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SUPPLIER SELECTION UNDER CIRCULAR ECONOMY: AN INTEGRATED ENTROPY-EDAS METHOD

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Abstract: The concept of circular economy (CE) is gaining attention from businesses and government agencies as a crucial approach to combat climate change. With increasing consumer concern for environmental and social issues, there is a growing emphasis on supporting sustainable and circular supply chains. The selection of appropriate suppliers is recognized as pivotal for achieving efficiency and profitability within a circular supply chain. This study conducts a thorough literature review to identify 16 supplier selection criteria, focusing on their suitability in CE framework. Criteria weights are determined using Entropy method, while Evaluation based on Distance from Average Solution (EDAS) method has been applied to identify the most suitable supplier. The results identified "Financial capability," "The technology required to supplement reverse logistics," and "Re-Use, Re-Manufacturing, Refurbishment" as the most predominant criteria. "Financial capability" drives circular investment, enhancing resource efficiency. "Technology for reverse logistics" optimizes material flow, reducing resource depletion. Practices like "Re-Use, Re-Manufacturing, Refurbishment" extend product lifecycles, curbing environmental impact. Using the EDAS method, Supplier 5 emerges as the top choice, reinforcing sustainable supply chain decisions. This promotes CE principles and aligns with sustainable development goals, aiding managers in policy-making and prioritizing supplier criteria.

Keywords: Circular economy, supplier selection, entropy weight, EDAS, MCDM.

MSC: 90B50, 91B06.

1. INTRODUCTION

The importance of sustainability in supply chain management (SCM) cannot be overstated in terms of the future of business and global economy. A sustainable SCM (SSCM) can help organizations to reduce waste and improve efficiency, leading to cost savings and increased profitability. Sustainability initiatives can even enhance organizational reputation and brand image, making it more attractive to customers and investors who are increasingly concerned about environmental and social issues. Incorporating sustainability into SCM can make a significant contribution to the overall viability of global economy. It can help to reduce greenhouse gas emissions, conserve natural resources, and promote responsible labor practices. Additionally, as worldwide regulatory bodies are enacting strict regulations related to sustainability, organizations that fail to adopt sustainable practices in their SCM may face severe legal and financial liabilities. Therefore, it is critical for organizations to implement sustainable practices in their SCM to not only avoid legal and financial setbacks but also improve their overall business operations. Due to these reasons, many organizations are now investing heavily in sustainability programs to reduce waste and carbon emissions. Hendiani et al. [1] reported that multinational corporations are exploring various sustainability-related initiatives, such as renewable energy, packaging design, alternative energy sources, optimal routes, and process management.

To ensure sustainable resource use and waste reduction, the concept of a CE has gained considerable momentum. The aim of a CE is to reduce and eventually eliminate waste while maximizing scarce resources. This is achieved through a closed-loop system that includes reuse, sharing, repair, refurbishing, remanufacturing, and recycling. Such practices reduce the number of resources initially put into the system and decrease waste, pollution, and carbon emissions [2]. By extending the life of products, equipment, and infrastructure, circular practices can reduce the need for raw materials, energy, and other resources, ultimately leading to cost savings. Crucial to the development of a CE is the extended use of products, equipment, and infrastructure, which increases their values [3]. Therefore, integrating circular practices into SCM has become a vital issue for the organizations to remain competitive in the marketplace. Furthermore, supplier selection within circular supply chains plays a pivotal role in combating climate change and achieving sustainability goals by promoting the efficient use of resources and minimizing waste. By choosing suppliers committed to sustainable practices such as recycling, remanufacturing, and using renewable materials, businesses can reduce their carbon footprint and reliance on finite resources. Responsible supplier selection ensures that products and materials circulate within the supply chain, reducing the need for new resource extraction and lowering emissions. Suppliers that prioritize energy-efficient and low-carbon production methods contribute to the overall environmental impact reduction. Thus, careful supplier selection within circular supply chains supports long-term sustainability and climate action initiatives.

The significance of a CE has expanded beyond its traditional role as an environmental strategy, as it has recently been linked to economic advantages [4]. Sustainability focuses on building ecologically friendly methods and practices that do not hurt the environment in the long run. CE, on the other hand, is concerned with the effective reuse and recycling of products, materials, and components that would otherwise go to waste. CE seeks to limit the quantity of waste created as well as the utilization of materials and resources. Furthermore, CE promotes product reuse and repair, as well as the development of new solutions for end-of-life items. CE also aims to increase the efficiency of production and consumption, as well as to promote the use of renewable resources and to reduce the environmental effect of operations [5]. There is a significant amount of study in the literature that is relevant to the motives, facilitators, barriers, and techniques of putting CE into effect. Pan et al. [6] researched CE application approaches in SC and revealed CE deployment practices, motivations, and problems in SCM. Govindan and Hasanagic [7] proposed a multi-perspective method to assessing CE implementation by tying stakeholder perspectives to CE practices, facilitators, and barriers. Mangla et al. [8] identified and examined the issues that stand in the way of an effective circular SCM in a manner quite similar to this. Bhatia et al. [9] found that the social and economic benefits associated with the closed-loop SC are a critical component in the implementation of circular practises in the Indian automobile industry. Prieto-Sandoval et al. [10] also conducted research to establish the extent to which the CE has been implemented by categorizing the essential constituent pieces. The study's findings help small and medium-sized businesses better understand their current position and the activities they need to take to enhance their circular performance. Choudhary et al. [11] investigated the performance and characteristics of environmentally sustainable SCM. Choosing the greatest possible supplier is critical for a company's performance in the global market as well as increasing its competitive edge. Despite the availability of research on the subject of supplier selection, there is a scarcity of published literature that investigates how CE might be used to shortlist suppliers. Therefore, the objective of this research is to develop a comprehensive set of selection criteria for suppliers that prioritize their ability to provide sustainable performance within the context of a CE, covering all four dimensions (economic, environmental, social, and circular). In particular, the following goals are addressed in this paper:

a) To review recently published scholarly articles that address the sustainable supplier selection issue in relation to CE.

b) To offer a framework of circular supplier selection criteria based on prior research.

c) To categorize the identified criteria into different categories including economic, environmental, social, and circular in order to fully assess and select suppliers.

d) To assess the relative importance of the criteria, measure their applicability, and then provide useful insights on how to operationalize these criteria.

e) To propose a decision-making model for supplier selection in CE environment.

2. LITERATURE REVIEW

2.1. Significance of CE in SCM

CE theory has received a lot of attention recently as a possible answer to the problem of sustainable development in academics as well as in businesses [12]. CE is a production mode that seeks to address the inadequacies of standard linear operating models by closing, narrowing, delaying, intensifying, and dematerializing resource cycles [13]. Adopting a CE approach transforms SSCM in two significant ways. To begin, this viewpoint reorients SC activities to allow organizations to satisfy sustainability imperatives. Second, it brings a fresh and engaging viewpoint to the SC sustainability topic [14]. One of the most important advantages of using CE in SCM is its ability to minimize waste output and energy consumption while encouraging reuse and recycling. This may be accomplished through designing items that are readily repairable, refurbishable, or recyclable, as well as implementing efficient logistical systems and fostering a circular culture inside the organization [15]. Organizations may decrease their environmental impact, promote social responsibility, and realize cost savings by minimizing waste and lowering the demand for raw materials by encouraging CE in SCM [16].

The adoption of CE principles in SCM requires a cohesive and integrated approach among multiple stakeholders, including manufacturers, suppliers, retailers, and consumers. Camilleri [17] argued that collaboration among various actors in the SC is essential to achieve a CE because it facilitates the sharing of resources and knowledge, establishes common goals, and aligns objectives. Thus, the creation of circular SCs necessitates a new collaborative approach to SCM that integrates multiple actors and addresses the challenges of interdependence. Furthermore, in recent years, the execution of CE concepts in SCM has grown in importance, and Industry 4.0 technologies have emerged as a potent instrument to aid this shift. The incorporation of cutting-edge technology such as big data analytics, IoT, and AI into SCM practices has the potential to revolutionize corporate operations and encourage sustainable practices. According to Rajput and Singh [18], Industry 4.0 is a digital revolution that enables firms to employ smart SCM practices. Organizations may optimize their SC operations and decrease waste by using the capabilities of these technologies. Furthermore, by adopting CE ideas, firms may strengthen their sustainability efforts and encourage responsible resource usage. Kerber et al. [19] emphasized the significance of incorporating Industry 4.0 technology into CE concepts in order to significantly increase SC efficiency. Execution of these technologies can enable firms to discover possible inefficiencies and execute remedial steps through real-time monitoring and predictive analysis. This can lead to cost savings and increased resource efficiency.

