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ORIGINAL RESEARCH

Causality of circular supply chain management in small and medium-sized enterprises using qualitative information: a waste management practices approach in Indonesia

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Abstract
Circular supply chain management (CSCM) is a promising way to achieve economic and environmental sustainability and address the waste problem. However, developing a fully circular supply chain system is costly and time-consuming, especially for small and medium-sized enterprises (SMEs). SMEs need to achieve better CSCM by implementing waste management practices. This study aims to (1) critically validate the hierarchical structure of CSCM for SMEs; (2) identify the causal interrelationships among the attributes; and (3) determine the practical attributes for SME improvement in Indonesia. An approach consisting of the fuzzy Delphi method (FDM), best worse method (BWM), and fuzzy decision-making trial and evaluation laboratory (FDEMATEL) is designed to fulfill the objectives of this study. The results show the hierarchical structure in CSCM implementation that benefit SMEs through performance improvement gains. Waste management practices and circular product design are causal aspects; in particular, waste management practices support SMEs in building CSCM as an alternative. The criteria to provide practical insights for CSCM in Indonesia are eco-design, sustainable product design, green technology, waste treatment capability, and designing for the environment.

Keywords Circular supply chain management · Waste management practices · Fuzzy Delphi method · Best worse method · Fuzzy decision-making trial and evaluation laboratory method

1 Introduction

In Indonesia, solid waste management problems threaten the country's long-term economic, social, and environmental survival (Ahangar et al., 2021; Kurniawan et al., 2022). Landfilling accounts for just 24.9% of total solid waste, with reduction, reuse, and recycling facilities accounting for only 0.8% (Ministry of Public Works and Public Housing of the Republic

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of Indonesia, 2021). Waste management needs to be practiced; however, waste management practices always face problems in improving solid waste reduction, reuse, and recycling. Circular supply chain management (CSCM) generates more economic benefits by reusing and recycling used materials and maximizing the usability of materials and resources by regaining their greatest environmental and economic value (Chen et al., 2023; Goyal et al., 2018; Lahanae et al., 2020). For instance, Lahane et al. (2020) noted that firms commonly make circles with forward linear supply chains, such as making-using-disposal, through a set of reverse actions, such as reusing, recycling, reproducing, or reconditioning raw resources and end-of-life goods, to utilize circular economy values. CSCM is used to manage waste to gain economic benefits for the industry. However, waste management practices in Indonesia are still lacking in terms of controlling the overall existing solid waste produced by factories and managed at landfills..

CSCM is supposed to be cost-effective for the producer by using a combination of reverse and forward logistics and managing waste or end-of-life products (Chen et al., 2021; Milios, 2021). The concept improves the sustainability and resilience of industrial supply chains while lowering the main needed resources (Baars et al., 2021; Mishra et al., 2023). For instance, Chen et al. (2021) claimed CSCM advantages in the circular economy model, including fostering opportunities to discuss the strength of environmentally friendly waste management practices and redesigning items to realize the process of dissembling and reintegrating productive business cycles in supply chains by developing a new business model (Xiong et al. (2022). CSCM is a promising way to achieve economic and environmental sustainability and address the waste problem. However, developing a fully circular supply chain system is costly and time-consuming, especially for small and medium-sized enterprises (SMEs). SMEs need to develop robust strategies to overcome these challenges by implementing waste management practices (Kharola et al., 2022; Thomas & Mishra, 2022). More specifically, this study argues that concerns for circular management disclosure become alarmingly high in SMEs, as these firms incessantly encounter resource constraints.

To overcome this challenge, firms need to utilize a waste management system to collect and separate waste. Silva et al. (2021) proposed that waste management system utilize solid waste as a resource for industrial products by circulating and recycling them into usable materials. Waste management practices can decrease the volume of natural materials used by reusing, recycling, or recovering items until they are no longer reusable (Andeobu et al., 2022; Mangla et al., 2018; Wangsa et al., 2023). CSCM improves resource allocation and waste separation and encourages sustainable production and consumption (Huang et al., 2022; Sarkar et al., 2022). Technically, used materials are separated into usable waste, which is placed in landfills. This study argues that waste management practices improve CSCM to achieve zero waste; in addition, these exchanged activities are subject to circular management disclosure among SMEs.

In the literature, CSCM is a model that encourages producers and sellers to take discarded materials and reuse them for resale or reproduction. The challenge for CSCM to function is that these activities are performed by different attributes; for instance, firms engage in cleaner production to minimize waste and emissions and maximize product output through source reduction strategies, and technology infusion/diffusion helps reduce or identify better choices in using materials and energy to avoid waste, wastewater generation and gaseous emissions (Farooque et al., 2022; Priyadarshini and Abhilash, 2020; Sarkar et al., 2022). In preventive strategies, a circular product design allows parts to contribute to the solution rather than to the problem regarding waste, increase a product's useful life and reduce energy and emissions (Wang et al., 2022). Circular management disclosure aligns information along multiple supply chains, and supply chain partners put their efforts together to implement

CSCM, such as by focusing on carbon emissions, reusable materials, pollutant emissions and social responsibility (Cui & Leonas., 2020; Fernando et al., 2022). Martin-Rios et al. (2020) emphasized that waste management practices in CSCM might be reduced by using technology, infrastructure, and facility restrictions. As a result, waste management practices can benefit CSCM as valid attributes.

CSCM attributes are described in qualitative data (Thomas & Mishra, 2022; Tseng et al., 2022). This study validates the set of measures using the fuzzy Delphi method (FDM) to screen out the less important attributes. The best worse method (BWM) is applied to validate the aspect group with consistency values. CSCM attributes are interrelated; hence, the fuzzy decision-making trial and evaluation laboratory (FDEMATEL) technique is utilized to visualize the cause-and-effect relationships (Ocampo et al. 2018; Tseng et al., 2021). In practice, this study also weighs the top practical criteria to improve CSCM performance. The objectives of this study are as follows:

Determine the CSCM valid attribute sets in qualitative data
Visualize aspects in the cause-effect model under uncertainties
Indicate the decisive criteria for SMEs' practical improvements in Indonesia

The contributions of this study are threefold as follows: (1) presenting CSCM attributes to construct a CSCM hierarchical structure using qualitative data; (2) visualizing the interrelationships among attributes under uncertainties; and (3) weighing the decisive criteria for practical improvements. There are six sections in this study. The first section sets the stage by providing background information on CSCM. Section two contains a literature review on CSCM, the proposed method and the measures. Section three describes the FDM and fuzzy DEMATEL employed in this study. The results are presented in the fourth section. The fifth section discusses the theoretical and practical implications. The conclusion, limitations and directions for further study are noted in the concluding section.

2 Literature review

This section discusses the theoretical perspectives on CSCM, the proposed methods and the proposed measures.

2.1 Circular supply chain management

CSCM is defined as the integration of circular thinking into the management of the supply chain and its surrounding industrial and natural ecosystems to achieve a zero-waste objective (Tseng et al., 2022; Mishra et al., 2023; Xiong et al., 2022). CSCM is used in conjunction with CE to create a supply chain concept that decreases waste, pollution, and carbon footprints while minimizing resource inputs (Nascimento et al., 2019). For instance, Batista et al. (2018) noted that CSCM links forward and reverse supply networks, strengthening the three criteria of organizational sustainability by adding value-generating components from commodities, byproducts, and positive waste flows across an extended life cycle. Bernon et al. (2018) added that CSCM is concerned with repairing and renewing natural resources to improve their utilization and collect source values. Farooque et al. (2019) clarified that system-wide innovation in business models and supply chain operations improves circularity capabilities. In addition, Chen et al. (2023) presented a multidimensional sustainable circular economy concept to integrate sustainability and a circular economy to enhance stakeholder awareness and launch sustainable production and consumption in industry practices. However, all stakeholders throughout a product's life cycle, including product producers, service providers, consumers, and users, are involved in all supply chain operations, from product design through end-of-life and waste management. In summary, a circular supply chain is obtained by combining the circular economy with the supply chain concept implemented in an organization that provides a valuable benefit to supply chain operation sustainability. The extant literature on the circular supply chain includes industrial scenarios and is not concerned with waste management practices merging with the supply chain. The supply chain has to integrate the circularity concept into daily operations.

In this context, CSCM is arguing to support circularity in firms and supply chain networks, and there is a need to present a reliable and robust methodology to examine the relative importance of key attributes of implementing CSCM in the industrial sector. CSCM presents novel opportunities for enhancing sustainability objectives in supply chain operations. The circular supply chain is projected to be more cost-effective for firms by combining reverse and forward logistics (Chen et al., 2021; Milios, 2021; Tseng et al., 2022). Xiong et al. (2022) argued that the circular supply chain aims to keep both goods and resources in their most usable condition in the organization by recovering their best economic and environmental values. Firms often loop the forward "make-use-disposal" linear supply chain through a series of reverse activities, such as reusing, recycling, remanufacturing, or reconditioning raw materials and end-of-life items or components. The role of CSCM in recovering economic and environmental value by keeping materials and resources at their highest utility is crucial to consider in the first stage prior to involving another aspect, such as the circular economy. Depending on firms' need to focus on different CSCM attributes, for instance, enabling technologies, performance indicators and best practices, firms could easily raise their knowledge about practices, methodologies, and technological solutions that may be helpful to support their CSCM activities.

2.2 Waste management practices

Waste management practices have become a crosscutting issue that has an impact on all three aspects of sustainability, namely, the environment, economics, and society (Goyal et al., 2018; Oliveira & Morais, 2021). Andeobu et al. (2022) noted that waste management is a complicated topic with several technological, sociological, ecological, and political issues. Poor waste management is thought to have a detrimental impact on people's health, the environment, and the economy of an area. Lin et al. (2022) posited that environmental protection is always a problematic topic with waste management practices because as civilizations evolve and demand grows, humans produce increasing amounts of garbage. Additionally, Mulya et al. (2022) stated that abandoned or inadequate waste management practices cause major issues, such as impairments in social health, ecological system degradation, biodiversity deficits, and negative economic and social implications. Therefore, if waste is not properly handled, waste management practices can be a serious problem for many aspects of human life. Waste management practices are fundamental before involving circular supply chain networks.

