Received: 21 April 2022 | Revised: 18 November 2022 | Accepted: 30 November 2022
DOI: 10.1002/sd.2472

RESEARCH ARTICLE

Sustainable Development WILEY

Impediments of product recovery in circular supply chains: Implications for sustainable development

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Abstract

Product recovery has fascinated the concentration of organizations and is prominent among industry practitioners and researchers due to improved environmental concerns, social awareness, and economic benefits. Circular supply chain (CSC) compounds the concept of product recovery in global supply chain management to present a sustainable perspective. Therefore, this study aims to determine impediments of product recovery and CSC toward sustainable production and consumption in the background of manufacturing organizations. This study determines potential impediments from literature and in consultation with experts. Further, a fuzzy VIKOR approach is practiced to prioritize the impediments of product recovery and CSC. Then, a sensitivity analysis is conducted to verify the robustness of the framework attained. The results from the study reflect that "lack of collaboration from supply chain performers", "lack of tax policies for facilitating CSC models" and "limited expertise, technology, information on CSC practices" are the critical impediments to product recovery in CSCs. The findings of the study could assist industry managers and practitioners in developing procedures and strategies to attain sustainable development.

KEYWORDS
circular supply chains, fuzzy VIKOR, Product recovery, sustainable development

1 | INTRODUCTION

In the domain of supply chain management, the earlier approach was on the forward movement of the product from the manufacturer to the end consumer in a single direction. This forward movement of the product contributes toward the exhaustion of natural resources around the globe (Yang et al., 2018). The reverse flow of products comprises the movements essential to obtaining obsolete products from consumers to retain value and ultimately demolish them (Prahinski & Kocabasoglu, 2006). Under the reverse flow of products, product recovery practices recover the component and products that are either disposed off or returned and assist in reducing waste (Dwivedi & Madaan, 2020). In past decades, the reverse flow of products from end consumers did not receive much attention in academia and industry (Loomba & Nakashima, 2012). Therefore, many nations are revising their environmental measures to include product recovery practices for attaining sustainable production and consumption (Patil et al., 2021).

It can be perceived that the existing linear supply chain is not sustainable, and there is a requirement to move toward a circular supply chain (CSC) that separates economic advancements from resource reduction (Agarwal et al., 2021). To meet sustainable development initiatives, there is a requirement for the supply chain to transition from linear to the reverse flow of products through different practices such as remanufacturing, recycling, and reuse (Nasir et al., 2017). After advocating for more combined approaches toward sustainable supply chain design, the design for CSC must consider a comprehensive perspective that combines the different types of circular movements that enable product recovery (Bals & Tate, 2018; Batista et al., 2019). The employment of circular movements that consist of closed and open loops of waste products increases the complications and extends the opportunity for CSC operations (Govindan & Hasanagic, 2018). CSC stands for a recovery arrangement in which resources progress toward a constant cycle of end-of-life movements, such as recycling and remanufacturing (Nikolaou & Tsagarakis, 2021; Ozkan-Ozen et al., 2020). The adoption of CSC practices provides contingency to cater to worldwide obstacles such as resource depletion, climate change, and pollution (Mangla et al., 2018). In the concept of CSC sourcing in businesses, the opportunity of abandoned products is strained by the demand for the primary product (Prosman & Sacchi, 2018). The CSC concept outlines the various paths to reutilize or dispose off the abandoned product (Blomsma & Brennan, 2017; Bracquené et al., 2020).

The transformation from linear to CSC is ambitious for industries and organizations (Levering & Vos, 2019). Thus, many researchers and practitioners have considered including the CSCs as a business approach to enhancing sustainability fallouts (Lewandowski, 2016). In relation to sustainability goals, CSC considers sustainable and efficient use of resources to protect the triple bottom line of sustainability. The conversion to CSC highlights the impediments associated with recycling products to enhance environmental efficiency (Linder et al., 2017; Webster, 2013). Despite the concerns of policy makers and organizations in the CSC, it remains unclear how organizations can enhance their CSCs environmentally (Geissdoerfer et al., 2017; Lieder & Rashid, 2016).

To contribute toward CSC literature, the present study aims to recognize the impediments of product recovery and CSC toward attaining sustainable production and consumption. The study adopts a fuzzy VIKOR approach to rank the identified impediments. The study caters to the following Research Questions (RQs):

- RQ1: What are the impediments of product recovery and CSC toward sustainable production and consumption?
- RQ2: How can the impediments of product recovery and CSC be separated based on their similarity?
- RQ3: How can the identified impediments be ranked and various measures suggested to cater them?

To answer the above RQs, this study develops a CSC framework by identifying the most prominent impediments to product recovery and CSC. A comprehensive literature analysis is performed to analyze the studies relevant to identifying impediments. Then, the proposed methodology, fuzzy VIKOR, contributes to the existing literature by prioritizing the identified impediments. The results from the study could assist industry managers in catering to the challenges specific to CSC implementation.

The remainder of the study is organized as follows. Section 2 presents the related literature specific to product recovery, CSC, and sustainable production and consumption. Section 3 highlights the methodology adopted in the study, and the discussion and findings of the result are detailed in Section 4. Managerial implications are highlighted in Section 5, and the conclusion and scope for future study are highlighted in Section 6.

2 | LITERATURE REVIEW

The literature analysis in this study is summarized into three phases. The first phase is specific to product recovery and CSCs; the second discusses studies related to sustainable production and consumption in supply chains; and the third analyzes literature to identify the potential impediments of product recovery and CSCs.

2.1 | Studies specific to product recovery and circular supply chains

The CSC has the potential to implement new arrangements and assist communities to attain sustainable initiatives at a low expense for products and the environment (Ghisellini et al., 2016). The product recovery and circular practices reflect that a transition from linear to CSCs needs considerable modifications in the organization framework and supply chain movements (van Loon & Van Wassenhove, 2020). This section explores studies related to product recovery and CSCs. Orji et al. (2022) examined determinants of CSC implementation in the manufacturing sector. Alavi et al. (2021) proposed a decision support system for the sustainable supplier section in CSC. Similarly, Chen et al. (2021) presented a strategy for supply chain recovery from COVID-19 disruption by changing the product type to cope with it. The study proposed a mixed integer liner programming (MILP) model that adopted a heuristic algorithm reflecting that the model can assist manufacturers in deciding an optimal recovery strategy from sudden disruptions. Also, Salim et al. (2021) developed a system dynamics (SD) model for managing rooftop solar photovoltaic panels based on the concept of CE. The study argued for a shared responsibility system across the supply chain for better recovery and fewer disruptions. Similarly, Prakash et al. (2021) analyzed the changes in the supply chain on the usage of recycled concrete aggregate instead of natural aggregate as a constituent material in concrete. Further, Raghuram and Harisankar (2021) employed a SD approach in developing a model that analyses the impact of non-availability of parts and cost of recovery for the supplier after a sudden, unpredictable disruption. Diabat and Jebali (2021) proposed a multi-product multi-period MILP model, with an extension aimed toward take-back legislations to analyze the closed loop supply chain (CLSC) performance for durable products. Also, Pant et al. (2021) developed a CLSC model for the paper industry to analyze ways to maximize supply chain surplus and incorporate sustainability through minimizing carbon content.

Ali et al. (2020) designed a MILP model to find optimal solutions to fulfilling demand and revenue needs by focusing on a strategic location. The model was compiled based on data recovered from the

Indian based manufacturing unit of a Saudi Arabian industrial air conditioner manufacturer. Similarly, Robles et al. (2021) studied waste supply chain optimization through a system-modeling approach to recover value-added products from organic fraction municipal solid waste. Also, Garrido-Hidalgo et al. (2020) studied the scenario for the recovery of electric vehicle battery packs through a proposed CSC framework while evaluating its information requirements and capabilities of internet of things (IoT). Further, Ma et al. (2020) developed a mixed integer linear nonlinear programming (MINLP) model to study the multi-period supply chain network of hazardous products. The results from the study highlight that the expansion strategy saves expenses while raising the collection rate of hazardous wastes. Further, Parsa et al. (2020) studied a CLSC comprising of a manufacturer, retailer, supplier, material cover facility, and recycling facility to maximize chain-wide profits. The study proposed a branch and bound algorithm and a heuristic approach for the optimal solution.

Vermunt et al. (2019) identified and studied various barriers to implementation for different circular business models (CBMs). The study investigated strategies adopted by organizations to overcome such barriers. Also, Jiang et al. (2019) developed a MILP model to perform optimal decisions on selection of transportation mode while analyzing the impact of supply chain uncertainties on sustainable supply chain (SSC) design. Further, Waqas et al. (2018) studied and identified major barriers to the employment of reverse logistics in manufacturing organizations. The study adopted a mixed approach of Delphi method and structural equation modeling (SEM). Similarly, Yu and Solvang (2018) proposed a MILP model for developing Pareto solutions between profitability and environmental performance of a multi-product multi-echelon sustainable reverse logistics system. Shahparvari et al. (2018) highlighted a reverse logistic supply chain model to optimize profit for a recycling supply chain under uncertainty. Further, Aksoy and Gupta (2018) modeled a hybrid system as an open queueing network for a single re-manufacturable product to optimize remanufacturing system decisions and adopted a Bayesian approach. John et al. (2018) developed a mathematical model using integer linear programming formulation to optimize reverse logistic network design for two commonly used electronic goods: mobile phones and digital cameras.