Circular SCM (CSCM) has become a prominent area of research in recent years, with several experts researching into various elements of the discipline. Montag [20], for example, did a thorough literature assessment and presented a research plan for CSCM, stressing six archetypal aspects and four propositions that characterize its distinctiveness. Other researchers, such as Del Giudice et al. [21], have revealed that CE practices can improve company performance inside a CSC. Similar to this, Manavalan and Jayakrishna [22] provided a case study on the application of CE principles in SCM, and Ribeiro et al. [23] carried out a meta-analysis of 115 articles on SCM and CE to pinpoint the key topical clusters and significant authors, journals, nations, and institutions. Gartner [24] presented three CE techniques to increase SC resilience and sustainability, while Lieder and Rashid [25] performed a study of literature on CE application in the manufacturing industry to suggest research topics and problems.

Additionally, Govindan and Hasanagic [7] reviewed articles on CE from a SC perspective and found that environmental awareness, legislation, economic benefits, and competitive advantage are the most common drivers, while lack of knowledge and skills, high initial costs, lack of collaboration, and market uncertainty are the most common barriers. They also identified waste management, product design, reverse logistics, and remanufacturing as the most common practices. Genovese et al. [26] proposed a conceptual framework that integrates sustainable SCM and CE and presented some applications of CE practices in various sectors, while Niero and Olsen [27] critically analyzed the concept of CE and its implications for sustainability. Finally, Batista et al. [28] proposed a circular SC archetype and identified research gaps and future directions.

2.2. Significance of supplier selection in CE using MCDM

The selection of suppliers in CE is an essential problem that has the potential to have a significant influence on the reduction of costs across the network as well as the deterioration of the environment [29]. An ideal supplier selection process under CE should prioritize environmentally responsible procurement and the reuse of raw materials. This will result in less waste and increased use of raw resources [30]. The evaluation of a suitable circular supplier is a rigorous exercise that satisfies the standards to attain sustainable criteria incorporated into the traditional supplier evaluation process [1]. As a consequence of this, selecting an appropriate circular supplier in the CE is an essential step in the process for businesses to do before they can effectively manage their SCs. With the use of the linguistic Entropy weight technique, Feng et al. [31] developed a multi-objective model for choosing the supplier for a green SC. Liu et al. [32] highlighted the need of considering environmental and social factors when making sustainable supplier selection decisions, and they proposed a number of solutions for implementing a sustainable, circular approach to the supplier selection process in the manufacturing sector. Using a fuzzy best-worst method (FBWM), Alavi et al. [33] presented a dynamic fuzzy decision support system for sustainable supplier selection in an CSC. With the assistance of fuzzy set theory, Haleem et al. [3] developed a methodology for evaluating the supplier in regard to the CE implementation. By employing structural equation modelling for sustainable performance, Dey et al. [34] advocated for the incorporation of CE into the process of choosing industrial suppliers for SMEs. BWM was utilised by Bai et al. [35] in the development of a multi-objective model for the purpose of choosing suppliers for circular SCM. Alikhani and colleagues [36] presented a strategy for doing research that integrates quantitative and analytical methodologies. This strategy addresses the issue of supplier selection by concurrently taking into account both the sustainability and risk considerations posed by suppliers in CE. A thorough analysis of the literature on choosing circular suppliers for a sustainable SC was provided by Khalili Nasr et al. [37]. The authors carried out a thorough examination of the research on the topic of choosing circular suppliers, and they came up with a number of criteria. Li et al. [38] proposed a hierarchical model on dynamic supplier selection and order allocation for a sustainable SC. In this study, the authors propose a novel hierarchical approach for the selection of sustainable suppliers, whereby the selection criteria are jointly determined by the supplier's environmental and social performance and the customer's economic and environmental objectives. A genetic algorithm was suggested by Soleimani et al. [39] to determine sustainable supplier selection for a closed-loop SC. This approach utilized fuzzy logic and multi-objective optimization. Pourmehdi et al. [40] developed an integrated strategy for a closed-loop SC in the manufacturing technology of the steel industry. Using BWM and VIekriterijumsko KOmpromisno Rangiranje (VIKOR) method, Kusi-Sarpong et al. [41] presented a methodology that was based on industry 4.0 within the context of CE adoption. The purpose of this framework was to analyze and choose the best sustainable supplier. Tushar et al. [42] developed a multi-criteria approach for circular supplier selection process in industry that combines a fuzzy analytical hierarchical procedure with a preference ranking organization technique to enhance assessment. According to Lacy et al. [43], concentrating on products and services provide a tremendous potential to promote strategic growth, brand value, customer engagement, and long-term competitiveness by reducing costs and guaranteeing an endless supply of raw materials in CE.

3. RESEARCH METHODOLOGY

The goal of decision-making methods is to translate judgements and views into quantitative terms in order to determine the most effective possibilities and/or pertinent criteria. In the current study, Entropy method was employed to assess several sustainability selection parameters for suppliers. Entropy method is predicated on pairwise comparisons, and the end result is a priority level that is assigned to each criterion based on a nine-point ratings framework. The most important parameters are given the maximum weightage, and the weights are standardized so that they may be compared with one another. The criteria selection was based on previous studies and was done in a participatory way. The experts were selected on the basis of their knowledge and experience. The local-global prioritization was used to identify the most important criteria and to determine the relative importance of the criteria. Finally, the aggregation of weights was used to calculate the overall score of each criterion. The findings from this current study highlight the significance of the criteria within the decision-making process, shedding light on their pivotal role in enhancing the overall quality of decision-making. The insights gleaned from the study contribute valuable information that can be utilized to refine and optimize decision-making processes.

3.1 Research Gaps

In general, the selection criteria for suppliers heavily rely on the particular businesses and industries. On the one hand, each company has its own unique organizational structure, management philosophy, workplace culture, and other aspects of their business. Contrarily, the background of the business makes a significant difference and has a significant influence on the choice of suppliers. In addition, the approach for selecting suppliers based on their performance is increasingly shifting from using a single algorithm to using a mix of a number of different methods. However, the already used approaches to decision-making about suppliers still have a great deal of room for improvement. Most supplier selection models are also limited in their ability to evaluate the performance of the suppliers over time, which could be important for long-term supplier relationships and most of the existing models are limited in their ability to capture the complexity of supplier selection process. For instance, analytical hierarchy process (AHP) is the most frequently used method for determining criteria weights in the supplier selection process, as it involves a straightforward computation that is easy to implement. However, AHP assumes that criteria are unrelated to one another and does not take into account the mutual effect of criteria. A review of the available research reveals that the majority of assessment and selection of sustainable suppliers do not take into account connections between parameters. However, there must be a link or contradiction between the factors used for selection process that need to be taken into consideration. As a result, our primary responsibility is to devise a comprehensive evaluation ranking system for sustainable suppliers and to enhance the assessment process for sustainable suppliers. The current study is one of the initial attempts of its kind to give criteria the relative weightage for the selection of suppliers in a CE context. Organizations would benefit from using the suggested framework to execute CE-based supplier selection process. To better evaluate suppliers, businesses may use the specified criteria and sub-criteria, while also providing suppliers with guidance as they need to create a CE-based model of SC.

3.2 Identification of Drivers

The entire criteria list is divided into the four groups, as shown below. It is worth mentioning that the criteria were also finalized and determined through an analysis of McKinsey's various CE reports.