Solid waste includes garbage generated in local neighborhoods, business districts, industrial zones, or regular development areas, as well as rubbish generated during demolition processes and municipal services (Dutta & Jinsart, 2020; Wangsa et al., 2023). To utilize solid waste as a resource for making an industrial product, waste management practices play an important role by circulating and recycling resources into materials used. Economic studies in the past have focused heavily on the prospect of recycling to prevent resources from being exploited (UNEP, 2020). On the other hand, economists are beginning to consider the ability to recycle to minimize pollution from waste and greenhouse gas emissions. Given this new viewpoint, the concept of a circular economy arose as a feasible option for a more sustainable cradle-to-cradle economic model, which refers to a circular supply chain in which recycling is one of the foundations (Lafforgue & Lorang, 2022). As a result, waste management in the linear economy focuses solely on waste minimization; however, in the circular economy, trash is diverted for recycling, and recovered items are used as new products throughout society (Sarkar et al., 2022). The use of waste management practices is an alternative way to recycle and utilize garbage economically by achieving CSCM as a goal.

Waste management technology is well recognized as an innovative approach to meet challenges, enhance CSCM and provide digital solutions in circular management disclosures, process reengineering, and optimizing waste management practices to facilitate a sustainable competitive advantage (Albayati et al., 2020; Chen et al., 2021; Farooque et al., 2022). A circular product design introduces design principles based on circularity and life cycle assessment thinking using design concepts reflected in supply chain networks. This study argues that cleaner production management in processes, circular product design for remanufacturing, reuse and recycling, waste management practices for servitization and industrial symbiosis support CSCM implementation.

2.3 Challenges of this study

In CSCM, a large amount of waste generated by the community in an area is processed using waste management practices. However, recycling and reusing all rejected products in the same supply chain is difficult (Kurniawan et al., 2022). As a result, CSCM pushes the boundaries to discover the value of indirect waste not only inside but also across the supply chain with partners from the same industry and/or other industries so that it may eventually be correctly handled and exploited by the firm. In the linear economy, waste management focuses solely on waste minimization; however, in CSCM, garbage is diverted for recycling, and recovered items are used as new products. Priyadarshini and Abhilash (2020) asserted that CSCM is a system, method, or technique that operates at the industrial, eco-industrial, or regional level in that it emulates natural processes through recycling and waste reduction and elimination. Circular supply chains provide growth opportunities by recovering value from waste management systems through collaboration inside and between industries (Dulia et al., 2021). Therefore, the waste produced by the community in certain areas could be well treated to gain some benefit and help fully carry out CSCM.

Waste is thought to be an unnecessary byproduct of a linear economy model based on a "take, produce, and dispose" supply chain method, in which raw materials are utilized to manufacture goods and residuals are discarded after usage. It has been established that doing little or nothing to handle waste management incurs substantial costs on society, the environment, and the economy in general. In contrast, the development of economic circularity policies has supported the notion of "reusing, reducing, and recycling," ensuring energy and raw material savings, trash recycling, carbon emissions reductions and other advantages for industrial firms. Lahane and Kant (2021) stated that CSCM implementation in industrial firms has various advantages, including reduced negative environmental effects, improved resource efficiency, reduced energy use, improved product design, improved competitiveness, and improved social and economic benefits and job creation. In other words, in CSCM, trash is no longer viewed as a problem but as a new resource that can be recycled and sorted to ensure a zero-waste society (Goyal et al., 2018). Increased trash recycling and the abandonment of landfill use would result in reduced environmental consequences, lower energy usage, and lower economic impacts. As a result, CSCM objectives would have to be aligned with waste management methods and a reduction in the waste created.

In summary, CSCM implementation is vital to ensure that organizations develop operational systems compatible with the environment's ecosystem by minimizing waste, particularly in Indonesia. The firm needs waste management to reuse, reduce, and recycle solid products used by society to benefit the firm as a new resource related to the CSCM concept. CSCM adoption in solid waste management implemented by firms in Indonesia is necessary to achieve strategic benefits by generating new resources from recycled waste. Therefore, a waste management system that allows a firm to experience the more likely benefits offered by CSCM is required as an alternative that utilizes the solid waste of used products to reproduce another product and eventually builds the CSCM system by itself.

Regarding the nature of qualitative measures, Ocampo et al. (2018) employed FDM to reduce features and remove uncertainties based on expert judgments. Tseng et al. (2021) utilized the FDM to validate attributes before using a decision-making trial and evaluation laboratory technique. The study implemented a linguistic scale to collect experts' opinions. A test involving 30 experts yielded the valid qualities utilized in the questionnaire. The qualities utilized in the questionnaire were chosen after conducting a survey of other studies in the literature. After the conversation, respondents were asked to list the top five significant features within the waste management method that was an alternative to CSCM; the responses were then utilized to create the questionnaire. The FDM is applied to verify measurable qualities using qualitative data and language preferences (Ocampo et al., 2018). The literature validating the aspect group is lacking (Tseng et al., 2021). The BWM is applied to validate the group of criteria for each aspect. The fuzzy decision-making trial and evaluation laboratory (FDEMATEL) approach is employed to visualize the causal interrelationships among the attributes.

2.4 Proposed measures

This study is developed based on the implementation of solid waste management in Indonesia to propose a CSCM framework comprising cleaner production, circular product designs, waste management practices, circular management disclosures, and technology infusion and/or diffusion.

During industrial operations, cleaner production management (A1) plays a significant role in reducing water consumption, energy, virgin materials, and waste creation (Farooque et al., 2019). This aspect is a complex and preventative strategic countermeasure for the ongoing execution of industrial activities to boost the efficiency of the ecology and decrease the impact risks on people and the environment (Cui et al., 2022). For the production process to build the CSCM, cleaner production management in the waste management system necessitates the conservation of virgin materials and energy, reduced usage of harmful materials, and a reduction in toxicity and the amount of waste prior to its release into the environment. Cleaner production has generally been examined as a stand-alone practice, even though it is regarded as one of the core firm-level CSCM practices. On the other hand, there is a lack of knowledge about the role of the manufacturing process role in supply chain sustainability as part of an integrated strategy (Gu & Gao, 2021). As a result, a systems approach is needed, with cleaner manufacturing examined as part of CSCM.

A circular product design (A2) regarding waste allows items to be part of the solution rather than the problem (Mangla et al., 2018; Wang et al., 2022). A circular product design presents design ideas according to circularity and end-of-life considerations (i.e., a cradle-to-cradle approach) that differ from earlier design approaches expressed in the study of supply chain sustainability (Wang et al., 2022). The cradle-to-cradle method stresses product design to constantly enhance and eventually attain indeterminate resource cycling. Farooque et al. (2022) mentioned that circular product design techniques primarily aim to slow and close resource loops by developing long-life goods and prolonging their lifespans, retaining product integrity, and avoiding and reversing product or component obsolescence. As a result, a fundamental step in CSCM management is the ’circular product design’ in waste management systems.

The notion of waste as pollution is gradually giving way to the notion of waste as a resource that is recoverable, reusable, and recyclable—or even a source of energy (Laurent et al., 2014). Garbage management includes collecting waste from various sources, such as houses, streets, and business premises, storing it temporarily at specified locations, and transporting it to a landfill for eventual disposal (Lahane et al., 2020). Waste management practices (A3) aim to protect people and the environment, extend product life and reduce energy and space usage. Waste management processes are crucial for recirculating and recovering residual value within the product system since the purpose of this study is to achieve circularity in supply chains. Farooque (2022) mentioned that among the features are a system for managing circular resource flows via proper reuse, refurbishment, remanufacturing, and recycling methods, and a collection and treatment system to support them. In brief, waste management practices in circular supply chain adoption are necessary to recirculate the value within the system product.

The selection of suppliers, supplier alliance strategies, green certifications, and green procedures used by suppliers are all actions that allow suppliers to help firms achieve their sustainable development goals; circular procurement (A4) in solid waste management is crucial to CSCM operations (Bag et al., 2020). The component promotes the use of natural, nonvirgin, renewable, biodegradable/restorable, and nonhazardous materials in supply chains, contributing to energy and material loop closure (European Commission, 2021). Bag et al. (2020) mentioned that circular procurement might practically lead to vertical and horizontal cooperation aimed at generating flows of circular resources, introducing new procurement channels, and lowering costs by sharing and reusing resources. In summary, a firm’s ability to practice remanufacturing and recycling-based activities in its solid waste management system is completely contingent on how it handles procurement and logistical flows to create CSCM (Lafforgue & Lorang, 2022).

According to Wijewickrama et al. (2021), reverse logistics (A5) refers to a set of operations that must be completed to collect used items and resources from clients. The aspect addresses material movements in the opposite direction of the primary flow, with consequences that distinguish it from the resource forward flow (Lin et al., 2022). The process by which a manufacturer recovers previously delivered goods or components from the point of consumption for recycling, remanufacturing, or disposal is known as reverse logistics (Lin et al., 2022). Therefore, reverse logistics may be viewed as a complex process that covers a wide range of activities and decisions that, in this study, are classified into strategic, tactical, and operational considerations. As a result, in a circular supply chain, reverse logistics is a vital function for returning end-of-life products to upstream supply chain actors for reuse and the recovery of value. In summary, reverse logistics in waste management is necessary to optimize circular supply chain implementation.

The industry is increasingly being transformed by digital technologies, which are described as manufacturing tools, systems, devices, and resources that can produce, store, or analyze data (Lyu & Liu, 2021). Digital technology (A6), such as information and communication technology, artificial intelligence, big data technology, and cloud technology, has enabled the creation of new educational goods, including software, platforms, and gadgets. To ensure maximum circular supply chain implementation toward solid waste management, the use of advanced digital technology is considered. Sarkar et al. (2022) emphasized that advanced digital technologies, such as Internet of Things and blockchain technology—key enablers of the CSCM implementation—may be able to assist firms in improving supply chain traceability and transparency. As a result, modern digital waste management technology is seen as a key component in accomplishing CSCM objectives.

