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ORIGINAL RESEARCH

From barriers to solutions: an ensemble ranking-based framework for circular economy adoption

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Abstract

Several governments and organizations have embraced the Circular Economy (CE) model to promote sustainable economic development. While implementing the CE, organizations face various barriers that hamper their adoption. In this regard, this study investigates the various barriers to CE adoption and their overcoming solutions. Therefore, this study proposes a robust framework for assessing CE adoption barriers and their overcoming solutions. The proposed framework is grounded on the half-quadratic (HQ) based ensemble ranking to prioritize the solutions by considering CE barriers. Twenty barriers to CE adoption and their solutions are identified through Systematic Literature Review (SLR) and domain expert input. These identified barriers are prioritized using the Best Worst Method (BWM). Further, the identified solutions are also prioritized using Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Weighted Aggregated Sum Product Assessment (WASPAS), and Combined Compromise Solution (CoCoSo) methods. An HQ-based ensemble ranking that is more robust and reliable is employed to obtain the aggregated rank of these solutions. Based on the aggregated rank, "top management consciousness and participation," "consumer awareness," "develop the CE business model," "alignment of CE goals with strategic objectives," and "reward and appreciation policies for CE" five most effective solutions for CE adoption. The findings suggest that organisations need to employ high-ranking solutions on a priority basis for CE adoption. The finding is also helpful for an organization that seeks CE adoption, especially in developing countries. Further, the proposed framework helps managers and policymakers assess the barriers and solutions for adopting CE in their context.

Keywords Circular economy · Barriers · Half-quadratic theory · Ensemble ranking · Solution framework

1 Introduction

Rising populations, economic growth, and increasing consumption have intensified the exploitation of natural resources, leading to higher input costs, environmental pollution, and sustainability challenges (Javaid et al. 2025). Despite these pressures, many organizations still depend on on the linear model, which generates waste, depletes resources, and harms the environment (Bhawna et al., 2024). To address these issues, the CE has emerged as a sustainable alternative, aiming to minimize waste, reduce resource scarcity, and support economic growth (Kirchherr et al. 2025). The recent circularity report indicates that the volume of resource extraction and utilization over the past six years has exceeded the cumulative total of such activities throughout the entire 20th century[1]. Therefore, several

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[1] https://www.circularity-gap.world/2024.

countries are making concerted efforts to transition from a linear economy to CE. For example, the European Commission introduced a CE strategy and action plan aimed at "closing the loop" (Carus and Dammer 2018), China introduced a CE promotion law, and India constituted a circular economy cell[2] for fostering the CE principles in various sectors. Decoupling economic growth from resource exploitation and promoting the creation of sustainable economic systems that guarantee ecological survival requires a shift towards a CE (Abbas et al. 2025). However, the circularity report shows that the percentage of the world economy that follows circular principles is just 7.2%, and it has been progressively falling over time. The global industrial ecosystem has mostly failed to integrate the central idea of a CE despite tremendous efforts to promote sustainable development goals.

Designed to be restorative and regenerative, the CE approach delivers benefits in terms of cost reduction, environmental sustainability, and waste minimization (Zeinalnezhad et al. 2025). Used items such as apparel and electronics products are refurbished and sold again on the secondary market, extending their lives and supporting the CE (Rinder et al. 2026). CE can be a panacea for several environmental and sustainability problems, especially in developing countries (Rataj et al. 2024). Mostly, developing countries rely on a linear economy to fulfil their needs by extracting many natural resources and generating waste in the same proposition (Perçin 2025). For example, according to the Central Pollution Control Board[3], India generates more than 62 million tonnes of waste each year, of which about 70% (approximately 43 million tonnes) is collected. However, only around 12 million tonnes of the collected waste is treated, while the remaining 31 million tonnes is disposed of in landfills. Waste generation is projected to reach 165 million tonnes by 2030[3]. Therefore, it is imperative to establish robust mechanisms for repairing, remanufacturing, and recycling products. As a result, the product cost can be reduced (economics), pollution can be minimized (environment) through recycling, and the environment can be protected through "non-discard" behaviour, along with providing low-cost recycled products to the local community (social). In spite of the acclaimed CE potential, its adoption remains underperformed in contemporary industries located in developing economies (Ibrahim and Zayed 2025).

Literature on CE adoption in business suggests a variety of reasons or barriers for the slow adoption of CE (Brändström et al. 2024). These barriers emerge from various perspectives such as management (Sundar et al. 2023), cultural (Saharan et al. 2024), technological (Kumar et al. 2024) and many more. Therefore, getting a comprehensive insight into barriers that impede or slow the transition to a CE is vital. Developed countries like the United States, the European Union, Denmark, the Netherlands, Japan, Italy, and other developed countries have well-established CE practices that are continuously refined to enhance overall CE adoption (Peyravi et al. 2024). In contrast, the CE adoption remains concealed in countries like India, largely due to its vast population and huge waste generated (Kamble et al. 2021). Furthermore, the CE practices are inadequate, primarily due to limited awareness and insufficient technological advancements in developing countries. The literature suggests that significant scientific work has been done on CE adoption in the context of developed countries, and a few attempts have been made to identify the barriers in emerging economies (Brändström et al. 2024; Rataj et al. 2024). Considering the importance of CE-related barriers, a systematic study must be conducted to identify and analyze CE barriers in the context of emerging nations. The identification of the barriers provides only half of the solution to CE adoption; therefore, it is also important to propose solutions to overcome these identified barriers. Overcoming these barriers is essential to effectively adopt the CE practices and ensure a successful transition towards sustainability. Barriers can slow down or completely block progress toward CE transition. Therefore, solutions need to be developed to streamline the CE initiatives and ensure progress towards CE. The proposed solutions help managers and policymakers to overcome these barriers during CE implementation. Therefore, a systematic approach is required to investigate CE barriers that hamper their adoption and find solutions to overcome these barriers.

Several studies have focused on investigating the barriers and their overcoming solutions using various tools (Javaid et al. 2023). Businesses are not able to implement all aspects of the CE simultaneously, so attempting to overcome all barriers at once would be a resource waste. Hence, there is a need for a systematic analysis specific to CE barriers and their solutions. The use of relatively new methods in making decisions has become increasingly important in recent years to achieve an accurate assessment (Babaei et al. 2025). Organizations will be able to better deal with barriers to CE adoption by understanding the nature of these barriers and finding solutions to overcome them. Thus, the paper proposes a robust framework for identifying and assessing various barriers to CE adoption and develops solutions for addressing them. In this regard, the present study establishes the following research objectives:

- To identify the CE adoption barriers and their overcoming solutions.
- To propose a MCDM based framework for analyzing the barriers and solutions.

[2] https://www.niti.gov.in/circular-economy-cell.

[3] https://cpcb.nic.in/annual-report.php.

- To prioritise the barriers and solutions using the proposed framework in the context of emerging economies.

A framework is proposed to address the above research objectives. Initially, SLR and expert feedback were used to identify CE adoption barriers and their potential solutions in the context of emerging economies. These barriers and solutions are ranked by using multi-criteria decision-making (MCDM) method. Further HQ-based aggregation is used to determine the final ranking of solutions.

1.1 Research gap, motivation, and contributions

Despite growing research on CE adoption in recent years, several theoretical and methodological gaps persist. Existing studies largely focus on identifying sector-specific barriers (González-Sánchez et al. 2023; Ruiz De Azua Lahidalga et al. 2025; Zeinalnezhad et al. 2025) without systematically linking them to actionable solutions. Reliance on single techniques also limits robustness, and there is a lack of integrated frameworks that aggregate multiple MCDM perspectives for reliable prioritization (Alves et al. 2024; Mohammadi and Rezaei 2020). Moreover, most studies are concentrated on developed economies, while emerging economies face unique challenges such as institutional inefficiencies, financial constraints, skill shortages, and policy uncertainty (Rataj et al. 2024). The relative importance of technological, cultural, market, and regulatory barriers remains contested, and no comprehensive framework resolves these conflicts.

To bridge these gaps, this study proposes a MCDM–based framework that evaluates both CE adoption barriers and their corresponding solutions, employing an ensemble ranking with HQ-based aggregation for methodological rigour. The study makes four key contributions: (1) it identifies significant barriers from technological and cultural perspectives to support the transition from a linear to a CE; (2) it prioritizes these barriers to enable organizations to address them systematically and assess overcoming solutions; (3) it provides prioritized solutions that assist managers and policymakers in allocating resources effectively and planning interventions for CE transformation; and (4) it demonstrates the robustness and applicability of the HQ-based aggregation framework in the CE context, enhancing reliability beyond single-method approaches.

The remainder of this paper is organized as follow: Sect. 2 focuses on CE and their adoption-related studies. Section 3 outlines the proposed methodology and Sect. 4 identifies and prioritizes the barriers and solutions. Section 5 discusses the findings of this study to gain more valuable insights. Section 6 provides the implications of the study in terms of managerial and academic. Finally, Sect. 7 presents some concluding remarks, highlighting some of the limitations and avenues for further research of this study.

2 Background of study

The concept of CE aims to achieve sustainability by closing loops and increasing resource efficiency (Saharan et al. 2024). As a result, CE has attracted increasing scholarly attention, particularly in relation to the identification of barriers that hinder its practical implementation. Although the literature on CE barriers is sufficient and increasing at a decent pace (Brändström et al. 2024; Kumar et al. 2024), a critical assessment reveals that most of the studies remain fragmented, sector-specific, and methodologically constrained, limiting their theoretical advancement and practical applicability.

Early CE studies largely emphasized technological constraints as the primary impediments to adoption (Pan et al. 2015; Ueberschaar et al. 2017). Consequently, barriers were predominantly framed in terms of inadequate technologies, infrastructure gaps, and process inefficiencies (Govindan et al. 2022). However, this technologically deterministic perspective has been increasingly challenged. Empirical studies now suggest that technological readiness alone does not guarantee CE adoption and that non-technological barriers often exert a stronger influence (Kirchherr et al. 2018). Cultural resistance, lack of consumer awareness, and misalignment between organisational values and circular principles have emerged as critical barriers, yet these barriers remain weakly theorised and inconsistently prioritized across studies (Saharan et al. 2024). Beyond cultural issues, market and economic barriers further complicate CE implementation. Some studies have highlighted low virgin material prices and high upfront investment costs as disincentives for adopting circular practices (Grafström and Aasma 2021). However, existing research often treats these barriers descriptively, without systematically assessing their importance or their interaction with policy, regulatory, and organizational factors (Magalar et al. 2026).