3.2.1 Economic (ECO): Economics based on transaction costs and a resource-based perspective on the organization served as the foundation for the fundamental idea behind the supplier selection dilemma. Economics criteria mainly focuses on the cost of transactions between the organization and its suppliers and the resources that the organization possesses. The maximizing of profits should be the major focus of an organization, according to the transaction cost economics theory. This theory assumes that price is always the most important factor in supplier selection decisions, however, this is not always the case. Other criteria such as quality, delivery times, customer service and technological capabilities may be more important to organizations than price in certain cases [44]. Some of the major economic criteria for supplier selection are given in Table 1.

Table 1: Economic Criteria for supplier selection

Criteria	Description	Reference
Financial capability (ECO_1)	Assessing a supplier's financial capability is crucial in circular supply chains as it indicates their ability to invest in sustainable practices like resource recovery and waste management technologies. Suppliers with strong finances are more likely to innovate and adapt to circular economy models, ensuring long-term partnerships. Financially stable suppliers can also manage market risks and fluctuations, providing consistent and reliable service.	Prieto-Sandoval et al.[10]; Choudhary et al. [11]; Baskaran et al. [44]; Mani et al. [45]; Alavi et al. [33]; Alikhani et al. [36]; Bai et al. [35]
Quality management (ECO_2)	Effective quality management is essential for maintaining high standards in circular supply chains. Suppliers must implement rigorous quality controls to ensure that recycled, remanufactured, or reused materials meet performance and safety specifications. High-quality products and materials contribute to customer satisfaction and brand reputation, crucial for the success of circular supply chains.	Li et al. [38]; Liu et al., [15]; Haleem et al. [3]; Kirchherr et al. [46]; Lacy et al. [43]
Cost/price (ECO_3)	While cost and price are important factors in supplier selection, they must be balanced with the long-term benefits of circular supply chains. Lower prices should not sacrifice sustainability or quality. Suppliers who offer competitive pricing while adhering to circular economy principles help ensure that cost savings do not compromise environmental goals and ethical practices.	Govindan et al. [29]; Kannan et al. [30]; Hendiani et al. [1]; Yuan and Moriguichi [4]
Technology capability (ECO_4)	Suppliers with strong technology capabilities are better positioned to innovate and adopt circular economy practices, like resource recovery and material tracking. Advanced technologies streamline processes, boost efficiency, and promote the use of renewable or recycled materials. Choosing suppliers committed to cutting-edge technology ensures that the supply chain stays adaptable and forward-thinking in achieving sustainability goals.	Bernon et al. [5]; Pan et al. [6]; Govindan and Hasanagic [7]; Mangla et al. [8]

3.2.2 Social (SOC): Social sustainability is concerned with preserving and increasing people's quality of life today and in the future. This includes considering economic, social, and cultural aspects such as access to healthcare, education, housing, nutrition, and job prospects. It also includes the protection of civil freedoms and human rights for all persons, the abolition of discrimination, and the promotion of equal opportunity [45]. The goal of social sustainability is to guarantee that all members of society have equitable access to resources, including the right to participate in decision-making processes and to be valued and included in the creation of solutions to social and environmental concerns. These social norms are critical for ensuring equitable treatment of SC employees, respect for their human rights, and the prevention of child or forced labour. It also attempts to guarantee that all workers in the SC are properly rewarded and have access to adequate training and education to enable them to do their jobs efficiently. The primary societal criteria for supplier selection are listed in Table 2:

Table 2: Social Criteria for supplier selection

Criteria	Description	Reference
Training related to carbon management (SOC_1)	Training in carbon management is crucial for suppliers to understand and implement practices that reduce carbon emissions across their operations. Well-trained suppliers are more likely to innovate in the areas of energy efficiency and waste reduction, directly supporting circular supply chain goals. Selecting suppliers with a strong foundation in carbon management helps ensure a lower overall environmental impact and alignment with broader sustainability targets.	Haleem et al. [3]; Kirchherr et al. [46]; Lacy et al. [43]
Government regulations and policies towards CE (SOC_2)	Suppliers who adhere to government regulations and policies regarding the circular economy demonstrate a commitment to sustainable practices. Compliance with such regulations often requires a shift towards more responsible resource use, waste minimization, and product lifecycle extension. By selecting suppliers who prioritize regulatory compliance, businesses can avoid legal risks and contribute to the broader goals of a sustainable circular economy.	Govindan and Hasanagic [7]; Mangla et al. [8]; Bhatia et al. [9]; Prieto-Sandoval et al. [10]
Compliance with CE policy and legislature (SOC_3)	Suppliers who comply with circular economy policies and legislature are likely to prioritize environmentally responsible sourcing, production, and disposal methods. Such compliance ensures alignment with the company's sustainability goals and may enhance its reputation as a socially responsible entity. Choosing compliant suppliers can also facilitate smoother business operations by minimizing potential conflicts and ensuring adherence to industry standards.	Yuan and Moriguichi [4]; Bai et al. [35]; Chen and Lin [2]; Dey et al. [34]

Internal/external awareness towards CE practices (SOC_4)	Suppliers who actively promote awareness of circular economy principles both internally and externally are better positioned to drive meaningful change in their operations and supply chains. Internal awareness ensures employees are engaged and informed about sustainability goals, leading to consistent, eco-friendly practices. Externally, suppliers who champion circular economy concepts can influence other stakeholders, including customers and partners, furthering the overall impact on circular supply chain goals.	Hendiani et al. [1]; Yuan and Moriguichi [4]; Bernon et al. [5]; Pan et al. [6]

3.2.3 Environmental (ENV): In order to promote sustainable practices and reduce the environmental effect of a company's SC, environmental factors for supplier selection must be considered. A corporation may ensure that its SC corresponds with its environmental aims and values by reviewing potential suppliers' sustainability, energy efficiency, and waste management practices. Furthermore, choosing suppliers who prioritize environmental preservation might aid a company's reputation as a socially responsible organization. Finally, adding environmental parameters into supplier selection can help to create a more robust and sustainable company model. Among the primary environmental factors for supplier selection are presented in Table 3.

Table 3: Environment Criteria for supplier selection

Criteria	Description	Reference
Use of harmful materials (ENV_1)	Assessing the use of harmful materials is crucial in circular supply chains because it directly affects product safety, environmental health, and overall sustainability. Suppliers that minimize or eliminate toxic substances from their processes and products contribute to reducing environmental pollution and health risks to consumers and workers. Prioritizing suppliers that adopt safer alternatives and adhere to strict regulatory standards supports the transition to a circular economy, where products are designed for disassembly, reuse, and recycling without negative environmental impacts.	Kusi-Sarpong et al. [41]; Li et al. [38]; Liu et al. [15]; Haleem et al. [3]
Environmental management system (ENV_2)	A supplier's environmental management system (EMS) is a key indicator of their commitment to sustainability and continuous improvement. An effective EMS demonstrates a supplier's ability to manage environmental risks, comply with regulations, and optimize resource use. In circular supply chains, selecting suppliers with robust EMS practices ensures that they can efficiently integrate sustainable processes, such as waste reduction and recycling, into their operations, contributing to a lower overall carbon footprint.	Nußholz [47]; Pourmehdi et al. [40]; Soleimani et al. [39]; Tushar et al. [42]

Life cycle cost management (ENV_3)	Evaluating suppliers based on life cycle cost management aligns with the circular economy's goal of maximizing resource efficiency and minimizing waste. Suppliers that consider the total cost of ownership, including production, use, and end-of-life phases, are better equipped to deliver sustainable and cost-effective solutions. By selecting suppliers that prioritize long-term economic and environmental viability over short-term gains, businesses can create more resilient and circular supply chains.	Mani et al. [45]; Alavi et al. [33]; Alikhani et al. [36]; Bai et al. [35]
Resource consumption/ minimum amount of virgin material used (ENV_4)	Reducing resource consumption and using the minimum amount of virgin materials are fundamental aspects of circular supply chains. Suppliers that optimize material usage and incorporate recycled or renewable materials help to conserve natural resources and lower the environmental impact of production. By prioritizing suppliers with innovative approaches to material efficiency, businesses can support a shift towards more sustainable and circular supply chains, leading to decreased waste and a reduced ecological footprint.	Prieto-Sandoval et al. [10]; Choudhary et al. [11]; Baskaran et al. [44]; Mani et al. [45]

3.2.4. Circular (CIR): The CE is a production and consumption concept that entails minimizing waste by making the most of existing resources and commodities for as long as feasible. This concept strives to extend the life of materials and products by reducing, reforming, recovering, repairing, refurbishing, and recycling them. The main purpose of CE is to develop a regenerative system in which resources are used, reused, and recycled rather than the usual linear strategy of "take-make-waste." This paradigm is centered on creating goods and processes to avoid waste and pollution, keeping products and resources in use for as long as feasible, and renewing natural systems. Some of the primary circularity requirements for supplier selection are enlisted in Table 4.