The CSCM concept is based on waste and pollution reduction, environmentally conscious behavior, and smart incentive schemes for all stakeholders, including suppliers, manufacturers, and customers (Cui & Leonas, 2020). Under circular supply chain management disclosure (A7), all types of information, such as carbon emissions, corporate responsibility, and pollutant emissions, must be delivered on a timely basis in the supply chain (Cui & Leonas, 2020). Gunarathne et al. (2021) mentioned that corporate communication, especially in the context of CSCM, refers to the techniques through which a corporation communicates its performance and position to its internal and external stakeholders. Organizations can utilize disclosure frameworks to offer nonfinancial data that have been examined, compared, and verified in accordance with national and/or international standards (European Commission, 2021). Opferkuch (2022) also supported the concept that the importance of disclosure frameworks in CSCM implementation can influence how a firm develops and manages its sustainability goals and strategy. Therefore, it is important to include circular management disclosure in this study.

Technology infusion and diffusion (A8) in CSCM is a method for decreasing waste in all phases of the manufacturing process—from preharvest activities through final product production. The recovery of waste through technology diffusion to allow for the recycling of recovered resources is an important component. Recirculation decreases the need to extract virgin resources, eliminates pollution, and offers some financial advantages by transforming waste into useful resources for recreating the product (Martin-Rios et al., 2020). Additionally, Kharola (2022) stated that waste reduction in CSCM may be achieved using certain technology diffusion. Magnusson (2022) mentioned that waste may be reduced using technology, infrastructure, and facility restrictions since different types of trash must be handled for various reasons to achieve optimal reduction or usage, particularly in CSCM. On the other hand, Mulya et al. (2022) added that the existence and diffusion of technology in CSCM may result in changes in business practices or the demise of established industries. Waste may be reduced early in the planning phase to gain economic and environmental benefits from CSCM implementation in the sector by addressing ground-level constraints, such as sustaining technical diffusion, skills, productivity, and training.

3 Method

This section includes the study background and proposed methods, including the FDM, BWM, and FDEMATEL.

3.1 Study background

The Indonesian Ministry of Environment and Forestry has enacted legislation requiring industry to engage in the waste management of the items it produces (Kuo et al., 2021; Statistics of Indonesia, 2020). Indonesia generates significant quantities of garbage, pollution, and carbon emissions on a daily basis and produces 64 million tons of garbage each year, with biodegradable organic waste accounting for 60%, plastics accounting for 14%, and paper accounting for 9% (Tseng et al., 2020). However, only 24.9% of total solid waste is landfilled, and only 0.8% is managed by reducing, reusing, and recycling facilities from a technical standpoint (Ministry of Public Works and Public Housing of Republic of Indonesia, 2021). In this case, waste management practices are applicable as an alternative to building CSCM, as supported by the existence of volumes of waste generated annually in Indonesia. Indonesia has steadily transitioned from a linear to a circular economy by using CSCM in waste management practices, which encourages resource recovery through recycling and trash reduction in the linear economy. CSCM is at the center of the government's attention in providing value to society, especially regarding environmental and economic aspects.

SMEs face problems operating CSCM due to its costly and time-consuming implementation (Milios, 2021). CSCM in Indonesia has failed to achieve an effective resource recovery and waste reduction operation, and it is declared that this is due to high operating costs and time flow constraints. The implementation is in terms of gaining financial growth within the firm, particularly when generating profits through the recycling process. CSCM aims to recover the highest economic and environmental value from materials and resources to optimize their usage. However, the implementation costs in terms of high budgets force firms—especially SMEs in Indonesia—to find an alternative to CSCM to generate similar benefits. The original attributes were scrutinized, and a large proportion of these attributes were rejected based on their response to screening items (see Appendix 1), response patterns and missing data. Overall, these efforts ensured the rigor of the data collection process for obtaining qualitative data. An SME expert sample of 30 respondents was considered for use in the analysis. The consistency value presented the valid group for each group. Appendix 2 provides a summary of the sample distribution. Demographic details are presented. Figure 1 shows the CSCM aspects in Indonesia.

3.2 Fuzzy Delphi Method

To enhance the validity of the questionnaire, this study asks experts to screen out the criteria based on their knowledge and experience by utilizing linguistic terms. However, these linguistic terms possess a qualitative feature that cannot directly be used in the computation (Bui et al., 2020). Addressing this limitation, this study integrates fuzzy set theory and the Delphi method to obtain screening criteria for further discussions. Assuming that there are x expert numbers that screen out y criteria, these experts' linguistic terms can be denoted as S_{xy}. However, these terms also need to be contrasted with those in Table 1 to be converted into corresponding triangular fuzzy numbers for further evaluation. Accordingly, these linguistic terms can be rewritten as the following equation.

$$S_{xy} = \left(\ell_{xy}, m_{xy}, r_{xy}\right) \tag{1}$$

The following equation is used to obtain the weightage of the criteria.

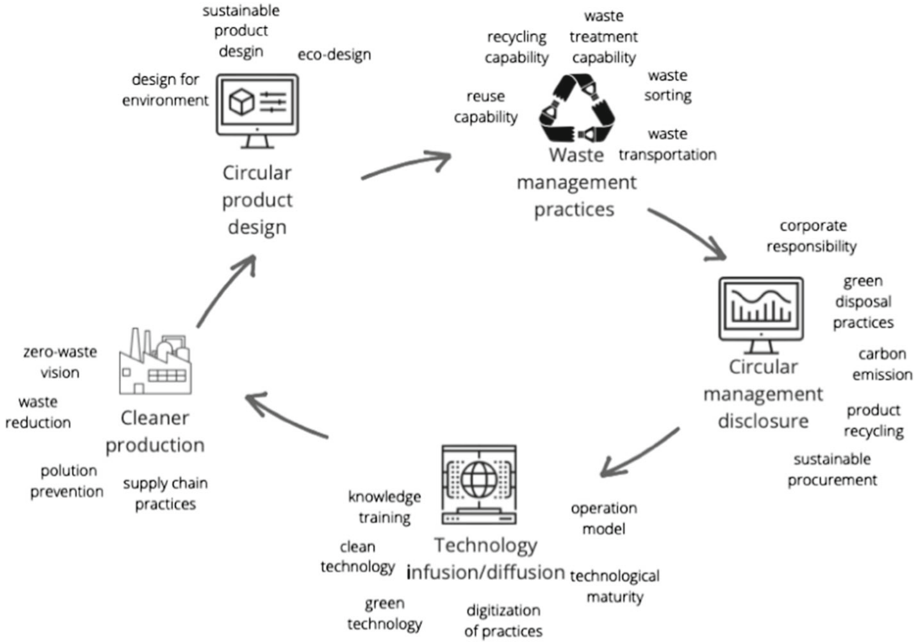

Fig. 1 CSCM for SMEs in Indonesia

Table 1 FDM language word transformation

Linguistic terms (performance/importance)	Corresponding triangular fuzzy numbers (TFNs)
Extreme	(0.75, 1.0, 1.0)
Demonstrated	(0.5, 0.75, 1.0)
Strong	(0.25, 0.5, 0.75)
Moderate	(0, 0.25, 0.5)
Equal	(0, 0, 0.25)

$$W_y = \left[\min\left(\ell_{xy}\right), \left(\prod_{1}^{x} m_{xy}\right)^{\frac{1}{x}}, \max\left(r_{xy}\right)\right] = \left(w_y^{\ell}, w_y^{m}, w_y^{r}\right) \tag{2}$$

Subsequently, the convex integration method generates the value by applying the α cut, as presented in the equations below.

$$L_y = w_y^r - \alpha\left(w_y^r - w_y^m\right) \tag{3}$$

$$R_y = w_y^{\ell} - \alpha\left(w_y^m - w_y^{\ell}\right) \tag{4}$$

where $\alpha = 0.5$ is presented as the common situation, and $\alpha = [0, 1]$ can be used to represent the positive or negative opinions of experts.

After convex integration, the following equation is applied to obtain the precise value.

$$P_y = \int\left(L_y, R_y\right) = \tau \times \left[L_y + (1 - \tau) \times R_y\right] \tag{5}$$

where τ represents the optimistic level of the decision maker balancing the assessments among the entire expert group.

The following equation calculates the threshold value for identifying the necessary criteria.

$$\delta = \sum \left(\frac{P_y}{x} \right) \tag{6}$$

If $P_y \geq \delta$, the y^{th} criterion is the necessary one; otherwise, the criterion needs to be eliminated.

3.3 Best–Worst Method

After screening the necessary criteria, these remaining criteria need to be compared in parallel by asking experts to assess their importance based on their knowledge and experience. However, these assessments cause the consistency issue that has been argued in previous studies (Rezaei, 2015; Zhang et al., 2017). To address this critical issue, Rezaei (2015) and Rezaei (2016) proposed the best–worst method (BWM) by utilizing less information to enhance the consistency of the assessments. First, identifying the best criterion over all of the criteria by using a scale from 1 to 9 to present it and these best-to-other results can be presented as the following equation.

$$B_{\overline{y}} = \left[b_{\overline{y}1}, b_{\overline{y}2}, \cdots, b_{\overline{y}\beta} \right] \tag{7}$$

$b_{\overline{y}z}$ represents the best remaining $\overline{y}^{th}$ criterion over criterion β^{th}.

Next, using a similar concept from the first step to determine the worst criterion, the other-to-worst results can be denoted as

$$W_{\tilde{y}} = \left[\omega_{1\tilde{y}}, \omega_{2\tilde{y}}, \cdots, \omega_{\gamma\tilde{y}} \right]^{'} \tag{8}$$

$\omega_{\gamma\overline{y}}$ shows the remaining γ^{th} criterion over the worst $\tilde{y}^{th}$ criterion. Moreover, $b_{\overline{yy}}$ and $\omega_{\tilde{y}\tilde{y}}$ are equal to 1 in Eqs. (7) and (8).

The following equations adopt the linear model and min–max method to acquire the set of $\left\{ \left| \frac{b_{\overline{y}}}{b_\beta} \right|, \left| \frac{\omega_\gamma}{\omega_{\tilde{y}}} \right| \right\}$.

$$\max absolutedifference = \left\{ \left| C_\beta - b_{\overline{y}\beta} \right|, \left| D_\gamma - \omega_{\gamma\tilde{y}} \right| \right\} \tag{9}$$

where $C_\beta = \left| \frac{b_{\overline{y}}}{b_\beta} \right|$ and $D_\gamma = \left| \frac{\omega_\gamma}{\omega_{\tilde{y}}} \right|$.