Sector-specific studies also demonstrate the fragmented nature of CE barrier-related studies. Several studies have been conducted across industries, including manufacturing (Debnath et al. 2023; Ruiz De Azua Lahidalga et al. 2025), agriculture (Martínez et al. 2024), textiles (S. S. Ali et al. 2024), mining (Osei et al. 2023), and construction (Durdyev et al. 2023). While these studies enrich sectoral understanding, they largely replicate similar barrier lists without providing solutions to overcome these barriers. A similar pattern is observed in operational-level studies focusing on procurement, packaging, and recycling. Onyia et al. (2025) identified an extensive set of barriers to circular procurement implementation, while Ada et al. (2023) examined packaging and recycling-related challenges. These studies are focused on a single aspect of the CE rather than a holistic approach.

Furthermore, most CE barrier studies employ single MCDM techniques to analyze and prioritize barriers (S. S. Ali et al. 2024; Durdyev et al. 2023). While these methods are methodologically sound, reliance on a single technique introduces potential bias and limits the robustness of the resulting rankings (Mohammadi and Rezaei 2020; Zaidan et al. 2025). As different MCDM methods often yield divergent prioritization outcomes, the lack of aggregation or ensemble-based approaches undermines the reliability of decision-support recommendations derived from existing studies.

The limitations of the current literature are particularly evident in the context of emerging economies. While several studies conducted in emerging countries, however it has primarily concentrated on identifying and modelling barriers within individual sectors. Jaiswal and Mukti (2024) examined e-waste circularity and identified lack of incentives, limited consumer awareness, and weak policy support as key constraints, while Sharma et al. (2023) highlighted cultural and technological barriers across Indian manufacturing firms. Although these studies offer valuable contextual insights, they fall short of systematically linking barriers to prioritized solutions, thereby limiting their usefulness for policymakers and practitioners seeking implementation guidance.

Based on the above discussion, it is evident that the extensive body of literature on CE adoption barriers exists; however, the field remains characterized by descriptive dominance, methodological fragmentation, and limited contextual sensitivity. Existing studies tend to (i) focus on barrier identification over solutions, (ii) rely on a single-MCDM technique, and (iii) inadequately address the distinct structural realities of emerging economies. These limitations underscore the need for an integrated, robust, and context-aware decision-support framework that simultaneously evaluates CE adoption barriers and their overcoming solutions, thereby advancing both CE theory and practice.

3 Methodology

The study follows a four-phase approach to systematically identify and analyse the barriers and solutions for CE adoption in a developing country, as illustrated in Fig. 1. First phase starts with the identification of barriers and solutions of the CE through SLR using the PRISMA framework. Further, an expert panel is formed to validate these barriers in terms of their relevance in contemporary business. To reduce biases, this study ensures diversity in the expert group by selecting experts from the CE domain, including both industry professionals and academia. This panel further classified the identified barriers into four groups based on their suitability.

The second phase started with the ranking of the identified barriers as per their importance. Barrier prioritisation is beneficial for efficiently allocating resources, formulating strategies to address high-priority barriers, and evaluating proposed solutions by considering these barriers as criteria. There are numerous approaches for prioritizing barriers, such as the Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), and BWM. BWM is selected for barrier prioritization due to its advantages compared to other MCDM approaches. Specifically, BWM requires fewer pairwise comparisons by evaluating only the most and least significant barriers against others. This makes BWM more efficient and preferable compared to other MCDM approaches like AHP and ANP. Additionally, BWM provides higher consistency in decision-making since it minimizes inconsistencies in pairwise comparisons, which are more common in AHP and ANP. Moreover, BWM requires fewer expert judgments, reducing cognitive load and making it easier to implement, particularly in real-world decision-making scenarios (Saharan et al. 2024). Furthermore, BWM is flexible and adaptable to various domains, making it a suitable choice for prioritizing barriers in complex decision environments (Wu et al. 2024). Based on the result of BWM, the barriers are ranked, and these barriers are treated as criteria for assessing the solution.

The third phase consists of evaluating the mitigation solution of CE barriers. Three different MCDM methods, TOPSIS, WASPAS, and CoCoSo, were used for ranking the solutions based on multiple criteria (i.e. barriers). Each of these methods presents specific strengths and limitations; by complementing one another, they enhance the robustness of decision-making and are employed to evaluate the solutions for mitigation. To collect data from the expert panel, a structured questionnaire was developed, ensuring that it is compatible with all three methods—TOPSIS, WASPAS, and CoCoSo. The expert panel was asked to respond to the developed structured questionnaire. After collecting the responses from the expert panel, the TOPSIS, WASPAS, and CoCoSo methods were applied to evaluate the solutions. Each method provides a distinct ranking based on its unique approach to MCDM. To ensure a reliable and robust ranking, the individual rankings from these methods must be aggregated.

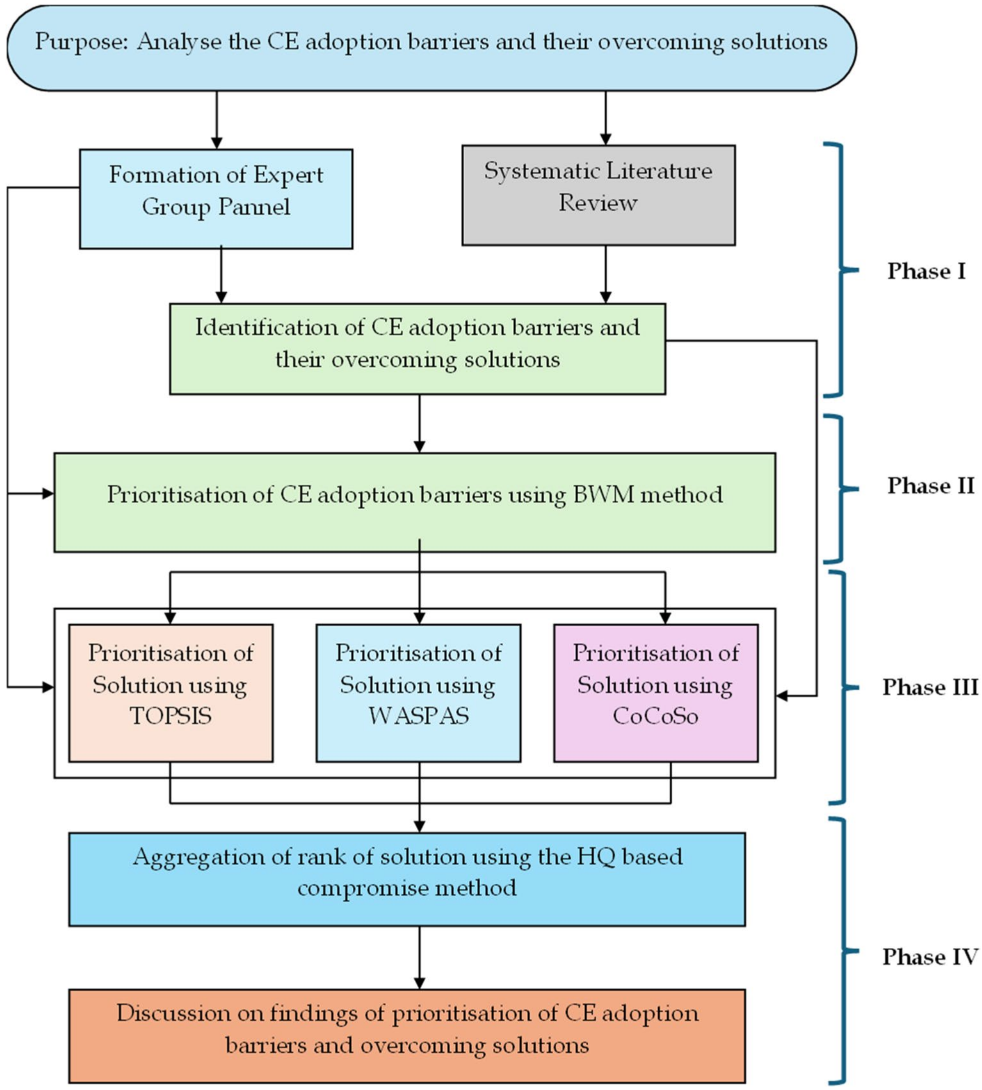

Fig. 1 Proposed framework for CE adoption barriers and solutions

The fourth phase is the aggregation of rankings obtained from TOPSIS, WASPAS and CoCoSo methods using the HQ theory to produce a final, unified ranking that reflects the perspectives of all three methods. The HQ-based method calculates the optimal weights for each MCDM ranking approach, which are then aggregated to produce the final ranking (Mohammadi and Rezaei 2020). These weights comply with the non-negativity and unit-sum requirements, fundamental to MCDM techniques (Mohammadi and Rezaei 2020). Additionally, this method is objective, as weight computation does not rely on expert input, thereby minimizing potential biases. Unlike conventional averaging methods, it is robust against outliers due to the use of HQ functions. Finally, the rankings generated for CE solutions using the HQ-based method are validated through an expert panel. The steps for implementing the applied MCDM methods are outlined as follows:

3.1 BWM

Step 1: Identify the set of barriers.

Identify the barriers to CE adoption ("n" number of criterion: C_1, C_2, C_3,….C_n) through SLR and validate with expert's input.

Step 2: Establish the most and least significant barriers.

Using input from the expert panel, determine the most important barriers or sub-barriers (best) and the least important barriers or sub-barriers (worst).

Step 3: Obtaining a reference comparison for the selected best barrier.

To determine which barrier is preferred over the other barriers, an expert group scale of 1–9 is used to determine the best barrier preference. With a score of 1, the best barrier is equal to all other barriers, and with a score of 9, the best barrier is highly preferred over all other barriers. This reference comparison is represented by the vector (A_B) as:

$$A_B = (a_{B1,}a_{B2}, \ldots\ldots, a_{Bn}) \tag{1}$$

Where A_B represents a "Best-to-Other" vector, a_{Bj} represents the preference of the best criteria B over criteria j and a_{BB}= 1.

Step 4: Obtain the reference comparison for the selected worst barrier.

The expert panel is asked to rate the preferences of all barriers relative to the worst barrier on a scale of 1–9, where 1 indicates equal preference and 9 represents an extreme preference. A_W represents the reference comparison as:

$$A_W = \begin{Bmatrix} a_{1w} \\ a_{2w} \\ a_{3w} \\ \vdots \\ a_{nw} \end{Bmatrix} \tag{2}$$

Where A_W is the "Others-to-Worst" vector, a_{jW} represents the preference of j barrier over the worst barrier C_W and a_{WW}= 1.

Step 5: Obtaining the optimal weights ($w_1^*, w_2^*, \ldots ..w_n^*$).

The optimal weight ($w_1^*, w_2^*,\ w_3^* \ldots ..w_n^*$) is computed. To calculate the optimal weights, each pair must satisfy $w_B/w_j = a_{Bj}$ and $wj/w_W = a_{jW}$. To fulfil these requirements for all j, the maximum absolute differences in the set{| $\frac{w_B}{w_j} - a_{Bj}$|, | $\frac{w_j}{w_w} - a_{jw}$|} are mininsed. This problem can be translated as a subsequent model:

Min-max {| $\frac{w_B}{w_j} - a_{Bj}$|, | $\frac{w_j}{w_w} - a_{jw}$|}.