Table 4: Circular criteria for supplier selection

Criteria	Description	Reference
Eco-friendly raw materials and packaging (CIR_1)	The use of eco-friendly raw materials and packaging is fundamental to reducing environmental impact and supporting a circular economy. Suppliers who prioritize sustainable materials and packaging contribute to minimizing waste, energy consumption, and carbon emissions throughout the supply chain. Additionally, these suppliers can offer products that are safer for consumers and easier to recycle or reuse at the end of their lifecycle, enhancing overall sustainability.	Lacy et al. [43]; Khalili Nasr et al. [37]; Nußholz [47]; Pourmehdi et al. [40]
Re-Use, Re-Manufacturing, Refurbishment (CIR_2)	The emphasis on re-use, re-manufacturing, and refurbishment extends the life cycle of products and components, reducing the demand for new raw materials and energy-intensive manufacturing processes. Suppliers that excel in these areas can provide valuable services and products that align with circular economy principles,	Pourmehdi et al. [40]; Soleimani et al. [39]; Tushar et al. [42]

	fostering resource efficiency and waste reduction. Selecting such suppliers can improve the overall resilience and sustainability of the supply chain.	
The technology required to supplement reverse logistics (CIR_3)	Technology plays a crucial role in enabling efficient reverse logistics, allowing for the tracking, processing, and management of returned goods. Suppliers who invest in advanced reverse logistics technology can optimize product returns, remanufacturing, and recycling processes, enhancing overall supply chain efficiency. This technology also facilitates data-driven decision-making, improving the adaptability and sustainability of circular supply chains.	Prieto-Sandoval et al. [10]; Haleem et al. [3]; Kirchherr et al. [46]; Lacy et al. [43]; Bai et al. [35]
Eco-friendly transportation and warehousing (CIR_4)	Eco-friendly transportation and warehousing reduce the environmental impact associated with moving and storing goods. Suppliers that adopt sustainable practices, such as using electric vehicles and optimizing storage space, contribute to lower greenhouse gas emissions and energy consumption. Choosing suppliers committed to these practices supports a greener supply chain and aligns with broader sustainability goals.	Yuan and Moriguichi [4]; Mani et al. [45]

3.3 MCDM Methods

MCDM is a technique that may help organizations prioritize SS criteria by analyzing numerous elements such as cost, quality, delivery time, and supplier reliability (Panchal et al. [48]; Gupta et al. [49). The importance of MCDM in prioritizing SS criteria is due to its capacity to provide a systematic and objective method to decision-making. MCDM allows organizations to examine and analyze several criteria at the same time, assigning weights to each criterion based on its relative relevance. As a result, MCDM may assist organizations in making educated decisions based on a thorough knowledge of the elements involved in SS (Stević et al. [50]; Modibbo et al. [51]). Additionally, MCDM helps lessen the risk of picking suppliers that do not satisfy the standards. MCDM may assist organizations in identifying suppliers that not only provide cost-effective solutions but also meet other critical requirements such as quality and delivery time by taking into account various factors. This can assist organizations in avoiding possible expenses and interruptions caused by picking inappropriate suppliers [52].

The selection of Entropy method for determining criteria weights and EDAS method for supplier evaluation in the study were based on their specific strengths and suitability for the research objectives. Entropy method is chosen for criteria weight determination due to its ability to handle complex decision-making scenarios by quantifying the uncertainty and diversity in the data, providing a robust and objective approach to assigning weights to criteria. This method is particularly useful in situations where there is a need to prioritize multiple criteria effectively [53]. On the other hand, EDAS method is employed for supplier evaluation as it offers a comprehensive assessment by considering both the positive and negative aspects of alternatives, allowing for a more balanced and thorough evaluation process. By using EDAS method, the study aims to ensure a holistic evaluation of suppliers, taking into account various factors that impact decision-making in supplier selection processes. The combination of these two methods provides a structured and rigorous framework for decision-making, enhancing ability of this study to make informed and objective decision.

3.3.1 Entropy Method

Entropy method is a technique used to quantify a system's entropy from a given set of outcome alternatives. The key idea behind this technique is that the entropy of a system is directly related to the total importance placed on each conceivable result. Therefore, the greater the likelihood of an event, the more entropy is given to it. Both the degree of order inside a system and its related uncertainty may be assessed using this method [54]. Assigning weights to different outcomes using the entropy weight approach is a useful tool in decision-making analysis because it allows the expected result of a decision to be calculated. Researchers may use this technique to examine how uncertainty affects the efficiency of your systems and processes. Furthermore, this method is often used to compare the effectiveness and efficiency of various systems and processes [55]. In machine learning and artificial intelligence, entropy is used to measure the uncertainty of a given prediction. Low entropy indicates that the prediction is certain, while high entropy indicates that the prediction is uncertain. Therefore, the weight of the prediction is higher when the entropy is lower, indicating that the prediction is more certain [56]. Assume *m* alternatives are available for the evaluation of *n* assessment requirements, let S_{ij} is the initial assessment value of the decision matrix. Entropy method for estimating criteria weights is described below:

Step i) Normalize the decision matrix:

$$R_{ij} = S_{ij} \Big/ \sum_{i=1}^{m} S_{ij} \quad \text{, i=1,2,3,…,m and j=1,2,3,…,n} \tag{1}$$

Where R_{ij} is the normalized value of the decision matrix.

Step ii) Calculate the entropy for each criterion:

$$A_j = -(In\, m)^{-1} \sum_{i=1}^{m} S_{ij} In(S_{ij})$$

Step iii) Calculate the weight of each criterion:

$$w_j = \frac{(1-A_j)}{\sum_{j=1}^{n}(1-A_j)} \tag{2}$$

Where $0 \le w_j \le 1 \; and \; \sum_{j=1}^{n} w_j = 1$. Here w_j is the weight attached with each of the attributes.

3.3.2 EDAS Method

Keshavarz Ghorabaee et al. [57] developed evaluation based on distance from average solution (EDAS) method to rank alternatives. This method determines the best alternative by measuring how far it is from the average solution. EDAS method provides two essential measurements: "Positive Distance from Average (PDA)" and "Negative Distance from Average (NDA)". These measurements indicate the variation between each alternative and the average solution, with the most desirable alternative having higher PDA values and lower NDA values. Therefore, alternatives with higher PDA and/or lower NDA values are better than the average answer. The application of EDAS method in conjunction with entropy can result in improved decision-making as well as a deeper comprehension of the alternatives that are at one's disposal. The following steps are involved in EDAS method:
Step 1) The first step is to develop a decision matrix that consist of criteria and alternatives.
Step 2) Eqn. (3) is used to obtain the mean (average) solution for each criterion:

$$\bar{X} = \frac{\sum_{i=1}^{n} x_{ij}}{n} \tag{3}$$

Step 3) The calculation of PDA and NDA is determined by a specific set of criteria. If a criterion falls under the benefit criteria set, Eqs. (4) and (5) are used. Conversely, if a criterion falls under the cost criteria set, Eqs. (6) and (7) are utilized.

$$PDA_{ij} = \frac{\max\left(0,(X_{ij}-\bar{X})\right)}{\bar{X}} \tag{4}$$

$$NDA_{ij} = \frac{\max\left(0,(\bar{X}-X_{ij})\right)}{\bar{X}} \tag{5}$$

$$PDA_{ij} = \frac{\max\left(0,(\bar{X}-X_{ij})\right)}{\bar{X}} \tag{6}$$

$$NDA_{ij} = \frac{\max\left(0,(X_{ij}-\bar{X})\right)}{\bar{X}} \tag{7}$$

Step 4) Next, we need to apply Eqs. (8) and (9) to compute the weighted sum of PDA and NDA for each alternative.

