdom of diverse stakeholders, the Delphi Method mitigates individual biases and fosters consensus, resulting in more robust and reliable outcomes. The Consistency Validity Ratio (CVR) is calculated using the formula:

$$CVR = \frac{NPE - \frac{N}{2}}{\frac{N}{2}} \tag{1}$$

In this equation, CVR represents the Consistency Validity Ratio, NPE denotes the Number of experts indicating the criteria is essential, and N stands for the Total number of Experts. The threshold value of CVR is set at 0.29 (Dohale et al., 2021; Emovon et al., 2018). Any criterion with a CVR value of 0.29 or higher is retained, while the remaining criteria are rejected. Methodology of this study is shown in Figure1.

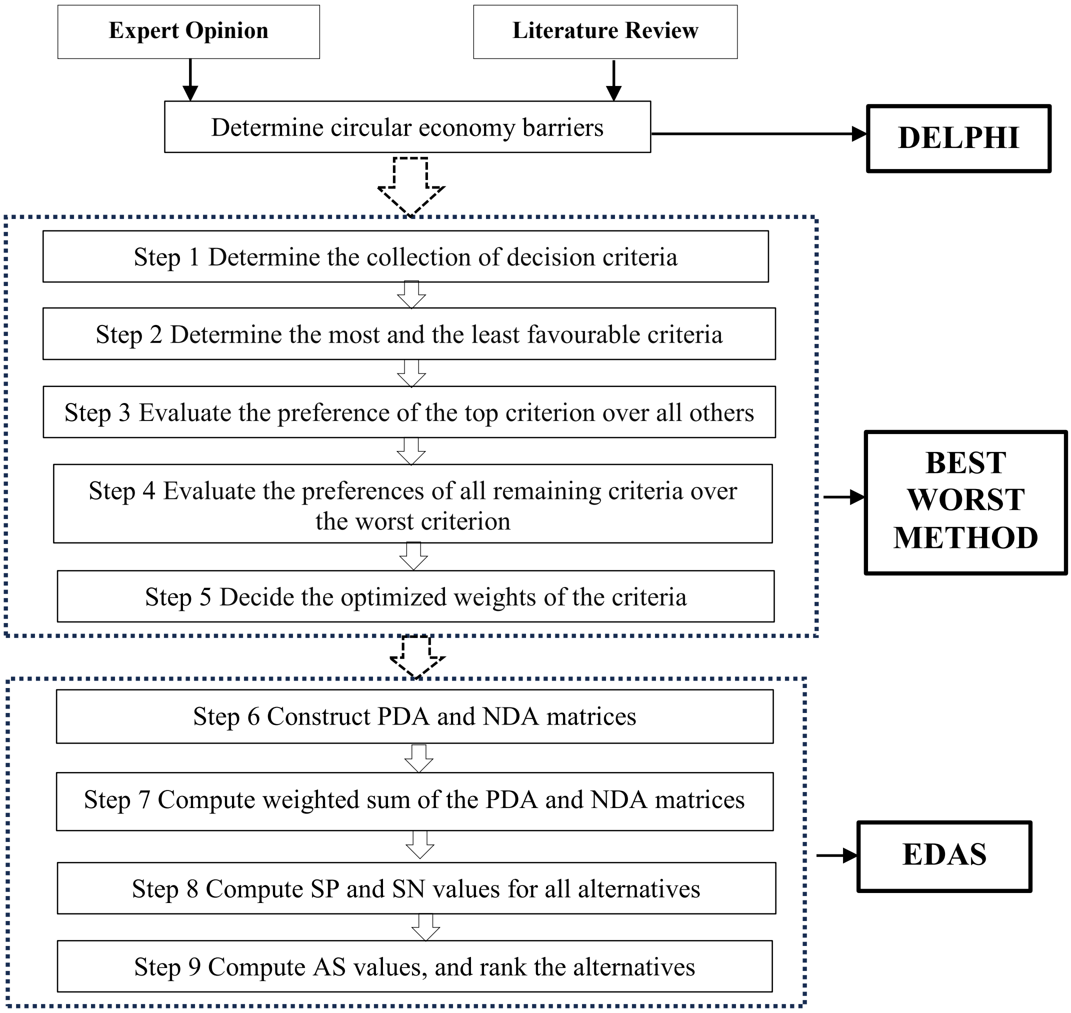


Figure 1. Methodology

3.2 Best Worst Method

Jafar Rezaei (Rezaei, 2015) introduced a novel decision-making approach known as the BWM, which relies on pairwise comparisons. Since its inception, it has been widely applied across various fields of research. The BWM holds significant importance in decision-making processes across various domains due to its structured and systematic approach to evaluating and prioritizing alternatives. By soliciting input on the best and worst attributes of each option from stakeholders or experts, BWM enables a nuanced analysis that accounts for diverse perspectives and priorities. This approach enhances the accuracy and robustness of decision-making by ensuring that all relevant factors are taken into consideration. Moreover, BWM fosters transparency and consensus-building among stakeholders by providing a clear framework for evaluating alternatives and reaching agreement on priorities. In this way, the BWM not only facilitates more informed and effective decision-making but also promotes collaboration and alignment among decision-makers, ultimately leading to better outcomes in a wide range of applications

The stages of the linear model for BWM are outlined as follows:

Step 1. Identify the collection of decision criteria.

Step 2. Identify the most favourable and the least favourable criteria.

Step 3. Assess the preference of the top criterion over all others, assigning a value from 1 to 9, and establish the vector ranking the best against the others. The elements of this vector, denoted by a_{B_j}, signify the significance of the top criterion over criterion *j*.

Step 4. Assess the preferences of all remaining criteria over the worst criterion using an integer ranging from 1 to 9, and establish the others-to-worst vector. The elements of this vector, denoted by a_{jW}, indicate the importance of criterion *j* over the worst criterion.

Step 5. Determine the optimized weights (w_1^*, w_2^*,….., w_n^*) and ξ^{L^*} by solving the following linear model:

$$Min\ \xi^L\ s.t.\ |w_B - a_{Bj}w_j| \le \xi^L, \text{ for all } j|w_j - a_{jW}w_W| \le \xi^L \text{ , for all } j\textstyle\sum_j w_j = 1 w_j \ge 0 \text{ for all } j. \quad (2)$$

To tackle the consistency issue in this model, Liang et al. (Liang et al., 2020) introduced a technique centered on input data, termed the input-based method. The input-based consistency ratio is defined as follows:

$$CR^I = max_j CR_j^I \quad (3)$$

where,

$$CR_j^I = \begin{cases} \frac{|a_{Bj}\times a_{jW} - a_{BW}|}{a_{BW}\times a_{BW} - a_{BW}} & a_{BW} > 1 \\ 0 & a_{BW} = 1 \end{cases} \quad (4)$$

in the provided equations, CR^I represents the overall input-based consistency ratio for all criteria, while CR_j^I indicates the local consistency level indicator for the criterion C_j (Liang et al., 2020). In this research, the linear model of BWM was utilized to derive the optimized weights of criteria. To accomplish this, the "solver" add-in within the BWM Excel program was employed (Rezaei, 2016).

3.3 EDAS

EDAS is a method that stands out due to its unique normalization process, which differentiates it from traditional methods such as TOPSIS and VIKOR (Torkayesh et al., 2023). This distinct feature of EDAS plays a key role in its application and provides a different approach for ranking and decision-making compared to other commonly used techniques. The steps of the EDAS technique are as follows (Ghorabaee et al., 2015):

Step 1 involves constructing the decision-making matrix *X,* where X_{ij} represents the performance value of the *i*th alternative on the *j*th criterion.

$$X = [\ X_{ij}]_{n\times m} = \begin{bmatrix} X_{11} & X_{11} & \cdots & X_{1m} \\ X_{21} & X_{22} & \cdots & X_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ X_{n1} & X_{n1} & \cdots & X_{nm} \end{bmatrix} \quad (5)$$

Step 2 determines the average solution (*AV*) by considering all criteria,

$$AV = [AV_j]_{1\times m}, \quad (6)$$

where,

$$AV_j = \frac{\sum_{i=1}^n X_{ij}}{n}. \quad (7)$$

Step 3 computes the Positive Distance from Average (*PDA*) and Negative Distance from Average (*NDA*) matrices based on the nature of the criteria (benefit or cost).

$$PDA = [PDA_{ij}]_{n\times m}, \quad (8)$$

$$NDA = [NDA_{ij}]_{n\times m}, \quad (9)$$

if the *j*th criterion is beneficial,

$$PDA_{ij} = \frac{\max(0, (X_{ij} - AV_j))}{AV_j}, \quad (10)$$

$$NDA_{ij} = \frac{\max(0, (AV_j - X_{ij}))}{AV_j}, \quad (11)$$

and if the *j*th criterion is non-beneficial,

$$PDA_{ij} = \frac{\max(0, (AV_j - X_{ij}))}{AV_j}; \quad (12)$$

$$NDA_{ij} = \frac{\max(0, (X_{ij} - AV_j))}{AV_j}, \quad (13)$$

Step 4 calculates the weighted sum of *PDA* and *NDA* for all alternatives.

$$SP_i = \sum_{J=1}^{m} w_j \, PDA_{ij}; \quad (14)$$

$$SN_i = \sum_{J=1}^{m} w_j \, NDA_{ij}, \quad (15)$$

where w_j is the weight of the jth criterion.