These acquired values are arranged into the min–max model using the equation below.

$$\begin{cases} \min \max(\beta) \left\{ \left| C_\beta - b_{\bar{y}\beta} \right|, \left| D_\gamma - \omega_{\gamma\tilde{y}} \right| \right\} \\ \sum\limits_\beta b_\beta = 1 \text{ and } \sum\limits_\gamma \omega_\gamma = 1 \end{cases} \tag{10}$$

Adopting the linear programming model provides the optimal weights via the following equation.

$$\begin{cases} \min \pi \\ \left| b_{\bar{y}} - b_\beta b_{\bar{y}\beta} \right| \leq \mu, \left| \omega_\gamma - \omega_{\tilde{y}} \omega_{\gamma\tilde{y}} \right| \leq \pi \\ \sum\limits_\beta b_\beta = 1 and \sum\limits_\gamma \omega_\gamma = 1, b_\beta, \omega_\gamma \geq 0 \end{cases} \tag{11}$$

Accordingly, the optimal weights b_β, ω_γ in the ideal weight of π can be obtained. For $\mu \in (0, 1)$, a value close to zero expresses higher consistency; in contrast, a value close to 1 indicates inconsistency.

3.4 Fuzzy DEMATEL

DEMATEL enables the identification of the causal interrelationships among the screened-out criteria by transforming the experts' linguistic terms into quantitative data by associating them with fuzzy set theory (Tseng et al., 2021; Wu et al., 2021). This transformation relies on fuzzy set theory to defuzzify triangular fuzzy numbers into clear values. Suppose that expert assessments can be denoted as A_{op}^{δ}, which means that the o^{th} criterion affects the p^{th} criterion assessed by the δ^{th} expert. Then, these presented linguistic terms need to be contrasted with those in Table 2 to be transferred into corresponding triangular fuzzy numbers, which can be presented as the following equation.

$$A_{op}^{\delta} = \left(a_{op}^{\ell\delta}, a_{op}^{m\delta}, a_{op}^{r\delta}\right) \tag{12}$$

These obtained corresponding triangular fuzzy numbers need to be applied to the following equation for normalization.

$$\overline{A}_{op}^{\delta} = \left(\overline{a}_{op}^{\ell\delta}, \overline{a}_{op}^{m\delta}, \overline{a}_{op}^{r\delta}\right) = \left[\frac{\left(a_{op}^{\ell\delta} - \min a_{op}^{\ell\delta}\right)}{\theta}, \frac{\left(a_{op}^{m\delta} - \min a_{op}^{m\delta}\right)}{\theta}, \frac{\left(a_{op}^{r\delta} - \min a_{op}^{r\delta}\right)}{\theta}\right] \tag{13}$$

where $\theta = \max a_{op}^{r\delta} - \min a_{op}^{\ell\delta}$

The equations below are used to calculate the left $\left(\overline{L}_{op}^{\delta}\right)$ and right $\left(\overline{R}_{op}^{\delta}\right)$ normalized values.

$$\overline{L}_{op}^{\delta} = \frac{\overline{a}_{op}^{m\delta}}{\left(1 + \overline{a}_{op}^{m\delta} - \overline{a}_{op}^{\ell\delta}\right)} \tag{14}$$

$$\overline{R}_{op}^{\delta} = \frac{\overline{a}_{op}^{r\delta}}{\left(1 + \overline{a}_{op}^{r\delta} - \overline{a}_{op}^{m\delta}\right)} \tag{15}$$

Adopting the following equation generates clear values.

$$I_{op}^{\delta} = \frac{\left[\overline{L}_{op}^{\delta} \times \left(1 - \overline{L}_{op}^{\delta}\right) + \overline{R}_{op}^{\delta} \times \overline{R}_{op}^{\delta}\right]}{\left(1 - \overline{L}_{op}^{\delta} + \overline{R}_{op}^{\delta}\right)} \tag{16}$$

Table 2 TFN's FDEMATEL language scale

Scale	Linguistic terms	Corresponding TFNs
1	No influence	(0.0, 0.1, 0.3)
2	Low influence	(0.1, 0.3, 0.5)
3	Moderate influence	(0.3, 0.5, 0.7)
4	High influence	(0.5, 0.7, 0.9)
5	Very high influence	(0.7, 0.9, 1.0)

Aggregating these generated clear values into a direct relation matrix utilizes the following equation.

$$J = \frac{\sum_1^{\delta} I_{op}^{\delta}}{\delta} = \left[j_{op} \right]_{z \times z} \tag{17}$$

where z represents the number of remaining criteria after the FDM screening-out process.

The following equations are used to generate the total interrelationship matrix.

$$\overline{J} = \frac{j_{op}}{\max\limits_{1 \le o \le z} j_o} \tag{18}$$

$$T = \overline{J} \times \left(U - \overline{J} \right)^{-1} = \left[t_{op} \right]_{z \times z} \tag{19}$$

where U represents the unit matrix.

Subsequently, the dependence (H) and driving (V) power are generated from the following equations.

$$H = \left[\sum_{o=1}^{z} t_{op} \right]_{z \times 1} = [t_o]_{z \times 1} \tag{20}$$

$$V = \left[\sum_{p=1}^{z} t_{op} \right]_{1 \times \mathrm{z}} = \left[t_p \right]_{1 \times \mathrm{z}} \tag{21}$$

The cause-and-effect diagram is drawn by mapping the screened-out criteria in accordance with the coordinate $(H + V, H - V)$. $(H + V)$ is the x axis that represents the importance of the criteria. Then, $(H - V)$ is the y axis that can diagnose the criteria in the cause and effect group. If $(H - V) > 0$, the criterion possesses the causal feature; conversely, the criterion has the effect feature.

4 Analytical results

1. Initially, this study proposed 8 aspects and 43 criteria to assist SMEs in assessing their CSCM (as shown in Appendix 1). However, these proposed attributes rely on expert assessments to enhance validity. Table 3 presents the screened-out result by employing Eqs. (1) to (6). Therefore, the circular procurement (A4), reverse logistics (A5), and technology infusion/diffusion (A8) aspects are not able to pass the threshold value in accordance with the experts' assessments. Moreover, 23 out of the 43 criteria passed the threshold value $\delta = 0.5904$. The passing rate is 53.5% by utilizing the FDM method.

To address the consistency issue presented in previous studies, this study utilizes the BWM to confirm the consistency. Table 4 shows the consistency result obtained by applying Eqs. (7) to (11). Therefore, μ is used to identify the consistency. A μ close to zero indicates that the experts' assessments have higher consistency. Accordingly, the obtained BWM results expressed that the analytical results possess higher consistency for further discussion and address the previous consistency concern.

Equations (12) to (17) are used to aggregate clear values from 30 experts into a direct relation matrix, as presented in Table 5. Therefore, the computation of C1 is $\frac{\sum_1^{30} I_{C1C1}^{30}}{30} =$

Table 3 The FDM result

Criteria	P_y	Screened-out Result
C1	0.6715	Accepted
C2	0.6113	Accepted
C3	0.6681	Accepted
C4	0.6009	Accepted
C5	0.6866	Accepted
C6	0.6852	Accepted
C7	0.6856	Accepted
C8	0.5817	Unaccepted
C9	0.6966	Accepted
C10	0.5817	Unaccepted
C11	0.5968	Accepted
C12	0.6862	Accepted
C13	0.5986	Accepted
C14	0.5909	Accepted
C15	0.5891	Unaccepted
C16	0.3333	Unaccepted
C17	0.5526	Unaccepted
C18	0.6655	Accepted
C19	0.5745	Unaccepted
C20	0.5941	Accepted
C21	0.3333	Unaccepted
C22	0.5817	Unaccepted
C23	0.5878	Unaccepted
C24	0.5724	Unaccepted
C25	0.5695	Unaccepted
C26	0.5736	Unaccepted
C27	0.3333	Unaccepted
C28	0.5878	Unaccepted
C29	0.3333	Unaccepted
C30	0.3333	Unaccepted
C31	0.5639	Unaccepted
C32	0.6908	Accepted
C33	0.5639	Unaccepted
C34	0.5627	Unaccepted
C35	0.6694	Accepted
C36	0.6672	Accepted
C37	0.6769	Accepted
C38	0.5922	Accepted
C39	0.6913	Accepted
C40	0.5804	Unaccepted
C41	0.6956	Accepted

Table 3 (continued)

Criteria	P_y	Screened-out Result
C42	0.6797	Accepted
C43	0.6956	Accepted
Threshold (δ)	0.5904	

Table 4 The results of the BWM consistency test

Aspects	Criteria	b_β, ω_γ	Ranking	μ	
Cleaner Production management (A1)	C1	Zero-waste visions	0.276	1	0.045
	C2	Waste reduction	0.253	2	
	C3	Supply chain practices	0.192	3	
	C4	Pollution prevention	0.177	4	
Circular product design (A2)	C5	Eco-design	0.285	1	0.032
	C6	Design for environment	0.238	2	
	C7	Sustainable product design	0.169	3	
Waste management practices (A3)	C10	Waste treatment capability	0.296	1	0.043
	C9	Reuse capability	0.278	2	
	C11	Waste sorting	0.175	3	
	C8	Recycling capability	0.098	4	
	C12	Waste transportation	0.065	5	
Circular management disclosure (A4)	C17	Carbon emissions	0.268	1	0.038
	C14	Product recycling	0.231	2	
	C15	Corporate responsibility	0.165	3	
	C16	Green Disposal practices	0.088	4	
	C13	Sustainable procurement	0.072	5	
Technology infusion/diffusion (A5)	C18	Green technology	0.307	1	0.025
	C20	Clean technology	0.271	2	
	C19	Digitization of practice	0.185	3	
	C21	Knowledge training	0.109	4	
	C22	Operation model	0.085	5	
	C23	Technological maturity	0.077	6	

$$\frac{\left(\begin{array}{l}0.673+0.678+1.000+0.120+0.667+0.720+0.673+0.678+0.500\\+0.300+0.667+0.720+0.667+0.720+1.000+0.720+0.743+0.720\\+0.743+0.743+0.743+0.743+0.743\\+0.743+0.667+0.720+0.743+0.743+0.720+0.720)\end{array}\right)}{30} =$$