Subject to:

$$\begin{aligned} &\textstyle\sum_j w_j = 1 \\ &w_j \geq 0; \forall_j \end{aligned} \tag{3}$$

Model (3) can be transformed into the following linear model.

min ξ^L

Subject to.

$$\begin{aligned} &\left|\frac{W_B}{W_j} - a_{Bj}\right| &\leq \xi^L; \forall j \\ &\left|\frac{W_j}{W_W} - a_{jw}\right| &\leq \xi^L; \forall j \\ &\sum_j w_j = 1 \\ &wj \geq 0\ \forall j \end{aligned} \tag{4}$$

Weights for each barrier ($w_1^*, w_2^*,\ w_3^* \ldots ..w_n^*$) and consistency ratio (ξ^L) were obtained by solving the linear model (4). A consistency ratio (ξL) value closer to 0 is required for better consistency (Rezaei 2016).

3.2 TOPSIS

TOPSIS is widely recognized as an efficient approach for addressing MCDM problems. The method can be implemented through the following steps:

Step 1: Construct a decision matrix.

The decision matrix [X] is constructed with m rows (consisting of m criteria) and n columns (n alternatives) as repesrented in Eq. (5). Each element of this matrix (x_{ij}) represents the alternative's importance concerning j^{th} criteria. Each alternative is evaluated against the individual criteria using a five-point scale (1–5).

$$X = \begin{bmatrix} x_{11} & x_{12} & \ldots & x_{1j} & \ldots & x_{1n} \\ x_{21} & x_{22} & \ldots & x_{2j} & \ldots & x_{2n} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ x_{i1} & x_{i2} & \ldots & x_{ij} & \ldots & x_{in} \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ x_{m1} & x_{m2} & \ldots & x_{mj} & \ldots & x_{mn} \end{bmatrix} \tag{5}$$

Step 2: Determine the normalized decision matrix.

The normalized decision matrix is constructed by normalizing each element of the original decision matrix using Eq. 6.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}} i = 1, 2, \ldots, m; j = 1, 2, \ldots\ldots\ldots, n \tag{6}$$

Step 3: Develop the weighted normalized decision matrix.

The weighted normalized decision matrix is obtained by multiplying the normalized decision matrix by its corresponding weights, as expressed in Eq. 7.

$$v_{ij} = r_{ij}\ {}^{*}W_j \tag{7}$$

where w_j implies the weight of the j[th] criterion and $\sum_{j=1}^{n} wj=1$.

Step 4: Identify the ideal solutions

The positive ideal solution (A^+) and negative ideal solution (A^-) is determined through Eqs. 8 and 9, respectively.

$$A^+ = \{V_1^+, V_2^+, \ldots\ldots, V_N^+\}\ i = 1,\ 2, \ldots..n \tag{8}$$

$$A^- = \{V_1^-, V_2^-, \ldots\ldots, V_n^-\}\ i = 1,\ 2, \ldots..n \tag{9}$$

Step 5: Calculate the separation measures

The separation measure is calculated for each alternative by determining the Euclidean distance between the A^+ and A^- using the Eqs. 10 and 11. For the j[th] alternative, the distance of j[th] alternative to A^+ is D_j^+, and A^- is D_j^- and computed as:

$$D_j^+ = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_j^+)} \quad i = 1,\ ,\ 2,\ \ldots, m; j = 1,\ 2, \ldots, n \tag{10}$$

$$D_j^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_J^-)} \quad i = 1,\ 2,\ \ldots, m; j = 1,\ 2,\ \ldots, n \tag{11}$$

Step 6: Calculate the relative closeness,

The relative closeness of the i[th] alternative is computed as Eq. 12:

$$CC_i = \frac{D^-}{D^+ + D^-} \tag{12}$$

Here, $0 \leq CC_i \leq 1$, $i = 1, 2, \ldots, m$.

Step 7: The alternatives are ranked by arranging their relative closeness values in descending order.

3.3 WASPAS

Zavadskas et al. (2012) introduced the WASPAS method, which integrates the Weighted Sum Model (WSM) and the Weighted Product Model (WPM), utilizing both additive and multiplicative utility functions for evaluation. The implementation of the WASPAS method follows the steps (Zavadskas et al. 2012):

Step 1: Construct the Decision Matrix.

The decision matrix is developed with input from experts, following the procedure outlined in the TOPSIS method. It is represented mathematically in Eq. 5.

Step 2: Obtain the normalised decision matrix.

The normalized decision matrix is obtained through linear normalization, as depicted in Eqs. 13 and 14.

For the benefit criterion:

$$x_{ij}^* = \frac{x_{ij}}{max_i\, x_{ij}} \tag{13}$$

For the cost criterion:

$$x_{ij}^* = \frac{min_i\, x_{ij}}{x_{ij}} \tag{14}$$

Where, x_{ij}^* Is the normalized value of the x_{ij}.

Step 3: Calculate the measures of WSM and WSP

A measure of WSM (S_i) and a measure of WPM (P_i) is calculated for each alternative using Eqs. 15 and 16, respectively.

$$S_i = \sum_{j=1}^{n} w_j * x_{ij} \tag{15}$$

$$P_i = \prod_{j=1}^{n} (x_{ij}^*)^{w_j} \tag{16}$$

where w_j is the weight of the j[th] criterion, and $\sum{}_j w_j = 1$.

Step 4: Aggregated measure for alternative.

The aggregated measure (Q_i) for each alternative is determined as per Eq. 17:

$$Q_i = \lambda S_i + (1 - \lambda) P_i \tag{17}$$

Where, λ represents the WASPAS method parameter, which can take any value between 0 and 1. Usually, the value of the parameter (λ) is chosen to be 0.5, which represents the equal importance of (S_i) and (P_i).

Step 5: Ranking of Alternatives.

The alternatives are prioritized based on Q_i values, where a higher Q_i corresponds to a higher ranking.

3.4 CoCoSo

The CoCoSo technique was introduced by (Yazdani et al. 2019) and is one of the most recent MCDM methodologies. Combining simple additive weighting with an exponentially weighted product model is the basis of this method. This method may accomplish a ranking or selection of alternatives against certain criteria (Ali et al. 2022). The steps of CoCoSo are:

Step 1: Construct the Decision Matrix.

The decision matrix is developed with input from experts, following the procedure outlined in the TOPSIS method. It is represented mathematically in Eq. 5.

Step 2: Develop the normalize decision matrix.

In order to normalize the initial decision-making matrix, Eqs. 2 and 3 are applied.

For benefit criteria

$$r_{ij} = \frac{x_{ij} - \min_i x_{ij}}{max_i x_{ij} - \min_i x_{ij}} \tag{18}$$

For non-benefit/cost criteria

$$r_{ij} = \frac{\max_i x_{ij} - x_{ij}}{max_i x_{ij} - \min_i x_{ij}} \tag{19}$$

Step 3: Determine the comparability sequences.

Weighted comparability sequences (S_i) and power weights of comparability sequences (P_i)) are calculated based on Eqs. 20 and 21.

$$S_i = \sum_{j=1}^{n} (w_j r_{ij}) \tag{20}$$

$$P_i = \sum_{j=1}^{n} (r_{ij})^{w_j} \tag{21}$$

Step 4: Determine the relative weights.

The relative weights of each alternative are determined using three aggregation approaches, as shown in Equations (22) to (24):

$$k_{ia} = \frac{S_i + P_i}{\sum_{i=1}^{m} (P_i + S_i)} \tag{22}$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \tag{23}$$

$$k_{ic} = \frac{\lambda\ (S_i) + (1 - \lambda\ ) (P_i)}{(\lambda \max_i S_i + (1 - \lambda\ )\max_i P_i)} \tag{24}$$

Experts may select the parameter value (λ) according to the requirements, or 0.5 can be used.

Step 5: Alternatives' importance weight is based on their value of k_i, which was calculated in accordance with Eq. 25.

$$k_i = (k_{ia} k_{ib} k_{ic})^{\frac{1}{3}} + \frac{1}{3}(k_{ia} + k_{ib} + k_{ic}) \tag{25}$$

As a result, the alternatives are ranked according to descending order of k_i, which infers that the highest value (k_i) holder alternative represents the first rank.

3.5 An HQ-based compromise method

This HQ-based ensemble method can be applied to a wide variety of MCDM algorithms. Under this assumption, let there be M MCDM methods used to rank K alternatives across n criteria. As a means of estimating the overall ranking, a Euclidean distance is minimized from each computed ranking. The Eq. (26) is used for the minimisation of Euclidean distance from each computed ranking:

$$\min_{R^*} \frac{1}{2} \sum_{m=1}^{M} \| R^m - R^* \|_2^2 \tag{26}$$

Where, M is the count of MCDM methods, and R^m represent the rank of the m^{th} MCDM method. The minimization of Eq. (26) has a closed-form solution as Eq. 27,

$$R^* = \frac{1}{M} \sum_{m=1}^{M} R^m \tag{27}$$

Equation 27 denotes the average ranking derived from various methods. The average, however, is not a reliable estimation method because it is sensitive to outliers (Demšar 2006), just as are all loss function estimation methods that use the Euclidean norm. In aggregating rankings, if one of the MCDM methods has a different ranking from the others, the aggregated ranking may be significantly affected. Therefore, the final rank is calculated in accordance with the consensus index and trust level derived using the HQ functions, which are unaffected to outliers (Mohammadi and Rezaei 2020). The optimization model to determine R^* is,

$$\min_{R^*}\frac{1}{2}\sum_{m=1}^{M} g\|\ R^m - R^*\ \|_2 \tag{28}$$

where g (.) is an HQ function. Even though minimization (3) is not convex, half-quadratic programming can be used to solve it efficiently (Geman and Reynolds 1992; Nikolova and Ng 2006). By rewriting minimization (28) in the HQ multiplicative form, we get,

$$\min_{R^*,\alpha} J(R^*,\ \alpha\ ) = \tfrac{1}{2}\sum_{m=1}^{M}\alpha_{\ m} \\ \|R^m - R^*\|_2^2 + \psi\ (\alpha_{\ m}) \tag{29}$$

where $\alpha \in R^M$ is the half-quadratic auxiliary variable. An HQ program requires iteration of the following steps until both variables are at convergence,

$$a_m = \delta(\|\ R^m - R* \|_2), m = 1, 2, ...M \tag{30}$$

$$R^* = \underset{R^*}{argmin}\sum_{m=1}^{M}\alpha_{\ m}\|\ R^m - R^*\ \|_2^2 \tag{31}$$

The optimum rank can be determined by setting the derivative of the objective function to zero, i.e.

$$\frac{dj}{dR*} = 0 \\ \Rightarrow \textstyle\sum_{m=1}^{M} a_m(R^m - R*) = 0 \\ \Rightarrow R * \textstyle\sum_{m=1}^{M} a_m R^m \\ \Rightarrow R* = \textstyle\sum_{m=1}^{M} w_m R^m \tag{32}$$

Where,

$$w_m = \frac{\alpha_{\ m}}{\sum_{\ j=1}^{\ M}\alpha_{\ j}} \tag{33}$$

The final aggregated ranking is obtained by applying the minimizer function to compute the weighted sum of all MCDM rankings. An interesting point to note is that the MCDM rankings in (31) have non-zero weights that satisfy the unit-sum property, which is a requirement of the MCDM method. Since the HQ functions are used, the optimization model is not constrained, and all these properties are met.