Pedram et al. (2017) designed a CLSC to optimize profits and provide waste management decisions while attempting to integrate both a forward and reverse supply chain. The study was performed in the context of the tire manufacturing industry. Further, Ishigaki et al. (2017) designed basic models to study CLSC with stochastic product returns for optimizing the manufacturing and remanufacturing process, and study various management choices on economic and environmental factors.

2.2 | Sustainable production and consumption in the supply chain

Organizations are considering sustainable production and consumption practices to enhance their societal and environmental importance (Jonkutė & Staniškis, 2016). Analyzing developments for sustainability can be easily understood from the manufacturer's part, but attempts are required for both sustainable production and consumption to attain a sustainable future (Blok et al., 2015). This section discusses the studies specific to sustainable production and consumption in the supply chain. Liu et al. (2021) analyzed the barriers to implementing sustainable food production and consumption by adopting a fuzzy DEMATEL approach. The study highlighted the requirement of enhanced regulatory attention for accountability and new education initiatives to address the lack of environmental education. Adelodun et al. (2021) analyzed the implemented measure during COVID-19 pandemic, focusing on the agri-food system and its impact on decarbonization of the agricultural ecosystem. The study adopted a CE approach reflecting sustainable, localized food production and consumption. Similarly, Dorr et al. (2021) quantified and analyzed the environmental impact of a circular food production system at a mushroom farm. The study suggested measures for future improvement through a reduction in energy consumption and efficient transport schemes.

Ngammuangtueng et al. (2020) developed a tool to assess nexus resource efficiency and bio-economy management. The results were discussed while suggesting measures toward a less resource-intensive society. Also, Julianelli et al. (2020) studied the critical success factors (CSFs) of reverse logistics for a company and its supply chain. The study reflected a framework highlighting the inter-relations between CSFs and reverse logistics in the context of CSC. Patwa et al. (2021) found that the adoption of CE principles in developing economies differs from those faced by industrialized economies in terms of resource availability, varied government policies, and consumer behavior. Similarly, Coderoni and Perito (2020) evaluated the influence of socio-demographic and psychological factors in consumer engagement within the CE of purchasing waste-to-value (WTV) food. The results from the study suggested that many people had positive attitudes toward the idea of buying WTV food. Further, Taghikhah et al. (2019) evaluated research on SSCs while positing concern over the lack of attention shown toward consumer behavior. The study proposed a framework to construct supply chain sustainability and measures to improve their economic and socio-economic performance. Kusumowardani et al. (2022) studied mitigation strategies to reduce waste in the food supply chain (FSC) and proposed a framework for CE principles. Wong and Ngai (2021) studied the business sustainability capability implementation using a two-phase method and measured their effect on firm performance. Chinnici et al. (2019) analyzed the CE of the citrus industry through a developing model. The study evaluated the waste and by-products and suggested measures to enhance sustainability in the supply chain. Also, Nasir et al. (2017) assessed the environmental gains through the concept of CE compared to traditional linear production systems in the context of construction industry. The study reflected the challenges and market dynamics of emerging supply chain management. The recent literature related to

TABLE 1 Recent literature specific to CSC, product recovery and sustainable development

Reference	Objectives	Methodology	Outcomes	Limitation/Remarks
Tseng et al. (2022)	Develops a hierarchical circular supply chain structure from big data.	Fuzzy Delphi and DEMATEL	The results reflect I4.0 and digitalization, and product recovery practice represents to the causal group, while circular business strategy is reflected in the effect group.	The study evaluates five attributes and 23 criteria for validation.
Ayati et al. (2022)	Performs a literature review to reflect the barriers from 3R perspective in context of CSC.	Systematic Literature Review	The findings from the study highlight that consumer willingness to purchase recovered products impacts reuse, deficient supportive regulations impact 3R approaches.	The findings from the study reflect the lack of connection among theory and practice of executing recovery approaches.
Dwivedi et al. (2022)	Provided a decision support model to evaluate product recovery performance	SEM-FTOPSIS Approach	The results highlight that "Technology Capacity" is the highest-ranked KPI for successfully implementing recovery practices.	The study adds to the existing literature by proposing a two-phase SEM-TOPSIS approach to measure the impact of KPIs.
Kazancoglu et al. (2022)	Identified barriers to CSCs in context of textile industries.	DEMATEL Methodology	The findings from the study reflect lack of collecting, sorting and recycling as one of the most prominent barriers to CSC.	The study reflects causal relations among the identified barriers.
Nag et al. (2021)	Identified drivers of CSC in context of automobile companies	Gray DEMATEL approach	The study represents causal interactions among the drivers to develop product service systems in CSC.	The study suggests several implications related to design, sourcing, and marketing functions to create circular value.
Zhang et al. (2021)	The study presents a literature review analysis to highlight studies related to CSC management	Literature Review	The review analysis reflects that CSCM comprises of various dimensions, including CLSC, reverse SCM, recycling SCM, and so forth.	The literature review comprises of 68 real-life CE implementation cases and 124 publications in domain of operations and supply chain management.
Lahane and Kant (2021a, 2021b)	Presented solutions to mitigate risks related to CSC management	Pythagorean fuzzy analytic hierarchy process (PF-AHP) and Pythagorean fuzzy VIKOR (PF-VIKOR)	The study is conducted in context of Indian manufacturing organizations.	The rankings for the solutions assists the decision-makers focus on the best solutions and develop the strategies for efficiently handling CSC-related risks.
Garrido-Hidalgo et al. (2020)	Proposed a CSC framework for End of Life management	Qualitative Evaluation	The study proposes a heterogeneous IoT network deployment in pursuit of a digital CSC information infrastructure.	The study is limited to EoL reverse supply management.

CSC, product recovery and sustainable development is presented in Table 1.

2.3 | Impediments of product recovery and circular supply chains

Based on the literature review analysis and discussion with industry professionals (see Section 3.1), the potential antecedents of product recovery and CSCs are identified, as presented in Table 2.

Based on the expertise of industry professionals, the identified potential impediments are categorized under five different prospects:

2.3.1 | Economic prospect

Lack of economic benefits in short-run (A_2), lack of industry incentive toward sustainable practices (A_4), and high costs related to recycled products in CSC (A_{14}) are impediments related to economic prospects.

2.3.2 | Society prospect

Lack of awareness within society toward product recovery and CSC (A_3), lack of collaboration from supply chain performers (A_{10}), organization of reverse infrastructure (A_{13}), and challenges of take-back from other organizations (A_{15}) are impediments to society prospects.

TABLE 2 Impediments of product recovery and circular supply chains

Code	Impediments of product recovery and circular supply chains	Description	References
A_1	High purchasing cost of environmental friendly products	The infrastructure development, training and certifications programs increase the product cost that is eventually transferred to the end customer.	Trivedi et al. (2015); Govindan and Hasanagic (2018); Li et al. (2018).
A_2	Lack of economic benefits in short-run	Consumers often find difficulties in rationalizing additional payment for product recovery and activities facilitating CSC.	Mangla et al. (2018); Kashiwagi et al. (2018)
A_3	Lack of awareness within society toward product recovery and CSC	Limited awareness is often derived from higher product prices and negative associations with sustainable products.	Nandi et al. (2021); Vermunt et al. (2019)
A_4	Lack of industry incentive toward sustainable practices	The short-term contradictory relationship between commercial goals and sustainable practices requires incentivization for product recovery.	Jin et al. (2017); Ozkan-Ozen et al. (2020); Sinha (2021)
A_5	Unclear vision in regards of product recovery in CSC	Due to the nascent stage of CSC development, stakeholders counter difficulty in estimating the return on implementing CSC practices.	Pan et al. (2015); Reike et al. (2018); Kazancoglu et al. (2020)
A_6	Product technology improvement for recovery activities	Product collection from the customer is a complex process. The infrastructure development for product collection from customers, sorting activities and recycling requires cost-effective and innovative solutions.	Madaan et al. (2012); Dwivedi and Madaan (2020)
A_7	Lack of information regarding product tracking in CSC	Awareness of IoT-facilitated tracking and recovery is necessary for efficient, cost-effective product recovery.	Mangla et al. (2021); Ozkan-Ozen et al. (2020)
A_8	Lack of successful business models to implement product recovery in CSC	Limited instances of successful product recovery models act as a significant limitation in the widespread adoption of CSC.	Vermunt et al. (2019); Mishra et al. (2018)
A_9	Lack of appropriate training and development programmes for CSC	New concepts of CSC and product recovery necessitates the development of new competencies. There is a requirement to conduct awareness programs in the entire value chain.	Ciulli et al. (2020); Mangla et al. (2018)
A_{10}	Lack of collaboration from supply chain performers	Lack of trust and conflicting goals regarding implementing CSC practices are significant hindrances.	Kushwaha et al. (2022), Sudusinghe and Seuring (2021); Farooque et al. (2019)
A_{11}	Ineffective product recovery policies	The transition toward CE requires resilient and adaptable policies supporting global consensus, transparency and accountability.	Shaharudin et al. (2015); Vermunt et al. (2019); Arena et al. (2021)
A_{12}	Lack of tax policies for facilitating CSC models	Due to the intensive investment nature of CSC policies, regulators must introduce tax-based incentivization for CSC practices.	Van Fan et al. (2021); Kazancoglu et al. (2021); Ozkan-Ozen et al. (2020)
A_{13}	Organization of reverse infrastructure	Building infrastructure supporting reverse logistics is expensive and requires research, development and innovation.	Kongar et al. (2015); Vermunt et al. (2019); Ambekar et al. (2021)
A_{14}	High costs related to recycled products in CSC	Due to the involvement of additional stakeholders for the recovery, recycling and reusability process, the cost of products increases.	Banasik et al. (2017); Govindan and Hasanagic (2018); Sandvik and Stubbs (2019)
A_{15}	Challenges of take-back from other organizations	The conflicting interest of different stakeholders and uncertain value generation from take-back activities hinders the implementation of CE practices.	Lacity et al. (2008); Hvass and Pedersen (2019)
A_{16}	Limited expertise, technology and information related CSC practices	Due to confidentiality issues, lack or inaccuracy of tracing information, lack of best practices related to CSC, lack of framework and limited domain knowledge restricts the growth of CE practices.	Farooque et al. (2019)); Kumar et al. (2020); Dulia et al. (2021)
A_{17}	Design challenges to reuse and recovery products	At the nascent stage, product design requires modification to accommodate product recovery. Thus, significant investment in product and process redesign is required.	Kane et al. (2018)
A_{18}	Existing loose environmental regulations	Product recovery infrastructure development requires a complementary relationship between economic development and environmental regulations.	Wang, Zhang, and Zhang (2019); Narimissa et al. (2020); Ada et al. (2021)

