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RESEARCH ARTICLE

Aligning Financing Strategies With Circular Business Principles: A Multicriteria Decision Framework

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ABSTRACT

Circularity principles, evident in closed-loop systems, aim to minimize waste and maximize value through material and product reuse, repair, refurbishment, and recycling. Circular practices can be financed using diverse models with different characteristics. Examples include pay-as-you-go, which involves usage-based payments; performance-based financing, which links funding to outcomes; grants, which provide nonrepayable support; public–private partnerships, which combine public and private resources; green bonds, which fund eco-friendly projects; and impact investing, which addresses social or environmental impacts alongside financial gains. To establish the correlation between circular supply chain principles and financing strategies, this study employed two multicriteria decision-making methods: the analytic hierarchy process (AHP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The obtained results were compared with findings from diverse manufacturing industries in existing literature.

1 | Introduction

The transition towards circular businesses presents significant opportunities for reducing environmental impact and enhancing competitiveness (Kazancoglu et al. 2021). However, financial barriers and uncertainties hinder widespread adoption (Calzolari, Genovese, and Brint 2021). This study aims to address this gap by developing a comprehensive framework for assessing the financial feasibility and sustainability of circular supply chain initiatives. This framework will consider the interplay of economic, environmental, and social factors, enabling a more informed decision-making process for businesses.

Therefore, strategically aligning financing methods with circular principles is critical. The selection of the appropriate financing model for a specific circular practice can significantly influence its financial viability (Awan and Sroufe 2022). Financing methods can enhance sustainability by incentivizing resource efficiency and extending product lifespans (Whalen 2019). Furthermore, these methods can mitigate supply chain risks, promoting wider adoption of circular practices and leading to more cost-effective operations through optimized resource recovery and waste reduction (Pan et al. 2015).

A report by European Environment Agency (2019) estimated that transitioning Europe to a circular supply chain requires an investment ranging from €500 billion to €1 trillion. According to EMF (2019), the projected investment for circular economy projects in Europe by 2030 could amount to €420 billion. Fleischmann et al. (2023) determined that the annual investment required for circular economy projects in Europe by 2030 might reach €100 billion. Regarding various aspects of the circular supply chain, estimated investment needs are projected as follows: €150 billion to €300 billion for waste management, €100 billion to €200 billion for resource efficiency, and €250 billion to €500 billion for the development of new products and services (Figure 1).

Lately, circularity concerns have gained visibility and are being incorporated into organizational management through supply chain policies. As stated by Genovese et al. (2017), continuous

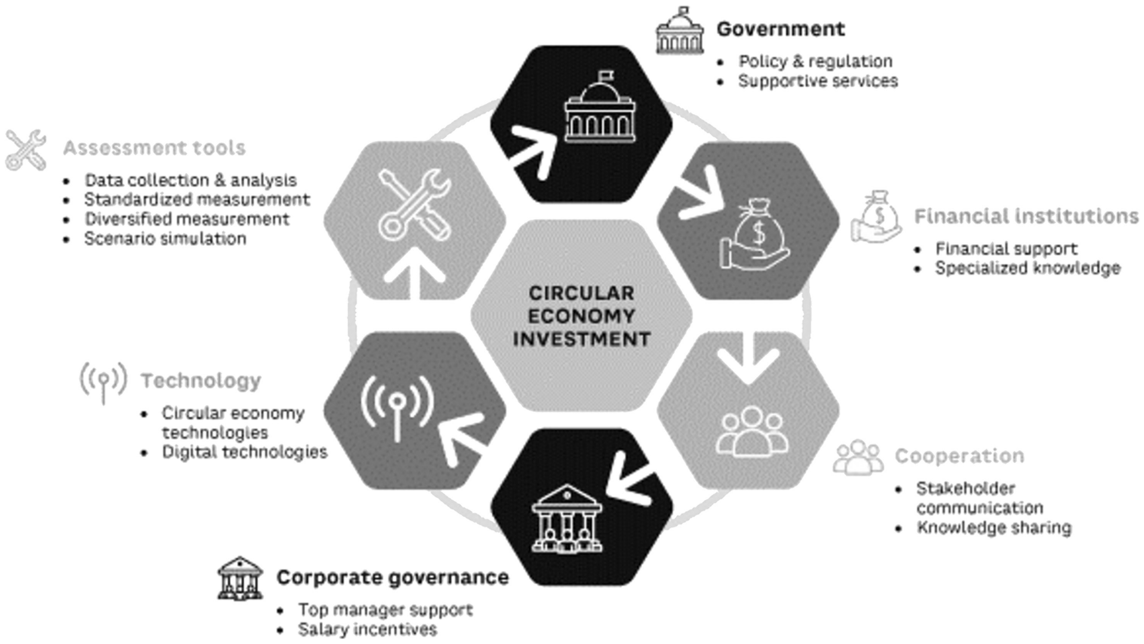

FIGURE 1 | Circular economy investment (https://www.cutter.com/article/circular-economy-investment-practical-insights-literature).

improvement in supply chain management contributes to a broader implementation of circular management programs and promotes closer relationships among supply chain agents (Hussain and Malik 2020), thereby encouraging innovation and the adoption of new cultural practices.

The circular economy's potential benefits for Europe by 2030, as per European Environment Agency (2019), include €1.3 trillion in net economic gains, €600 billion in cost savings, €300 billion in waste management, €200 billion in resources, €100 billion in other costs, €700 billion in new revenue, €400 billion in new products/services, €200 billion in productivity, and €100 billion other revenue. MGI (2020) suggests the circular economy could generate 6–7 million new jobs in Europe by 2030: 3–3.5 million in manufacturing, 1.5–2 million in services, and 1–1.5 million in construction.

Through the implementation of circular practices, supply chains can not only reduce their negative impact on the environment but also enhance their competitive edge. Therefore, it is crucial for supply chains to understand their resources and capabilities and identify and implement practices that align with their environmental strategy and strengthen their competitive positioning. As demonstrated by Pullman, Maloni, and Carter (2009), this implementation significantly influences various aspects of supply chain management, including resource optimization (Koh et al. 2017), waste reduction (Jain, Jain, and Metri 2018), cost efficiency (Jain, Jain, and Metri 2018), product design (Burke, Zhang, and Wang 2023), risk management (Chhimwal, Agrawal, and Kumar 2021), consumer preferences (Hunka, Linder, and Habibi 2021), and regulatory compliance (Silva and Pålsson 2022).

Driven by growing consumer awareness of environmental issues and regulations (Ji, Gunasekaran, and Yang 2014; González-Sánchez et al. 2020), resource scarcity, and fluctuating prices, circular supply chains aim to minimize waste and achieve sustainability. Consequently, supply chains perceive themselves as obligated to adopt circular practices, seeking to maximize recycling and product reuse while mitigating environmental impacts (Calzolari, Genovese, and Brint 2021). Through the implementation of circular practices, supply chains have the potential to mitigate their environmental impact, enhancing their competitive position (Pullman, Maloni, and Carter 2009). Therefore, supply chains should evaluate their resources and capabilities, strategically selecting practices that align with their environmental strategies and contribute value to their competitive approach (Christmann 2000).

Several drivers contribute to the adoption of circular supply chain management practices, including consumer demand, organizational factors, and societal responsibility. As shown in Figure 2, barriers such as regulation, lack of legitimacy, and investment needs for redesigning processes also impact implementation (Govindan and Hasanagic 2018). Therefore, both drivers and barriers can originate from within the organization (internal) and from external sources (Zhu, Sarkis, and Lai 2013). Elements like organizational culture and resource allocation within a company significantly influence the adoption and success of circular practices (Salvioni and Almici 2020).

However, the transition to a circular supply chain economy faces financial barriers arising from factors such as uncertainty regarding new technologies (De Lima and Seuring 2023) and the consequent lack of appropriate assessment methods for circular businesses (Walzberg et al. 2021). On the other hand, government incentives for circular policies create market biases that hinder access to capital, particularly impacting small- and medium-sized enterprises. Furthermore, Kazancoglu et al. (2023) observed a general lack of understanding regarding the financial benefits and risks associated with circular supply chains. In fact, although circularity practices can be seen as a way to reduce costs and improve the supply chain's performance (Calzolari, Genovese, and Brint 2022), some firms are still hesitant to embrace some aspects, such as environmental regulation.

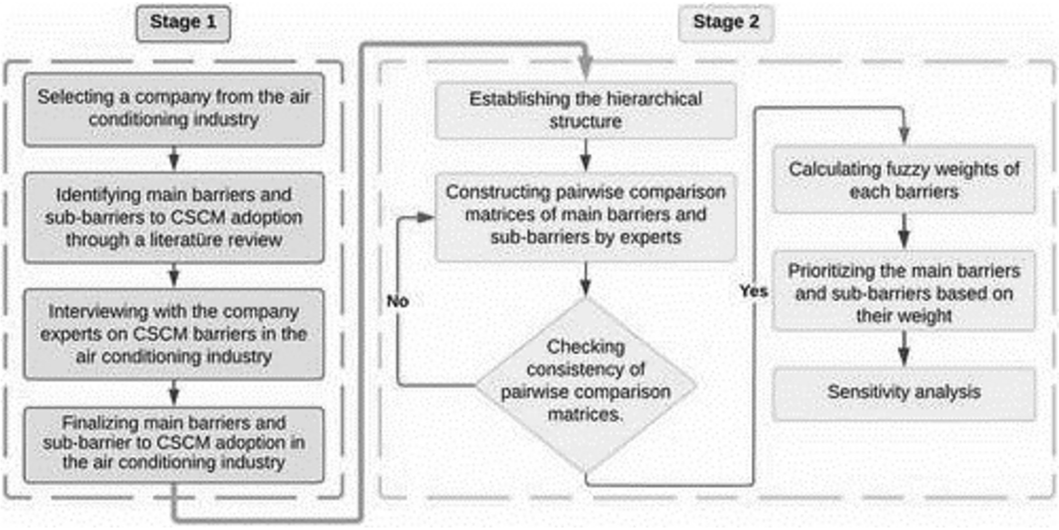

FIGURE 2 | Barriers to circular supply chains (Çıkmak and Kesici 2023).