This consensus index indicates how well the MCDM techniques agree on the obtained final ranking and the same is determined by Eq. 34.

$$C\left(R^*\right) = \frac{1}{KM}\sum_{k=1}^{K}\sum_{m=1}^{M}\frac{\mathcal{N}_\sigma\left(R^m - R^*\right)}{\mathcal{N}_\alpha\ (0)} \tag{34}$$

Where, $C\left(R^*\right)$ represents the "consensus index" of the R^* and $\mathcal{N}_\alpha$ shows the probability density function for a normal distribution with mean 0 and standard deviation σ.

The trust level of an ensemble ranking is determined by Eq. 35, which represents the acceptability (or reliability) of the ranking.

$$T\left(R^*\right) = \frac{1}{K}\sum_{k=1}^{K}\sum_{m=1}^{M} w_m q_{km} \tag{35}$$

Where, $T\left(R^*\right)$ signifies the trust level of the R^*.

4 Data analysis

The proposed framework is used to fulfil the research objectives. First, an SLR and expert feedback identify the main barriers and solutions for CE adoption. Barriers are then prioritized using BWM, followed by ranking the solutions via TOPSIS, WASPAS, and CoCoSo. Finally, the soltions' ranking are aggregated through the HQ-based approach. Each phase is detailed in the following sub-sections.

4.1 Identification of CE adoption barriers and their overcoming solutions

To identify barriers and solutions to CE adoption, an SLR and expert feedback are utilised. This study adopts a systematic, transparent, and reproducible SLR methodology to identify CE adoption barriers and corresponding solutions, following established guidelines proposed by de Oliveira Neto et al. (2022) and Tranfield et al. (2003). The review process is structured in accordance with the PRISMA framework, which is widely recognized for ensuring methodological rigour and reliability in SLR studies (Cassia et al. 2020; Ghobakhloo et al. 2022). Relevant publications were retrieved exclusively from the Scopus database, selected due to its comprehensive coverage and reliability as a source of peer-reviewed scientific literature. For the initial search, we used keywords such as "CE", "circular practice", "closed-loop supply chain", "circular supply chain", "barriers", "challenges", "obstacles", "strategies", "solutions" and "enablers". These keywords were systematically combined using Boolean operators (AND/OR), and the search was restricted to article titles, abstracts, and keywords, with a time range between 2011 and 2024*.

The initial search resulted in 478 records, of which only English-language journal articles were considered for further evaluation. To maintain the document quality, we removed books, editorials, chapters, monologues, conference proceedings, and book reviews from the data collection. Using these guidelines, the article numbers were lowered to 334. Only articles describing the CE adoption barriers and solutions, or both, are taken into consideration for further analysis. By doing so, 277 articles were removed, and the remaining 57 articles were finalised for further analysis. To remove the biases, the article selection is done independently by the two authors. After that, minor discrepancies are found that are resolved through discussion with the rest of the authors. After applying the inclusion and exclusion criteria outlined in Table 1, nine articles were removed to ensure consistency. Subsequently, a full-text content analysis was performed on the remaining 48 articles, which were considered relevant and significant for the study. These articles were comprehensively reviewed, and a total of twenty-four barriers were identified, and eighteen solutions were proposed. A panel of experts is then formed to finalize the barriers and solutions. The expert group consists of ten members: eight industrial professionals, one business consultant, and two academics. The industry experts have held managerial positions for the last ten years with leading companies that focus on sustainability. Academicians are engaged in a variety of projects relating to CE projects and closed-loop supply chains to improve sustainability. Appendix A presents a brief profile of the participants who provided feedback on the significance of the barriers and solutions identified. The experts have recommended to drop four barriers and three solution measures, as they are irrelevant to contemporary business operations. In this manner, twenty barriers and fifteen solutions are to be considered for further analysis. These barriers are further categorized into four main categories, as illustrated in Table 2.

Based on the SLR and expert panel feedback, fifteen solutions were identified to address the CE adoption barriers. The finalized solutions are presented in Table 3.

Furthermore, Fig. 2 illustrates a hierarchical structure between barriers, sub-barriers and solutions.

Table 1 SLR procedure for identification of barriers and solutions to CE adoption

Objective	Identify the barriers to CE adoption and their solutions
Time Period	2011- June 2024*
Database	Scopus
Search Field	TITLE-ABS-KEY
Search String	*(TITLE-ABS-KEY ("Circular economy" OR "circular supply chain" OR "close loop supply chain" OR "circular practice") AND TITLE-ABS-KEY ("barriers" OR "challenges" OR "obstacles" OR "strategies" OR "solutions" OR "enabler") AND TITLE-ABS-KEY ("developing countries" OR "emerging economies")) AND PUBYEAR > 2010 AND PUBYEAR < 2025*
Inclusion criteria	Search results comprising studies relevant to emerging economies
Exclusion criteria	• Excluding non-English articles, book reviews, conference proceedings, and editorials, • Not related to research objectives
Validity	Two independent authors collected the articles and finalized them with the authors by verifying the inclusion and exclusion criteria
Outcome	Twenty-four barriers and eighteen solutions for CE adoption are identified.
Number of articles	48

4.2 Ranking of CE adoption barriers

The CE adoption barriers and sub-barriers are prioritized using the BWM. We developed a questionnaire to collect data from the expert panel to apply BWM. This questionnaire has two sections; the first provides basic demographic information about the experts, and the second provides a reference comparison matrix for the barriers and sub-barriers to CE adoption. The same expert panel that participated in identifying barriers is called to respond to the questionnaire. In expert-based studies, the formation of an expert panel does not adhere to statistical representativeness norms. The sample size typically ranges from five to thirty, while applying the MCDM method (Rezaei 2015). A very small number of experts (e.g., 2–3) limits the generalizability of results, while a larger group (20–30) increases the complexity in reaching consensus and may lead to high inconsistency (Pun and Hui 2001). Thus, this study selected a panel of ten experts, which lies well within the recommended range and is commonly adopted in similar MCDM and expert-based studies. This number was considered sufficient to address the heterogenous perspectives across industries and roles while maintaining manageable consistency in expert evaluations. Recent studies used a similar number of experts in the application of the MCDM method (S. S. Ali et al. 2025; Li et al. 2025; Mohammed et al. 2025).

A purposive sampling approach was used to select experts with demonstrated CE- and supply-chain-related expertise, at least 10 years of relevant experience, diverse functional roles, from industry or academia. Potential biases were mitigated through the inclusion of experts from multiple industries and functional roles, reducing sector-specific and role-dominant bias. Both industry practitioners and academic experts were included to balance practical

Table 2 Barriers and sub-barriers to CE adoption

S. No	Barriers	Sub-barriers	Code	Description	References
1.	Government and regulation-related barriers	Lack of tax subsidies	GR1	Government encouragement and assistance are inadequate regarding subsidiary policies for tax, import, and excise duties and the adoption of CE practices.	(Chenavaz and Dimitrov 2024)
2.		Lack of environmental regulation	GR2	As energy consumption increases, carbon emissions grow, and ecological problems intensify, the government and other regulatory agencies should frame environmental regulations accordingly.	(Kirchherr et al. 2018)
3.		Lack of standard for refurbishment	GR3	Regulations and standards regarding refurbishment and refurbished products are not effective or are not present in most countries.	(Abbas et al. 2025; Ma et al. 2022)
4.		Inadequate CE performance measurement	GR4	Circular supply chains are not evaluated using a standard evaluation system, which impedes their adoption.	(Saidani et al. 2019)
5.	Management-related barriers	Lack of adoption at the supply chain level	MB1	CE practices are adopted at the firm level rather than the supply chain level, which affects the objectives of the CE.	(Erol et al. 2022)
6.		Lack of management support and commitment	MB2	The implementation of CE concepts can only be achieved with management's support and the involvement of the supply chain, which are not effectively present in the current supply chain.	(Abbas et al. 2025; S. Khan and Haleem 2021)
7.		High Capital cost	MB3	Like other new adoptions at the organizational level, initiating CE causes some capital costs for setting up new business models, conducting pilot studies, recruiting new people, etc. This increased capital cost restricts CE adoption.	(Chhimwal et al. 2022)
8.		Ineffective linkage of CE practices with the existing process	MB4	A lack of efficient integration of CE practices with the current supply chain process is a problem for management and practitioners.	(Dey et al. 2022; Irani et al. 2017)
9.		Wide communication gap	MB5	Ineffective information flow among stakeholders on CE benefits and implementation-related issues	(Orji 2019; Smol et al. 2018)
10.		Negative perception toward economic return	MB6	A strong perception exists among management that circular practices lead to low economic returns.	(Irani and Sharif 2016; Mishra et al. 2022)
11.	Technological Barriers	Supply chain Complexity	TB1	Adopting CE practices within the conventional supply chain is challenging due to the network and process complexities.	(Chenavaz and Dimitrov 2024); Mishra et al. 2022)
12.		Complexities in creating circular loops	TB2	Several complexities are present in creating loops (by reuse, refurbishment, and recycling), and it requires knowledge, experience, human resources, and an intensive workforce.	(Barford and Ahmad 2023; Corona et al. 2019)
13.		Lack of adequate technologies	TB3 Badhotiya	In the absence of sufficient technology, it is difficult to remanufacture products and reuse them.	(Badhotiya et al. 2022; Dey et al. 2022)
14.		Lack of technical expertise	TB4	Technically sound personnel and experts are required to design the CE process and layout, but many organizations do not have them.	(Singh and Ordoñez 2016; Sundar et al. 2023)
15.		Lack of Information about used product	TB5	Information about the used component/product is unavailable and/or inaccessible, making it difficult to track down the product before recovery, refurbishment, and recycling in the supply chain.	(Su et al. 2013); (Maitre-Ekern and Dalhammar 2019)

and theoretical perspectives, and a moderator facilitated the consensus-building process among experts. The responses for determining the barriers were collected from carefully selected experts with extensive experience in CE practices, ensuring the reliability and relevance of the insights. An author briefs the expert's panel about BWM and their steps before collecting the responses so that they fill out the questionnaire correctly. One of the authors moderated the expert's discussion so they could reach a consensus. After the discussion, the expert group identified the best and worst barriers to CE adoption. Following that, they compared the best and worst barriers individually using a 9-point scale, as suggested in the methodology section. Pairwise comparisons of the barriers to CE adoption are obtained, and the resultant reference comparison matrix is presented in Table 4.