Step 5 normalizes the values of *SP* and *SN* for all alternatives.

$$NSP_i = \frac{SP_i}{\max_i(SP_i)}; \quad (16)$$

$$NSN_i = 1 - \frac{SN_i}{\max_i(SN_i)}. \quad (17)$$

Step 6 calculates the Appraisal Score (*AS*) for all alternatives.

$$AS_i = \frac{1}{2}(NSP_i + NSN_i), \quad (18)$$

where $0 \le AS_i \le 1$.

Step 7 ranks the alternatives in descending order based on their *AS* values, with the highest *AS* value representing the most favourable choice.

4. Case Study

The case company, as one of Turkiye's leading industrial equipment manufacturers, is dedicated to embracing sustainability and CE principles. However, it requires a systematic approach to identify and prioritize the barriers it encounters during this transition. This case study aims to elucidate the methodologies employed to establish the company's sustainability objectives, pinpoint the barriers encountered in transitioning to a circular economy, and prioritize these barriers. The company has adopted a set of SDGs that align with its strategy. Utilizing the BWM, the company's SDGs were weighted. A committee comprising five experts, each with a minimum of five years of experience, was assembled within the company to identify the most critical barriers to transitioning to a circular economy. The Delphi method was employed by these experts to identify the most important barriers. Subsequently, these important barriers were amalgamated with the weighted SDGs and prioritized using the EDAS method. This approach was utilized to ascertain the barriers that necessitate prioritized attention from the company.

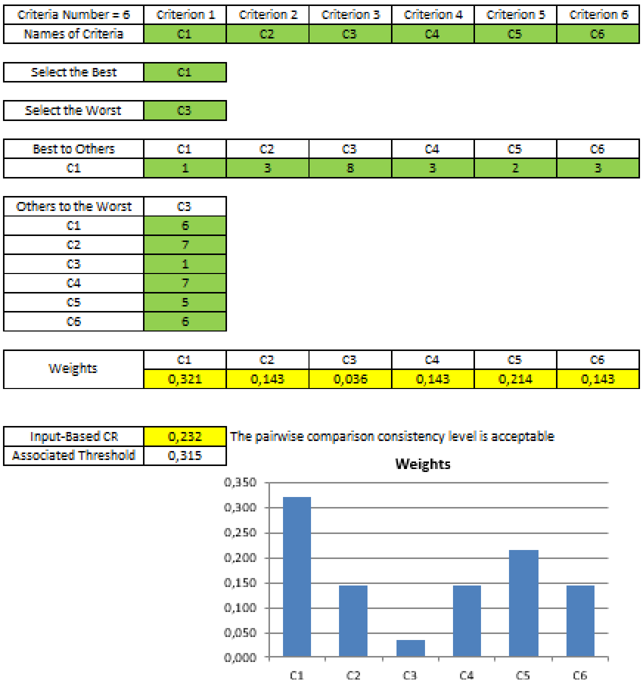
This study assumes that the company is in the early stages of transitioning to a CE and that the selected SDGs align with the sector and the company's activities. Additionally, it is assumed that the barriers identified from the literature are compatible with the company's current capacity and Turkiye's legal regulations. To achieve these SDG goals, further assumptions include the company's efficient use of resources, its capacity to generate employment opportunities, the development of effective strategies to minimize environmental impacts, and efforts to build resilient structures against climate change. From among the barriers identified through the literature review in Table 2, the ones that could be most critical for the company have been selected using the Delphi method, as summarized in Table 3.