Some time before, De Angelis, Howard, and Miemczyk (2018) had already argued that circular supply chains necessitate investments to facilitate the completion of their continuous loops and to effectively reduce environmental impact. However, these investments often fail to yield substantial increases in certain contexts (Linder and Williander 2017). Some supply chains exhibit unique characteristics—such as impulse buying tendencies, product life-cycle variations, high volatility, and low predictability (Mehrjoo and Pasek 2016). Hence, these supply chains have experienced recent transformations due to global sourcing practices (Figure 3) and escalated price levels, introducing significant uncertainty regarding the successful implementation of circular initiatives. This uncertainty further accentuates the need for heightened operational investments to drive circularity (Sanchez Rodrigues et al. 2008).

Finance models play a crucial role in supporting the transition towards a circular supply chain, particularly in facilitating market development (De La Cuesta-Gonzalez and Morales-García 2022), supporting investment, managing risks, and optimizing resource allocation (Tian 2018). Moreover, these models have the potential to incentivize circular practices through partnerships and impact measurement mechanisms (Veleva and Bodkin 2018).

To evaluate and rank the feasibility of various financing methods for adopting circular supply chain principles, multicriteria decision-making (MCDM) techniques can be utilized. The analytic hierarchy process (AHP) method is applied to rank the financing methods, while the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method is employed to prioritize the circular principles. Considering that the selected financing methods significantly impact the implementation of circular practices, Sharma et al. (2020) emphasize the importance of comprehending prevailing methods and identifying influential circular principles.

The subsequent section of the paper encompasses a literature review detailing prior approaches to the technical aspects of the relationship between circularity and finance. The methodology section addresses the proposed MCDM techniques and their application to the research problem. Subsequently, a demonstrative case study is outlined, culminating in contributions discussed in the conclusions section.

2 | Literature Review

For Hearnshaw and Wilson (2013), supply chains represent intricate networks characterized by unique properties and individual structures. The representation of a supply chain comprises numerous nodes, each representing a supply chain agent, interconnected to facilitate the delivery of products or services. Assessing the supply chain's efficiency is typically accomplished by gauging its complexity level, as depicted in the topological map showcasing material flows (refer to Figure 4).

Therefore, Diallo et al. (2017) defined circular supply chains as closed-loop systems where the products and materials can undergo different procedures: recycling, refurbishing, or reusing, reducing waste and promoting sustainability. In line with Ma et al. (2019), the process of recycling materials contributes significantly to resource conservation. By refurbishing items, there is an effective reduction in the demand for new products, saving resources and energy. Product reusing reduces waste generation and helps reduce the environmental footprint (Cooper and Gutowski 2017).

2.1 | Key Drivers and Practices in Circular Economy

Additional authors, including Pagell, Wu, and Murthy (2007), contemplate the establishment of supply chains dedicated to repurposing products that might not be viable for traditional recycling. Building upon this perspective, Jayaraman and Luo (2007) defend for establishing repurposing lines equipped to disassemble items, salvage functional components, and innovate new product designs utilizing these salvaged parts.

Regarding the transition from traditional linear supply chains, De Angelis, Howard, and Miemczyk (2018) advocates for procedures

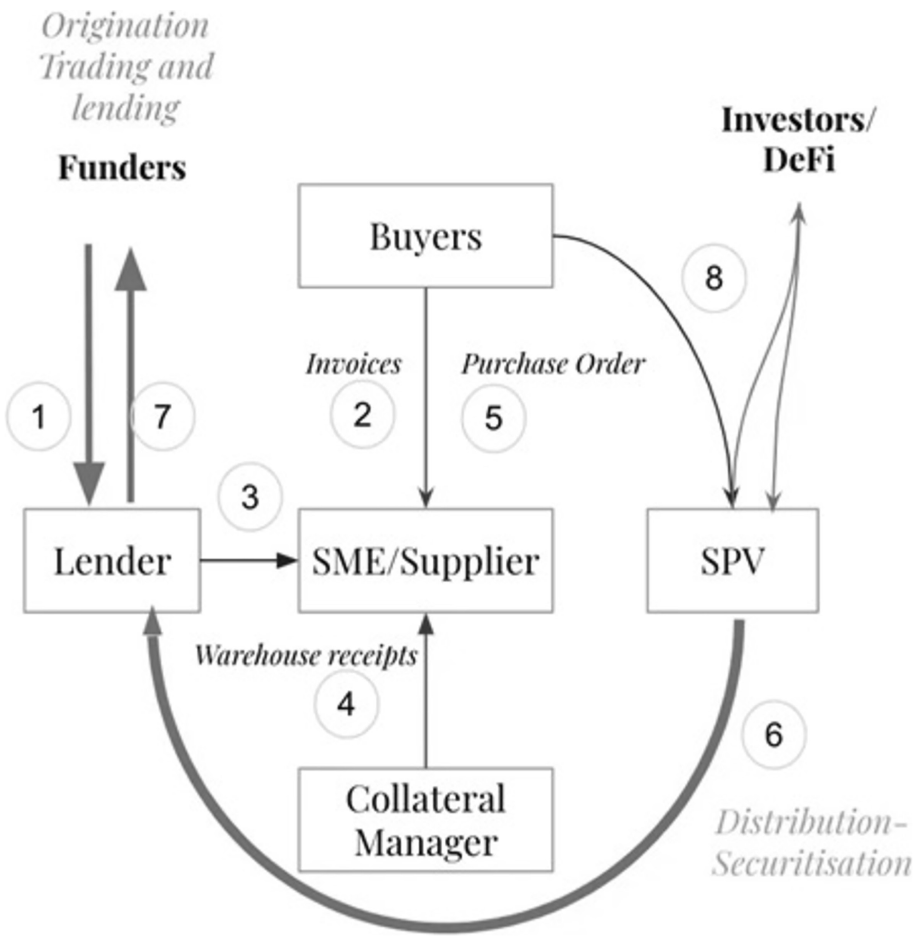

FIGURE 3 | Tokenized supply chain (https://www.medium.com/).

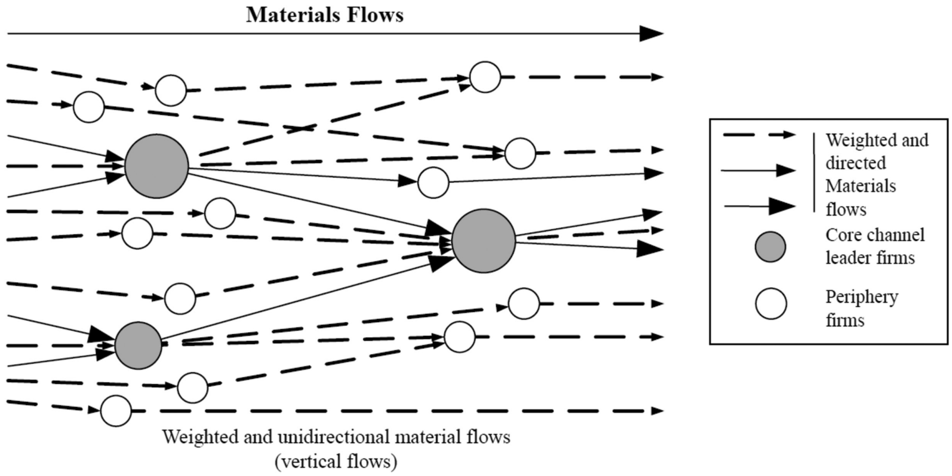

FIGURE 4 | Material flow topology in efficient supply chains (Hearnshaw and Wilson 2013).

enabling the extraction of value from returned products. This involves recommending the adoption of advanced logistics technologies and establishing partnerships with remanufacturing facilities. According to Hsu, Tan, and Mohamad Zailani (2016), supply chains prioritizing reverse logistics gain competitive advantages, not only by reducing costs but also by ensuring environmental sustainability and meeting customer expectations.

Additionally, Weetman (2016) confirmed that the circular-component life-cycle value design effectively enhances supply chain efficiency, highlighting the influence of product design changes on manufacturing processes. Speaking about waste reduction strategies and the implementation of recycling procedures calls to attention Drumwright (1994), who discussed social responsibility within a circular context.

Consequently, factors such as the take-back ratio, system holding costs, and the evolution of new technologies significantly influence decision-making in controlling inventory within a circular supply chain (Vlachos, Georgiadis, and Iakovou 2007). Diabat and Govindan (2011) utilized an interpretive structural modeling (ISM) approach to identify a set of logistics practices that significantly contribute to the adoption of circular economy drivers (Table 1).