Table 2 (continued)

S. No	Barriers	Sub-barriers	Code	Description	References
16.	Organizational culture and consumer-related barriers	Lack of customer awareness about CE	OC1	Low consumers awareness about CE ideas and related advantages restricts the consumers' contribution to consuming the CE product and their related activities.	(Kazancoglu et al. 2023; Maitre-Ekern and Dalhammar 2019)
17.		Ignorance of human factors	OC2	Several organizations have not considered the human factors that eventually affect CE implementation and their business performance.	(Clube and Tennant 2023); Chiappetta Jabbour et al. 2019)
18.		Consumer perception of CE product	OC3	Consumers who develop concerns over quality, safety, and health-related issues generally do not recognize refurbished products. As a result of this misconception, used products cannot be sold to customers, which forces remanufacturers to refrain from remanufacturing.	(Russo et al. 2019; Velis and Vrancken 2015)
19.		Lack of education and training about CE practices	OC4	Training and development programs should be designed to develop competencies that will enable companies to design, reuse, refurbish, and recycle products circularly.	(Schroeder et al. 2019; Tiippana-Usvasalo et al. 2023)
20.		Ineffective employee engagement	OC5	Engaging employees in decision-making activities and empowering them improves their efficiency and facilitates the CE adoption.	(Veleva et al. 2017)

In the same manner as the barrier, the expert panel evaluated each barrier category's best and worst sub-barriers. Afterwards, a nine-point linear comparison is performed between the sub-barriers of each barrier category (i.e., government, management, technological and organizational) of CE adoption. Table 5 illustrates the reference comparisons for sub-barriers.

Model 2 is devolved and solved using the pairwise comparison matrix to calculate the weights for each barrier and sub-barrier. The consistency ratio is also calculated as part of the solution to model 2. The consistency ratio infers how logically coherent the expert's opinion is when comparing barriers. It provides insight into whether the pairwise comparisons between the Best, Worst, and other criteria are reliable. Theoretically, the consistency ratio can vary from 0 to 1. The values near 0 show greater consistency, whereas values near 1 indicate a lesser level of consistency. Usually, the consistency ratios should not exceed 0.1 to maintain high levels of consistency. As shown in Table 6, each barrier and sub-barrier has a consistency ratio value of less than 0.1. As a result of these tests, we can conclude that barriers and sub-barriers are ranked and pose high consistency. Each barrier and sub-barrier are assigned a local weight according to their importance weight, which is calculated through BWM. As a result of this weight, a local rank of barriers/sub-barriers is determined and presented in Table 6. Further, a global importance weight is calculated for each sub-barrier based on its local weight as well as the barrier weight corresponding to the barrier. Table 6 presents the global ranking of all sub-barriers based on the global weight.

4.3 Ranking the solutions for CE adoption barrier

In the third phase, the solutions are prioritised using the TOPSIS, WASPAS, and CoCoSo approaches. The decision matrix is required to apply these methods, which are developed by assessing the solution by treating the sub-barriers as an assessment criterion using the five-point scale. To obtain the decision matrix, a structured questionnaire was developed and sent to the same experts who were involved in the barriers ranking (in phase II). Further, two follow-up emails are sent to collect the responses from the experts. Finally, eight valid responses were received that are used for further analysis. The obtained eight decision matrices were arithmetically averaged and presented in Table 7.

Furthermore, this decision matrix is utilized to calculate the weight of each solution using the TOPSIS, WASPAS, and CoCoSo methods. The ranking obtained using the TOPSIS, WASPAS and CoCoSo methods is then aggregated by the HQ-based method to determine the final ranking. To obtain the importance weight and rank of each solution measure, TOPSIS, WASPAS and CoCoSo are applied separately (refer to supplementary material). To apply the TOPSIS method, the steps outlined in the TOPSIS method are followed (see Eqs. 5, 6, 7, 8, 9, 10, 11, 12) using the decision matrix as illustrated in Table 7. As a result, the importance weight and rank of each solution measure are determined and presented in Table 8. Similarly, the same decision matrix (i.e. Table 7) is used to determine the importance weight of each solution by applying the WASPAS method (see Eqs. 13, 14, 15, 16, 17). The resultant obtained importance weight and rank of each solution measure are shown

Table 3 Solutions to overcome CE adoption barriers

S. No	Solutions	Code	Description	References
1.	Top management consciousness and participation	SO1	The top management should understand the notion of the CE and its impact on their firm, and therefore, they should provide support to the CE practices in terms of vision, plan, resources, and expertise.	(Eisenreich et al. 2022; Govindan et al. 2020)
2.	Early adoption of CE culture	SO2	Educate and train the working personnel about CE at the beginning so that it offers a positive impact by facilitating adaptation to new working environments with CE practises.	(Xu et al. 2023)
3.	Traceability Implementation	SO3	Product, component, and material traceability is essential for an effective circular supply chain and has therefore been implemented throughout the supply chain.	(Falcetti et al. 2025; Roy et al. 2024)
4.	Develop the reverse logistics infrastructure.	SO4	CE deals with several types of flows of material and information in forward and reverse directions, that make reverse logistics significantly important to implement CE practices.	(Orji et al. 2022; Sonar et al. 2024)
5.	Create consumer awareness	SO5	The concept of CE and associated benefits are communicated to the consumer so that they become interested in buying the CE product, and consequently, it will improve the demand for CE products.	(Lynch and Ferasso 2023; Papadopoulou et al. 2022)
6.	Preferential tax policies for CE product	SO6	Government should provide tax subsidies and easy loan policies to the organisations which have implemented the CE practices	(Singh et al. 2023; Wuni 2023)
7.	Eco Design and manufacturing	SO7	CE products are designed with the least environmental effects by adopting the design principle for reuse, remanufacture and reassembly, and it has been manufactured through green manufacturing practices.	(Ataeiyan et al. 2025; Govindan et al. 2020)
8.	Develop the standard for remanufactured/refurbished product	SO8	There is a need to develop an efficient and implementable standard for refurbished and remanufactured products.	(Abdulla et al. 2024; Aydin and Mansour 2023)
9.	Training and skill development program	SO9	Training and skill development programs for employees and suppliers are conducted to foster a CE culture within the organization.	(Singh et al. 2023)
10.	Design for longevity, reliability and durability	SO10	CE products are designed to be long-lasting, reliable, and durable by focusing on longevity, reliability, and durability.	(Khan et al. 2022; Mestre and Cooper 2017)
11.	Synergistic partnerships	SO11	Collaborate with the product users to develop synergistic partnerships and bring together the consumers and producers of the product.	(Russell et al. 2020)
12.	Develop the CE business model	SO12	Several CE business models are present, so there is a need to select or design the CE business model which is best suited to their particular CE supply chain through the morphological analysis of existing CE business models.	(Husain et al. 2021; Lopes De Sousa Jabbour et al. 2023)
13.	Alignment of CE goals with strategic objectives	SO13	To facilitate the rapid adoption of CE practices, organizations should align their strategic objectives with the CE goals.	(Khan et al. 2022, 2024)
14.	Reward and appreciation policies	SO14	The organisations link the adoption of CE practices to reward and appreciation to get motivated and reduce the resistance to change.	(Hazen et al. 2021; Singh et al. 2023)
15.	Increase employee participation	SO15	Every new adoption requires employee participation, and organisations which are willing to adopt the CE practices need to increase employee participation related to CE activities	(Singh et al. 2023)

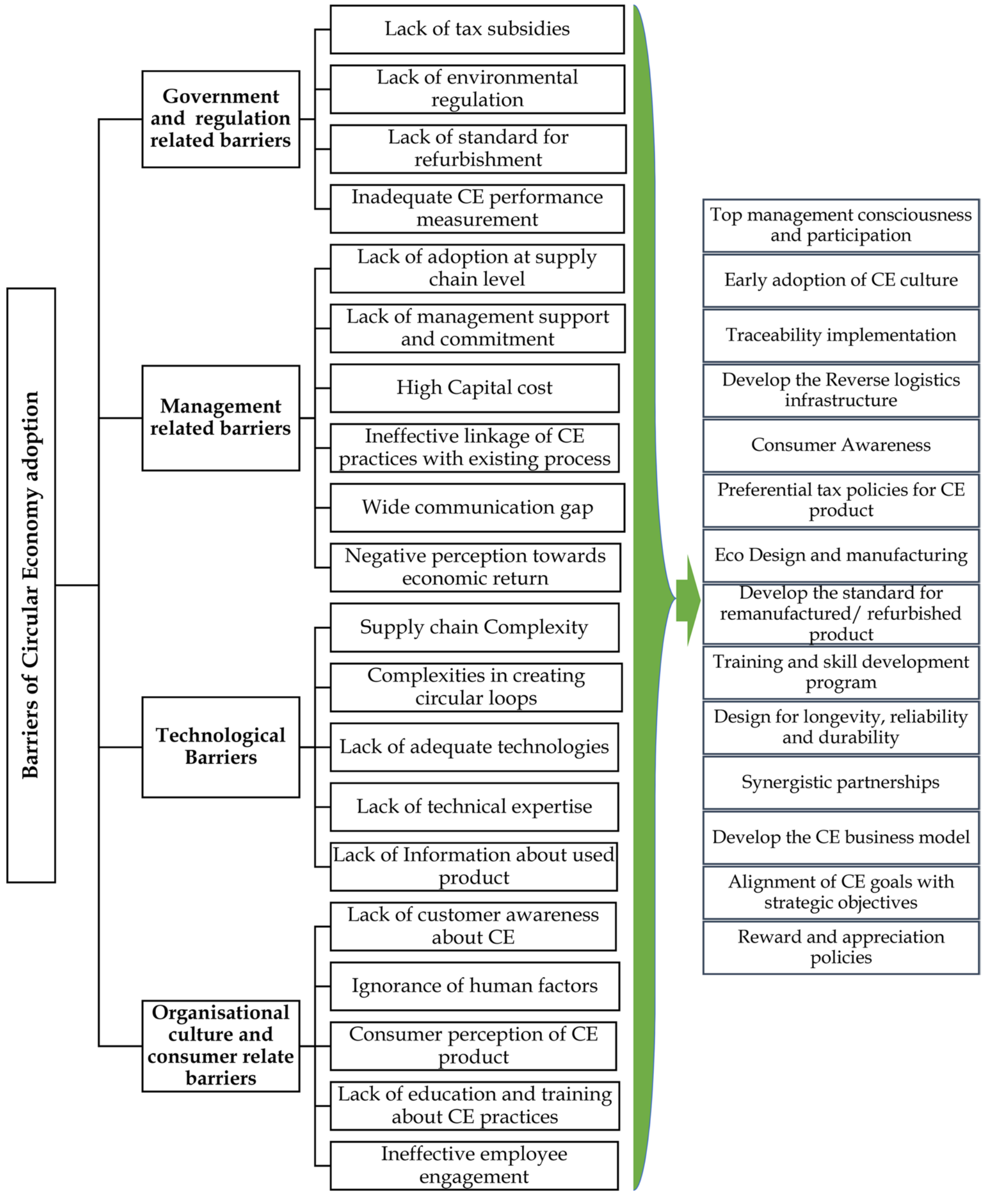

Fig. 2 Hierarchical structure of barriers and solutions of CE adoption

Table 4 Reference comparison of barriers to CE adoption

Comparison	GR	MB	TB	OC
Best (MB) to Other	3	1	4	2
Other to Worst (TG)	2	4	1	3
Consistency Ratio: 0.0517				