$$WP_i = \sum_{j=1}^{m} w_j \, PDA_{ij} \tag{8}$$

$$WN_i = \sum_{j=1}^{m} w_j \, NDA_{ij} \tag{9}$$

w_j are the weights of each criterion obtained using Entropy method.
Step 5). In order to normalize the values obtained in step 4, we need to use Eqs. (10) and (11).

$$NormWP_i = \frac{WP_i}{max_i(WP_i)} \tag{10}$$

$$NormWN_i = 1 - \frac{WN_i}{max_i(WN_i)} \tag{11}$$

Step 6) Finally, Appraisal Score (AS) for each alternative is calculated by using Eqns. (12).

$$AS_i = \frac{1}{2}(NormWP_i + NormWN_i) \tag{12}$$

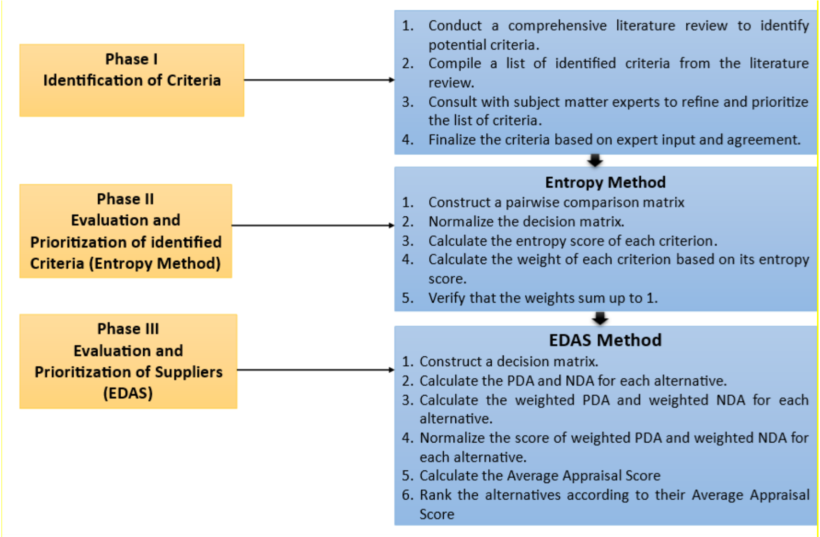

Figure 1: Flowchart of the proposed model

3.4 Identification of Experts

The significance of CE criteria was assessed by soliciting the opinions of industry professionals. In this particular research, the contributions of ten different professionals and academics were taken into consideration. The screening process involved presenting the aims and methods of the study, without specifying the background of the criteria, to exclude any possibility of outside influence on the experts' decisions. Academics with several years of expertise in CE, SCM, and sustainability were approached. The ten professionals whose inputs were utilized for this study are listed in Table 5. To determine the significance of CE criteria, consideration was given to responses from both academics and industry professionals, with five from each group.

Table 5: Profiles of Experts

Expert	Role	Industry	Experience in years
Expert 1	Expert in SCM and CE	Academic	18
Expert 2	Expert in in sustainability	Academic	25
Expert 3	Expert in in sustainable development and CE	Academic	10
Expert 4	Expert in in SCM	Academic	15
Expert 5	Expert in in Sustainability and CE	Academic	9
Expert 6	General Manager - SC	Textile	10 Years
Expert 7	Quality Control Manager	Tourism and Hospitality	13 Years
Expert 8	Inventory Control Manager	Energy and Power	17 years
Expert 9	Storage and Distribution Manager	Electronics and Technology	8 Years
Expert 10	Purchasing Manager	Food and Agriculture	9.5 Years

A pre-screening was done with two experts before the criteria were given out to all of the experts in order to identify whether or not any pertinent criterion had been missed. As a result of the unfavourable findings of the study, the criteria were not altered. Instead, the local and global priority mixed technique was described to all of the professionals, and they agreed that this approach included a number of advantageous qualities (e.g. its ability to aggregate a substantial number of criteria). The use of the Likert scale is able to mitigate the effects of this constraint, notwithstanding the possibility that the approach may provide inaccurate findings in the event that the criteria that make up a category are properly linked with the weight that is assigned to the same category.

4. RESULT ANALYSIS AND DISCUSSION

In the ear of Industry 4.0, business houses encounter significant challenges in identifying suppliers suitable for their CE initiatives. The shift towards a CE demands suppliers not only adopt sustainable practices but also actively contribute to effective product life cycle management, maintain transparent SCs, and demonstrate a commitment to fostering innovation and collaboration. As sustainability and CE principles become increasingly central to business strategies, forming partnerships with suppliers who share similar values and aspirations for environmental stewardship is crucial. However, the process of identifying the right supplier is intricate, requiring a comprehensive examination of various facets, including economic, social, environmental, and circular criteria. Successful integration of these criteria ensures that businesses align with suppliers capable of supporting their goals towards sustainability and CE practices.

In order to overcome this challenge, businesses have settled on four main aspects for assessing potential suppliers: economic, social, environmental, and circular. The economic criterion is the first one to consider, and it evaluates the supplier based on how stable, profitable, and capable of investing in sustainable practices they are. This criterion is crucial, as it ensures that the supplier can support the industry's CE initiatives over the long run. A supplier's financial capability can also indicate their commitment to sustainability since investing in eco-friendly practices often requires significant financial resources (Govindan et al. [29]; Kannan et al. [30]; Hendiani et al. [1]; Yuan and Moriguichi [4]). The second criterion is social, which evaluates the supplier's commitment to promoting social responsibility, ethical labor practices, and human rights. This criterion is becoming increasingly important as consumers are becoming more aware and concerned about social issues. Collaborating with suppliers who prioritize social responsibility can help the industry enhance its reputation and brand value while promoting social welfare (Govindan and Hasanagic [7]; Mangla et al. [8]; Bhatia et al. [9]; Prieto-Sandoval et al. [10]). The third criterion is environmental, which assesses the supplier's environmental performance, including their carbon footprint, waste management, and resource conservation practices. Selecting suppliers with strong environmental credentials is critical for the industry to achieve its CE goals and minimize its environmental impact. By partnering with eco-friendly suppliers, the industry can reduce its carbon emissions, conserve resources, and promote sustainable production practices (Nußholz [47]; Pourmehdi et al. [40]; Soleimani et al. [39]; Tushar et al. [42]). The fourth criterion is circular, which evaluates the supplier's ability to support CE initiatives, including re-use, re-manufacturing, and waste reduction. This criterion is essential for the industry to achieve its CE goals, which require a shift towards a closed-loop system that minimizes waste and maximizes resource efficiency. By partnering with suppliers who prioritize circularity, the industry can reduce its environmental impact, promote sustainability, and enhance its reputation (Pourmehdi et al. [40])

To assess potential suppliers, a comprehensive evaluation of each supplier's performance using the selected criteria is necessary. This evaluative process includes the collection and analysis of data concerning each supplier's financial performance, social responsibility, environmental impact, and CE initiatives, aligning with the 16 specified criteria. The engagement in meaningful discussion with potential suppliers is also considered equally essential, allowing insights into their values, goals, and commitments towards sustainability. The hierarchical structure of the supplier selection problem in the context of CE is visually represented in Fig. 2, offering a structured framework for managing the intricacies of the supplier evaluation and selection process.