Even though costs linked to legislation and health and safety risks hold significant importance in circular supply chains, González-Sánchez et al. (2020) argue that supply chains should prioritize activities optimizing costs and emphasize a compliance-driven approach. Consequently, Tišma and Škrtić (2023) and Holt and Ghobadian (2009) advocate for the adoption of circular practices, not solely for improved environmental performance but also for achieving enhanced productivity levels.

In order to extend product lifecycle and reduce waste, Ertz and Patrick (2020) suggested the reintroduction into the supply chain in one of these stages: repaired, refurbished, or repurposed. For products that cannot be reintroduced, Coelho, Castro, and Gobbo (2011) indicated that the extraction of materials and the disposal of nonrecyclable materials minimize environmental impact.

Growing environmental concerns are fueling awareness about circular supply chain management. With informed consumers potentially driving demand for circularly sourced products, supply chain agents are investing in R&D to reduce linear practices. Wang et al. (2012) highlighted this shift, advocating for circular supply chain investments via a risk assessment model (Figure A1), where a specific circular initiative showed the lowest value on the value risk index (ARI).

Linder and Williander (2017) argued that circular supply chain projects involve new risks due to innovative technologies and uncertain market conditions. This demand for effective risk-sharing and management is further supported by De Angelis, Howard, and Miemczyk (2018), who emphasize the need for financing strategies that can effectively address the unique risks associated with circular supply chain projects.

Investigating the effectiveness of government incentives in encouraging SMEs to participate in circular supply chains, Lee (2008) analyzed the incentives offered by governments, including financial support and supply chain agents' matchmaking programs. Furthermore, Mangla et al. (2018) and Kazancoglu et al. (2021) emphasized the importance of regulatory frameworks and provided examples of specific circular practices' incentives such as subsidies and tax reductions.

2.2 | Financing Strategies and Economic Implications

Several studies have highlighted the need for alignment between circular supply chains and the nature of financing. Agrawal et al. (2023) proposed the use of specific financial instruments, such as green bonds, to support circular initiatives. Moretto et al. (2019) previously discussed a collaborative finance approach involving multiple supply chain agents and third-party

TABLE 1 | Circular economy drivers (Diabat and Govindan 2011).

Circular economy drivers	Mean (man)	SD	Rank
Legislative influence			
UK's current environmental legislation	4.20	0.97	1
EU's current environmental legislation	3.93	1.16	2
Forthcoming environmental legislation	3.47	1.09	8
Future environmental legislation	3.12	1.18	14
Average rank			6.25
Internal drivers			
Reduction of health and safety risk	3.83	1.09	4
Reduction of the public's perceived risk	3.41	1.16	9
Culture of the organization	3.32	1.14	10
CEO commitment to environmental improvement	3.23	1.29	11
Employees' pressure	2.48	1.02	22
Average rank			11.2
Competition			
Better performance than competitors	3.65	1.35	5
New market opportunities	3.17	1.38	12
Competitors' activities matching	3.10	1.37	15
Operational cost savings	2.95	1.37	17
Average rank			12.25
Supply chain			
Upstream supply chain agents' requirements	3.53	1.36	7
Downstream supply chain agents' encouragement	3.13	1.20	13
Individual consumers/service pressure	2.71	1.27	19
Suppliers' influence	2.60	1.06	21
Average rank			15
Societal			
Presentation of an environmentally responsible image	3.57	1.13	6
Public opinion/societal expectation	2.77	1.21	18

(Continues)

TABLE 1 | (Continued)

Circular economy drivers	Mean (man)	SD	Rank
Pressure from green action groups	2.18	1.20	23
Pressure from the insurance industry	3.05	1.18	16
Pressure from shareholders and investors	2.68	1.19	20
Average rank			16.6

agents. Most recently, Fallahi et al. (2023) advocated for the role of third-party supply chain agents such as impact and venture capital firms, in funding startups and businesses that embody circular business models.

On the other hand, Saidani et al. (2019) and Velasco-Muñoz et al. (2021) have previously highlighted that supply chain agents are increasingly searching for indicators capable of assessing the impact of circular practices, encompassing not only economic benefits but also environmental achievements, especially in measuring return on investment. Hence, according to Dalhammar (2016), financing strategies ought to align with investment risks associated with new technologies, material recovery, and eco-design strategies.

Due to the distinct nature of circular supply chains, they necessitate appropriate financing strategies to incentivize the adoption of circular supply chain principles. According to A. Zhang et al. (2021), leasing models—where customers pay for service or utility without owning the product—offer a viable solution. Additionally, as noted by Masood, Cherifi, and Moalla (2021), the performance-based contracts encourage product reusability. Furthermore, Besiou and Van Wassenhove (2016) examined collection and disposal systems, concluding that extending the responsibility of supply chain agents incentivizes the creation of easily disassembled products.

Table 2 presents a comparative analysis of case studies centered on circular supply chains. It outlines industry sectors, supply chain interactions, waste disposal solutions, and recycling evidence in each case. The table succinctly illustrates diverse strategies employed across varied industry contexts to promote circularity. Simpson (2010) additionally examined the relation between circular practices, supply chain agent performance, and market awareness within these case studies.

2.3 | Public–Private Partnerships (PPPs) and Regulation in Aligning Circular Financing Strategies

Eisenreich, Füller, and Stuchtey (2021) and Veleva and Bodkin (2018) argued that circular supply chain initiatives necessitate the integration of resources, expertise, and funding, alongside active involvement from governmental bodies, businesses, and nonprofit organizations (Figure 5). Consequently, considering the interconnection among supply chain entities and external participants, Xie et al. (2022) recommended the establishment of PPPs within the framework of the supply chain. Additionally, in alignment with this perspective, Leclerc and Badami (2020) and Mayanti and Helo (2024) proposed the adoption of extended producer responsibility (EPR) legislation within supply chains. Such legislation incentivizes financing, take-back schemes, and recycling initiatives managed by the supply chain agents themselves (Figure 6).

Nevertheless, as highlighted by Henson and Humphrey (2010), governmental regulations and directives wield significant influence over multinational supply chains, leading to uncertainties in implementing circular projects and subsequent returns. Within this context, Hu and Hsu (2010) conducted an analysis of critical factors impacting the execution of circular supply chains, identifying four dimensions: product recycling, lifecycle management, supplier management, and organizational involvement. It was concluded by Oliveira et al. (2016) that these factors may pose challenges in evaluating the value of circular practices, subsequently impacting the ability to persuade supply chain agents to invest in such projects.

Mollaoglu et al. (2016) think that some companies adopt ISO environmental standards for a competitive edge. Circular impacts identified by Geissdoerfer et al. (2018) aid supply chains in efficiency and reducing environmental impact. Nechifor et al. (2020) agree, saying that despite Chinese efforts, a quicker shift to circular supply chains is crucial considering long-term environmental costs. Mavropoulos and Nilsen (2020) and Zhu, Sarkis, and Lai (2013) confirm that, within the WTO,[1] Chinese industries like automobiles, power, and electronics seek circularity due to high environmental pressures. In a manufacturers sample, Zhu and Sarkis (2007) observed that organizations feel increasing pressure to improve their environmental footprint due essentially to legislation. Oddly, they also observed less pressure related to social motivations and supply chain pressures from customers.

Furthermore, Table 2 highlights that most supply agents effectively identify waste materials in their processes, reflecting a comprehensive understanding of economic and noneconomic value of these materials. Additionally, substantial levels of supply chain interaction were observed, promoting information exchange and joint initiatives to minimize costs.

3 | Methodology

The financing of circular supply chain models is complex, requiring consideration of the unique characteristics of these models. Two MCDM methods, TOPSIS and AHP, can be used to compare financing options for circular supply chain models (Petrillo, Salomon, and Tramarico 2023; Khan, Chaabane, and Dweiri 2018).

AHP is particularly useful for determining the weights of various financing methods. Once these weights are established, the TOPSIS method can be employed to analyze responses obtained for circular drivers, allowing the establishment of

TABLE 2 | Comparison of circular case studies (Simpson 2010).