in Table 8. Furthermore, the CoCoSo method is applied to determine the weight and rank of each solution method by following the prescribed CoCoSo steps (see Eqs. 18, 19, 20, 21, 22, 23, 24, 25) using the decision matrix (Table 7). The resulting importance weight and rank of each solution method are presented in Table 8. It is evident from Table 8 that the ranking of solutions differs across methods, emphasizing the need for aggregation to achieve a more robust and reliable final ranking.

Each MCDM technique follows a specific methodology and, thus, produces a different ranking for most solutions as shown in Fig. 3. Therefore, to obtain the resultant rank, the HQ-based compromise method (using Eqs. 26, 27, 28, 29, 30, 31, 32, 33) is employed to aggregate the rankings derived from the TOPSIS, WASPAS and CoCoSo approaches. As a result, the final ranking of each salutation measure is obtained and shown in Table 9. Further, a consensus index of 0.966 and a trust level of 0.981 for the final ranking were obtained by applying Eqs. 34 and 35. These values indicate a high degree of consensus and reliability, demonstrating the robustness of the aggregated ranking derived from the HQ-based method. Table 9 presents the final ranking of each solution.

Table 5 Reference comparison of sub barriers

Government and regulation-related barriers reference comparison						
Comparison	**GR1**	**GR2**	**GR3**	**GR4**		
Best (GR1) to Other	1	2	5	3		
Other to Worst (GR3)	5	3	1	2		
CR = 0.0230						
Management-related barriers reference comparison						
Comparison	**MB1**	**MB2**	**MB3**	**MB4**	**MB5**	**MB6**
Best (MB2) to Other	3	1	5	2	4	7
Other to Worst (MB6)	5	6	3	5	4	1
CR = 0.0852						
Technological barriers rreference comparison						
Comparison	**TB1**	**TB2**	**TB3**	**TB4**	**TB5**	
Best (TB1) to Other	1	3	2	5	4	
Other to Worst (TB4)	5	3	4	1	2	
CR = 0.0573						
Organisational culture and consumer related barriers reference comparison						
Comparison	OC1	OC2	OC3	OC4	OC5	
Best (OC3) to Other	2	4	1	5	6	
Other to Worst (OC5)	6	3	7	3	1	
CR = 0.0880						

Table 6 Prioritisation of barriers and sub barriers

Barriers	Weights	ξ^L	Sub Barriers	Local Weight	Local rank	ξ^L	Global Weight	Global Rank
GR	0.1724	0.0517	GR1	0.4846	1	0.0230	0.0836	4
			GR2	0.2538	2		0.0438	8
			GR3	0.0923	4		0.0159	17
			GR4	0.1692	3		0.0292	12
MB	0.4655		MB1	0.1515	3	0.0852	0.0705	5
			MB2	0.3693	1		0.1719	1
			MB3	0.0909	5		0.0423	10
			MB4	0.2273	2		0.1058	3
			MB5	0.1136	4		0.0529	7
			MB6	0.0473	6		0.0220	15
TB	0.1034		TB1	0.4158	1	0.0573	0.0430	9
			TB2	0.1577	3		0.0163	16
			TB3	0.2366	2		0.0245	14
			TB4	0.0717	5		0.0074	20
			TB5	0.1183	4		0.0122	19
OC	0.2586		OC1	0.2639	2	0.0880	0.0683	6
			OC2	0.1320	3		0.0341	11
			OC3	0.4399	1		0.1138	2
			OC4	0.1056	4		0.0273	13
			OC5	0.0587	5		0.0152	18

5 Discussion

Based on the emerging economies perspective, this study ranks the barriers to CE adoption and the solutions to overcome them. The prioritization of barriers and solutions provides some deeper insights into CE adoption, which are discussed in detail.

5.1 CE adoption barrier prioritization

The result shows that the important order of CE adoption barriers is 'management-related barriers,' 'organizational culture and consumer related barriers', 'government and regulation related barriers,' and 'technological barriers.' This prioritization provides important insights when compared

Table 7 Decision matrix of solutions

Solution	GR1	GR2	GR3	GR4	MB1	MB2	MB3	MB4	MB5	MB6	TB1	TB2	TB3
SOL1	1.000	1.125	1.875	2.000	4.750	4.875	2.750	4.125	4.750	2.750	4.625	2.125	2.250
SOL2	1.000	1.875	2.000	1.125	2.750	2.000	1.125	5.000	2.750	4.125	2.250	2.000	4.000
SOL3	1.000	1.125	3.375	1.250	4.750	2.750	1.125	2.750	2.750	5.000	2.000	4.625	2.250
SOL4	1.000	1.875	2.000	1.875	4.625	2.500	1.125	2.500	1.875	1.875	1.875	2.000	4.000
SOL5	1.625	1.875	3.625	1.875	4.500	4.750	2.000	4.250	2.625	4.250	2.125	2.000	1.750
SOL6	4.375	1.875	3.625	2.000	3.000	4.500	2.625	1.875	1.875	2.625	1.875	2.250	3.000
SOL7	1.875	3.625	4.000	3.000	3.000	2.000	4.625	4.000	1.875	2.625	2.000	2.250	2.875
SOL8	1.125	3.750	4.250	4.250	3.000	2.000	1.125	1.875	1.875	4.000	2.125	4.000	2.000
SOL9	1.000	1.125	2.000	3.000	2.000	1.000	1.125	1.125	3.875	2.375	4.125	4.000	2.250
SOL10	1.125	2.000	3.750	4.250	4.375	1.000	1.125	1.125	2.000	4.000	1.750	2.500	2.000
SOL11	1.000	1.000	3.750	4.250	4.375	2.000	2.000	3.875	3.875	2.500	3.875	2.000	1.500
SOL12	1.875	2.000	4.000	4.125	4.375	3.125	2.000	3.875	2.000	4.000	1.875	2.375	4.000
SOL13	1.125	1.250	4.000	4.250	4.250	4.250	1.125	2.250	2.375	4.000	3.875	2.375	2.125
SOL14	1.000	1.125	3.625	4.125	4.250	4.250	1.125	1.875	3.875	2.500	2.000	1.750	2.000
SOL15	1.000	1.125	3.625	2.000	3.125	4.250	1.125	1.125	3.875	2.500	1.875	2.000	1.500

TB4	TB5	OC1	OC2	OC3	OC4	OC5
1.625	2.125	2.250	3.875	2.375	4.250	4.625
2.250	2.250	4.000	4.000	2.500	2.500	4.000
1.625	5.000	2.125	1.125	2.375	1.125	1.125
2.125	4.000	2.125	1.375	1.375	1.375	1.375
1.750	4.000	5.000	4.000	4.000	3.000	2.750
2.875	1.750	2.875	1.375	1.000	2.875	1.000
3.000	1.750	3.000	1.125	3.000	2.875	1.000
2.125	4.000	2.000	1.250	2.750	2.500	2.500
4.500	2.250	2.000	4.000	2.625	4.750	4.000
2.125	2.125	2.000	1.125	4.000	1.000	2.375
2.000	2.000	2.125	2.500	2.500	4.000	1.000
3.875	2.125	4.000	2.625	2.500	4.125	2.750
3.875	2.125	4.000	2.750	2.625	4.750	2.750
1.875	2.000	2.250	5.000	2.625	4.750	5.000
3.875	2.250	4.125	4.875	2.250	2.625	4.625

Table 8 Prioritisation of solutions to overcome the barriers

Solutions	TOPSIS		WASPAS		CoCoSo	
	CC_i	Rank	Q_i	Rank	K_i	Rank
SOL1	0.034	3	0.6768	2	2.1242	4
SOL2	0.024	9	0.5489	8	1.8195	6
SOL3	0.021	12	0.4951	11	1.6237	12
SOL4	0.019	14	0.4452	13	1.4750	13
SOL5	0.037	2	0.7328	1	2.4429	1
SOL6	0.038	1	0.5535	7	1.7424	10
SOL7	0.027	7	0.5763	6	1.7862	7
SOL8	0.020	13	0.4889	12	1.6546	11
SOL9	0.016	15	0.4279	15	1.3830	14
SOL10	0.022	11	0.4300	14	1.3288	15
SOL11	0.022	10	0.5428	9	1.7447	9
SOL12	0.028	6	0.6432	3	2.2169	2
SOL13	0.029	4	0.6218	4	2.1312	3
SOL14	0.028	5	0.5864	5	1.9065	5
SOL15	0.027	8	0.5391	10	1.7523	8

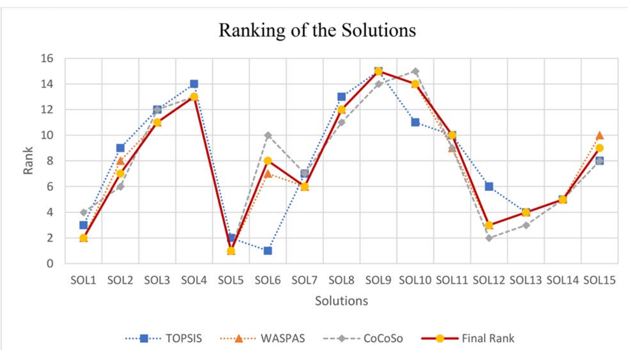

Fig. 3 Ranking of the solution using different methods

Table 9 Aggregated rankings of solutions using Half-quadratic based methods

Solution	TOPSIS	WASPAS	CoCoSo	R^*	Final Rank
SOL1	3	2	4	2.898	2
SOL2	9	8	6	7.339	7
SOL3	12	11	12	11.508	11
SOL4	14	13	13	13.119	13
SOL5	2	1	1	1.119	1
SOL6	1	7	10	7.458	8
SOL7	7	6	7	6.508	6
SOL8	13	12	11	11.729	12
SOL9	15	15	14	14.610	15
SOL10	11	14	15	14.034	14
SOL11	10	9	9	9.119	10
SOL12	6	3	2	2.966	3
SOL13	4	4	3	3.610	4
SOL14	5	5	5	5.000	5
SOL15	8	10	8	8.984	9
Weights	0.119	0.492	0.390		
Confidence Index	0.966				
Trust Level	0.981				

with existing CE literature, particularly regarding the relative dominance of managerial and cultural constraints over technological challenges in emerging economies. However, earlier CE studies often positioned technological limitations as the dominant challenge, implicitly if managerial support would naturally follow technological readiness (Chauhan et al. 2022). This study challenges this assumption n by empirically demonstrating that even when technologies are available, the absence of top management commitment, weak supply chain-level CE integration, and communication gaps significantly impede CE adoption.