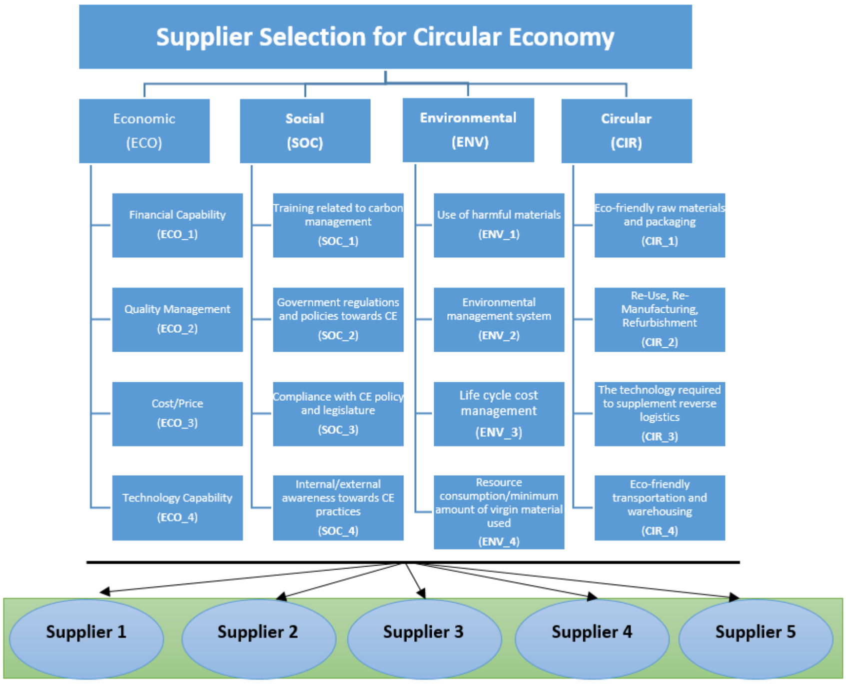

Figure 2: The hierarchical structure

4.1 Application of Entropy method

In this study, Entropy method is initially employed to calculate the weights of various criteria used for evaluating suppliers. Entropy method offers a quantitative measure of the relative importance of the criteria used in supplier selection for CE. This enables the identification of the most crucial criteria and their respective importance in the decision-making process. This information serves as a basis for deciding which criteria to prioritize when selecting a supplier for CE. Ten experts conducted pair-wise comparisons of supplier performance and criteria, resulting in matrices for each expert. Table 6 and Table 7 show the comparative opinions for supplier and criteria, as given by Expert 1 and Expert 2 respectively. The aggregated decision matrix of Table 8 is derived by averaging the values from comparisons made by all ten experts, offering a comprehensive perspective on supplier priorities across the criteria. Entropy method directly utilizes the information provided in the decision matrix to compute weights, ensuring that the sum of weights does not exceed 1. This method maintains the integrity of the information contained in the decision matrix while ensuring that the derived weights accurately reflect the experts' collective assessments without disproportionate influence. Eqn. (1) is employed to normalize the aggregated average decision matrix, and the results are presented in Table 9. The entropy values, degree of diversity, and final weights of all criteria are calculated using Eqs. (2) and (3) respectively and the results are presented in Table 10.

Table 6: Decision matrix obtained from Expert 1

Supplier	ECO_1	ECO_2	ECO_3	ECO_4	SOC_1	SOC_2	SOC_3	SOC_4
S1	6	5	8	6	9	3	3	6
S2	2	2	5	2	4	3	5	6
S3	2	9	9	6	6	3	8	8
S4	8	7	3	3	9	4	8	8
S5	7	3	4	4	7	5	7	2

ENV_1	ENV_2	ENV_3	ENV_4	CIR_1	CIR_2	CIR_3	CIR_4
8	6	8	3	3	2	5	9
7	6	6	3	3	8	2	8
5	9	3	6	6	2	4	4
4	7	7	8	6	8	2	2
6	4	2	2	8	7	3	3

Table 7: Decision matrix obtained from Expert 2

Supplier	ECO_1	ECO_2	ECO_3	ECO_4	SOC_1	SOC_2	SOC_3	SOC_4
S1	7	4	3	8	2	5	3	5
S2	9	8	3	4	9	8	4	4
S3	9	4	4	6	8	8	4	2
S4	3	2	3	8	6	8	7	9
S5	8	8	6	2	5	2	8	2

ENV_1	ENV_2	ENV_3	ENV_4	CIR_1	CIR_2	CIR_3	CIR_4
2	9	8	3	7	5	2	8
9	8	5	6	8	7	9	8
3	3	8	2	8	4	3	4
5	3	8	5	6	9	3	9
3	5	7	2	6	6	2	6

Table 8: Aggregated average decision matrix

Supplier	ECO_1	ECO_2	ECO_3	ECO_4	SOC_1	SOC_2	SOC_3	SOC_4
S1	4.14	5.50	4.70	2.20	2.60	5.06	3.60	4.50
S2	5.37	5.85	4.24	4.40	4.53	5.82	4.51	4.64
S3	3.65	4.94	3.68	4.40	5.40	4.45	6.70	5.50
S4	4.86	3.50	4.41	3.20	5.22	3.10	4.80	3.70
S5	5.04	4.40	5.41	3.80	3.10	3.90	4.18	5.30

ENV_1	ENV_2	ENV_3	ENV_4	CIR_1	CIR_2	CIR_3	CIR_4
3.10	4.60	2.20	1.52	7.20	4.20	1.83	4.10
4.30	6.28	3.76	6.42	4.69	6.23	3.63	4.20
4.10	4.99	5.30	4.61	7.10	5.11	5.40	5.60
3.60	3.46	4.42	3.09	4.20	5.10	3.81	4.62
4.83	5.26	4.70	5.50	4.43	4.92	6.30	4.20

Table 9: Normalized matrix

Supplier	ECO_1	ECO_2	ECO_3	ECO_4	SOC_1	SOC_2	SOC_3	SOC_4
S1	0.200	0.204	0.250	0.244	0.259	0.199	0.215	0.233
S2	0.134	0.145	0.206	0.178	0.250	0.139	0.214	0.157
S3	0.278	0.242	0.187	0.244	0.217	0.261	0.262	0.196
S4	0.239	0.182	0.187	0.211	0.149	0.175	0.207	0.224
S5	0.066	0.227	0.183	0.122	0.125	0.227	0.177	0.190

ENV_1	ENV_2	ENV_3	ENV_4	CIR_1	CIR_2	CIR_3	CIR_4
0.206	0.203	0.260	0.173	0.257	0.262	0.258	0.162
0.181	0.141	0.217	0.230	0.152	0.188	0.182	0.194
0.216	0.255	0.184	0.254	0.170	0.176	0.173	0.187
0.242	0.214	0.231	0.238	0.160	0.164	0.300	0.238
0.156	0.187	0.108	0.196	0.261	0.141	0.087	0.207

Table 10: Entropy values with criteria weights

Supplier	ECO_1	ECO_2	ECO_3	ECO_4	SOC_1	SOC_2	SOC_3	SOC_4	ENV_1
S1	0.322	-0.324	-0.346	-0.344	-0.350	-0.321	-0.330	-0.339	-0.325
S2	-0.269	-0.280	-0.325	-0.307	-0.347	-0.274	-0.330	-0.290	-0.309
S3	-0.356	-0.343	-0.314	-0.344	-0.332	-0.350	-0.351	-0.320	-0.331
S4	-0.342	-0.310	-0.314	-0.328	-0.283	-0.305	-0.326	-0.335	-0.343
S5	-0.179	-0.337	-0.311	-0.257	-0.260	-0.336	-0.306	-0.316	-0.289
Entropy Value	0.518	0.563	0.568	0.558	0.555	0.560	0.580	0.565	0.564
Degree of Diversity	0.482	0.437	0.432	0.442	0.445	0.440	0.420	0.435	0.436
Weight	.0682	.0619	.0612	.0626	.0631	.0623	.0595	.0616	.0617
Rank	1	11	14	7	4	8	15	13	12

Supplier	ENV_1	ENV_2	ENV_3	ENV_4	CIR_1	CIR_2	CIR_3	CIR_4
S1	-0.325	-0.324	-0.350	-0.303	-0.349	-0.351	-0.349	-0.295
S2	-0.309	-0.276	-0.331	-0.338	-0.286	-0.314	-0.310	-0.318

S3	-0.331	-0.349	-0.312	-0.348	-0.301	-0.306	-0.304	-0.313
S4	-0.343	-0.330	-0.338	-0.342	-0.294	-0.296	-0.361	-0.342
S5	-0.289	-0.314	-0.240	-0.319	-0.350	-0.276	-0.213	-0.326
Entropy Value	0.564	0.562	0.555	0.583	0.558	0.545	0.542	0.563
Degree of Diversity	0.436	0.438	0.445	0.417	0.442	0.455	0.458	0.437
Weight	0.0617	0.0621	0.0630	0.0591	0.0626	0.0645	0.0648	0.0619
Rank	12	9	5	16	6	3	2	10

Among all the considered criteria, financial capability (ECO_1) takes the first rank with a weight of 0.0682, as it plays a crucial role in determining the supplier's ability to provide goods or services. Quality management (ECO_2) secures the 11th rank with a weight of 0.0619, assessing how well the supplier maintains and meets the quality standards of the product or service. Cost/price (ECO_3) holds the 14th place among sub-criteria, with a weight of 0.0612. This criterion evaluates the price of the goods or services provided, ensuring the supplier offers a competitive price. Technology capability (ECO_4) attains the 7th rank with a weight of 0.0626, measuring the supplier's ability to provide goods or services with the latest technology. All these criteria are essential for organizations in CE (Consumer Electronics) as they contribute to ensuring the supplier can meet the organization's demands. Economic criteria assist businesses in assessing the long-term viability of their supply chain. By selecting suppliers who can provide sustainable products or services at a competitive price, businesses can reduce their reliance on non-renewable resources, creating a more resilient and adaptable SC.