TABLE 2 (Continued)

Code	Impediments of product recovery and circular supply chains	Description	References
A_{19}	Requirement for data integration	Efficient coordination and collaboration among the multitude of stakeholders require trust and accountability. A streamlined data flow among stakeholders is necessary for developing trust and accountability.	Jukic and Nicholas (2010); Selma et al. (2012)
A_{20}	Lack of adequate waste infrastructure	Management of waste collection, sorting, transport, disposal and recovery activities requires suitable infrastructure that is resilient, cost-effective and adaptable over diverse backgrounds. The lack of such infrastructure hinders the CSC initiatives.	Tansel (2017); Jambeck et al. (2018).

2.3.3 | Environment prospect

High purchasing cost of environmental friendly products (A_1), ineffective product recovery policies (A_{11}), design challenges to reuse and recover products (A_{17}), and existing loose environmental regulations (A_{18}) are the impediments to environmental prospects.

2.3.4 | Government prospect

Unclear vision regarding product recovery in CSC (A_5), lack of successful business models to implement product recovery in CSC (A_8), lack of appropriate training and development programs for CSC (A_9), lack of tax policies for facilitating CSC models (A_{12}), and lack of adequate waste infrastructure (A_{20}) are the impediments under this prospect.

2.3.5 | Technical prospect

Product technology improvement for recovery activities (A_6), lack of information regarding product tracking in CSC (A_7), limited expertise, technology and information CSC practices (A_{16}), and requirements for data integration (A_{19}) are the impediments highlighted under the technical prospect.

2.4 | Research gaps

The literature review reflects the studies relevant to antecedents, challenges, and approaches in the context of product recovery, CSC, and sustainable production and consumption. The studies highlight that CSCs contribute significantly toward attaining sustainability and facilitating reuse and recycling (Lahane & Kant, 2021a, 2021b). Further, there are fewer studies in the literature related to examining the interactions among product recovery and CSCs. A recent study highlighted the need to clarify the characteristics of different elements affecting the implementation of CSC and propose effective measures to mitigate the impediments of CSC practices (Tan et al., 2022). Therefore, this study aims to recognize the impediments of product recovery and CSC for attaining sustainable production and consumption.

3 | RESEARCH METHODOLOGY

The discussion of the study's methodology is segregated into three sections. The first section describes the data collection processes for the study; the second presents a detailed description of fuzzy VIKOR technique; and the third describes the sensitivity analysis.

3.1 | Questionnaire development and data collection

In the present study, the impediments of product recovery and CSCs are categorized under five prospects (environment, society, economic, government, and technical) in consultation with industry professionals. A questionnaire was finalized to perform the data gathering for the fuzzy VIKOR approach. The questionnaire provided detailed information on each impediment specific to product recovery and CSCs.

The data was collected through the experts' functional in different professional areas such as industry managers, professionals, and academics. A total of nine experts distributed as four experts from academia, three CSC and sustainability professionals, and two managers in the manufacturing industry. Since this study focuses on product recovery, CSC, and sustainable production, the experts were elected to ensure expertise in the respective areas. The experts were given information regarding the study's objective through telephone conversations and face-to-face interactions. Figure 1 depicts the research framework for performing the analysis.

3.2 | Fuzzy VIKOR

Opricovic (1998) developed the VIKOR approach based on improved multi criteria decision making (MCDM) programming. This approach generates a compromise solution for addressing problems with contradictory criteria, which aids decision-makers in reaching a conclusion (Shemshadi et al., 2011). This technique categorizes the ideal choice in dynamic conditions. The alternatives are evaluated using discrete

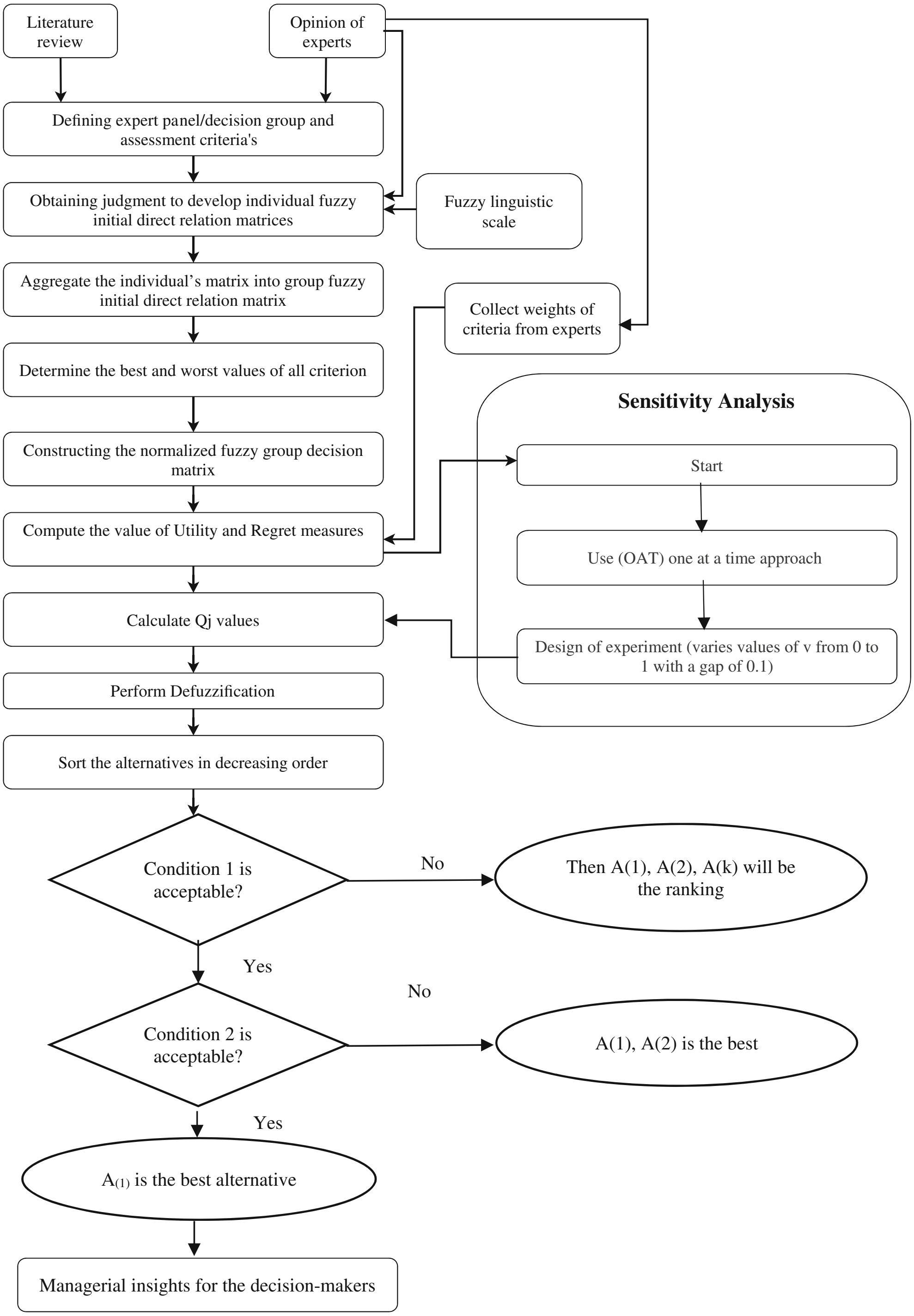

FIGURE 1 Research framework adopted for the study

TABLE 3 Linguistic variables and fuzzy numbers

Linguistic terms	Trapezoidal fuzzy numbers
Very low influence (VL)	(0, 0, 0.05, 0.2)
Low influence (L)	(0.05, 0.2, 0.3, 0.45)
Medium influence (M)	(0.3, 0.45, 0.55, 0.7)
High influence (H)	(0.55, 0.7, 0.8, 0.95)
Very high influence (VH)	(0.8, 0.95, 1, 1)

criteria and compromised leveling can be performed by estimating the nearness measure to the ideal alternative (Opricovic, 2011). VIKOR approach focuses on ranking a collection of options against several potentially conflicting and incommensurable choice criteria, assuming that compromise is acceptable for conflict resolution. VIKOR, like other MCDM methods such as TOPSIS, tries to find closeness to the ideal solution with the help of aggregating function, but unlike TOPSIS, introduces a ranking index based on a specific measure of closeness to the ideal solution (Shemshadi et al., 2011). VIKOR method has