The following significant barriers are the 'organizational culture and consumer related barriers,' including the lack of employee training, customer unawareness about CE ignorance of human factors, and consumer perception of CE products. Kirchherr et al. (2018) also argued that cultural barriers outweigh technological ones; the present study corroborates this argument while adding empirical prioritization. Consumers are encouraged to buy new things regularly by the linear economy's usual business model, even if their existing products are still in excellent condition. These consumer-related barriers are quite detrimental to the demand for CE products in their second life (Kara et al. 2025). Further, the consumer is not aware of the benefits and importance of CE products, which leads to low demand that hampers the organization's shift toward CE.

Government and regulation-related barriers are the next important barrier to CE adoption, a finding that partially aligns with prior studies but also reveals important contextual nuances. Several studies have positioned regulatory barriers as the primary constraint to CE adoption (Besiktepe and Gurgun 2025; Zighan et al. 2025). While the present findings confirm the importance of policy support, they suggest that regulatory deficiencies exert a secondary yet reinforcing effect in emerging economies. The government can play an important role in this transition by enforcing environmental laws and regulations. Environmental laws can adopt two different strategies (carrot or stick): using taxes and subsidies to encourage certain behaviors (the carrot) or using bans to attempt to eradicate behaviors (the stick). Government and regulation-related barriers include the 'lack of tax subsidies', 'lack of environmental regulation', and 'lack of a standard for refurbishment'. These barriers are resolved with the government's support by providing tax subsidies and drafting environmental regulations (Singh et al. 2023). The lack of tax incentives, weak environmental regulations, and absence of refurbishment standards amplify financial risks and quality uncertainties, thereby discouraging managerial commitment to adopt CE.

Technological barriers were ranked lower than managerial, cultural, and regulatory barriers, which contrasts with earlier CE studies that emphasized technological readiness as the dominant enabler of circularity (Chauhan et al. 2022; De et al. 2024). This finding supports recent studies that question the technology-centric view of CE transitions (Kirchherr et al. 2018; Takacs et al. 2022; Valkokari et al. 2024). The technological barriers include 'supply chain complexity', 'lack of adequate technologies', and 'lack of technical expertise'. These technological barriers are important at an operational level in the CE environment. The lack of adequate technologies hinders the condition monitoring for repair, product traceability and recovery, and design for the multi-life product. Further, the technical expertise in the context of CE is limited, especially in emerging economies. Due to these barriers, the adoption of CE is very low in emerging countries.

5.2 Solution to overcome CE barriers

The solution of the CE barriers adoption is prioritized, and the result shows the importance of "top management consciousness and participation," $\succ$ "consumer awareness," $\succ$ "develop the CE business model," $\succ$ "alignment of CE goals with strategic objectives," $\succ$ "reward and appreciation policies" $\succ$ "eco-design and manufacturing" $\succ$ "early adoption of CE culture" $\succ$ "preferential tax policies for CE product" $\succ$ "increase employee participation" $\succ$ "synergistic partnerships" $\succ$ "traceability implementation" $\succ$ "develop the standard for remanufactured/refurbished product" $\succ$ "develop the reverse logistics infrastructure" $\succ$ "design for longevity, reliability and durability" $\succ$ "training and skill development program". These solutions need to be deployed systematically to achieve the CE transformation sustainably.

5.2.1 Top management consciousness and participation

The most effective solution for "top management consciousness and participation" needs to be addressed on a priority basis. This finding is consistent with prior CE studies that identify managerial commitment as a key enabler of CE initiatives (Koistinen et al. 2022). However, the present study extends existing literature by demonstrating that top management involvement is not merely a facilitating condition but a primary solution capable of simultaneously addressing multiple interrelated barriers. This solution addresses several barriers especially the lack of management support and commitment, ineffective linkage of CE practices with existing processes, and negative perception toward economic return. Top management support facilitates resource allocation, aligns strategies, and provides leadership in the adoption process, creating a supportive environment for CE integration. The top management needs to be concerned about CE values and their long-term sustainability to provide their support for CE initiatives.

5.2.2 Consumer awareness

Consumer awareness is also considered a vital element in the demand for CE-based products. Through consumer awareness, the barriers, such as a lack of customer awareness about CE, and consumer perception of CE products, can be addressed. This finding aligns with prior studies that emphasize the role of demand-side factors in enabling CE transitions (Anderluh et al. 2025; Chapman et al. 2024); however, the present study advances this perspective by empirically positioning consumer awareness as a strategic lever. Studies show that consumers do not prefer to buy used or refurbished products due to their perception of low quality (Zhang et al. 2025), especially in developing or underdeveloped countries (S. A. R. Khan et al. 2025). Considering this evidence, organisations should create awareness about the CE product and promote the notion of CE through effective marketing mechanisms.

5.2.3 Develop a CE business model

One important solution for effective CE adoption is developing a CE business model. While prior CE studies have acknowledged the importance of business model innovation, the present findings empirically reinforce the argument that CE adoption cannot be sustained without a fundamental reconfiguration of the business model (Husain et al. 2021; Puntillo 2023). Lack of CE adoption at the supply chain level, lack of management support and commitment and negative perception toward economic return can be reduced through the development of the CE business model. Existing studies have established a strong relationship between CE-oriented business models, sustainability performance, and organizational resilience (Jedrzejczak et al. 2025; Lopes De Sousa Jabbour et al. 2023). Several CE business models exist, such as sharing platforms, product life extension, and product as a service. The organization should select the appropriate CE business model that fits its objectives or create an innovative CE business model among these CE business models.

5.2.4 Alignment of CE goals with strategic objectives

Alignment of CE goals with strategic objectives for better adoption of CE. Consistent with Khan et al. (2024), the present study demonstrates that strategic alignment elevates CE from an operational concern to a strategic priority. This alignment reduces the existing barriers such as a lack of management support & commitment, and lack of adoption at the supply chain level. The core CE principles (i.e. resource efficiency, waste minimization, product lifecycle extension, and closed-loop systems) can improve cost efficiency and profit improvement using new revenue streams such as leasing and refurbishing, and this might fulfil the strategic objectives of the organisations.

5.2.5 Reward and appreciation policies

Organizations need well-structured reward and appreciation policies that motivate employees, supply chain partners, and consumers to actively participate in CE-related activities. Rewarding employees for adopting CE practices and acknowledging their contributions encourages greater participation and commitment across the organization, thus mitigating the barriers such as ineffective employee engagement. Prior studies acknowledge that employee motivation and behavioral alignment are essential for implementing sustainability-oriented practices (Hazen et al. 2021). In addition, this solution might encourage the stakeholders to adopt sustainable behaviours and innovation towards the CE. Further, the working personnel, suppliers and customers also support the idea of CE as they get appreciation from the organisations or management (Singh et al. 2023).

5.2.6 Eco-design and manufacturing

Among the various solutions for implementing a CE, eco-design and manufacturing are recognized as a technical approach that are essential for achieving CE objectives at both the operational and functional levels. Eco-design ensures that products are created with the intention of being remanufactured or recycled, incorporating technology and design elements that make reuse easier and more cost-effective. Several studies advocate the role of eco design for the CE (Ataeiyan et al. 2025). This facilitates the eradication of barriers, including lack of standards for refurbishment, lack of adequate technologies, and lack of technical expertise.

5.2.7 Early adoption of CE culture

The early adoption of CE culture is one of the significant solutions to overcome the CE barriers in order to take first mover advantage. This finding reinforces the view that CE adoption is not merely a technological or structural transition but a profound cultural transformation that reshapes organizational values, routines, and decision-making processes. Consistent with (Beaurain et al. 2023), the present study confirms that organizational culture plays a pivotal role in enabling the adoption of new philosophies such as CE. Dey et al. (2022) also recognize the importance of CE culture when it comes to CE adoption. The CE culture enables the management to educate and train their working personnel about the CE process and practices for long-term sustainability (Singh et al. 2023). Barriers related to the organizational culture and consumers are addressed through this solution. Early adoption of a CE culture sets an environment for the whole supply chain and company, enabling greater awareness and acceptance of CE products.

5.2.8 Government initiatives

Government initiatives such as preferential tax policies for CE products can provide a thrust for CE adoption (Sharma et al. 2023). The special tax policies motivate organizations to adopt CE for their economic sustainability. Government incentives, such as preferential tax policies, encourage businesses to invest in CE practices and reduce financial burdens. This finding is consistent with the Rajpal et al. (2025). The relaxation in the tax creates a positive environment for CE adoption and shows the government's support for this initiative. In addition, the government can make favourable policies for CE goals, such as mandates for manufacturers to take responsibility for the end-of-life disposal of their products and a ban on Single-Use Plastics.

5.2.9 Employee participation

From the operational perspective, increasing employee participation emerges as a crucial solution for effective CE adoption. Our findings align with prior research emphasizing that employees are the driving force behind organizational change, and their active involvement is essential for successful CE implementation (Bag et al. 2022). CE training and sustainability awareness programs help employees understand the importance of waste reduction, resource efficiency, and circularity. This promotes the employee's contribution to reducing material waste by following best practices in resource utilization. Involving employees in CE initiatives and decision-making empowers them to drive change, creating a more participatory and motivated workforce. This addresses the barriers, such as ineffective employee engagement and lack of management support and commitment.

5.2.10 Synergistic partnerships

Synergistic partnerships bring together multiple stakeholders, including governments, businesses, academia, regulatory bodies and consumers to accelerate the transition to CE. Our findings indicate that such partnerships effectively address barriers like communication gaps and supply chain complexity, which are widely acknowledged in the literature as critical impediments to CE implementation (Calicchio Berardi & Peregrino De Brito, 2021; Dominidiato et al. 2025). For instance, one company's waste becomes another's raw material, and this requires an effective partnership between the organisation and industry. Through these synergistic partnerships, the material recovery facilities and circular infrastructure can be developed and utilised. Therefore, a synergistic partnership is needed across the circular supply chain for CE adoption.