Among the social sub-criteria considered for supplier selection, training related to carbon management (SOC_1) secures the 4th position with a weight of 0.0631. This is critical because suppliers need to be aware of the environmental impacts of their operations and implement measures to reduce their carbon footprint. Government regulations and policies toward CE (SOC_2) (0.0623) occupy the 8th position, emphasizing the necessity for suppliers to comply with laws and regulations governing CE activities. Compliance with CE policy and legislature (SOC_3) (0.0595) takes the 15th position, highlighting the importance of suppliers adhering to all relevant CE regulations and laws. Internal/external awareness toward CE practices (SOC_4) (0.0616) secures the 13th position, underscoring the need for suppliers to stay informed about current environmental regulations and practices. Selecting a socially responsible supplier is a crucial criterion because it ensures that the company is contributing to creating a better society. A socially responsible supplier should actively work to reduce their environmental impact, uphold ethical labor and business practices, and reinvest in the communities where they operate. Business houses should prioritize suppliers committed to sustainable development, fair trade, and transparency in their operations. Additionally, a supplier should be dedicated to delivering high-quality products and services and be open to customer feedback.

Within the environmental sub-criteria, use of harmful materials (ENV_1) (0.0617) holds the 12th position, emphasizing the need to avoid such materials to protect the environment and those interacting with the products. Environmental management system (ENV_2) (0.0621) secures the 9th place, ensuring that suppliers adhere to environmental regulations and guidelines. Life cycle cost management (ENV_3) (0.0630) attains the 5th place, aiding in identifying and minimizing costs associated with the entire life cycle of a product or service. The last position (16th) is occupied by resource consumption/minimum amount of virgin material used (ENV_4) (0.0591), as it ensures that suppliers use resources efficiently and minimize waste. Considering environmental criteria in supplier selection allows businesses to collaborate with partners who share their commitment to sustainability, minimizing the environmental impact of operations and reducing waste and pollution.

Circular criteria play a crucial role in supplier selection in the context of CE, ensuring that suppliers prioritize sustainability and circularity in their production processes. Among the circular sub-criteria, the 6th position is secured by eco-friendly raw materials and packaging (CIR_1) (0.0626). This criterion encourages suppliers to utilize environmentally friendly materials and packaging, thereby reducing the environmental impact of products and materials. Re-use, re-manufacturing, refurbishment (CIR_2) (0.0645) holds the 3rd position, enabling companies to re-use and re-manufacture existing products and materials instead of producing new ones, thereby lessening the burden on the environment. The 2nd position is obtained by the technology required to supplement reverse logistics (CIR_3) (0.0648), assessing the supplier's ability to use technology to optimize the reverse logistics process and ensure efficient reuse and recycling of materials. The 10th position is secured by eco-friendly transportation and warehousing (CIR_4) (0.0619), assessing the supplier's ability to use environmentally friendly transportation and warehousing methods to minimize their carbon footprint. Selecting circular suppliers can yield benefits such as reduced waste, cost savings, and improved brand reputation. Therefore, circular criteria should be a crucial consideration for any business seeking to operate in a Consumer Electronics environment.

4.2 Application of EDAS method

EDAS method is now used to select suppliers for CE based on four criteria: economic, social, environmental, and circular. EDAS method computes each alternative's relative proximity to the average solution, which is derived by averaging the normalized performance values of all alternatives for each criterion [58]. This means that EDAS method may choose alternatives that are closer to the average solution, even if they score badly on some criteria. In the application of EDAS method, initially Eqn. (3) is employed to calculate average values for all the criteria. Subsequently, Eqs. (4) and (5) are used to determine the positive distance from the average solutions, with the results detailed in Table 11. Following that, Eqs. (6) and (7) are applied to compute the negative distance from the average solution, as illustrated in Table 12. Furthermore, Eqn. (8) is used to calculate the weighted sum from the positive distance array, as presented in Table 13, and Eqn. (9) is employed for calculating the weighted sum from the negative distance array, as depicted in Table 14. Finally, Eqs. (10) to (12) are employed for calculating supplier rank, as shown in Table 15.

Table 15 reveals that supplier S3 obtained the top ranking with an appraisal score of 0.94, indicating that this supplier exhibited the best overall performance across all four criteria and 16 sub-criteria. Supplier S2 secured the second position with an appraisal score of 0.86, followed by supplier S5 with an appraisal score of 0.73. Suppliers S4 and S1 occupied the fourth and fifth places, respectively, with Supplier S1 having the lowest appraisal score of 0.13. These findings suggest that the selected suppliers demonstrate varying performance levels across the four considered criteria. Supplier S3, with the highest rank, appeared to perform exceptionally well, scoring highly in each criterion. Conversely, Supplier S1, positioned last, exhibited unsatisfactory performance across all criteria.

Among all the considered criteria, financial capability (ECO_1) takes the first rank with a weight of 0.0682, as it plays a crucial role in determining the supplier's ability to provide goods or services. Quality management (ECO_2) secures the 11th rank with a weight of 0.0619, assessing how well the supplier maintains and meets the quality standards of the product or service. Cost/price (ECO_3) holds the 14th place among sub-criteria, with a weight of 0.0612. This criterion evaluates the price of the goods or services provided, ensuring the supplier offers a competitive price. Technology capability (ECO_4) attains the 7th rank with a weight of 0.0626, measuring the supplier's ability to provide goods or services with the latest technology. All these criteria are essential for organizations in CE (Consumer Electronics) as they contribute to ensuring the supplier can meet the organization's demands. Economic criteria assist businesses in assessing the long-term viability of their supply chain. By selecting suppliers who can provide sustainable products or services at a competitive price, businesses can reduce their reliance on non-renewable resources, creating a more resilient and adaptable SC.

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Circular criteria play a crucial role in supplier selection in the context of CE, ensuring that suppliers prioritize sustainability and circularity in their production processes. Among the circular sub-criteria, the 6th position is secured by eco-friendly raw materials and packaging (CIR_1) (0.0626). This criterion encourages suppliers to utilize environmentally friendly materials and packaging, thereby reducing the environmental impact of products and materials. Re-use, re-manufacturing, refurbishment (CIR_2) (0.0645) holds the 3rd position, enabling companies to re-use and re-manufacture existing products and materials instead of producing new ones, thereby lessening the burden on the environment. The 2nd position is obtained by the technology required to supplement reverse logistics (CIR_3) (0.0648), assessing the supplier's ability to use technology to optimize the reverse logistics process and ensure efficient reuse and recycling of materials. The 10th position is secured by eco-friendly transportation and warehousing (CIR_4) (0.0619), assessing the supplier's ability to use environmentally friendly transportation and warehousing methods to minimize their carbon footprint. Selecting circular suppliers can yield benefits such as reduced waste, cost savings, and improved brand reputation. Therefore, circular criteria should be a crucial consideration for any business seeking to operate in a Consumer Electronics environment.