TABLE 4 Aggregate fuzzy weights against the criteria and alternatives

Alternative/Criteria	C1	C2	C3	C4	C5
A_1	(0.106, 0.256, 0.356, 0.506)	(0.217, 0.367, 0.467, 0.617)	(0.55, 0.7, 0.8, 0.95)	(0.383, 0.533, 0.633, 0.783)	(0.55, 0.7, 0.8, 0.95)
A_2	(0.05, 0.2, 0.3, 0.45)	(0.55, 0.7, 0.8, 0.95)	(0.55, 0.7, 0.767, 0.817)	(0.3, 0.45, 0.55, 0.7)	(0.8, 0.95, 1, 1)
A_3	(0.272, 0.422, 0.522, 0.672)	(0.133, 0.283, 0.383, 0.533)	(0.3, 0.45, 0.55, 0.7)	(0.217, 0.367, 0.467, 0.617)	(0.3, 0.45, 0.55, 0.7)
A_4	(0.272, 0.422, 0.522, 0.672)	(0.383, 0.533, 0.633, 0.783)	(0.383, 0.533, 0.633, 0.783)	(0.217, 0.367, 0.467, 0.617)	(0.467, 0.617, 0.717, 0.867)
A_5	(0.078, 0.228, 0.328, 0.478)	(0.383, 0.533, 0.633, 0.783)	(0.217, 0.367, 0.467, 0.617)	(0.467, 0.617, 0.717, 0.867)	(0.383, 0.533, 0.633, 0.783)
A_6	(0.272, 0.422, 0.522, 0.672)	(0.3, 0.45, 0.533, 0.633)	(0.217, 0.367, 0.467, 0.617)	(0.55, 0.7, 0.767, 0.817)	(0.133, 0.283, 0.383, 0.533)
A_7	(0.522, 0.672, 0.772, 0.922)	(0.05, 0.2, 0.3, 0.45)	(0.467, 0.617, 0.717, 0.867)	(0.05, 0.2, 0.3, 0.45)	(0.383, 0.533, 0.633, 0.783)
A_8	(0.05, 0.2, 0.3, 0.45)	(0.55, 0.7, 0.8, 0.95)	(0.217, 0.367, 0.467, 0.617)	(0.55, 0.7, 0.8, 0.95)	(0.383, 0.533, 0.633, 0.783)
A_9	(0.272, 0.422, 0.522, 0.672)	(0.3, 0.45, 0.533, 0.633)	(0.383, 0.533, 0.633, 0.783)	(0.55, 0.7, 0.767, 0.817)	(0.467, 0.617, 0.717, 0.867)
A_{10}	(0.606, 0.756, 0.844, 0.961)	(0.483, 0.6, 0.678, 0.794)	(0.522, 0.672, 0.756, 0.856)	(0.361, 0.444, 0.511, 0.628)	(0.55, 0.7, 0.789, 0.906)
A_{11}	(0.078, 0.228, 0.328, 0.478)	(0.633, 0.783, 0.85, 0.9)	(0.3, 0.45, 0.55, 0.7)	(0.467, 0.617, 0.7, 0.8)	(0.3, 0.45, 0.55, 0.7)
A_{12}	(0.8, 0.95, 1, 1)	(0.217, 0.367, 0.467, 0.617)	(0.467, 0.617, 0.717, 0.867)	(0.133, 0.283, 0.383, 0.533)	(0.383, 0.533, 0.633, 0.783)
A_{13}	(0.522, 0.672, 0.772, 0.922)	(0.05, 0.2, 0.3, 0.45)	(0.383, 0.533, 0.633, 0.783)	(0.05, 0.2, 0.3, 0.45)	(0.467, 0.617, 0.717, 0.867)
A_{14}	(0, 0, 0.05, 0.2)	(0.383, 0.533, 0.633, 0.783)	(0.717, 0.867, 0.933, 0.983)	(0.467, 0.617, 0.717, 0.867)	(0.633, 0.783, 0.867, 0.967)
A_{15}	(0.05, 0.2, 0.3, 0.45)	(0.633, 0.783, 0.867, 0.967)	(0.383, 0.533, 0.633, 0.783)	(0.717, 0.867, 0.933, 0.983)	(0.217, 0.367, 0.467, 0.617)
A_{16}	(0.328, 0.478, 0.578, 0.728)	(0.3, 0.45, 0.55, 0.7)	(0.383, 0.533, 0.633, 0.783)	(0.3, 0.45, 0.55, 0.7)	(0.467, 0.617, 0.717, 0.867)
A_{17}	(0.772, 0.922, 0.978, 0.994)	(0.217, 0.367, 0.467, 0.617)	(0.133, 0.283, 0.383, 0.533)	(0.133, 0.283, 0.383, 0.533)	(0.217, 0.367, 0.467, 0.617)
A_{18}	(0.05, 0.2, 0.3, 0.45)	(0.717, 0.867, 0.933, 0.983)	(0.217, 0.367, 0.467, 0.617)	(0.633, 0.783, 0.867, 0.967)	(0.383, 0.533, 0.633, 0.783)
A_{19}	(0.522, 0.672, 0.772, 0.922)	(0.033, 0.133, 0.217, 0.367)	(0.467, 0.617, 0.7, 0.8)	(0.017, 0.067, 0.133, 0.283)	(0.633, 0.783, 0.85, 0.9)
A_{20}	(0.078, 0.228, 0.328, 0.478)	(0.717, 0.867, 0.933, 0.983)	(0.383, 0.533, 0.633, 0.783)	(0.633, 0.783, 0.867, 0.967)	(0.467, 0.617, 0.717, 0.867)

TABLE 5 Aggregate fuzzy weights of each criterion

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Aggregate Fuzzy Weight
C1	H	H	M	H	VH	H	H	M	H	(0.522, 0.672, 0.767, 0.9)
C2	M	H	VH	H	M	M	M	VH	M	(0.467, 0.617, 0.706, 0.822)
C3	L	H	H	H	M	L	M	H	M	(0.356, 0.506, 0.606, 0.756)
C4	VL	L	L	L	H	VL	M	L	M	(0.15, 0.267, 0.356, 0.506)
C5	H	M	VH	M	M	H	H	VH	H	(0.522, 0.672, 0.761, 0.878)

TABLE 6 The fuzzy best and worst values

	C1	C2	C3	C4	C5
Fj*	(0.8, 0.95, 1, 1)	(0.717, 0.867, 0.933, 0.983)	(0.8, 0.95, 1, 1)	(0.717, 0.867, 0.933, 0.983)	(0.8, 0.95, 1, 1)
Fj-	(0, 0, 0.05, 0.2)	(0.033, 0.133, 0.217, 0.367)	(0.133, 0.283, 0.383, 0.533)	(0.017, 0.067, 0.133, 0.283)	(0.133, 0.283, 0.383, 0.533)

some advantages over other MCDM methods; it estimates the largest group utility and least individual regret value (Opricovic, 2011). The VIKOR approach is extended to discover a fuzzy compromise solution for MCDM problems. In a fuzzy environment, the VIKOR approach resolves the problem. The fuzzy VIKOR approach employs linguistic characteristics, as it might be challenging for a decision-maker to identify an exact performance assessment for an option under consideration. Different types of fuzzy numbers are adopted to deal with imprecise numerical values.

The VIKOR approach and its variants have been used in solving various problems. Yazdani and Graeml (2014) performed a literature analysis to evaluate the role of VIKOR in solving problems in the MCDM paradigm. Mardani et al. (2016) performed a literature analysis on VIKOR and its applications. Most of the authors used a triangular fuzzy number (TFN) to capture the vagueness of a model. Chen and Wang (2009) used fuzzy VIKOR to optimize partner choice in outsourcing IT projects. Opricovic (2011) applied it for water resource planning; they also gave the k^{th} weighted mean method for the de-fuzzification of TFN. Lahane et al. (2021) adopted Pythagorean fuzzy VIKOR to model the risk associated with CSC. However, Shemshadi et al. (2011) used trapezoidal fuzzy number (TrFN) to perform fuzzy VIKOR analysis to solve the supplier selection problem and added entropy measures. Liu et al. (2012) applied TrFN based VIKOR to evaluate risk in failure mode and effects analysis; Vahabzadeh et al. (2015) applied the fuzzy VIKOR method using interval-valued TrFN to solve reverse logistics problem, and Wang, Pan, and He (2019) introduced interval type-2 TrFN with the VIKOR method. Sunarsih et al. (2020) performed a case study in Indonesia using TrFN VIKOR for a watershed re-forestation problem.