5.2.11 Traceability implementation

A traceability system is a digital framework that enables tracking and monitoring of materials, products, and waste throughout the entire lifecycle. It is required for product recovery, which is an essential part of the CE ecosystem. A traceability system is required to track and trace the CE product for its condition monitoring or recovery. The effective traceability system addresses the barriers, such as lack of information about used products, complexity in creating circular loops, and inadequate CE performance measurement. The findings align with prior studies, which emphasize that accurate tracking of product origin, condition, and reusability is essential for facilitating product recovery and optimizing resource efficiency (Carlsson and Nevzorova 2025; Horn and Silvennoinen 2025). The product needs to be traced and tracked to gain information about its reusability, origin, and condition and enable proper measurement of CE performance. Several smart technologies, such as IoT and blockchain, are used for the traceability of the products and services.

5.2.12 Develop the standard for remanufactured/refurbished product

To ensure the quality and reliability of remanufactured or refurbished products, regulatory bodies should establish standards specifically for these products (Aydin and Mansour 2023). Our findings indicate that the absence of such standards contributes to low adoption at the supply chain level and undermines stakeholder confidence in circular products. This aligns with prior studies emphasizing that standardized guidelines, such as BS 8001 and ISO 8887, are critical for enabling effective remanufacturing, reuse, and refurbishment practices (Formentini et al. 2025). These standards guide the organisation in ensuring the quality of the remanufactured/refurbished products. The lack of standards for refurbishment and the lack of adoption at the supply chain level might be resolved through quality standard development.

5.2.13 Development of reverse logistics infrastructure

One prominent solution is the development of reverse logistics infrastructure, which is the prime requirement for the adoption of CE. Reverse logistics help the product recovery and maintain the demand for the used product. Our findings indicate that insufficient reverse logistics infrastructure exacerbates technological and operational barriers, hindering the efficient collection, transportation, processing, and reintegration of used products, components, and materials. This is aligned with (Braz & Marotti De Mello, 2022), who emphasize that complex supply chain networks and inadequate take-back systems significantly impede CE implementation. Similarly, Sonar et al. (2024) highlight that well-structured reverse logistics networks facilitate resource efficiency, enable product refurbishment, and maintain market demand for used products. Creating robust reverse logistics ensures the effective return and reuse of products, solving logistical challenges and reducing barriers related to technological barriers.

5.2.14 Design for longevity, reliability and durability

Designing for longevity, reliability, and durability is an important solution to overcome CE barriers such as negative perception toward economic return. The CE principle encourages life extension and multiple life cycles, and this opens new business avenues such as repair, remanufacture and rental services. This is consistent with prior studies, which emphasise that extending product life through repair, remanufacturing, and rental services creates both economic and environmental value (Kristensen and Mosgaard 2020). Kristensen and Mosgaard (2020) also advocate supporting the life extension of circular products in terms of longevity and durability. Longevity ensures that products remain functional and valuable for extended periods, reducing frequent replacements, thus generating less waste. The modular design and standardized components might facilitate the longevity and reliability of the product.

5.2.15 Training and skill development program

Training and skill development programs are important solutions for overcoming the CE barriers. This finding aligns with prior studies emphasizing that human resource capability development is essential for successful sustainability transitions (Akhavan and Philsoophian 2025). Training ensures that employees have the necessary skills to implement CE practices, empowering them to participate effectively. This supports eradicating the barriers, including lack of technical expertise and ineffective employee engagement. This skill development program helps the working personnel gain knowledge and skills about CE. Organizations need a skilled workforce with expertise in areas such as remanufacturing, sustainability, reverse logistics, eco-design, and resource efficiency. A suitable training and skill development program will help employees at all levels understand and implement CE principles and practices across the supply chain.

6 Implication of the study

6.1 Managerial implications

This study might benefit industrial practitioners, regulatory bodies, policy planners, and other stakeholders involved in CE-oriented businesses. The identified barriers help the managers/practitioners remove these barriers to CE adoption. The findings show that lack of top management support is one of the major barriers to the adoption of CE. Therefore, operations managers should initiate structured executive engagement mechanisms. These include presenting CE initiatives through long-term business prospects that quantify lifecycle cost savings, risk mitigation (e.g., resource volatility), and regulatory readiness. This recommendation is particularly applicable in organizations operating under cost pressure or short-term performance targets, where CE investments may initially appear unattractive. In addition, to track the progress, some monitoring metrics can be used, such as top management participation in CE initiatives, CE-related capital allocation, and progress toward long-term sustainability indicators. Further, the prioritization of the CE barriers supports the organization in systematically overcoming these identified barriers. Managers should address high-rank barriers (i.e. managerial and cultural) before investing in advanced technologies or process redesign. This systematic approach reduces implementation risk and resource misallocation. This study also suggest that there are cultural barriers to CE adoption because of the existing linear economy, which views items as made for a single use before being discarded. A substantial cultural shift is needed to promote a CE, where items are made for many uses and material recovery. Therefore, managers should formally embed CE principles into the organization's mission, operational policies, and standard operating procedures. This can be supported by cross-functional CE teams and internal communication campaigns that reinforce circular thinking.

This study also helps managers systematically overcome existing barriers. The proposed solution helps the managers to take the initiative to overcome the identified barriers and inculcate the idea of CE. As all the proposed solutions cannot be deployed in the organization simultaneously, prioritization is done to deploy the solution systematically. The finding suggests that the most appropriate solution for CE adoption is the top management consciousness and their participation. Priority should be given to this solution by motivating the top management to take the CE initiatives for long-term sustainability. To operationalize CE strategies, organizations must develop technological, and managerial capabilities. Periodic hands-on training programs focused on CE tools, lifecycle thinking, and problem-solving should be introduced. Linking CE-related performance to incentive systems can further reinforce behavioral change. In addition, effective marketing strategies such as social media marketing create consumer awareness about the CE. To manage the dynamic nature of CE transformation, managers should adopt a systems-thinking or system dynamics perspective, enabling scenario analysis under varying market and regulatory conditions. This approach supports informed decision-making during the transition phase.

6.2 Academic implications

As this study is one of the few initial attempts to identify and analyse the barriers to CE adoption and its overcoming solution, it makes a significant contribution to the academic literature on CE and operations management. One of the primary contributions lies in the explicit conceptualization of CE adoption barriers as multidimensional constructs encompassing managerial (e.g., top management support), organizational (e.g., culture and mindset), technology-related factors. An organization seeking to transform into CE may greatly benefit from obtaining such a comprehensive list of barriers to CE adoption and solutions. The barriers can be analyzed as per the specific supply chain, such as circular manufacturing, circular textiles, and circular healthcare supply chains. By empirically prioritizing these barriers, the study moves beyond descriptive listings and clarifies their relative theoretical importance, thereby advancing understanding of why CE implementation remains uneven across organisations. From the methodological perspective, this study applied the novel concept of aggregating the rank obtained from the different MCDM methods. The proposed framework applied the ensemble ranking using the HQ-based aggregation, which is more reliable than a single method-based ranking and demonstrates how methodological pluralism can strengthen theory-building in operations management research. Further, this study also demonstrates that the successful application of HQ-based aggregation in the CE domain opens new methodological avenues for studying complex, multi-dimensional sustainability challenges. In addition, this study prioritizes the solution to overcome the CE barriers that help the researchers to develop their theoretical framework for strategy development in the various sectors, for instance, textile, automobile, and electronic equipment.

7 Conclusion, limitation, and areas for future research

The CE is considered a panacea for several environmental and social problems. The shift towards CE attracts the attention of several organizations, regulatory bodies, and governments who want to make the industrial system more sustainable. In the given circumstance, the organization is putting much effort into adopting the CE, but they face several barriers that hinder or slow the adoption. Thus, this study is conducted to address the CE adoption from a barrier and solution perspective. Initially, we proposed a framework for analyzing the barriers and their overcoming solution. As per the proposed framework, the SLR identifies the barriers to CE adoption, which are finalized with expert input. Twenty barriers are finalized and suggested, and four different categories are classified: "management-related barriers," "organizational culture and consumer-related barriers," "government and regulation-related barriers," and "technological barriers." These barriers are prioritized based on their importance and weight using the BWM method. By doing this, the barriers are overcome more systematically. Further, the solutions are ranked using the TOPSIS, WASPAS, and CoCoSo methods. These methods provide different ranks to the identified solutions. HQ-based ensemble ranking is applied to get the proposed solution's aggregate rank. This aggregation method is more robust and reliable. Based on the aggregated rank, "top management consciousness and participation," "consumer awareness," "develop the CE business model," "alignment of CE goals with strategic objectives," and "reward and appreciation policies for CE" are major solutions for mitigating the CE adoption barriers. The originations need to employ these solutions as a priority for CE adoption. The findings of this study are helpful for organizations that seek CE adoption, especially in developing countries. Further, managers and policymakers can utilize the proposed framework to assess barriers and solutions to CE adoption.

This study has certain limitations that future research could address. The identification of CE barriers and solutions relies on SLR and expert input, which may result in some relevant factors being overlooked. Additionally, assessments may be influenced by the experts' positions and industry backgrounds. These limitations could be mitigated by integrating grey, fuzzy, or rough set theories with the adopted methodology. Further, some advanced state-of-the-art MCDM method such as MARCOS, Combined Compromise for Ideal Solution (CoCoFISo), Bayesian MCDM and Machine-Learning-Integrated MCDM frameworks, can be used for ranking of solutions. Additionally, this study was conducted in emerging economies, which limits its generalizability to other countries. Future studies could compare the findings with those of underdeveloped or developing countries.

Further, the aggregation is done only with HQ-based methods that could be extended to other aggregation methods. In future studies, several case studies could be conducted to validate the findings of this study. The hierarchical and structural relationship among the barriers or solutions can be determined in the future through interpretive structural modelling, DEMATEL, WINGS, and structural equation modelling techniques.

Appendix A

Table 10 Experts' profiles who participated in the study

Expert No	Qualification	Experience (Years)	Industry	Roles
1	Postgraduate	17+	Automobile	General Manager
2	Graduate	13+	Textile	Operations Manager
3	Postgraduate	11+	Automobile	Procurement manager
4	Postgraduate	15+	Manufacturing	Operations Manager
5	PhD	14+	Supply Chain	Business Consultant
6	Postgraduate	12+	Manufacturing	Quality Inspector
7	Graduate	13+	Warehousing	Warehouse Managers
8	Postgraduate	12+	Leather	Logistics managers
9	PhD	16+	Academic	University Professor
10	PhD	34+	Academic	University Professor

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Declarations

Conflict of interest The authors state that they have no conflicts of interest, and that this paper is not under consideration anywhere else.

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