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Table 11: Positive distance from average solution

Supplier	ECO_1	ECO_2	ECO_3	ECO_4	SOC_1	SOC_2	SOC_3	SOC_4	ENV_1	ENV_2	ENV_3	ENV_4	CIR_1	CIR_2	CIR_3	CIR_4
S1	0	0.137	0.047	0	0	0.133	0	0	0	0	0	0	0.303	0	0	0
S2	0.164	0.209	0	0.222	0.086	0.303	0	0	0.079	0.277	0	0.518	0.000	0.219	0	0
S3	0	0.021	0	0.222	0.295	0	0.408	0.163	0.029	0.015	0.300	0.090	0.285	0	0.288	0.232
S4	0.054	0	0	0.000	0.252	0	0.009	0	0	0	0.084	0	0	0	0	0.017
S5	0.093	0	0.205	0.056	0	0	0	0.121	0.212	0.070	0.153	0.301	0	0	0.502	0

Table 12: Negative distance from average solution

Supplier	ECO_1	ECO_2	ECO_3	ECO_4	SOC_1	SOC_2	SOC_3	SOC_4	ENV_1	ENV_2	ENV_3	ENV_4	CIR_1	CIR_2	CIR_3	CIR_4
S1	0.1023	0	0	0.3889	0.3765	0	0.2434	0.0482	0.2223	0.0647	0.4603	0.6405	0	0.1784	0.5637	0.0977
S2	0	0	0.0553	0	0	0	0.0521	0.0186	0	0	0.0775	0	0.1510	0	0.1345	0.0757
S3	0.2086	0	0.1800	0	0	0.0036	0	0	0	0	0	0	0	0.0004	0	0
S4	0	0.2766	0.0174	0.1111	0	0.3059	0	0.2174	0.0968	0.2965	0	0.2692	0.2397	0.0023	0.0916	0
S5	0	0.0905	0	0	0.2566	0.1267	0.1215	0	0	0	0	0	0.1980	0.0376	0	0.0757

Table 13: Weighted sum from PDA

Supplier	ECO_1	ECO_2	ECO_3	ECO_4	SOC_1	SOC_2	SOC_3	SOC_4	ENV_1	ENV_2	ENV_3	ENV_4	CIR_1	CIR_2	CIR_3	CIR_4
S1	0	0.0085	0.0029	0	0	0.0083	0	0	0	0	0	0	0.0190	0	0	0
S2	0.0112	0.0130	0	0.0139	0.0054	0.0189	0	0	0.0049	0.0172	0	0.0306	0	0.0141	0	0
S3	0	0.0013	0	0.0139	0.0186	0	0.0243	0.0101	0.0018	0.0009	0.0189	0.0053	0.0179	0	0.0186	0.0144
S4	0.0037	0	0	0	0.0159	0	0.0005	0								
S5	0.0063	0	0.0126	0.0035	0	0	0	0.0075								

0	0	0.0053	0	0	0	0	0.0010
0.0131	0.0043	0.0096	0.0178	0	0	0.0325	0

Table 14: Weighted sum from NDA

Supplier	ECO_1	ECO_2	ECO_3	ECO_4	SOC_1	SOC_2	SOC_3	SOC_4
S1	.00698	0	0	0.024	0.024	0	0.014	0.003
S2	0	0	0.003	0	0	0	0.003	0.001
S3	0.01423	0	0.011	0	0	0	0	0
S4	0	.01713	0.001	0.007	0	0.019	0	0.013
S5	0	.00561	0	0	0.016	0.008	0.007	0

ENV_1	ENV_2	ENV_3	ENV_4	CIR_1	CIR_2	CIR_3	CIR_4
0.014	0.004	0.029	0.038	0	0.012	0.037	0.006
0	0	0.005	0	0.009	0	0.009	0.005
0	0	0	0	0	0	0	0
0.006	0.018	0	0.016	0.015	0	0.006	0
0	0	0	0	0.012	0.002	0	0.005

Table 15: Appraisal scores with supplier ranking

Supplier	$NormWP_i$	$NormWN_i$	Appraisal score (AS)	Rank
S1	0.26	0	0.13	5
S2	0.89	0.833	0.86	2
S3	1.00	0.879	0.94	1
S4	0.18	0.437	0.31	4
S5	0.73	0.733	0.73	3

5. MANAGERIAL IMPLICATIONS

Managerial implications of this study are significant for industries interested in implementing circular SC practices. The study highlights the importance of considering a wide range of characteristics when selecting suppliers for CE efforts. Identification of "financial capability", "the technology required to supplement reverse logistics", "re-use, re-manufacturing, refurbishment", "training related to carbon management" and "use of harmful materials" as the most crucial criteria for supplier selection highlights the need for effective environmental management in achieving sustainability goals. This finding can help organizations focus on improving their environmental management systems and ensuring that their suppliers have strong environmental practices.

The study also underscores the importance of incorporating complex decision-making techniques into SS procedures. EDAS method provides a practical framework for decision-making in SCM by identifying the most suitable supplier based on objective criteria. By adopting a data-driven approach, managers can make more informed decisions, rather than relying on subjective judgements.

Findings of this study can aid managers in developing policies and strategies that prioritize critical factors for selecting suppliers in a CE. For instance, managers may prioritize selecting suppliers with strong environmental management systems and a commitment to reducing resource consumption and minimizing the use of virgin materials. Encouraging suppliers to adopt practices such as re-use, re-manufacturing, and refurbishing can also reduce waste and contribute to a more sustainable SC. By focusing on these factors, managers can build a more sustainable and profitable SC that aligns with CE principles. Moreover, this research emphasizes the importance of incorporating sustainability and CE concepts into SCM. As customer demand for socially and environmentally responsible products and services continues to grow, businesses that embrace CE principles are likely to have a competitive advantage in the long run. By selecting suppliers based on their potential for sustainable performance, managers can promote sustainability throughout the SC and create a competitive edge for their organizations. This study provides a valuable framework for managers seeking to implement CE ideas in their SCM and can help them make informed decisions that advance both sustainability and profitability.

6. CONCLUSION, LIMITATION AND FUTURE SCOPE

This study integrates Entropy and EDAS methods in order to develop a comprehensive framework for selecting the best supplier for CE. The study proposed 16 criteria for choosing suppliers based on their potential for long-term performance within the context of a CE. The results revealed that "financial capability", "the technology required to supplement reverse logistics", "re-use, re-manufacturing, refurbishment", "training related to carbon management" and "use of harmful materials" are the mot significant criteria. The study emphasizes the significance of addressing sustainability factors in supplier selection and presents a practical strategy for SCM decision-making. The findings of this study can be helpful for managers in developing policies and strategies for SS in a CE. The results can help managers to focus on the most critical criteria and choose the most suitable supplier, leading to more efficient and profitable circular SCs. Moreover, this study has methodological significance, demonstrating the usefulness of Entropy method in conjunction with EDAS method for decision-making in SCM.

While this study depends on the opinions of the ten experts for Entropy and EDAS method-based evaluations may seem limited, it actually highlights the depth of expert input. Although economic, social, environmental, and circular factors were considered, other critical criteria for supplier selection in CE contexts, like regulatory compliance, geographical proximity, and technological compatibility, can also be explored. Integrating a broader range of expert opinions and criteria could enhance the evaluation of supplier suitability within circular supply chains. Additionally, the challenges associated with using Entropy and EDAS methods for supplier selection in CE present opportunities for improvement. The requirement for precise data and consistent measurement across criteria highlights the rigor of the evaluation process. Limitations in accounting for qualitative factors, such as a supplier's commitment to CE practices and long-term sustainability goals, suggest areas for future research. Recognizing this study's limitations in fully capturing the dynamic nature of circular supply chains emphasizes the necessity for continuous monitoring and adaptation.

Future research could broaden the scope by assessing its suitability across various industries and contexts, thereby addressing potential limitations regarding generalizability. Validating the findings through empirical data collection would enhance the robustness of the model and mitigate any biases resulting from a limited expert sample size. Comparing the outcomes of the adopted approach with alternative MCDM methods can offer valuable insights into its relative effectiveness and identify areas for refinement. Investigating the broader implications of supplier selection on overall supply chain circularity and sustainability can provide more comprehensive understanding of its impact and holistic strategies can be formulated for advancing CE initiatives.

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