The VIKOR approach advanced with the introduction of the Lp measure, which is explained as follows.

$$L_{pj} = \left\{ \sum_{i=1}^{n} W_i \left[\left(\frac{f_i^* - f_{ij}}{f_i^* - f_i^-} \right) \right] \right\}^{\frac{1}{p}} 1 \le p \le +\infty; j = 1,2,\ldots,J \qquad (1)$$

In the VIKOR method, L_{1j} (S_i in Equation 6) and $L_{\infty j}$ (R_i in Equation 7) are applied to create the significance measures. The phases of the fuzzy VIKOR method (Opricovic, 2011) are reflected below. In this study, the alternatives and criteria are assessed by the TrFN $f_{ij} = (l_{ij}, m_{ij}, r_{ij}, q_{ij})$:

Step 1: Identify the problem and establish the goals of the decision-making process. The aims and composition of the structured problem are shown in Figure 1.

Step 2: Manage the group of decision-makers to identify and explain relevant criteria.

Step 3: Establish the linguistic term to be used by decision-makers to evaluate criteria and alternatives. The experts used a five-point scale to establish the significance of each criterion and measure the rating of the alternatives (Chen & Wang, 2009). Every linguistic term is related to a corresponding TrFN, as reflected in Table 3.

Step 4: Build a fuzzy decision matrix of alternatives obtained from decision-maker's (DMs) ratings. The fuzzy decision matrix for the alternatives is presented in Table 4.

Step 5: Construct a fuzzy decision matrix from the decision makers (DMs). This study employed nine DMs belonging to industry and academia. The fuzzy decision matrix for the criteria weights is presented in Table 5.

Step 6: Identify the best $f_j^* = (l_i^*, m_i^*, r_i^*, q_i^*)$ and worst $f_j^- = (l_i^-, m_i^-, r_i^-, q_i^-)$ values for criteria functions among the dedicated values. From Equations (2) and (3) below, aggregated fuzzy values and subjective importance weights are determined, as presented in Table 6.

$$f_j^* = \max_j \; f_{ij} \text{ and } f_j^- = \min f_{ij}, \; \text{for maximize criteria} \qquad (2)$$

$$f_j^* = \min_j \; f_{ij} \text{ and } f_j^- = \max f_{ij}, \; \text{for minimize criteria} \qquad (3)$$

Step 7: Calculate normalized fuzzy difference (d_{ij}) values. In this step, de-fuzzification of aggregate fuzzy values is performed (Opricovic, 2011). The results are listed in Table 7.

TABLE 7 The normalized fuzzy decision matrix

Alternative/Criteria	C1	C2	C3	C4	C5
A_1	(0.294, 0.594, 0.744, 0.894)	(0.105, 0.421, 0.596, 0.807)	(−0.173, 0.173, 0.346, 0.519)	(−0.069, 0.241, 0.414, 0.621)	(−0.173, 0.173, 0.346, 0.519)
A_2	(0.35, 0.65, 0.8, 0.95)	(−0.246, 0.07, 0.246, 0.456)	(−0.231, -0.058, 0.058, 0.231)	(0.017, 0.328, 0.5, 0.707)	(−0.231, -0.058, 0.058, 0.231)
A_3	(0.128, 0.428, 0.578, 0.728)	(0.193, 0.509, 0.684, 0.895)	(0.115, 0.462, 0.635, 0.808)	(0.103, 0.414, 0.586, 0.793)	(0.115, 0.462, 0.635, 0.808)
A_4	(0.128, 0.428, 0.578, 0.728)	(−0.07, 0.246, 0.421, 0.632)	(0.019, 0.365, 0.538, 0.712)	(0.103, 0.414, 0.586, 0.793)	(−0.077, 0.269, 0.442, 0.615)
A_5	(0.322, 0.622, 0.772, 0.922)	(−0.07, 0.246, 0.421, 0.632)	(0.212, 0.558, 0.731, 0.904)	(−0.155, 0.155, 0.328, 0.534)	(0.019, 0.365, 0.538, 0.712)
A_6	(0.128, 0.428, 0.578, 0.728)	(0.088, 0.351, 0.509, 0.719)	(0.212, 0.558, 0.731, 0.904)	(−0.103, 0.103, 0.241, 0.448)	(0.308, 0.654, 0.827, 1)
A_7	(−0.122, 0.178, 0.328, 0.478)	(0.281, 0.596, 0.772, 0.982)	(−0.077, 0.269, 0.442, 0.615)	(0.276, 0.586, 0.759, 0.966)	(0.019, 0.365, 0.538, 0.712)
A_8	(0.35, 0.65, 0.8, 0.95)	(−0.246, 0.07, 0.246, 0.456)	(0.212, 0.558, 0.731, 0.904)	(−0.241, 0.069, 0.241, 0.448)	(0.019, 0.365, 0.538, 0.712)
A_9	(0.128, 0.428, 0.578, 0.728)	(0.088, 0.351, 0.509, 0.719)	(0.019, 0.365, 0.538, 0.712)	(−0.103, 0.103, 0.241, 0.448)	(−0.077, 0.269, 0.442, 0.615)
A_{10}	(−0.161, 0.106, 0.244, 0.394)	(−0.082, 0.199, 0.351, 0.526)	(−0.064, 0.224, 0.378, 0.551)	(0.092, 0.368, 0.506, 0.644)	(−0.122, 0.186, 0.346, 0.519)
A_{11}	(0.322, 0.622, 0.772, 0.922)	(−0.193, 0.018, 0.158, 0.368)	(0.115, 0.462, 0.635, 0.808)	(−0.086, 0.172, 0.328, 0.534)	(0.115, 0.462, 0.635, 0.808)
A_{12}	(−0.2, -0.05, 0.05, 0.2)	(0.105, 0.421, 0.596, 0.807)	(−0.077, 0.269, 0.442, 0.615)	(0.19, 0.5, 0.672, 0.879)	(0.019, 0.365, 0.538, 0.712)
A_{13}	(−0.122, 0.178, 0.328, 0.478)	(0.281, 0.596, 0.772, 0.982)	(0.019, 0.365, 0.538, 0.712)	(0.276, 0.586, 0.759, 0.966)	(−0.077, 0.269, 0.442, 0.615)
A_{14}	(0.6, 0.9, 1, 1)	(−0.07, 0.246, 0.421, 0.632)	(−0.212, 0.019, 0.154, 0.327)	(−0.155, 0.155, 0.328, 0.534)	(−0.192, 0.096, 0.25, 0.423)
A_{15}	(0.35, 0.65, 0.8, 0.95)	(−0.263, 0, 0.158, 0.368)	(0.019, 0.365, 0.538, 0.712)	(−0.276, -0.069, 0.069, 0.276)	(0.212, 0.558, 0.731, 0.904)
A_{16}	(0.072, 0.372, 0.522, 0.672)	(0.018, 0.333, 0.509, 0.719)	(0.019, 0.365, 0.538, 0.712)	(0.017, 0.328, 0.5, 0.707)	(−0.077, 0.269, 0.442, 0.615)
A_{17}	(−0.194, -0.028, 0.078, 0.228)	(0.105, 0.421, 0.596, 0.807)	(0.308, 0.654, 0.827, 1)	(0.19, 0.5, 0.672, 0.879)	(0.212, 0.558, 0.731, 0.904)
A_{18}	(0.35, 0.65, 0.8, 0.95)	(−0.281, -0.07, 0.07, 0.281)	(0.212, 0.558, 0.731, 0.904)	(−0.259, 0, 0.155, 0.362)	(0.019, 0.365, 0.538, 0.712)
A_{19}	(−0.122, 0.178, 0.328, 0.478)	(0.368, 0.684, 0.842, 1)	(0, 0.288, 0.442, 0.615)	(0.448, 0.759, 0.897, 1)	(−0.115, 0.115, 0.25, 0.423)
A_{20}	(0.322, 0.622, 0.772, 0.922)	(−0.281, -0.07, 0.07, 0.281)	(0.019, 0.365, 0.538, 0.712)	(−0.259, 0, 0.155, 0.362)	(−0.077, 0.269, 0.442, 0.615)

TABLE 8 The fuzzy variables (S_i, R_i and Q_i)