Firm	Industry sector	Ident.	Inform.	Interaction	Dominant waste disposal solution	Evidence of relationship-based recycling
A	Vehicle assembly	High	High	- Highly collaborative relationships - Seeks solutions through relationships - Contacts recycler to identify solutions on-site - Communicates with suppliers on recycling and take-back	- Supplier take-back - Recycler integration - Internal reuse - Approaching zero disposal to landfill	- Process integration with a third-party recycler - Suppliers being asked to take-back by-products - Suppliers offering to take away incidental wastes on an ad hoc basis - Collaborating with suppliers to identify and recycle unusual wastes
B	Brakes and clutch	Low	Low	- Low collaboration in relationships - Recycling not discussed in relationships	- Landfill only	None
C	Electronics	High	Medium	- Collaboration with customers and suppliers on operational issues - Recycling not discussed in relationships - Problem kept in-house	- Landfill - Major recycler - Internal reuse	- Returnable packaging design with suppliers - Using Kanban containers with customers.
D	Safety systems	Medium/high	Medium	- Collaboration with customers on operational issues - Recycling not discussed in relationships - Problem kept in-house	- Major recycler - Landfill	- Packaging sold to other local firms for reuse - Returnable packaging design with suppliers - Using Kanban containers with customer
E	Metal press	Low/medium	Low	- Low collaboration in relationships - Recycling not discussed in relationships	- Landfill	- Using Kanban containers with customers
F	Lighting and sound systems	Medium	Low	- Recycling not discussed in relationships - Hiding packaging waste from customers	- Landfill	None

(Continues)

TABLE 2 | (Continued)

Firm	Industry sector	Ident.	Inform.	Interaction	Dominant waste disposal solution	Evidence of relationship-based recycling
G	Electronics	Medium/high	High	- Partnering with competitors - Searches within all relationships and local organizations for solutions	- Local recyclers - Creates new markets - Internal reuse	- Employing a waste manager to identify recycling opportunities - Partnering with competitors to identify recycling opportunities - Actively searching for new markets for recyclables
H	Brakes and clutch	Low/medium	Medium–high	- Asks 3PLs to assist in identifying solutions - Communicates with suppliers on recycling and take-back	- Major recycler - Partnering with suppliers - Internal reuse	- Sending coolant back to the supplier for recycling - Selling waste metals to a major recycler - Making energy briquettes from waste - Working with a catering contractor

performance rankings (Torfi, Farahani, and Rezapour 2010). Therefore, TOPSIS assists in selecting the optimal supply chain design, considering factors such as sustainability and financial viability (W. Li, Wang, and Rehman 2024). The effectiveness of combining AHP and TOPSIS is confirmed by the studies of Hsueh and Lin (2017) and Wei (2021), both of which successfully integrated AHP and TOPSIS into the decision-making process.

3.1 | AHP

The AHP method is applied first to address the uncertainty and subjectivity inherent in decision-making. This process involves several steps, such as defining a decision problem and establishing a hierarchical structure. The identification of criteria begins with iterative expert consultations, followed by a systematic literature review. These criteria are then compared with existing frameworks, such as those proposed by Yazdani, Gonzalez, and Chatterjee (2021). A practical application of the Delphi method, which identifies six factors and 26 subfactors of green finance, is presented by C. Li, Solangi, and Ali (2023). The conclusion drawn is that AHP is ideal for measuring the importance of weights, while TOPSIS is ideal for defining the priority of solutions (Mangla, Kumar, and Barua 2015).

Subsequently, to define the relative importance of different financing methods and their impact on the principles of circular business models, the next step involves constructing a comparison matrix. Although a pairwise comparison matrix provides deeper insights when dealing with interrelated criteria, it requires judgments for every pair of elements (Kangas and Kangas 2002). To simplify the process, a rating matrix can be used, providing an adequate assessment given the number of alternative criteria (Alamerew et al. 2020).

The traditional AHP involves constructing a pairwise comparison matrix based on judgments between each pair of criteria using a rating scale (Saaty 1980). For n criteria C_i, the matrix A is as follows:

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & 1 \end{bmatrix}. \tag{1}$$

a_{ij}: relative importance of criterion i over criterion j.

Normalizing each element a_{ij} defines a normalized matrix:

$$a_{ij}^{\text{norm}} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}. \tag{2}$$

An approximation of the eigenvector can then be used to calculate the weight of each criterion:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} a_{ij}^{\text{norm}}. \tag{3}$$

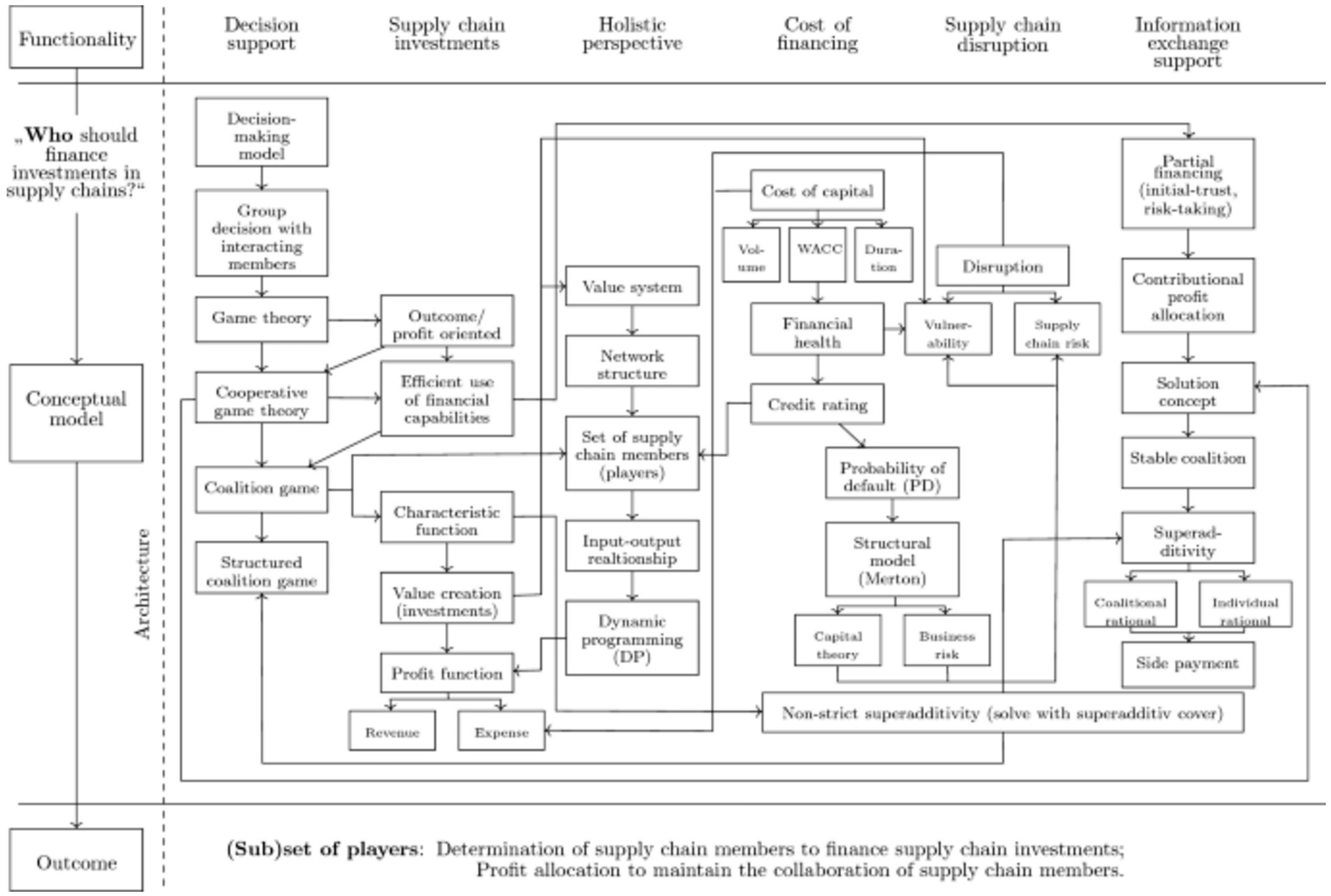

FIGURE 5 | Profit allocation to maintain supply chain collaboration (Somorowsky 2022).

Lahane and Kant (2021) provide an example of pairwise comparisons for ranking solutions aimed at mitigating circular supply chain risks. Instead of performing pairwise comparisons between alternatives, the AHP rating method, as applied to circular agri-food supply chain management by Yontar (2023), assigns a score to each alternative based on predefined criteria using a rating scale (e.g., 1–9) (Saaty 2006; Stam and Silva 2003). In the rating matrix, each entry reflects the score of an alternative *i* for a given criterion *j*. For *n* alternatives and *m* criteria, the rating matrix *R* is structured as follows:

$$R = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1m} \\ r_{21} & r_{22} & \dots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \dots & r_{nm} \end{bmatrix}. \tag{4}$$

r_{ij}: rating of alternative *i* for criterion *j*.

Normalizing the ratings ensures the sum of ratings for each criterion across all alternatives equals 1.

$$r_{ij}^{\text{norm}} = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}} \text{ for each criterion} j. \tag{5}$$

r_{ij}: rating of alternative *i* for criterion *j*.

The relative importance of each criterion is determined by its normalized weight:

$$w_j^{\text{norm}} = \frac{w_j}{\sum_{j=1}^{m} w_j}. \tag{6}$$

Each alternative's score is calculated by multiplying the ratings by the corresponding criteria weights:

$$S_i = \sum_{j=1}^{m} w_j^{norm} \cdot r_{ij}^{norm}. \tag{7}$$

S_i: overall score of alternative *i*; w_j: weight of criterion *j*; r_{ij}: rating of alternative *i* for criterion *j*.