0.769, as marked in bold font. Table 6 presents the total interrelationship matrix by employing Eqs. (18) to (21). Then, the criteria are arranged based on the coordinate $(H+V, H-V)$ to draw the cause and effect diagram for the criteria, as shown in Fig. 2. The y axis $(H-V)$ categorizes the criteria into two groups: $(H-V) > 0$ is the causal

Table 5 The direct relationship from aggregating clear values

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	**0.769**	0.648	0.561	0.540	0.494	0.550	0.589	0.604	0.549	0.550	0.555	0.539
C2	0.660	0.769	0.643	0.639	0.546	0.586	0.635	0.615	0.550	0.608	0.655	0.605
C3	0.532	0.473	0.729	0.497	0.386	0.434	0.533	0.490	0.453	0.466	0.489	0.451
C4	0.571	0.564	0.501	0.760	0.488	0.576	0.510	0.492	0.582	0.508	0.553	0.600
C5	0.621	0.631	0.560	0.573	0.736	0.512	0.593	0.634	0.649	0.620	0.655	0.594
C6	0.601	0.569	0.567	0.639	0.631	0.742	0.525	0.639	0.641	0.557	0.554	0.606
C7	0.640	0.672	0.506	0.599	0.671	0.577	0.734	0.540	0.643	0.613	0.570	0.527
C8	0.571	0.606	0.531	0.518	0.494	0.576	0.466	0.750	0.449	0.519	0.589	0.395
C9	0.552	0.617	0.531	0.482	0.533	0.619	0.528	0.539	0.754	0.545	0.582	0.527
C10	0.626	0.611	0.623	0.553	0.588	0.605	0.553	0.608	0.550	0.728	0.568	0.567
C11	0.594	0.610	0.600	0.572	0.646	0.541	0.497	0.624	0.602	0.579	0.749	0.517
C12	0.538	0.450	0.490	0.418	0.428	0.427	0.480	0.432	0.480	0.496	0.545	0.757
C13	0.552	0.472	0.469	0.406	0.405	0.394	0.409	0.363	0.429	0.437	0.474	0.413
C14	0.476	0.406	0.424	0.351	0.325	0.334	0.390	0.410	0.340	0.370	0.466	0.353
C15	0.508	0.485	0.458	0.510	0.462	0.507	0.456	0.521	0.469	0.476	0.551	0.495
C16	0.551	0.600	0.503	0.542	0.494	0.583	0.544	0.569	0.554	0.608	0.490	0.524
C17	0.522	0.508	0.514	0.582	0.571	0.538	0.581	0.576	0.530	0.512	0.644	0.571
C18	0.627	0.582	0.572	0.520	0.512	0.613	0.614	0.521	0.616	0.467	0.589	0.601
C19	0.550	0.418	0.540	0.505	0.481	0.534	0.532	0.435	0.551	0.456	0.522	0.456
C20	0.530	0.545	0.464	0.506	0.528	0.560	0.469	0.550	0.563	0.513	0.534	0.512
C21	0.540	0.599	0.594	0.586	0.641	0.616	0.582	0.602	0.600	0.630	0.648	0.592
C22	0.499	0.557	0.535	0.475	0.507	0.530	0.439	0.468	0.529	0.441	0.536	0.478

Table 5 (continued)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C23	0.528	0.459	0.415	0.379	0.426	0.381	0.345	0.431	0.455	0.493	0.414	0.447
	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	$\max\limits_{1\le o\le z} j_o$
C1	0.472	0.414	0.480	0.526	0.543	0.557	0.442	0.515	0.332	0.446	0.455	12.130
C2	0.538	0.475	0.527	0.672	0.562	0.574	0.460	0.483	0.650	0.563	0.518	13.535
C3	0.448	0.348	0.429	0.460	0.442	0.451	0.326	0.407	0.441	0.412	0.325	10.422
C4	0.452	0.378	0.470	0.513	0.544	0.486	0.311	0.510	0.596	0.488	0.445	11.899
C5	0.578	0.474	0.557	0.577	0.596	0.614	0.430	0.585	0.657	0.483	0.520	13.449
C6	0.572	0.485	0.528	0.581	0.591	0.633	0.318	0.584	0.500	0.541	0.421	13.025
C7	0.530	0.455	0.534	0.596	0.595	0.614	0.414	0.476	0.621	0.596	0.572	13.296
C8	0.530	0.317	0.438	0.519	0.503	0.549	0.312	0.480	0.478	0.523	0.581	11.693
C9	0.521	0.415	0.521	0.535	0.436	0.526	0.308	0.514	0.506	0.494	0.381	11.965
C10	0.585	0.469	0.501	0.632	0.575	0.560	0.346	0.512	0.547	0.550	0.579	13.036
C11	0.548	0.542	0.541	0.559	0.478	0.573	0.369	0.508	0.552	0.520	0.551	12.871
C12	0.458	0.400	0.387	0.474	0.458	0.432	0.254	0.434	0.409	0.420	0.359	10.427
C13	1.000	0.383	0.430	0.469	0.418	0.483	0.248	0.471	0.428	0.462	0.444	10.463
C14	0.392	0.778	0.377	0.397	0.376	0.417	0.226	0.439	0.338	0.375	0.411	9.172
C15	0.561	0.489	0.741	0.496	0.544	0.482	0.334	0.503	0.466	0.497	0.383	11.396
C16	0.534	0.476	0.526	0.726	0.511	0.502	0.315	0.527	0.508	0.469	0.419	12.075
C17	0.607	0.523	0.591	0.589	0.770	0.554	0.306	0.550	0.553	0.528	0.510	12.729
C18	0.588	0.574	0.519	0.619	0.628	0.752	0.380	0.568	0.619	0.623	0.651	13.357

Table 5 (continued)

	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	$\max_{1\le o\le z} j_o$
C19	0.537	0.389	0.437	0.607	0.556	0.495	0.755	0.572	0.548	0.490	0.555	11.918
C20	0.570	0.454	0.459	0.559	0.505	0.601	0.293	0.746	0.502	0.460	0.594	12.019
C21	0.659	0.554	0.596	0.641	0.605	0.630	0.514	0.656	0.750	0.625	0.594	14.056
C22	0.470	0.298	0.477	0.465	0.469	0.453	0.369	0.455	0.473	0.753	0.553	11.231
C23	0.542	0.280	0.469	0.486	0.516	0.497	0.413	0.500	0.558	0.503	0.771	10.710

Table 6 Total interrelationship matrix for criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C1	0.304	0.291	0.273	0.269	0.262	0.273	0.269	0.279	0.276	0.270	0.284	0.268
C2	0.326	0.328	0.307	0.303	0.293	0.303	0.300	0.307	0.305	0.302	0.321	0.300
C3	0.252	0.243	0.252	0.233	0.222	0.231	0.233	0.237	0.236	0.231	0.245	0.229
C4	0.286	0.280	0.265	0.281	0.258	0.271	0.260	0.267	0.275	0.264	0.280	0.269
C5	0.321	0.317	0.299	0.297	0.305	0.296	0.295	0.307	0.310	0.301	0.319	0.298
C6	0.311	0.303	0.291	0.293	0.289	0.304	0.282	0.299	0.301	0.288	0.303	0.290
C7	0.320	0.317	0.293	0.296	0.298	0.299	0.303	0.298	0.307	0.298	0.310	0.291
C8	0.282	0.279	0.263	0.259	0.255	0.267	0.253	0.281	0.261	0.260	0.278	0.250
C9	0.286	0.286	0.269	0.262	0.263	0.275	0.262	0.271	0.289	0.267	0.284	0.265
C10	0.312	0.306	0.295	0.287	0.286	0.294	0.283	0.297	0.294	0.300	0.303	0.287
C11	0.307	0.303	0.290	0.285	0.287	0.286	0.276	0.294	0.295	0.286	0.313	0.280
C12	0.252	0.241	0.235	0.227	0.225	0.230	0.229	0.232	0.237	0.233	0.248	0.251
C13	0.253	0.242	0.233	0.225	0.223	0.227	0.223	0.227	0.233	0.229	0.243	0.226
C14	0.220	0.211	0.204	0.196	0.192	0.198	0.197	0.205	0.201	0.198	0.216	0.196
C15	0.269	0.263	0.251	0.252	0.245	0.255	0.245	0.258	0.255	0.250	0.268	0.250
C16	0.287	0.286	0.268	0.268	0.261	0.274	0.265	0.275	0.276	0.274	0.279	0.266
C17	0.298	0.292	0.281	0.283	0.279	0.283	0.279	0.288	0.286	0.279	0.303	0.282
C18	0.318	0.310	0.297	0.290	0.286	0.300	0.293	0.296	0.305	0.287	0.311	0.295
C19	0.284	0.269	0.267	0.262	0.257	0.267	0.261	0.262	0.272	0.259	0.277	0.258
C20	0.284	0.281	0.264	0.264	0.262	0.271	0.258	0.272	0.275	0.265	0.280	0.264
C21	0.327	0.326	0.313	0.308	0.309	0.315	0.305	0.316	0.318	0.313	0.330	0.308
C22	0.266	0.266	0.254	0.247	0.246	0.254	0.241	0.251	0.257	0.245	0.265	0.247

Table 6 (continued)