Table 3. The CVR scores for the barriers selected via the Delphi method

Barriers	CVR value
(A1) Lack of information sharing	0.600
(A2) Environmental awareness among the stakeholders	0.600
(A3) Lack of infrastructure and unavailability of advance tool	1.000
(A4) Lack of government support and legislation	1.000
(A5) Low demand and acceptance of remanufactured products	0.600

(A6) Lack of knowledge toward the CE	0.600
(A7) Lack of top management commitment	1.000
(A8) Lack of technical and qualified personnel on the CE	1.000
(A9) Need for advancement of technology and facilities	1.000
(A10) High cost of eco-friendly material	1.000
(A11) Lack of information on product design and production	0.600

The company's SDGs are sustainable production and consumption (C1), material and resource effectiveness (C2), employment opportunities (C3), economic efficiency and operational performance (C4), mitigate waste and enhance environmental sustainability (C5), climate change and resilience (C6). The SDGs weights were determined using the BWM. The Excel Solver results used to solve the linear BWM model for the SDG weights can be seen in Figure 2.



Criteria Number = 6	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6
Names of Criteria	C1	C2	C3	C4	C5	C6

Select the Best	C1
Select the Worst	C3

Best to Others	C1	C2	C3	C4	C5	C6
C1	1	3	8	3	2	3

Others to the Worst	C3
C1	6
C2	7
C3	1
C4	7
C5	5
C6	6

Weights	C1	C2	C3	C4	C5	C6
	0,321	0,143	0,036	0,143	0,214	0,143

Input-Based CR	0,232	The pairwise comparison consistency level is acceptable
Associated Threshold	0,315	

Figure 2. Excel Solver results to solve the linear BWM model for the criteria weights

In the previous subsection, the significance weight of each SDG was determined using the BWM. All criteria are oriented towards maximizing benefits. The experts assessed each CE barrier against every criterion, as outlined in Table 4.

Table 4. Experts' evaluation of the alternatives

	C1	C2	C3	C4	C5	C6
A1	5	6	4	8	5	4
A2	5	4	3	5	8	8
A3	5	6	4	6	4	3
A4	4	3	5	6	3	4
A5	6	7	3	6	5	3
A6	6	6	4	6	2	3
A7	5	4	6	6	5	4
A8	5	6	7	6	5	3
A9	6	7	5	7	6	5
A10	7	8	4	7	6	4
A11	6	6	5	6	5	3

Tables 5 to 6 illustrate the results of step 3 in the EDAS approach, showcasing the values of PDA and NDA for each alternative of CE barriers.

Table 5. PDA matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
PDA-1	0.000	0.000	0.000	0.000	0.100	0.100	0.000	0.000	0.100	0.283	0.100
PDA-2	0.048	0.000	0.048	0.000	0.222	0.048	0.000	0.048	0.222	0.397	0.048
PDA-3	0.000	0.000	0.000	0.100	0.000	0.000	0.320	0.540	0.100	0.000	0.100
PDA-4	0.275	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.116	0.116	0.000
PDA-5	0.019	0.630	0.000	0.000	0.019	0.000	0.019	0.019	0.222	0.222	0.019
PDA-6	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.000

Table 6. NDA matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
NDA-1	0.083	0.083	0.083	0.267	0.000	0.000	0.083	0.083	0.000	0.000	0.000
NDA-2	0.000	0.302	0.000	0.476	0.000	0.000	0.302	0.000	0.000	0.000	0.000
NDA-3	0.120	0.340	0.120	0.000	0.340	0.120	0.000	0.000	0.000	0.120	0.000
NDA-4	0.000	0.203	0.043	0.043	0.043	0.043	0.043	0.043	0.000	0.000	0.043
NDA-5	0.000	0.000	0.185	0.389	0.000	0.593	0.000	0.000	0.000	0.000	0.000
NDA-6	0.000	0.000	0.250	0.000	0.250	0.250	0.000	0.250	0.000	0.000	0.250

Table 7. EDAS result matrix

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
SP	0.050	0.278	0.007	0.004	0.068	0.039	0.015	0.030	0.167	0.212	0.046
SN	0.031	0.111	0.113	0.243	0.054	0.173	0.076	0.069	0.000	0.004	0.042
NSP	0.180	1.000	0.024	0.013	0.244	0.140	0.055	0.108	0.602	0.763	0.167
NSN	0.872	0.544	0.537	0.000	0.778	0.288	0.687	0.718	1.000	0.982	0.828
AS	0.526	0.772	0.281	0.006	0.511	0.214	0.371	0.413	0.801	0.873	0.498