3.1.1 | Consistency Ratio

According to R. Zhang et al. (2013), the process of calculation involves obtaining the weighted sum vector by multiplying the comparison matrix by a normalized weight vector and then dividing each element of the weighted sum vector by the corresponding weight:

$$\lambda_i = \frac{(A \cdot w)_i}{w_i}. \tag{8}$$

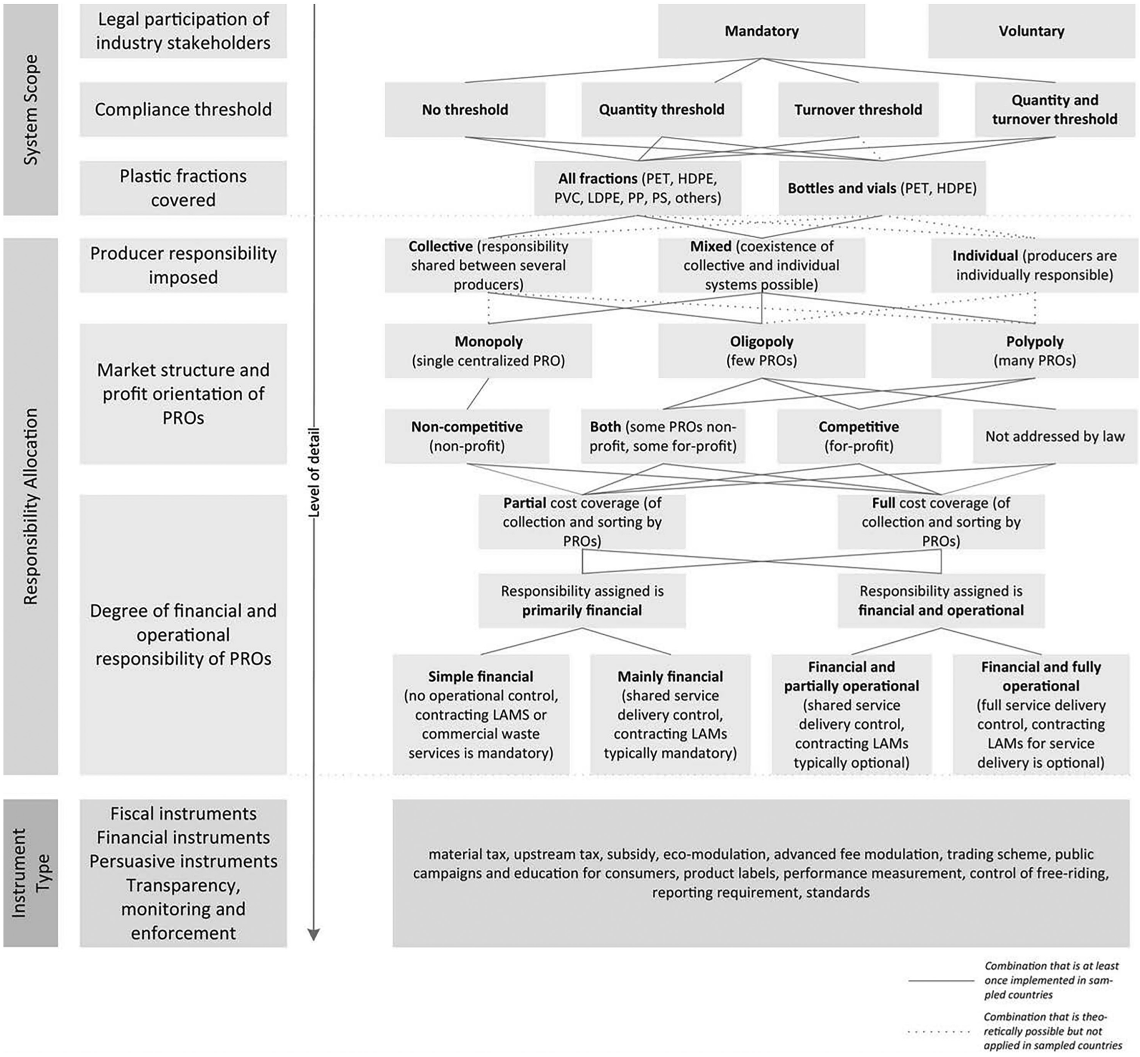

FIGURE 6 | Extended producer responsibility system hierarchy based on selected design features (Pruess 2023).

A: comparison matrix; $\lambda = [\lambda_1, \lambda_2, \ldots, \lambda_n]$: consistency vector; λ_i: consistency index (CI) for each criterion i; $A \cdot w$: weighted sum vector; w: normalized weight vector.

From the consistency vector λ, calculate the principal eigenvalue:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \lambda_i. \tag{9}$$

$\lambda_{\max}$: principal eigenvalue; n: number of criteria.

Thus, the degree of consistency in the pairwise comparisons can be measured by an index designated by CI:

$$CI = \frac{\lambda_{\max} - n}{n - 1}. \tag{10}$$

C. Li, Solangi, and Ali (2023) state that interpreting the degree of consistency involves determining the consistency ratio, which is derived from the comparison between the CI and a random index that depends on the size of the matrix (Amenta, Lucadamo, and Marcarelli 2020).

$$CR = \frac{CI}{RI(n)}. \tag{11}$$

CR: consistency ratio; CI: consistency index; $RI(n)$: random index.

According to Saaty (2008), if CR is less than a predefined threshold (0.1), the judgments can be considered consistent.

3.2 | TOPSIS Process

The TOPSIS is a method of multicriteria analysis developed by Hwang et al. (1981). Hwang, Lai, and Liu (1993) considered the goal of the method to be that the optimal solution should be closest to the positive ideal solution and furthest from the negative ideal solution in the geometric sense. Some authors, such as Georgiadis, Mazzuchi, and Sarkani (2013), criticized this method for not having sufficient capacity to deal with the subjectivity and lack of precision linked to the evaluation of individuals. However, the interpretation of Husain et al. (2021) allows us to conclude that, in the context of financing methods for a circular supply chain with various drivers, this method seems to be adequate.

The work of Garcia-Bernabeu et al. (2020) demonstrates that TOPSIS can assist in prioritizing financing approaches by considering different criteria associated with circularity. The process can be described in eight steps, with the first involving the determination of relevant weights, calculated through AHP. In the second step, linguistic preferences for each financing method are chosen, and a performance matrix is obtained. The third step involves deriving the matrix, allowing for the calculation of the normalized weighted matrix. In the subsequent steps, the positive and negative ideal solutions are calculated, followed by calculating the distance of each solution and determining the coefficient for each, respectively. The process begins with the definition of the decision matrices where each entry is the reciprocal of its counterpart:

$$x_{ij} \times x_{ji} = 1. \tag{12}$$

x_{ij}: element of the decision matrix X.

The process continues with the normalization of the decision matrix:

$$r_{ij} = \frac{\max(x_j) - \min(x_j)}{x_{ij} - \min(x_j)}. \tag{13}$$

r_{ij}: element of the normalized value of decision matrix; $\min(x_j)$ and $\max(x_j)$: minimum and maximum values for the jth criterion.

Next, obtaining the weighted normalized decision matrix:

$$v_{ij} = w_j \times r_{ij}. \tag{14}$$

v_{ij}: weighted normalized decision matrix; w_j: weight vector.

Then, calculating the ideal solutions:

$$s^+ = \max(v_{ij}), \tag{15}$$

$$s^- = \min(v_{ij}). \tag{16}$$

s^+: positive ideal solution; s^-: negative ideal solution.

Afterwards, measuring the distance by calculating the distance of each alternative from the s^+ and s^- using a suitable distance measure like Euclidean distance (Agrawal et al. 2021):

$$d^+(i) = \left(\sum_{j=1}^{n} (s^+ - v_j)^2 \right)^{\frac{1}{2}} \quad i = 1, \ \dots, m, \tag{17}$$

$$d^-(i) = \left(\sum_{j=1}^{n} (s^- - v_j)^2 \right)^{\frac{1}{2}} \quad i = 1, \ \dots, m. \tag{18}$$

Next, computing the similarity level of each alternative to the ideal solution using the distance values:

$$C^+(i) = \frac{d^-(i) + d^+(i)}{d^-(i)}, \tag{19}$$

$$C^-(i) = \frac{d^-(i) + d^+(i)}{d^+(i)}. \tag{20}$$

$d^-(i)$ and $d^+(i)$: distances of the ith alternative from the S^+ and S^+.

Finally, ranking the alternatives based on their similarity values. This method was also successfully employed by Prakash and Barua (2015) to identify and rank solutions for overcoming barriers to the adoption of reverse logistics. They utilized AHP to assign weights to the barriers through pairwise comparison and TOPSIS to prioritize the solutions for implementing reverse logistics. Similarly, Patil and Kant (2014) applied the same method to the adoption of knowledge management (KM) by the supply chain of a hydraulic valve manufacturer, concluding that positive leadership is the most effective solution for overcoming barriers to adopting KM in the supply chain.

Nazam et al. (2015) also employed the AHP–TOPSIS approach to evaluate the risk associated with adopting sustainable supply chain practices due to inherent uncertainty. Rather than pinpointing barriers, they focused on assessing the implementation risk itself, emphasizing its significance in impacting the circularity of supply chain management. Following Husain et al. (2021), AHP and TOPSIS methods were used to analyze how financing strategies relate to circular criteria (Saarinen and Aarikka-Stenroos 2022). AHP revealed interdependencies, while TOPSIS aided in selecting circularly aligned models. This synthesis provided insights crucial for balancing financing strategies and circular benchmarks in supply chain implementation.

3.3 | Fuzzy AHP

Goyal, Garg, and Luthra (2021) demonstrated that the methodology could be further enhanced through the application of fuzzy AHP and TOPSIS, a hybrid decision-making approach that integrates both methods. Given its effectiveness in addressing complex MCDM problems under uncertain conditions, Husain et al. (2021) employed this approach to analyze business models for circular economy implementation.