Alternatives	S	R	Q
A_1	(0.041, 0.927, 1.612, 2.63)	(0.154, 0.4, 0.571, 0.805)	(0.114, 0.214, 0.259, 0.44)
A_2	(−0.132, 0.5, 1.043, 1.964)	(0.183, 0.437, 0.613, 0.855)	(0.116, 0.192, 0.224, 0.401)
A_3	(0.274, 1.255, 2.001, 3.111)	(0.09, 0.314, 0.483, 0.736)	(0.113, 0.215, 0.268, 0.474)
A_4	(0.016, 0.915, 1.611, 2.653)	(0.067, 0.288, 0.443, 0.655)	(0.062, 0.15, 0.187, 0.359)
A_5	(0.198, 1.139, 1.858, 2.927)	(0.168, 0.418, 0.592, 0.83)	(0.146, 0.257, 0.308, 0.5)
A_6	(0.328, 1.253, 1.96, 3.034)	(0.161, 0.44, 0.629, 0.878)	(0.161, 0.286, 0.344, 0.542)
A_7	(0.091, 1.025, 1.743, 2.815)	(0.131, 0.368, 0.545, 0.808)	(0.109, 0.211, 0.264, 0.47)
A_8	(0.117, 1.026, 1.725, 2.764)	(0.183, 0.437, 0.613, 0.855)	(0.142, 0.251, 0.3, 0.489)
A_9	(0.059, 0.897, 1.55, 2.551)	(0.067, 0.288, 0.443, 0.655)	(0.068, 0.147, 0.178, 0.344)
A_{10}	(−0.195, 0.53, 1.107, 1.985)	(0.014, 0.125, 0.263, 0.456)	(0, 0, 0.01, 0.147)
A_{11}	(0.167, 1.019, 1.687, 2.722)	(0.168, 0.418, 0.592, 0.83)	(0.141, 0.239, 0.282, 0.469)
A_{12}	(−0.044, 0.741, 1.376, 2.378)	(0.049, 0.26, 0.421, 0.664)	(0.043, 0.108, 0.139, 0.323)
A_{13}	(0.075, 1.009, 1.728, 2.804)	(0.131, 0.368, 0.545, 0.808)	(0.107, 0.209, 0.262, 0.468)
A_{14}	(0.082, 0.872, 1.464, 2.308)	(0.313, 0.605, 0.767, 0.9)	(0.21, 0.322, 0.347, 0.445)
A_{15}	(0.136, 0.978, 1.632, 2.628)	(0.183, 0.437, 0.613, 0.855)	(0.145, 0.243, 0.286, 0.469)
A_{16}	(0.015, 0.909, 1.6, 2.632)	(0.038, 0.25, 0.4, 0.605)	(0.045, 0.128, 0.161, 0.328)
A_{17}	(0.196, 1.08, 1.777, 2.862)	(0.11, 0.375, 0.556, 0.793)	(0.113, 0.224, 0.276, 0.469)
A_{18}	(0.098, 0.921, 1.57, 2.576)	(0.183, 0.437, 0.613, 0.855)	(0.14, 0.235, 0.277, 0.461)
A_{19}	(0.115, 0.967, 1.622, 2.594)	(0.172, 0.422, 0.594, 0.822)	(0.136, 0.233, 0.273, 0.445)
A_{20}	(−0.035, 0.741, 1.359, 2.322)	(0.168, 0.418, 0.592, 0.83)	(0.111, 0.197, 0.233, 0.408)

$$d_{ij} = \left(f_j^* - f_{ij}\right) / \left(f_j^* - f_{ij}-\right), \text{ for the maximize criteria} \quad (4)$$

$$d_{ij} = \left(f_{ij} - f_i^*\right) / \left(f_j^* - f_{ij}-\right), \text{ for the minimize criteria} \quad (5)$$

Step 8: Calculate $S_i = (S_i^l, S_i^m, S_i^r, S_i^q)$ and $R_i = (R_i^l, R_i^m, R_i^r, R_i^q)$ and by the relations: The values of S_i and R_i for all alternatives were highlighted in Table 8, using Equations (6) and (7).

$$S_i = \sum_{j=1}^{m} \left(w_j * d_{ij}\right) \quad (6)$$

$$R_i = \max_j \left(w_j * d_{ij}\right) \quad (7)$$

Where,

w_j = weight of j^{th} criteria,

v = weight of maximum group utility and mostly kept 0.5.

Step 9: Calculate the $Q_i = (Q_i^l, Q_i^m, Q_i^r, Q_i^q)$ value employing the equation: The values of Q for all alternatives are highlighted in Table 7, using Equation (8).

$$Q_i = v\left(S_i - S_i^*\right) / \left(S_i - S_i^*\right) + (1-v)\left(R_i - R_i^*\right) / \left(R_i - R_i^*\right) \quad (8)$$

where $S_i^* = \min_i S_i$, $S_i^- = \max_i S_i$, $R_i^* = \min R_i$, $R_i^- = \max R_i$ and

v = maximum group utility,

1–v = weight of particular regret.

Step 10: Performing de-fuzzification of S_i, R_i, Q_i and sorting. Crisp values for S_i, R_i, Q_i are computed by the centroid method of de-fuzzification (Opricovic, 2007). The obtained values are arranged from minimum to maximum scores. The prefinal ranking of the alternatives based on S, R and Q are re-examined and shown in Table 9. Based on the Q_i table values, the prefinal ranking is found as:

$$A_{10} > A_{12} > A_{16} > A_9 > A_4 > A_2 > A_{20} > A_1 > A_{13} > A_7 > A_3 > A_{17} > A_{19} > A_{18} > A_{11} > A_{15} > A_8 > A_5 > A_{14} > A_6.$$

The best alternatives were found to be A_{10}.

There are two conditions that need to be satisfied before finalizing alternatives with the minimum score of Q_i as a compromise solution:

C1: The alternative $Q(A^{(1)})$ has an adequate preference if $Q(^{A(2)}) - Q(A^{(1)}) \geq 1/n-1$, where,

$A^{(2)}$ = Alternative with the second rank and n = number of alternatives.

C2: The alternative $Q(^{A(1)})$ is considered balanced, if it is ranked best in S and R.

In the present study, both the conditions are satisfied, since $QA_{10-}QA_{12} \geq 1/20-1$ and A_{10} is best ranked in all R, S and Q (see Table 9).

Step 11: Choose the most important alternative by selecting $Q(^{A(M)})$ as the best compromise solution having a minimum value of Q_i. "Lack

TABLE 9 The final ranking of alternatives

	S	R	Q	S Ranking	R Ranking	Q Ranking
A_1	1.277714	0.481713	0.261971	10	10	8
A_2	0.977342	0.521405	0.239985	2	17	6
A_3	1.63839	0.407033	0.274049	20	6	11
A_4	1.276644	0.362637	0.194795	9	4	5
A_5	1.509428	0.501559	0.307768	18	13	18
A_6	1.623842	0.525368	0.338151	19	19	20
A_7	1.395354	0.464101	0.26985	16	8	10
A_8	1.387351	0.521405	0.300704	15	18	17
A_9	1.243082	0.362637	0.189965	6	5	4
A_{10}	0.833681	0.218032	0.049066	1	1	1
A_{11}	1.379541	0.501559	0.288554	13	12	15
A_{12}	1.092981	0.349861	0.160835	4	3	2
A_{13}	1.381868	0.464101	0.267833	14	9	9
A_{14}	1.150984	0.638756	0.330027	5	20	19
A_{15}	1.321878	0.521405	0.29106	12	16	16
A_{16}	1.266391	0.322944	0.170935	7	2	3
A_{17}	1.462395	0.457416	0.275823	17	7	12
A_{18}	1.273417	0.521405	0.283877	8	15	14
A_{19}	1.300465	0.501496	0.27647	11	11	13
A_{20}	1.076673	0.501559	0.243342	3	14	7

of collaboration from supply chain performers" (A_{10}) is the most essential impediment with a minimum Q_i value of 0.0490.

3.3 | Sensitivity analysis

A sensitivity analysis is conducted to analyze the stability and reliability of the proposed approach. The sensitivity analysis is performed with a 0.1 increase between 0 and 1. Eleven experiments were conducted, as highlighted in Tables 10 and 11, and their related graphs are highlighted in Figures 2 and 3, respectively. In the sensitivity analysis ($v = 0$ to 0.1), the prioritization of the best five impediments—lack of collaboration from supply chain performers (A_{10}); lack of tax policies for facilitating CSC models (A_{12}); limited expertise, technology and information CSC practices (A_{16}); lack of appropriate training and development programs for CSC (A_9); and lack of industry incentive toward sustainable practices (A_4)—are consistently achieved adopting the suggested approach. However, a small modification is analyzed in the prioritized order of the impediments A_2, A_5, A_7, A_{11}, A_{13}, A_{15}, A_{18}, A_{19} and A_{20}. Further, in the sensitivity analysis ($v = 0.1$ to 0.2), the best five prioritized impediments are again discovered to be consistent. A minor difference is realized in the prioritized order of the impediments A_2, A_5, A_{11} and A_{19}. This study highlights that the "v" value corresponds to 0.5, while the Q values of each alternative impediment A_1 to A_{20} are 0.262, 0.240, 0.274, 0.195, 0.308, 0.338, 0.270, 0.300, 0.190, 0.249, 0.289, 0.168, 0.268, 0.330, 0.291, 0.171, 0.276, 0.284, 0.276 and 0.243, respectively. The prioritized order of the identified 20 impediments are $A_{10} > A_{12} > A_{16} > A_9 > A_4 > A_2 > A_{20} > A_1 > A_{13} > A_7 > A_3 > A_{17} > A_{19} > A_{18} > A_{11} > A_{15} > A_8 > A_5 > A_{14}$ and A_6. The Q values of each alternative impediment A_1 to A_{20} are 0.296, 0.341, 0.212, 0.161, 0.318, 0.345, 0.276, 0.341, 0.161, 0.000, 0.318, 0.147, 0.276, 0.471, 0.341, 0.116, 0.268, 0.341, 0.318 and 0.318, respectively when the v value is equivalent to 0.0 (see Table 10). The ranking of the impediments can be seen in Table 11 and is also highlighted in Figure 2. However, small variations are observed in the ranking of the remaining impediments (see Figure 3). Similarly, by altering the different values of "v", the other experiments can be performed. The sensitivity analysis results highlight that the proposed model is robust and less perceptive to the criteria weights.