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
C23	0.257	0.248	0.235	0.229	0.230	0.233	0.224	0.238	0.241	0.239	0.245	0.234
V	6.622	6.487	6.199	6.115	6.035	6.207	6.036	6.257	6.305	6.141	6.504	6.105
	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	H
C1	0.273	0.225	0.252	0.278	0.269	0.275	0.189	0.263	0.251	0.255	0.251	6.101
C2	0.307	0.252	0.281	0.316	0.298	0.304	0.209	0.287	0.301	0.290	0.281	6.821
C3	0.238	0.192	0.218	0.239	0.229	0.234	0.158	0.223	0.226	0.221	0.210	5.232
C4	0.268	0.219	0.248	0.272	0.266	0.266	0.177	0.259	0.266	0.254	0.246	5.996
C5	0.308	0.251	0.282	0.308	0.299	0.306	0.206	0.293	0.300	0.283	0.280	6.783
C6	0.299	0.244	0.272	0.299	0.290	0.298	0.191	0.284	0.280	0.278	0.264	6.552
C7	0.302	0.248	0.278	0.307	0.297	0.303	0.203	0.283	0.295	0.289	0.281	6.717
C8	0.270	0.211	0.242	0.269	0.259	0.267	0.174	0.253	0.254	0.253	0.253	5.892
C9	0.274	0.223	0.253	0.275	0.259	0.270	0.177	0.260	0.261	0.256	0.242	6.028
C10	0.300	0.243	0.270	0.303	0.289	0.293	0.194	0.279	0.283	0.279	0.276	6.555
C11	0.293	0.246	0.270	0.294	0.279	0.290	0.193	0.276	0.280	0.274	0.271	6.468
C12	0.238	0.196	0.214	0.239	0.230	0.232	0.152	0.224	0.223	0.221	0.212	5.222
C13	0.278	0.194	0.217	0.239	0.227	0.236	0.152	0.227	0.225	0.224	0.218	5.220
C14	0.207	0.202	0.189	0.207	0.199	0.205	0.133	0.200	0.193	0.193	0.192	4.553
C15	0.265	0.218	0.257	0.260	0.255	0.255	0.171	0.247	0.246	0.244	0.231	5.709
C16	0.277	0.229	0.255	0.291	0.266	0.270	0.179	0.263	0.262	0.256	0.247	6.074
C17	0.295	0.242	0.271	0.293	0.297	0.286	0.186	0.276	0.277	0.272	0.265	6.393

Table 6 (continued)

	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	*H*
C18	0.306	0.256	0.277	0.308	0.298	0.312	0.200	0.289	0.294	0.290	0.286	6.704
C19	0.274	0.219	0.245	0.279	0.266	0.266	0.209	0.263	0.262	0.254	0.254	5.987
C20	0.278	0.226	0.249	0.277	0.264	0.276	0.176	0.277	0.261	0.254	0.259	6.038
C21	0.325	0.266	0.295	0.324	0.310	0.318	0.219	0.309	0.317	0.303	0.295	7.068
C22	0.255	0.201	0.236	0.255	0.247	0.250	0.172	0.241	0.244	0.261	0.241	5.642
C23	0.250	0.192	0.226	0.246	0.240	0.243	0.168	0.235	0.240	0.233	0.248	5.373
V	6.382	5.194	5.796	6.378	6.133	6.255	4.189	6.011	6.038	5.936	5.803	**0.263**

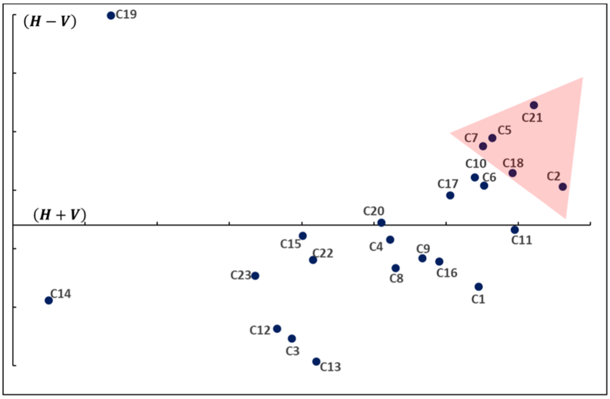

Fig. 2 Cause and effect diagram for criteria

group that includes C2, C5, C6, C7, C10, C17, C18, C19, C20 and C21; $(H - V) < 0$ is the effect group that includes C1, C3, C4, C8, C9, C11, C12, C13, C14, C15, C16, C22, and C23. Moreover, the red area presents the most influential criteria of CSCM for SMEs; these criteria cover knowledge training (C21), waste reduction (C2), eco-design (C5), green technology (C18) and sustainable product design (C7).

Repeating Eqs. (12) to (19) generates the total interrelationship matrix for aspects, as expressed in Table 7. Then, Eqs. (20) and (21) are adopted to compute the dependence (H) and driving (V) power for aspects. Drawing the influential diagram in accordance with the coordinate $(H + V, H - V)$ maps the aspects into a diagram, as shown in Fig. 3. Figure 3 clearly shows that management practices (A3) and circular product design (A2) are the causal aspects affecting other aspects. Therefore, A3 plays an important role in affecting the effect aspects (A5, A1 and A4). Although A2 also influences these effect aspects, the influential level is not as strong as that provided by A3.

Table 7 Total interrelationship matrix for aspects

	A1	A2	A3	A4	A5	H
A1	2.805	2.451	2.367	2.508	2.691	12.821
A2	2.745	2.737	2.427	2.663	2.762	13.333
A3	2.858	2.653	2.740	2.826	2.920	13.997
A4	2.582	2.483	2.260	2.850	2.807	12.982
A5	2.034	1.907	1.775	2.198	2.548	10.462
V	13.024	12.231	11.568	13.044	13.729	2.544

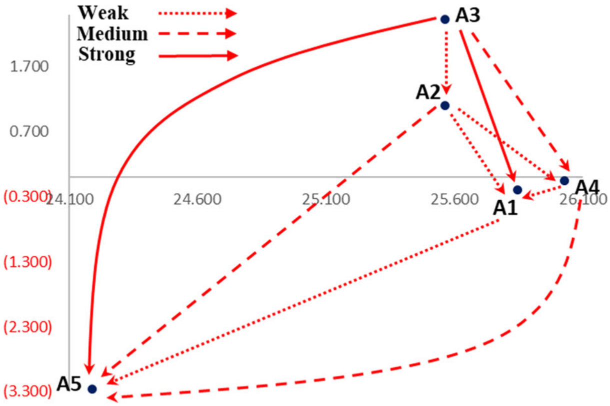

Fig. 3 The influential diagram for aspects

5 Discussion

The study offers both theoretical and managerial implications by determining the attributes that can influence CSCM implementation in Indonesia to be more environmentally and economically beneficial for firms. As a result, this section presents the theoretical and managerial implications.

5.1 Theoretical implication

The study identified the cause and effect model among CSCM attributes. Firms chose a different path to meet CSCM implementation. Waste management practices (A3) and circular product design (A2) are presented as the causal aspects, while cleaner production management (A1), circular management disclosure (A4), and technology diffusion/infusion (A5) appear as the effect aspects. The attributes address the environmental concerns in the process, such as waste management practices, cleaner production management, circularity in designing products, circular management disclosures, and the deployment of technology diffusion/infusion—more environmentally friendly by implementing cleaner production technologies—circular management disclosure, and streamlined processes to reduce waste discharge. As a result, firms often incur lower costs than those invested in the design of products and processes and waste treatment facilities to meet environmental regulations. Firms improve resource utilization and reduce waste discharge to achieve cost and economic performance advantages.

Waste management practices (A3) are a driving aspect that is confirmed to have a critical role in CSCM in managing the effective flows of reduced, recycled, and remanufactured residuals and taking them to the landfill process (Farooque et al., 2022; Lahane et al., 2020). Recovering residual value by reusing and recycling the waste within the production system involves generating benefits for the firm within the industry. This aspect strongly influences cleaner production management and technology diffusion/infusion. This aspect is highlighted as ecological efficiency and reducing risk impacts on humans and the environment as the approach proposed by CSCM, which could be prevented using cleaner production in the production process (Cui et al., 2022). In waste management practices, waste must be assured to be reduced, recycled, or reused, and reducing the waste as the cleaner production main practice is placed as the first consideration within the operator that adopts waste management thinking (Cui et al., 2022). In fact, firms can convert recycled waste into valuable resources for production using infrastructure equipped with advanced technology; therefore, waste management practices are optimally carried out (Kharola, 2022). Waste management practices have triggered firms to initiatively comply with the effectiveness of their waste management systems by involving external waste sources, such as households, streets, and commercial establishments, until they reach a landfill for final disposal to generate more profits (Mulya et al., 2022). This aspect contributes to driving a greater understanding of improved CSCM implementation in Indonesia for eliminating leftover materials and extracting virgin resources utilizing sophisticated technologies in the manufacturing industry.

The results reveal circular product design (A2) as another crucial aspect related to the causal group. A circular product design is a combination of long-life product design, closing resource loops, and end-of-life thinking, such as the cradle-to-cradle approach. Within this design, CSCM is built based on the integration of circular thinking and a waste minimization approach through which the managed wastes can be treated efficiently in the manufacturing and supplying process by maintaining product integrity that prevents product obsolescence (Farooque et al., 2022). The implementation of this design enhances the firm's efficiency in developing mechanisms for pursuing zero-waste objectives in the circular supply chain by controlling the product design circle as the principle and complying with the production procedures. However, building a circular product design is difficult since innovative activities are changing the evolution of the notion of manufacturing process effectiveness and how the design is effectively generated in terms of quantity, place, organization, and stakeholder participation. The innovative design concepts that utilize the circulation of resources assist businesses in gaining secret insights into CSCM deployment. Furthermore, maintaining end-of-life thinking, long-life product design, and circular thinking linked with CSCM during the design-making process is required in circular product design.

Although cleaner production management (A1), circular management disclosure (A4), and technology diffusion/infusion (A5) are the effect aspects, they still have a worth-to-consider role in CSCM implementation. On the one hand, circular management disclosure (A4) and cleaner production management (A1) are possibly classified as causal aspects by influencing technology infusion/diffusion, which also induces an impact on CSCM implementation. Circular management disclosure emerges from a set of circular management schemes, including pollution control, environmental behavior, incentive schemes for stakeholders, corporate communication, and trustworthy data (Opferkuch et al., 2022). Circular management disclosure through its disclosure framework that holds supply chain circularity contributes to supporting the firm in maintaining CSCM implementation and leads to sustainability goals. On the other hand, cleaner production tries to ensure that during the production process, the waste is limited, which is in line with waste management practices. Technology infusion/diffusion has been proven to achieve optimal reduction or usage of CSCM through various types of waste reduction by optimizing the use of technology, infrastructure, and facility restrictions (Magnusson, 2022). Proper technology diffusion implementation supports the firm in overcoming environmental issues by eliminating pollution while gaining financial benefits by transforming recycled waste into valued products.