Table 7 depicts the outcomes of steps 4 to 6 in the EDAS approach. SP_i and NSP_i values were calculated using the normalized weights derived from Figure 2. The AS values provided in Table 7 aid in categorizing the alternatives. The findings reveal that A10 emerges as the top-performing alternative, achieving an AS of 0.873. Following closely, A9 secures the second-best position among the alternatives with an AS of 0.801. A2 claims the third position with an AS of 0.772. A1, with an AS of 0.526, holds the fourth position, while A4 lags behind with the lowest AS score of 0.006, indicating it as the least favourable alternative. The EDAS result matrix is outlined comprehensively in Table 7. In summary, the top three CE barriers can be ranked as follows: high cost of eco-friendly material, need for advancement of technology and facilities, and environmental awareness among the stakeholders. A strategic roadmap was created for the case company to identify its sustainability goals and prioritize the barriers encountered in transitioning to a CE using a systematic approach. Based on the results of these analyses, the company can implement sustainability strategies more effectively and focus on accelerating the transition to a circular economy.

The results of our study demonstrate consistency throughout the entire process. The Delphi method was employed to achieve consensus among experts regarding the critical barriers to transitioning to a circular economy. The validity of the selected barriers was further assessed through the CVR values, as shown in Table 3, reinforcing the reliability of the Delphi results. Additionally, a CR value below 0.10 indicates acceptable consistency in the BWM results. In our study, the CR values for all expert evaluations were confirmed to be within the acceptable range, verifying the consistency of the weightings assigned to the SDGs. Finally, when the criterion weights were altered by ±5%, no changes were observed in the ranking of the alternatives, highlighting the robustness of the EDAS method and confirming the consistency of the results.

5. Conclusion

In today's world, sustainability and reducing environmental impacts are becoming increasingly important. In this context, transformations aimed at reducing the environmental impacts of economic activities are necessary. This study can be seen as an important step towards understanding and guiding this transformation process by identifying the barriers that a manufacturing company may encounter in transitioning to a circular economy. The findings of the study reveal that the top three CE barriers are identified as follows: the high cost of eco-friendly material, the need for advancement of technology and facilities, and environmental awareness among stakeholders. These findings underscore the critical importance of addressing the identified barriers in transitioning to a circular economy. The high cost of eco-friendly materials implies the necessity of exploring cost-effective alternatives or investing in sustainable material innovation. The need for advancement in technology and facilities highlights the importance of continuous innovation and investment in infrastructure to facilitate circular practices. Additionally, enhancing environmental awareness among stakeholders necessitates engagement, education, and collaboration initiatives. By prioritizing these barriers and implementing targeted strategies, the company can enhance its sustainability performance, reduce environmental impact, and foster long-term resilience and competitiveness in the market.

Ranking of the CE barriers can yield significant outcomes for companies by encompassing both SDGs and CE barriers. Primarily, such ranking can serve as a guiding tool for companies in setting and focusing on sustainability strategies. While SDGs steer companies towards overall sustainability efforts, prioritizing CE barriers can assist them in focusing on specific areas for solutions. Moreover, such ranking enables companies to manage their resources more effectively and develop strategies to address prioritized barriers. For instance, if the high cost of eco-friendly materials is ranked as the most significant barrier, it may encourage companies to explore alternative materials or optimize material usage. Similarly, identifying the need for advancement in technology and infrastructure as a primary barrier can contribute to directing companies towards research and development investments and technology-driven solutions. From a managerial perspective, such ranking can strengthen companies' strategic decision-making processes and provide clear guidance to the management level. Determining prioritized barriers can guide managers in effectively allocating limited resources and taking strategic steps to achieve long-term sustainability goals.

One limitation of the study is that it focuses solely on a company within the manufacturing sector. This may restrict the generalizability of the research and may not fully reflect the barriers encountered by companies in other sectors. For instance, companies operating in the service sector may face different types of barriers in transitioning to a circular economy. Therefore, the findings of the study may not be fully applicable to companies in other sectors. The study solely focused on the conditions of a developing country like Turkiye. It is conceivable that companies in developing countries may encounter different challenges, such as resource constraints, technological infrastructure deficiencies, and political uncertainties. These factors could significantly impact the transition to a CE and should be considered as limitations. Moreover, the study's reliance on crisp numbers may restrict its ability to fully account for uncertainty and variability in the evaluation of CE barriers. In the future CE transitions in sectors other than the manufacturing sector will be examined using various fuzzy MCDM methods, such as fuzzy Cognitive Map.

Conflict of Interest

The author declares no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Declaration of generative AI and AI-assisted technologies

During the preparation of this work the author used ChatGPT in order to improve language and readability.

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