4 | RESULTS AND DISCUSSIONS

Organizations encounter several challenges while implementing product recovery and CSC practices, and a number of approaches can be adopted to resolve these challenges. Conversely, the effectiveness of the approaches implemented in silos may prove counterproductive, so there is a need to understand these challenges to determine effective strategies. Thus, this study identified and modeled the impediment to product recovery and CSC in emerging and developed nations. The aim was to appraise the decision-makers of the most important impediments that need to be prioritized. A systematic approach to resolving these impediments will lead to multidimensional improvements and help organizations innovate their business models.

This study ranked the impediments based on their level of impact using a fuzzy VIKOR methodology. The results of fuzzy VIKOR indicate

TABLE 10 Q_i values obtained

Alternative/sensitivity	v = 0	v = 0.1	v = 0.2	v = 0.3	v = 0.4	v = 0.5	v = 0.6	v = 0.7	v = 0.8	v = 0.9	v = 1
A_1	0.295798	0.288945	0.282144	0.275386	0.268663	0.261971	0.255305	0.24866	0.242034	0.235425	0.22883
A_2	0.340687	0.320315	0.300062	0.279925	0.2599	0.239985	0.220176	0.200472	0.180868	0.161363	0.141953
A_3	0.212049	0.224429	0.236821	0.249224	0.261633	0.274049	0.286469	0.298893	0.31132	0.32375	0.336181
A_4	0.160938	0.167753	0.174538	0.181303	0.188054	0.194795	0.201528	0.208255	0.214977	0.221696	0.228411
A_5	0.318245	0.316081	0.313958	0.311869	0.309807	0.307768	0.305749	0.303745	0.301755	0.299777	0.297809
A_6	0.345261	0.343696	0.34221	0.340795	0.339444	0.338151	0.33691	0.335716	0.334567	0.333457	0.332383
A_7	0.276496	0.275104	0.273749	0.272425	0.271126	0.26985	0.268592	0.26735	0.266122	0.264907	0.263702
A_8	0.340687	0.332598	0.324563	0.316573	0.308622	0.300704	0.292815	0.284951	0.277109	0.269286	0.26148
A_9	0.160938	0.166721	0.172519	0.178327	0.184143	0.189965	0.195792	0.201622	0.207456	0.213291	0.219129
A_{10}	0	0.009813	0.019626	0.02944	0.039253	0.049066	0.058879	0.068692	0.078505	0.088319	0.098132
A_{11}	0.318245	0.312186	0.306197	0.300267	0.294388	0.288554	0.282759	0.276997	0.271266	0.26556	0.259879
A_{12}	0.147444	0.150043	0.15269	0.155375	0.158092	0.160835	0.1636	0.166383	0.169181	0.171993	0.174816
A_{13}	0.276496	0.274701	0.272943	0.271216	0.269514	0.267833	0.266171	0.264525	0.262893	0.261273	0.259663
A_{14}	0.47089	0.442339	0.414013	0.385873	0.357886	0.330027	0.302277	0.274619	0.247042	0.219534	0.192086
A_{15}	0.340687	0.330625	0.320639	0.310721	0.300863	0.29106	0.281306	0.271596	0.261926	0.252292	0.242691
A_{16}	0.115858	0.127003	0.138054	0.149049	0.160005	0.170935	0.181847	0.192744	0.20363	0.214508	0.22538
A_{17}	0.268482	0.269807	0.271214	0.272692	0.27423	0.275823	0.277461	0.279141	0.280858	0.282606	0.284384
A_{18}	0.340687	0.329181	0.317755	0.306401	0.29511	0.283877	0.272696	0.261562	0.25047	0.239417	0.2284
A_{19}	0.318059	0.309607	0.301233	0.292924	0.284672	0.27647	0.268311	0.26019	0.252103	0.244045	0.236015
A_{20}	0.318245	0.303097	0.28804	0.273066	0.258169	0.243342	0.228579	0.213877	0.199229	0.184633	0.170083

TABLE 11 Ranking of the alternatives

Alternative/Sensitivity	v = 0	v = 0.1	v = 0.2	v = 0.3	v = 0.4	v = 0.5	v = 0.6	v = 0.7	v = 0.8	v = 0.9	v = 1
A_1	10	10	10	11	9	8	8	8	8	9	10
A_2	17	15	12	12	7	6	6	4	3	2	2
A_3	6	6	6	6	8	11	16	18	19	19	20
A_4	4	5	5	5	5	5	5	6	7	8	9
A_5	13	14	15	17	18	18	19	19	18	18	18
A_6	19	19	19	19	19	20	20	20	20	20	19
A_7	8	9	9	8	11	10	11	12	14	14	16
A_8	18	18	18	18	17	17	17	17	16	16	15
A_9	5	4	4	4	4	4	4	5	6	5	6
A_{10}	1	1	1	1	1	1	1	1	1	1	1
A_{11}	12	13	14	14	14	15	15	15	15	15	14
A_{12}	3	3	3	3	2	2	2	2	2	3	4
A_{13}	9	8	8	7	10	9	9	11	13	13	13
A_{14}	20	20	20	20	20	19	18	14	9	7	5
A_{15}	16	17	17	16	16	16	14	13	12	12	12
A_{16}	2	2	2	2	3	3	3	3	5	6	7
A_{17}	7	7	7	9	12	12	13	16	17	17	17
A_{18}	15	16	16	15	15	14	12	10	10	10	8
A_{19}	11	12	13	13	13	13	10	9	11	11	11
A_{20}	14	11	11	10	6	7	7	7	4	4	3

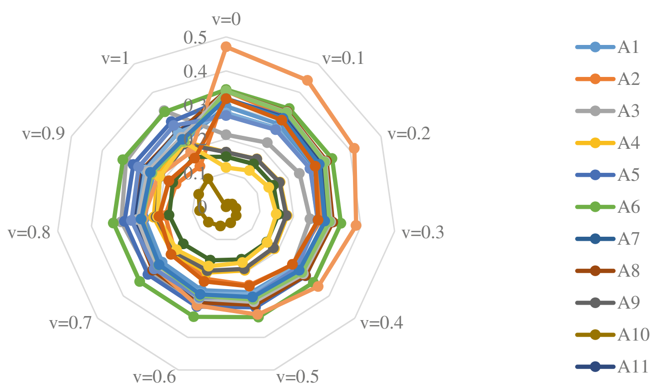

FIGURE 2 Sensitivity analysis of "Q" values

that lack of collaboration from supply chain performers (A_{10}) is the most critical impediment. This impediment is followed by lack of tax policies for facilitating CSC models (A_{12}); limited expertise, technology, and information on CSC practices (A_{16}); lack of appropriate training and development programs for CSC (A_9); and lack of industry incentive towards sustainable practices (A_4). The least impeding factors are unclear vision regarding product recovery in CSC (A5), high costs related to recycled products in CSC (A_{14}), and product technology improvement for recovery activities (A_6). The following paragraphs comprehensively discuss the most impactful impediments and their implications.

The most impactful impediment is the lack of collaboration from supply chain performers (A_{10}). Collaboration remains a critical issue in the supply chain. Also, Kazancoglu et al. (2020) identified a lack of cooperation as a barrier to integrating CE strategies in the textile supply chain. While the previous literature has dealt with coordination and collaboration issues in detail, proposing frameworks, strategies and models, new complexities emerge when organizations adopt product recovery and CSC. The recovery of products from customers requires complex interactions among various stakeholders. These complex interactions require innovative cooperation practices. In line with this recommendation, Sudusinghe and Seuring (2021) suggest redefining the inter-organizational relationship among supply chain stakeholders for a successful transition toward CSC. Also, Suchek et al. (2021) emphasize that cooperation and collaboration among stakeholders are essential to advance circular economy (CE) practices. One expert recommends increased use of emerging technology for improving coordination. Bet et al. (2018) highlight that individuals, businesses, and governments operate in a linear system that prevents product recovery. Thus, innovative collaborative mechanisms must be derived to promote sustainable practices without impacting profits and synergies with individual goals. Additionally, regulatory bodies have a critical contribution in promoting healthy competition and appropriate performance measures to promote CSC transition.