Innovations take time to be ready and are widely investigated due to their complex and costly implementation. Using the literature and practical background, this study attempts to provide knowledge about the essential factors impacting the spread of CSCM. The cause and effect model proposes a foundation and enriches the literature that identifies the appropriate approaches to optimize CSCM implementation. The findings offer an understanding of CSCM that involves waste management practices, circular product design, and circular management disclosure, which are complex to execute.

5.2 Managerial implications

In SMEs in Indonesia, CSCM systems are an unavoidable and objective trend. This study considers the collected criteria as a consequence of the data gathering and describe the industry's case and its remedies. Therefore, this study brings great benefits to firms and all stakeholders regarding the efficient management of waste in an effort to be eco-friendly and earn higher profits. In particular, CSCM has been developed with many features, such as circular product design, proper circular management, advanced technologies and waste management, requiring firms and stakeholders in Indonesia to research and develop efficient operations management. The waste management system becomes the favorable alternative by triggering the CSCM to generate itself by supporting SME recycling and reusing waste practices as new avenues of opportunity. This study discusses the significant criteria to provide practical insights for CSCM in Indonesia. These criteria are eco-design (C5), sustainable product design (C7), green technology (C18), waste treatment capability (C6), and designing for the environment (C10).

Eco-design (C5) increases the firm's attention to the environment, which leads to an increase in profits by reusing and recycling waste. Eco-design is related to the environmental factors and technologies of developing products by adopting CSCM principles, such as recycling product waste, and having an environmental impact (Chen et al., 2021). In Indonesia, CSCM implementation is challenging due to the demands of cooperation and knowledge training to identify and reduce all potential environmental consequences throughout the product's life cycle without jeopardizing the product's quality or applicability. Over and above that, including environmental considerations in product design is the first challenge of a CSCM model. By integrating eco-design to solve the problem, this firm can implement proposed solutions based on the derived criterion that tackles a product's environmental effect throughout its life cycle—from conception to disposal in CSCM models. In practice, the firm can use recycled materials as the source to produce products and maintain environmental stability while calculating the economic benefits of limiting the usage of virgin material sources. The firm can also regulate a system if products are returned due to customers' complaints of breakage. Therefore, instead of adding waste discharge, the firm may recycle and reuse the damaged product to produce a new product using CSCM processes to maintain environmentally friendly objectives. Employing realistic eco-design strategies is the solution to the case by allowing for the selection of low-impact resources and technology solutions that reduce waste and extend product lifecycles for easy disassembly and recycling to enhance CSCM in Indonesia.

Sustainable product design (C7) refers to a product sustainability design that considers reducing energy usage and using limited resources, thus impacting environmental performance, societal responsibility, and economic benefits (Zhang et al., 2017). In the CSCM context in Indonesia, sustainable product design aids in the most efficient and environmentally friendly use of a firm's resources, with the goal of pursuing system-level innovation and maximizing long-term value. In practice, however, most sustainable products have yet to enter the mainstream, which complies with the firm's standards. Therefore, firms can consider implementing practical solutions that reflect specific principles of sustainable product design that can improve the environmental and financial performance of businesses. In the application, the firm can avoid using materials that cannot be recycled, such as plastics and glass, as they may use substantial energy during the product making process and could have an unpleasant impact on the environment. Another way for the firm to engage in implementation is to make easy-dissembling products, which facilitates the knowledge training division within the firm to reuse and recycle part of the product in case it is damaged or broken. Therefore, the firm causes less undegradable waste produced by the damaged product to impact the environment. On the other hand, the firm can also provide products that can last longer. By doing so, the product may not be thrown away as often, which affects the stability of the ecosystem of the environment.

Designing for the environment (C10) helps firms create environmental regulations that impact overall human health and the environment itself in its life cycle related to implementing CSCM principles (Farooque et al., 2022). However, in the Indonesian context, many firms have difficulties keeping up with government regulations that insist that they consider the waste that they produce and the safety of the environment. Therefore, based on the study, the given criterion, which is designed for the environment, appeared as a solution for managing the problem. The firm can consider the regulation of the firm's produced waste process by involving CSCM principles so that it not only limits waste generation but also gains the economic benefit of utilizing the recycling process. As another specific action, the firm can also limit the use of unnecessary paper for packaging; instead, the firm can use reused materials to package the product. However, practicing designing for the environment is difficult since corporations must invest a large amount of money to do so. The firm can consider striking a strategic balance between lower production and remanufacturing costs, and high investment charges are one of the problems of designing for the environment. For that reason, as products are becoming increasingly recyclable and manufacturable, designing for the environment can benefit the firm, causing old items to have significant economic value since such designing can lower the cost of remanufacturing. In summary, the criterion demonstrates that product design has both economic and environmental benefits, providing essential evidence for designing for environment modeling.

Waste treatment capability (C6) is related to the waste treatment system, facilities, technology, and costs that help the firm efficiently save the environment and maximize its profits (Farooque et al., 2022). Increasing the various waste treatment capabilities owned by firms could be a very powerful way to scaffold CSCM implementation in Indonesia. However, as the amount of waste in Indonesian society increases annually, it significantly affects the need to provide the most efficient waste treatment by Indonesian firms, which need to manufacture recycled waste by adopting the CSCM concept. Therefore, the criterion of waste treatment capability appears to be the solution to the problem. Firms can directly and efficiently sort the existing waste produced by the manufacturer using sorting machines, facilitating the use of sanitary landfills, material recycling, and open landfills. Therefore, the emissions and solid waste produced by the manufacturer can be reused as a substitute for the primary production of virgin materials, which obviously enhances CSCM in Indonesia. As a result, the waste treatment cost capability can finally manage the profits gained from all processes.

Green technology (C18) refers to the strategy used by the firm to limit its pollution and emissions production during the production process, which indirectly impacts CSCM practices. However, in the Indonesian SME context, such innovative green technology implementation is complex and costly for firms to execute and many stakeholders are required to achieve the common goal. Therefore, the study results in a solution by offering green technology as a criterion. Green technology in the CSCM context helps realize the innovation of a firm using circular principles. The firm can directly communicate with stakeholders to join the green technology program. In practice, the firm can utilize the principle of green technology during the manufacturing process, which is affordable and suitable for SMEs.

The manufacturer can use LED lighting, and we know that such lighting costs only a small fraction of the costs of other lighting. The innovative method of green technology can benefit the environment as the main point, followed by economic advantages for the firm, as it limits emissions production. In the CSCM concept, the existence of green technology implementation can minimize the operational costs for some facilities for manufacturers who produce emissions and pollution (Thomas & Mishra, 2022). As a result, the budget prepared for facilities that use machines that generate pollution are limited, allowing energy to be conserved and used sufficiently and effectively.

6 Conclusion

CSCM is the system that helps a firm generate more benefits in terms of the environment and economy. Waste management practices became the basis before CSCM implementation. Additionally, many studies have revealed the importance of CSCM in the manufacturing process to achieve the goals of the firm, such as economic and environmental benefits. However, building CSCM generation by itself is costly and time-consuming, which leads to limitations for SMEs. Therefore, waste management with all of the detailed practices appears to support firms, especially SMEs, in building CSCM as an alternative. To alleviate this ambiguity, this study provides a hybrid approach combining the FDM and FDEMATEL to uncover the causal interrelationships among the variables.

The results reveal that the hierarchical structure helps firms with CSCM implementation whereby CSCM might benefit SMEs through performance improvements. The valid CSCM model has five aspects and 23 criteria for qualitative information. This study provides a comprehensive view of CSCM in the SME industry, including new construct development and validation. The results demonstrate the cause-and-effect model under uncertainties. The results show the hierarchical structure of CSCM implementation that benefits SMEs in gaining performance improvements. Waste management practices and circular product design are causal aspects; in particular, waste management practices support SMEs in building CSCM as an alternative. The criteria to provide practical insights for CSCM in Indonesia are eco-design, sustainable product design, green technology, waste treatment capability, and designing for the environment.

To elaborate, waste management practices impact cleaner production management and technology diffusion/infusion. Meanwhile, circular product design and circular management disclosure influence technology diffusion/infusion. In practice, CSCM implementation needs to enhance eco-design, designing for the environment, waste treatment capability, sustainable product design, and green technology for improvement. The CSCM hierarchical model is developed. This study makes four contributions: (1) waste management practices cause firms to take the initiative to comply with the effectiveness of their waste management systems, which involve external waste sources, such as households, streets, and commercial establishments, until they reach the landfill for final disposal, generating more profits; (2) cleaner production management plays an important role in industrial operations because it reduces the use of water, raw materials, energy, and waste; (3) maintaining product integrity and avoiding and reversing product/component obsolescence, circular product design techniques aim to slow and close resource cycles by developing long-life goods and prolonging their lifespans; and (4) circular management disclosure arises from a collection of circular management practices that include pollution control, environmental behavior, stakeholder incentive systems, corporate communication, and reliable data. Practical implications are also provided for SMEs practicing CSCM, such as eco-design, designing for the environment, waste treatment capability, sustainable product design, and green technology. Firms develop knowledge training for the circular economy in terms of obtaining circularity goals and bringing substantial benefits for the firm and stakeholders through reducing, recycling, and remanufacturing.

This study has limitations and suggests opportunities for future study. First, this study focused on building valid CSCM attributes, and future studies should include environmental and stakeholder outcomes from the SME industry. Second, the response sample comprises Indonesian SMEs across various industries. This study chose the CSCM context given the country's progress with environmental concerns. Similarly, other industries have adopted promising initiatives in CSCM implementation. This study suggests that future studies on CSCM implementation in multiple industries strengthen the validity and generalizability of CSCM-to-firm performance. Third, the improvement in CSCM performance appears in the cause and effect model in the SME industry. Future studies should focus on cross industries to take a closer look at cross industrial influences. Fourth, industry contingency factors are considered in CSCM performance attributes. Vision and leadership have been reported to positively affect firm performance. This study suggests that future studies explore the role of vision and leadership in a valid hierarchical structure. Finally, due to data collection challenges, most of our sample contains data collected from limited respondents. Perceptual measures were used for all attributes. Although this study did not find any evidence of preference bias affecting the results, future research may involve using secondary data at the industry level to gain new insights.