Fuzzy AHP uses triangular fuzzy numbers (TFNs) to represent varying preferences among the criteria in a designated fuzzy pairwise comparison matrix. Each element of this matrix is a TFN, defined by the following values:

$$\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}). \tag{21}$$

$\tilde{a}_{ij}$: TFN; l_{ij}: lower value; m_{ij}: middle value; u_{ij}: upper value.

With these TFNs, a fuzzy pairwise comparison matrix is constructed:

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & 1 \end{bmatrix}. \tag{22}$$

$\tilde{A}$: fuzzy comparison matrix; $\tilde{a}_{ij}$: TFN.

After stabilizing the fuzzy comparison matrix, the fuzzy weights are derived by applying the geometric mean method to the fuzzy numbers. For each row in the fuzzy matrix, a fuzzy geometric mean is calculated:

$$\tilde{G}_i = \left(\prod_{j=1}^{n} \tilde{a}_{ij} \right)^{\frac{1}{n}} = \left(\prod_{j=1}^{n} (a_{ij}^l, a_{ij}^m, a_{ij}^u) \right)^{\frac{1}{n}}. \tag{23}$$

$\tilde{a}_{ij}$: TFN; $\tilde{G}_i$: fuzzy geometric mean for the ith criterion.

The next step involves normalizing the fuzzy weights:

$$\tilde{w}_i = \frac{\tilde{G}_i}{\sum_{i=1}^{n} \tilde{G}_i}. \tag{24}$$

$\tilde{w}_i = (w_i^l, w_i^m, w_i^u)$: fuzzy weight for criterion i; $\tilde{G}_i$: fuzzy geometric mean for criterion i.

Subsequently, the fuzzy weights are defuzzified using the centroid method (Kayikci et al. 2021):

$$w_i = \frac{w_i^l + w_i^m + w_i^u}{3}. \tag{25}$$

w_i: defuzzified weight for criterion i.

3.4 | Fuzzy TOPSIS Process

Constructing the fuzzy decision matrix is the first step in the fuzzy TOPSIS process. It consists of a matrix composed of different alternatives evaluated against each criterion:

$$\tilde{D} = \begin{bmatrix} \tilde{d}_{11} & \tilde{d}_{12} & \dots & \tilde{d}_{1m} \\ \tilde{d}_{21} & \tilde{d}_{22} & \dots & \tilde{d}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{d}_{n1} & \tilde{d}_{n2} & \dots & \tilde{d}_{nm} \end{bmatrix}. \tag{26}$$

$\tilde{d}_{ij} = (d_{ij}^l, d_{ij}^m, d_{ij}^u)$: TFN in the ith row and jth column; n: number of alternatives; m: the number of criteria.

Because the values need to be compared across different criteria, the fuzzy decision matrix must be normalized. The application of circular principles and the preference of benefit criteria over cost criteria (Husain et al. 2021) led to the following definition for each element of the normalized decision matrix:

$$\tilde{r}_{ij} = \left(\frac{d_j^u}{d_{ij}^l}, \frac{d_j^u}{d_{ij}^m}, \frac{d_j^u}{d_{ij}^u} \right). \tag{27}$$

d_j^l, d_j^m, d_j^u: the lowest, most likely, and highest values for each criterion j across all alternatives; $\tilde{r}_{ij} = (r_{ij}^l, r_{ij}^m, r_{ij}^u)$: fuzzy number with a lower bound r_{ij}^l, middle value r_{ij}^m, and upper bound r_{ij}^u.

Using expression (27), the fuzzy synthetic extent calculation determines the priority of each criterion (Torkabadi, Pourjavad, and Mayorga 2018):

$$S_i = \frac{\sum_{j=1}^{n} \tilde{r}_{ij} \times \tilde{w}_j}{\sum_{j=1}^{n} \sum_{k=1}^{n} \tilde{r}_{jk}}. \tag{28}$$

$S_i = (l_i, m_i, u_i)$: fuzzy synthetic extent; $\tilde{w}_j = (w_j^l, w_j^m, w_j^u)$: fuzzy weight of the jth criterion.

The fuzzy synthetic extent must be converted into a crisp value (defuzzification). One way of doing this is by applying the centroid method:

$$C(S_i) = \frac{l_i + m_i + u_i}{3}. \tag{29}$$

l_i, m_i, and u_i: the lower, middle, and upper values of the fuzzy number S_i.

Multiplying each element of the normalized fuzzy decision matrix by the corresponding fuzzy weight produces a new TFN for each element in the weighted fuzzy decision matrix:

$$l_i = \sum_{j=1}^{m} r_{ij}^l \times w_j^l, \tag{30}$$

$$m_i = \sum_{j=1}^{m} r_{ij}^m \times w_j^m, \tag{31}$$

$$u_i = \sum_{j=1}^{m} r_{ij}^u \times w_j^u. \tag{32}$$

After the process of defuzzification, the crisp values must be normalized to obtain the weight of each criterion:

$$w_i = \frac{C(S_i)}{\sum_{i=1}^{n} C(S_i)}. \tag{33}$$

$C(S_i)$: defuzzified value for the ith criterion; w_i: normalized weight for the ith criterion.

This is followed by the computation of the weighted normalized decision matrix, where each normalized value (r_{ij}) is multiplied by its corresponding weight (w_j).

$$v_{ij} = r_{ij} \times w_j. \tag{34}$$

v_{ij}: the weighted normalized value for the ith alternative and the jth criterion.

Thus, with all collected elements, the ideal and negative ideal solutions can be calculated as follows:

$$A^* = \{v_1^*, v_2^*, \dots, v_n^*\} = \{\max_i(v_{ij}) \text{for benefit criteria}\}, \tag{35}$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\} = \{\min_i(v_{ij}) \text{for benefit criteria}\}. \tag{36}$$

A^*: ideal solution; A^-: negative ideal solution. Afterward, the distance between each alternative and the corresponding ideal solution can be calculated using the Euclidean distance formula:

$$d_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, \tag{37}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}. \tag{38}$$

d_i^* or d_i^-: distance between each alternative (v_{ij}) and the corresponding ideal solution (v_j^* or v_j^-).

With the distances to the ideal solutions, the closeness coefficient is calculated:

$$C_i = \frac{d_i^-}{d_i^* + d_i^-}. \tag{39}$$

After considering the use of fuzzy logic to manage uncertainty in decision-making, it can be concluded that the fuzzy AHP–TOPSIS framework allows for more nuanced judgments when criteria are difficult to quantify and when the ranking process is affected by high uncertainty (Bai, García, and Mishra 2022). However, applying the traditional AHP–TOPSIS method to our small demonstrative case study provides an adequate interpretation of the results, ensuring an efficient and effective decision-making process for evaluating supply chain management and sustainability (Zyoud and Fuchs-Hanusch 2017).

4 | Demonstrative Case Study

Table 3 defines several financial methods of circular initiatives. It points out that closed-loop supply chain (CLSC) financing seems to be the most effective financing model for supporting circular supply chains. Several justifications can be made; however Mishra, Hopkinson, and Tidridge (2018) argue that this is because it provides financing for all stages of the circular economy (product design, manufacturing, product use, and end-of-life management), ensuring the application of circular principles throughout the entire supply chain. Another effective financing model appears to be Product-as-a-Service, as it has been considered to promote product reuse and recycling, consequently reducing waste and extending the product's life cycle according to Kalliomäki (2022).

The objective is to devise a framework for evaluating various financing strategies (traditional linear financing, reverse logistics financing, Product-as-a-Service financing, and CLSC financing) for implementation within the circular supply chain. The prioritization process is based on the following principles: product reuse, recycling, waste reduction, energy efficiency, and overall sustainability. Thus, assigning ratings (on a scale of 1–9) for the alignment of each financing model method with each circular supply chain principle, Table 3 illustrated AHP ratings.

With the AHP results in hand, TOPSIS will determine the overall ranking of the four financing methods, using the concept

TABLE 3 | AHP ratings.

Financing method	Product reuse (Galbreth, Boyacı, and Verter 2013)	Recycling (Schwarz et al. 2021)	Waste reduction (Delchet-Cochet 2020)	Energy efficiency (Mavi and Mavi 2019)	Overall sustainability
Traditional linear financing (Owen, Vedanthachari, and Hussain 2023)	7	6	8	5	7
Reverse logistics financing (Lampón, Perez-Elizundia, and Delgado-Guzmán 2021)	8	7	6	5	8
Product-as-a-Service financing (Fallahi et al. 2023)	9	8	7	8	9
Closed-loop supply chain financing (Z. Zhang, Xu, and Chen 2021)	8	9	9	7	8

TABLE 4 | Normalized weights for the circularity supply chain principles.

Circular supply chain principle	Normalized weight
Product reuse	0.4985
Recycling	0.1202
Waste reduction	0.0935
Energy efficiency	0.2568
Overall sustainability	0.0310

TABLE 7 | Separation measures.

Financing method	Distance from s^+	Distance from s^-
Traditional linear financing	2.8034	0.8528
Reverse logistics financing	1.535	1.7054
Product-as-a-Service financing	0	2.4097
Closed-loop supply chain financing	1.8293	1.4622

TABLE 5 | Weighted normalized decision matrix.