Declarations

Conflict of interest We confirmed that there is no conflict of interests in relation to this manuscript submitted to *Annals of Operations Research*.

Appendix

See Tables 8 and 9

Table 8 Initial Proposed CSCM attributes

Aspects	Original Criteria	Description	References	
Cleaner Production (A1)	OC1	Zero-waste visions	A key difference relative to traditional supply chain sustainability concepts is that CSCM applies a zero-waste vision and enables value recovery not only within the original supply chains but across different supply chains through collaboration with firms in the same industrial sector and/or other sectors	(Farooque et al., 2022)
	OC2	Waste reduction	Production practices (cleaner production) must ensure material efficiency, energy conservation, waste, and emissions reduction at the highest level	
	OC3	Supply chain practices	the management aspires to implement circular supply chain practices to minimize wastes and increase value and also recruiting skilled personnel to facilitate the implementation plan	(Orji et al., 2022)
	OC4	Pollution prevention	Cleaner production which represents the environmental efforts of a firm's internal operations is aimed at preventing pollution at its source in the production process on a continuous improvement basis	

Table 8 (continued)

Aspects	Original Criteria	Description	References	
Circular product design (A2)	OC5	Eco-design	Unified most of them and claimed that eco-design focuses on the integration of environmental considerations into product development, and that eco-design tools ought to be made available to designers during the product development process	(Chen et al., 2021)
	OC6	Design for environment	Circular product design and circular procurement are proactive stances to minimize a product's environmental impact and are aimed at realizing product stewardship through strong stakeholder engagement	(Farooque et al., 2022)
	OC7	Sustainable product design	Sustainable design performances are measured in both the public and private sectors from emphasizing the absolute environmental performance to the eco-efficient design performance with carefully combined functional and environmental attributes	(Zhang et al., 2017)
	OC8	End-of-life thinking	The circular product design concept includes circularity and end-of-life thinking	

Table 8 (continued)

Aspects	Original Criteria	Description	References	
Waste management practices (A3)	OC9	Recycling capability	Energy savings and economic impacts of baseline and alternative waste management practices, including source reduction, recycling, combustion, composting, and anaerobic digestion and landfilling	(Jang et al., 2020)
	OC10	Resource circulation	As part of a broader product stewardship plan, EoL and waste management are "take-back" tactics for resource recirculation and recovery	
	OC11	Reuse capability	The application layer, as its name suggests, provides five key applications for users, namely agile product design, product life-cycle real-time monitoring and management, product recycling and after-sales service management, sustainability assessment management, and materials reuse management	(Wang et al., 2020)
	OC12	Waste treatment capability	Factors such as lower energy costs, savings from using recycled/reused materials, and reduced fees for waste discharge and treatment can reduce costs over the long-run	(Farooque et al., 2022)

Table 8 (continued)

Aspects	Original Criteria	Description	References	
	OC13	Waste sorting	Waste sorting policy was launched to promote C&D waste minimization which resulted in a substantial decrease in C&D waste, and the successful implementation of EU waste management policies have also brought about a sustainable reduction of waste	(Yu et al., 2022)
	OC14	Waste transportation	The majority of studies have transportation routes between the collection point of wastes to waste facilities	(Mulya et al., 2022)
Circular procurement (A4)	OC15	Green procurement	Green procurement (GP) has become a key idea on a national and worldwide level, assisting markets in moving toward environmental sustainability and delivering beneficial environmental outcomes	
	OC16	Green purchasing	Green purchasing is an environmentally conscious purchasing strategy that ensures that the items or materials acquired satisfy the firm’s environmental goals	

Table 8 (continued)

Aspects	Original Criteria	Description	References	
	OC17	Environmental purchasing	Environmental buying (EP) is obviously a subset of environmental supply chain management (ESCM), but it may be a sizable subset depending on the structure of a business and the relevance of the purchasing function	
	OC18	Sustainable procurement	Sustainable procurement provides an incentive for further waste recovery	(Shooshtarian et al., 2022)
	OC19	Green packaging	Eco-friendly packaging options for reducing waste. For instance, banana leaves with straw (paraali)	
	OC20	Product recycling	the circular supply chain includes reverse logistics, which is responsible for the recycling and recall of the product for reuse	(Wang et al., 2020)
Reverse logistics (A5)	OC21	Recall product	The reverse logistics component of the circular supply chain is responsible for product recycling and recall for reuse	(Farooque et al., 2022)
	OC22	Green products	To safeguard the environment, green products require green materials and degradable/reusable packaging materials	

Table 8 (continued)

Aspects	Original Criteria	Description	References	
	OC23	Remanufacturing material	Industrial symbiosis focuses on optimizing the materials cycle and adheres to the circular economy concepts of reusing, recycling, and remanufacturing materials, resulting in increased resource efficiency, reduced waste and pollution, and economic advantages	
	OC24	End-of-life products	The alarming rise in end-of-life (EOL) items has become a major environmental concern that may be effectively addressed by reintroducing them into the circular supply chain (CSCM) through reuse or recycling	(Zhang et al., 2022)
	OC25	Improving green logistics	Green logistics include all environmentally friendly methods such as the use of green packaging materials, low vehicle emissions, and adequate vehicle maintenance	
Advanced digital technology (A6)	OC26	Internet of Things technology	Internet of Things technology and associated systems have the ability to help promote the circular supply chain implementation of discarded electrical and electronic equipment	(Farooque et al., 2022)

Table 8 (continued)

Aspects	Original Criteria	Description	References	
	OC27	Artificial intelligence	Artificial intelligence technology help businesses to better predict waste material supply, reduce needless storage, and avoid prospective shortages, lowering costs and increasing profits while closing resource flows	
	OC28	Big data technology	Big data technology and analytics may help a business achieve its sustainability goals by collecting and analyzing data in real time across the supply chain for energy efficiency, waste and return management, and service and equipment maintenance	
	OC29	3D-printing technology	The influence of 3D printing on the economy's circular framework, as well as various recycling strategies for repurposing 3D printed trash for more circular economic structure uses	(Zhang et al., 2022)
	OC30	Use of robotics	Robotics is utilized in manufacturing to reduce waste	

Table 8 (continued)

Aspects	Original Criteria	Description	References	
	OC31	Blockchain technology	By effectively tracking materials, blockchain technology may assist enhance product returns and EoL goods, as well as waste management operations in reverse supply chains, boosting material recovery and circularity, which is at the core of CSCM	
Circular management disclosure (A7)	OC32	Corporate responsibility	The common goal of ERs is to persuade firms to do as little harm as possible to the environment as they conduct their business, a behaviour known as corporate environmental responsibility	(Han et al., 2021)
	OC33	Pollutant emission	While international trade involvement can dramatically reduce pollutant emission intensity, it can rarely reduce energy intensity or improve overall technology level, suggesting that advanced technology diffusion is not the primary mechanism underlying reduced emission intensity	
	OC34	Information disclosure	The substance of information disclosure regarding CSCM cannot be altered with once the Blockchain system is implemented	
	OC35	Green Disposal practices	Reduction in carbon emissions, zero landfill waste	(Kharola et al., 2022)

Table 8 (continued)

Aspects	Original Criteria	Description	References	
	OC36	Carbon emissions	The propensity toward cleaner production processes, management systems, and environmentally friendly technologies accessibility all can do good to reduce emission intensity	(Ma & Wang, 2021)
Technology infusion/difusion (A8)	OC37	Green technology	The objective of the plastic reforming industry is to maximize profit by reducing costs and obtaining a circular supply chain model by implementing green technologies to reduce emissions and 3D printing technology to minimize waste	(Thomas & Mishra, 2022)
	OC38	Digitization of practices	Transformation to a digital and smart agricultural system for economic, social, and environmental sustainability	(Kharola et al., 2022)
	OC39	Clean technology	Clean technology is demanded to attain cleaner manufacturing along with waste utilization	(Tseng et al., 2022)
	OC40	Information capture	Data capture include fast and accurate data processing, supply chain performance capture, and information infrastructure maintenance	

Table 8 (continued)

Aspects	Original Criteria	Description	References	
	OC41	Knowledge training	In addition, knowledge training, which includes skills, guidance, and failure correction, is also important and has been listed as another success factor in supply chain practice	(Huang et al., 2022)
	OC42	Operation model	information capture and the operations model are argued to be success factors driving supply chain practices	
	OC43	Technological maturity	Technological maturity could indirectly promote circular approaches and information disclosure, enriching environment, health, and safety managers' tools to improve the performance of circular management throughout the supply chain	

Table 9 Demographic profiles

Experts	Position	Years of experience	Education background
1	Chairman or equivalent	3–5 Years	High School
2	Researcher	> 5 Years	Master
3	Researcher	3–5 Years	Doctoral
4	Researcher	1–3 Years	Master
5	Lecturer	> 5 Years	Master
6	Lecturer	> 5 Years	Doctoral
7	Lecturer	> 5 Years	Master
8	Chairman or equivalent	> 5 Years	High School
9	Staff or equivalent	> 5 Years	Doctoral
10	Researcher	1–3 Years	Doctoral
11	Researcher	3–5 Years	Master
12	Staff or equivalent	> 5 Years	Bachelor
13	Staff or equivalent	> 5 Years	Bachelor
14	Researcher	1–3 Years	Master
15	Lecturer	> 5 Years	Master
16	Lecturer	3–5 Years	Master
17	Researcher	1–3 Years	Master
18	Chairman or equivalent	> 5 Years	Bachelor
19	Lecturer	3–5 Years	Bachelor
20	Researcher	< 1 Year	Bachelor
21	Staff or equivalent	1–3 Years	Master
22	Lecturer	1–3 Years	Master
23	Lecturer	1–3 Years	Master
24	Chairman or equivalent	3–5 Years	Bachelor
25	Staff or equivalent	> 5 Years	Bachelor
26	Chairman or equivalent	1–3 Years	Bachelor
27	Staff or equivalent	3–5 Years	High School
28	Chairman or equivalent	1–3 Years	Bachelor
29	Staff or equivalent	> 5 Years	Bachelor
30	Lecturer	1–3 Years	Bachelor

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