Financing method	Product reuse (0.4985)	Recycling (0.1202)	Waste reduction (0.0935)	Energy efficiency (0.2568)	Overall sustainability (0.0310)
Traditional linear financing	0	0.625	0	0.333	0
Reverse logistics financing	0.500	0	0.500	0	0.5
Product-as-a-Service financing	1	0.406	1	1	1
Closed-loop supply chain financing	0.591	1	0.5	0.667	0

TABLE 6 | Reference points.

Criteria	s^+	s^-
Product reuse	1	0
Recycling	1	0
Waste reduction	1	0
Energy efficiency	1	0
Overall sustainability	1	0

TABLE 8 | Relative closeness to the ideal solution (RC).

Financing method	RC
Traditional linear financing	0.2305
Reverse logistics financing	0.5256
Product-as-a-Service financing	1
Closed-loop supply chain financing	0.4405

of distance to identify the most preferred alternative financing model. The subsequent stage involves determining the relative importance of each criterion compared to others by assigning a weight between 0 and 1 to each criterion, ensuring that the cumulative weights sum up to 1. Consequently, by utilizing AHP, Table 4 illustrates the normalized weights allocated to each circular supply chain principle.

The weighted normalized decision matrix in Table 5 is derived from the multiplication of each normalized rating by its corresponding weight. Higher values for all criteria are considered better, allowing the construction of the weighted normalized decision matrix.

The next step involves identifying two reference points (Table 6): the positive ideal solution (s^+) and the negative ideal solution (s^-). The selected financing method will be the one with the shortest distance from the s^+ and the longest distance from the s^-. The s^+ is identified among the highest values for each beneficial circular principle across all financing methods, while the s^+ is identified among the lowest values for each beneficial circular principle across all financing methods (Kacprzak 2020).

Table 7 provides estimations of the separation measures, indicating that for each financing method and in accordance with expression (17), the Euclidean distance to the s^+ and s^- calculated using the weighted normalized ratings (Agrawal et al. 2021). This calculation aims to determine the relative closeness coefficient for each alternative financing method.

Calculating the relative closeness coefficient for each financing method using the formulas in (19), Table 8 illustrates the proximity to the ideal solution, indicating their alignment with the circular supply chain principles.

The circular supply chain financing ranking is as follows: Product-as-a-Service financing is deemed the most sustainable, followed by reverse logistics financing and CLSC financing, with traditional linear financing considered the least sustainable.

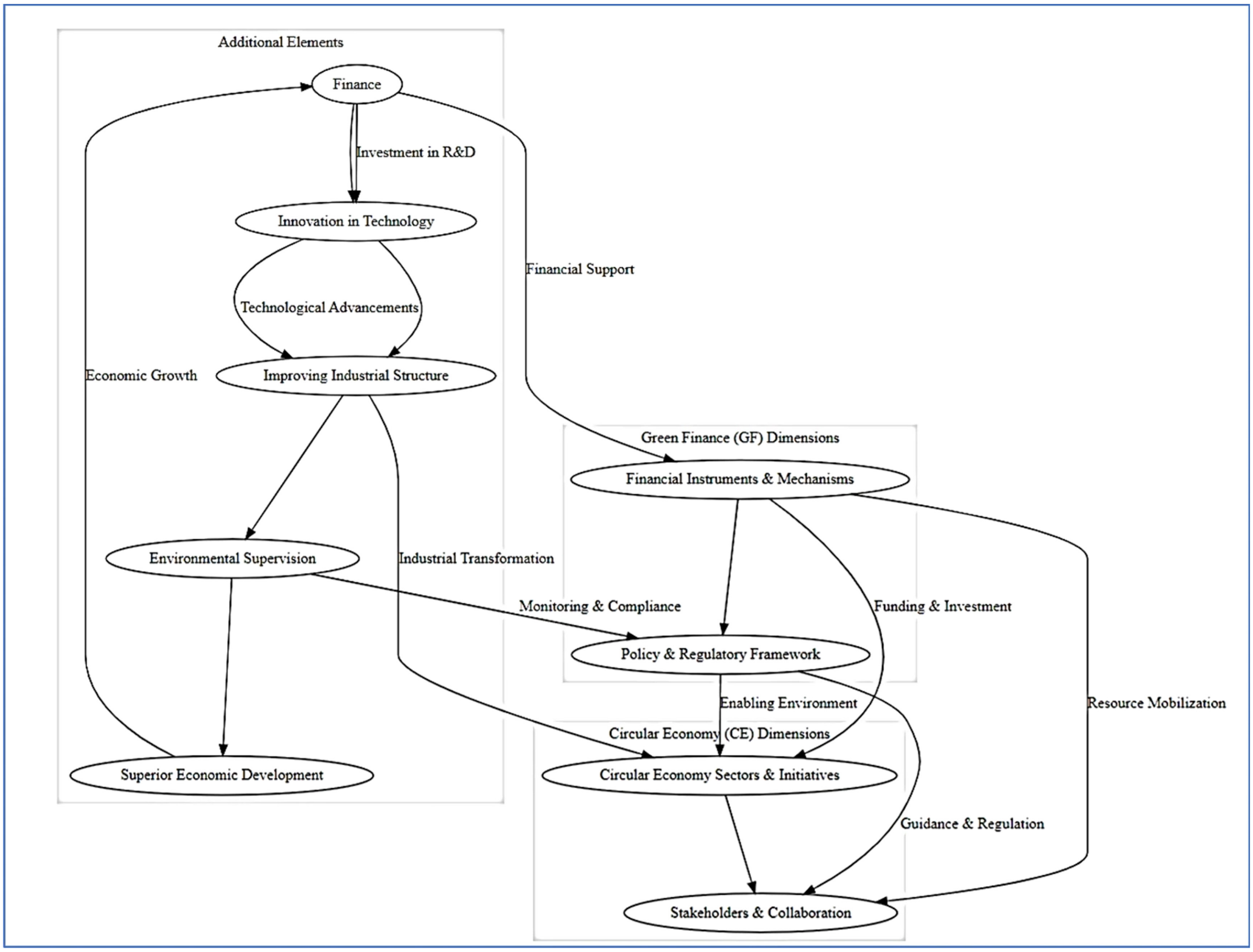

FIGURE 7 | Green finance and circularity principles: multidimensional conceptual framework (Kumar et al. 2024).

Therefore, based on weighted assumptions and in accordance with Zambotto (2023), Product-as-a-Service financing has the closest alignment with circular supply chain principles and emerges as the most circular financing option, displaying superior performance across all five circular supply chain principles. Both reverse logistics financing and CLSC financing also present viable choices, whereas traditional linear financing, confirming Brears (2018), lags behind in delivering circular economy benefits.

5 | Discussion

In terms of relevance, the analysis of the circularity principles reveals that product reuse is the most critical principle in a circular supply chain, accounting in about 50% of relevance followed by energy efficiency with about 25% and recycling and waste reduction with a combined 24%. Consequently and known the relative closeness to the ideal solution for each financing strategy, Product-as-a-Service financing appears as the strategy with the strongest alignment with circular economy principles. Reverse logistics financing and CLSC financing strategies demonstrated moderate levels of circularity alignment and traditional linear financing strategy obtained the weakest alignment level.

Pay-per-use financing shifts focus from product ownership to usage-based models, ensuring predictable revenue for providers and reducing upfront costs for consumers. It expands market reach by increasing accessibility for capital-constrained customers and supports balance sheet optimization and risk mitigation. However, drawbacks include price volatility, technological dependence, and risks of customer churn and revenue loss.

Transitioning to a circular economy requires aligning financing strategies with circular principles. Quantitative assessment enhances strategy optimization and cost reduction. Reverse logistics financing aligns moderately with waste reduction, while CLSC financing aligns with waste reduction, product reuse, and strongly with recycling. Tools such as cost–benefit analysis, inventory valuation, and risk assessment support reverse logistics, whereas cost accounting, life-cycle costing, and sustainable finance are suited for CLSCs. The relevance of these tools is supported by Kanzari et al. (2022), highlighting financial performance as a key driver of circular business model.

Methodologically, this research advances the literature on circular economy financing by developing a customized framework that integrates the AHP with the TOPSIS. This integrated approach provides a robust quantitative method for evaluating the alignment of various financing strategies with the core principles of circularity. Therefore, the refined framework enables a detailed evaluation of financial tools supporting circularity principles, including product reuse, waste reduction, and recycling. It disaggregates the performance of broad financing strategies (e.g., Product-as-a-Service financing and traditional linear financing) into actionable insights for specific tools, such as sustainable finance and life-cycle costing. Using the TOPSIS method, these financial tools are ranked based on their relative closeness to an ideal solution. This provides a robust quantitative approach to assessing the effectiveness of tools like cost–benefit analysis and inventory valuation in advancing circularity.

Findings depend on participant preferences at specific detail levels. While financing strategies and circular principles are generalizable, they remain preliminary indicators. Product-as-a-Service financing and CLSC financing involve higher risks due to uncertain returns and reliance on public–private collaboration (e.g., first-loss guarantees). The framework can assess tool alignment with policies like EPR and supports customizing EPR to integrate with risk models, fostering financial institution engagement in circular economy practices. Mayers et al. (2013) demonstrates a successful application of EPR in financing the Waste Electrical and Electronic Equipment (WEEE) Directive.

Analysis of Product-as-a-Service financing highlights the need for policies supporting the circular economy transition. Financial tools like green bonds, pay-for-success models, and impact investing promote PPPs to achieve circular goals. The AHP–TOPSIS framework quantitatively evaluates these tools, offering precise insights into their alignment with circular economy principles.

Product-as-a-Service financing is a key enabler of circularity principles, relying on financial tools like green bonds and guaranteed loans, alongside technologies such as blockchain, tokenization, and data analytics. Blockchain boosts investor confidence by enhancing traceability and risk assessment (Sadeghi, Mahmoudi, and Deng 2023). Tokenized green bonds allow fractional ownership and improved liquidity (Shankar 2022). Data analytics assess the impact of these strategies, supporting performance monitoring and risk management.

6 | Theoretical and Managerial Implications

This study provides significant theoretical and managerial insights into the connection between financing strategies and circular economy principles. It proposes a framework that outlines the interaction between financial tools, circular economy principles, policies, and innovations. This framework helps managers identify and implement financing strategies that align with circularity goals such as waste reduction, reuse, and recycling. It highlights finance tools like green bonds, cost–benefit analysis, and blockchain as effective mechanisms for resource efficiency and sustainable business practices. Figure 7 illustrates the framework, depicting the relation among financial mechanisms, circular economy principles, and enabling technologies.

The combined AHP–TOPSIS framework advances our theoretical understanding of the relationship between financial strategies and circularity. By providing a quantitative method to measure their impact, it moves beyond traditional qualitative assessments. This robust methodology enables an effective evaluation of how financing methods align with and support circular economy principles. This framework supports circular economy theories by emphasizing the critical role of financing strategies, such as CLSC financing and Product-as-a-Service financing, in advancing circular practices. These models emerge as the most impactful strategies for implementing circular principles, directly driving their practical application. Our findings also highlight the importance of integrating these financing strategies with supportive policy frameworks, such as EPR, to effectively enable circular economy principles. The successful implementation of CLSC financing and Product-as-a-Service financing relies on adopting technological innovations like blockchain and digital tokenization. Francisco Luis et al. (2021) describe blockchain as a service-based traceability platform that validates and supports circular economy principles in supply chain finance.

Beyond its theoretical contributions, this study provides valuable managerial insights. Managers can prioritize financing strategies that align their companies' strategic objectives with circular economy principles, facilitating product reuse and recycling while laying the groundwork for CLSC financing. Circular practices require frameworks that comply with regulations like the revised European Ecodesign Directive (Directive 2009/125/EC) and policies that incentive EPR. Lifset et al. (2023) highlight eco-modulation as a mechanism to tailor EPR financial incentives for circularity.

Using the AHP–TOPSIS framework, managers can develop platforms and information systems to effectively evaluate the performance of various financing strategies in achieving circularity goals. These platforms enable organizations to identify improvement areas by benchmarking their financing practices against industry best practices using relative closeness scores. The prioritized financing strategies in this study underscore the role of technological tools, such as blockchain or digital tokenization, in measuring and tracking consumer engagement with circularity practices across the supply chain. Analyzing consumer behavior related to circular strategies helps identify market objectives and financing approaches that align with circularity principles and support sustainable products and services. Peng and Chen (2023) demonstrated these insights by examining the impact of green finance strategies on China's renewable energy sector.

7 | Conclusions

The aim of this paper was to define an approach that allows ranking several financing methods considering circular business principles. The combination of AHP with TOPSIS methods resulted in a robust and executable approach to deal with the research problem. Furthermore, the detailed case study illustrates how the methodology can be applied to the prioritization of the financing strategies.

This study confirms the effectiveness of the AHP–TOPSIS method in selecting appropriate financing strategies for enhancing business models circularity. The MCDM approach demonstrates precision in evaluating complex interdependencies and allows for the weighting of circular principles. AHP enables the determination of the relative importance of financing methods through pairwise comparisons, contributing to consistent decision-making. Complementarily, TOPSIS provides a systematic approach to ranking alternative financing methods based on their distance from the ideal solution. The integration of these MCDM methods for selecting financing strategies that enhance circularity in business models offers a novel methodological framework.

The Product-as-a-Service financing approach is commonly observed in industries that offer service-oriented solutions, such as usage-based payments or continuous services. Its primary advantages stem from cost efficiency and improved cash flow management. However, the success of this financing model depends on technological integration, allowing for remote monitoring and data collection regarding product usage. While generally associated with technological items, this approach can also be applied in industries where production assets are leased. This broadens insights into the Product-as-a-Service model, suggesting its relevance to nontechnological sectors and highlighting the need for real-time data for financing success.

Adopting the Product-as-a-Service financing model has significant implications beyond financing circular supply chains, impacting business models. It encourages product designs that promote recyclability and ensure responsible end-of-life management. Furthermore, this financing model improves cash flow management and facilitates compliance with regulatory requirements. Several insights can be drawn about the Product-as-a-Service model's implications for business strategies and the underexplored link between sustainable product design and financing methods, offering a holistic view of sustainability.

However, certain limitations in this framework should be noted, particularly regarding the interaction between financing strategies and circular principles using AHP and TOPSIS. The selection of circular principles and the assignment of corresponding weights may introduce bias, as human judgment is inherent in MCDM approaches, potentially influencing the outcomes.

Endnotes

[1] World Trade Organization.

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Appendix A

Integrated Risk Assessment Model

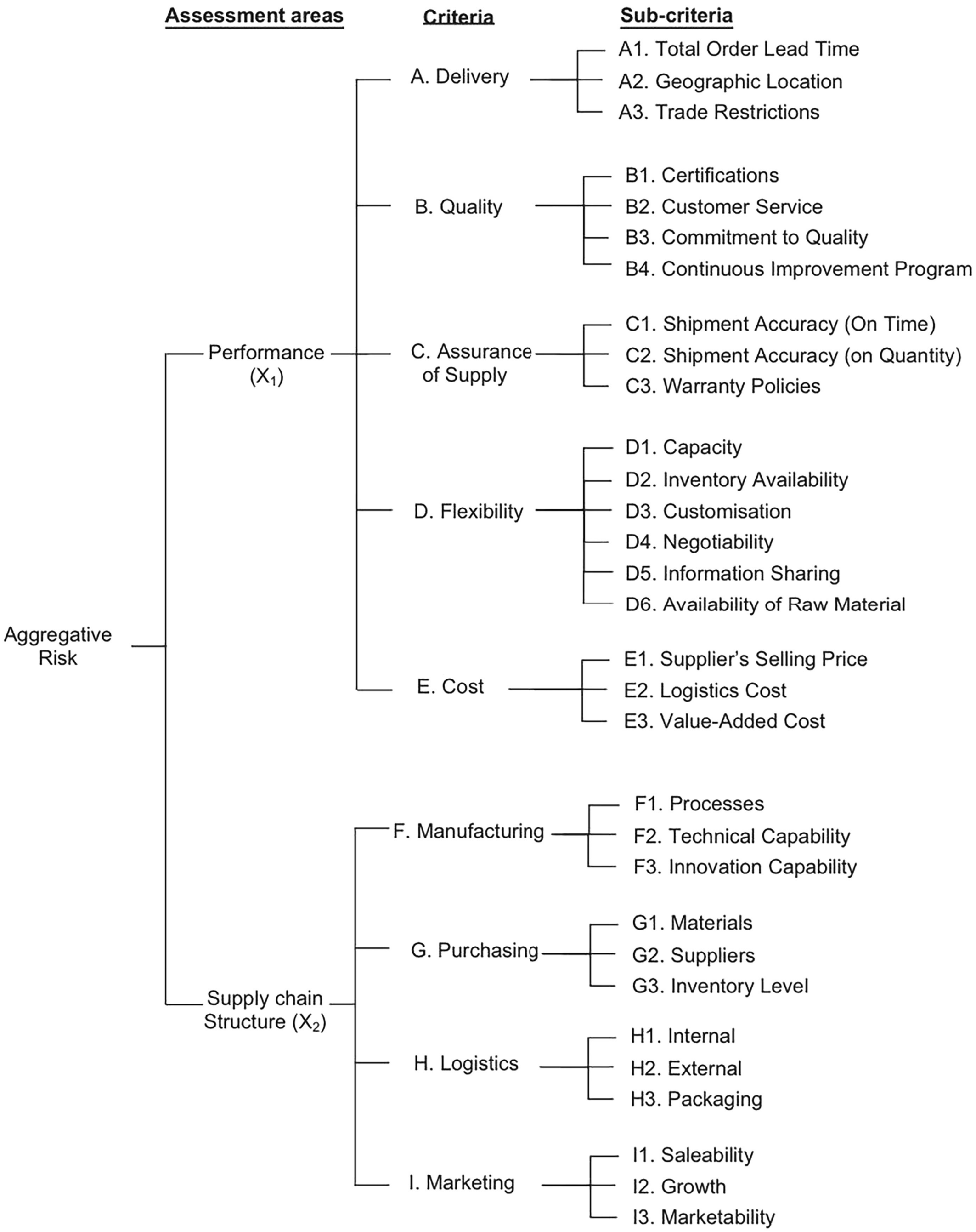

FIGURE A1 | Integrated risk assessment model for green initiatives (Wang et al. 2012).