This role of the regulatory body is reflected in the second most influential impediment that focuses on tax policies. Similar to this finding, Bet et al. (2018) report inadequate regulations as one of the main barriers toward CE and recommend governments intervene with suitable policy measures. The previous study discussed the extensive role of government and regulatory bodies to develop CSC. Since the

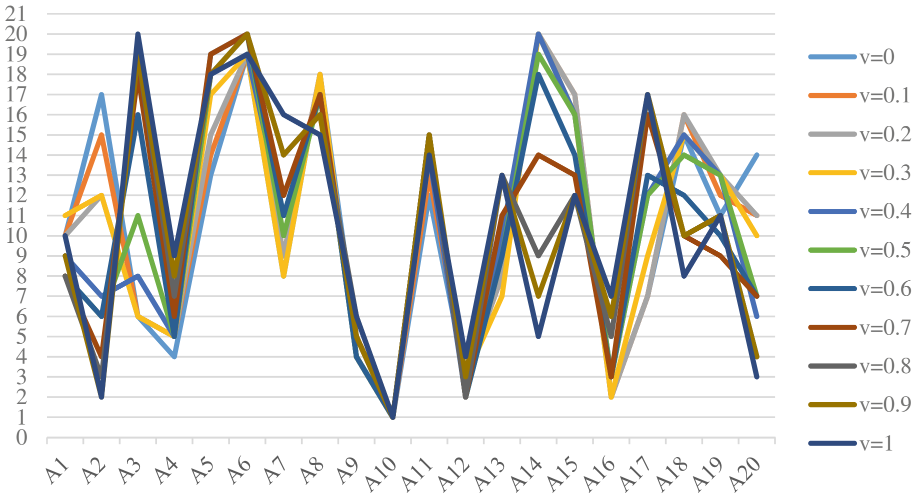

FIGURE 3 Sensitivity analysis of rankings

supply chain has become global and stakeholders from multiple countries interact to generate value, it is paramount that governments around the world synergize their sustainable programs. In 2019, a new International Organization for Standardization (ISO) technical committee comprising of experts from 65 countries was formed (Ghosh, 2020). In the future, decision-makers must enforce ISO/TC 323 standards at the global level. Regular monitoring of this standard and awarding tax-related subsidies will help fuel CSC growth. Further, governments can facilitate healthy competition and formulate supporting policies to ease the reverse flow of products. The reverse flow of products across international boundaries has several complexities. For example, various concerns have been raised previously for the reverse flow of pharmaceutical products (Alshemari et al., 2020). These concerns can be resolved by mutual agreements and increased dialog among the stakeholders. One key insight is that both governments and industries need to adopt a synergistic approach and be cautious of the individual challenges before introducing rules and regulations.

The third most impactful impediment this study reflects is the limited expertise, technology, and information on CSC practices (A_{16}). Since CBMs is at a nascent stage, a limited workforce possesses expertise regarding business transformations (Farooque et al., 2019). This lack of experts creates a hindrance and makes transformation expansive and cumbersome. Experts recommend increased investment in knowledge and skills creation. Further, technological innovation in combination with advanced information systems is paramount to facilitate product recovery and differentiate the benefits of CSC. For these, collaborative efforts from both industry and academia are required. Dulia et al. (2021) highlight the importance of technological maturity from the CSC perspective. Technological advancement is necessary to facilitate product recovery. Tracking issues and accurate information play a critical part in maximizing value from the product recovery process. Thus, experts favor the increased application of advanced information technology such as blockchain, IoT, and the internet of value.

The fourth impediment relates to training and development programs. As recommended above, the workforce needs to be trained and suitable skills are required to be generated among the workers to implement CE practices effectively. However, there are several restrictions in terms of limited knowledge regarding CSC, with very few successful business models and few case studies. Although the amount of theoretical literature has increased in recent years (Lahane et al. (2021), there remains a need for more successful business models that can be taught and practiced by others. Further, academics need to educate future managers regarding the CE and introduce various courses related to product recovery and CBMs.

One key differentiation in the current study is the transformation of barriers from previous CE-related studies. Rizos et al. (2016) attributed high importance to the lack of information regarding CE. Conversely, this study reports the lack of information in tenth place. This difference may be due to recent business transformations and increased awareness. A key recommendation is to frame resilient and adaptable policies in uncertain and unforeseeable circumstances, such as COVID-19. The COVID-19 pandemic saw panic buying and a huge production and consumption of single-use items such as masks, gloves, PPEs, and a plethora of packaging items. For example, Sharma et al. (2020) reported an increase of 370% in medical waste post-COVID-19 in Hubei Province. In this context, Sarkodie and Owusu (2021) recommend developing biodegradable and ecologically friendly protective gear. This recommendation resonates with the A17 impediment, design challenges to reuse and recovery products, which this study reported in twelfth place. Further, the lack of short-term economic benefits (A20) reported in seventh place adds to this critical problem by minimizing investment in such initiatives. One expert recommends sensitizing the public and government regarding investment in sustainable product design. Further, waste management practices are an essential part of post-disaster relief work. Thus, commercial supply chain stakeholders need to synergize their operations with humanitarian organizations to facilitate product recovery.

5 | IMPLICATIONS OF THE STUDY

CSC is viewed as a strategic approach to resolving several issues, including waste generation, resource scarcity, and long-term cost-effectiveness. The CE model of production and consumption replaces the prior linear economy model (take, manufacture, consume, dispose off) and is mostly concerned with waste reduction techniques. The use of CE strategic concepts provides several long-term benefits that organizations may reap. The research related to CE and product recovery has recently become critical due to increased consumption and an uncertain business environment. Numerous academicians worldwide have developed a rising interest in adopting CSC and product recovery practices in various organizations. The majority of CE-related studies lean toward building a better academic foundation for the circular industry. At the same time, this foundation has resulted in several economic, environmental, and social improvements. The present study adds to this foundation and provides a theoretical framework to promote sustainable production and consumption by focusing on the perspective of industrial decision-makers.

The framework refers to the extant literature and the experts for identifying and modeling the set of impediments that constrain the adoption of CE practices and hinder the development of product recovery practices. The study adopted a fuzzy VIKOR method to prioritize these impediments and performed a sensitivity analysis to confirm the robustness of the proposed framework. Decision-makers can use this priority order and frame the policies accordingly. In addition to the priority orders developed using the fuzzy VIKOR method, the study presents some critical insights into future businesses and how to resolve these impediments. The potential recommendations include upskilling managers in the early phase, insertion of supportive government policies, development and adoption of the standard, sensitization of the public, increased use of advanced IT applications, and increased investment in sustainable product design.

The study extensively discusses the critical role of coordination and collaboration among stakeholders operating at the regional and global levels. Further, the complexities that arise during product recovery and the role of diverse stakeholders at a global level have been highlighted. The findings indicate that multiple stakeholders must work synergistically to develop suitable tax policies, regulations, training modules and infrastructure. The critical insight is that enabling product recovery in the CE needs innovative technological solutions and business process redesign. This may require goal alignment at both local and global levels. Thus, the development of CE needs a holistic approach. Another critical recommendation has been proposed regarding the goal alignment between the diverse set of stakeholders. The study uniquely highlights the need to build a relationship between local and global stakeholders.

In addition to these key recommendations, industry practitioners can utilize the present study's findings to target the complexities that occur during the CSC implementation process and magnify the CSC adoption speed. The study's findings help practitioners quantify the benefits of the strategic measures and develop a mix of strategic solutions that should receive priority. A strategic approach can be proposed as a training and standardization module focusing on skill development and competition among peers. This approach will promote cross-organization best practices. Also, the decision-makers are recommended to sensitize stakeholders to increased investment in developing CSC-facilitating technologies. An increased focus on collaboration can complement this policy, thereby targeting the first and third most impactful impediments calculated in the study. Thus, the study paves the way to identify the strategic, tactical and operational measures to enhance CSC implementation.

6 | CONCLUSIONS, LIMITATIONS AND SCOPE FOR FUTURE STUDY

This section concludes the study, highlights the novelty of the study, mentions research limitations, and proposes essential research directions. This study explores the impediments of CSC and product recovery toward sustainable production and consumption. The existing study adopted a methodological approach to rank the identified potential impediments and facilitated the development of suitable policies to counter these impediments. This study organized interviews with several experts to synthesize some interesting implications and recommendations and enable product recovery and CE practices. The analysis reflects a significant impact from impediments belonging to economic and social prospects. These impediments can be experienced at every echelon of the value chain and require a robust and multiprong approach for a successful transition toward circularity. The study paves the way for future academicians to better understand and propose solutions to cater such impediments. The approach to exploring the product recovery and CSC in combination is rarely considered in existing studies. This study produced critical insights regarding the mechanisms of product redesign and how to achieve sustainable production. Further, the study highlights the requirement to develop training modules, successful business models, frameworks and innovative coordination mechanisms among diverse stakeholders. An extensive discussions on these recommendations have been included. Additionally, the study uniquely discusses the impact of these recommendations on the combination of product recovery and CSC.

This study has a few limitations related to the methodological approach and study context. All the experts consulted for the study were based in India, which may limit the applicability of the findings in the context of developing nations. Further, the study did not consider the interrelationship among these impediments. As highlighted in the discussion section, the impediments affect each other. Future research may explore the dynamics among these impediments. One of the essential research directions is exploring the measures facilitating product recovery and CSC implementation. Further, different sectors present different complexities; for example, policies in the case of the pharmaceutical sector will be very different from the textile sector. Thus, future research needs to explore product recovery from different sectors' perspectives. Additionally, researchers need to present the cost–benefit analysis of these measures. Also, the decision-makers need the implementation framework for sustainable production and recovery measures. Finally, future researchers are recommended to adopt game theory and simulation models to study the behaviors of different stakeholders regarding CSC practices.

ACKNOWLEDGMENT

Open access publishing facilitated by University of Technology Sydney, as part of the Wiley - University of Technology Sydney agreement via the Council of Australian University Librarians.

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REFERENCES

Ada, N., Kazancoglu, Y., Sezer, M. D., Ede-Senturk, C., Ozer, I., & Ram, M. (2021). Analyzing barriers of circular food supply chains and proposing industry 4.0 solutions. *Sustainability*, *13*(12), 6812.

Adelodun, B., Kareem, K. Y., Kumar, P., Kumar, V., Choi, K. S., Yadav, K. K., Yadav, A., El-Denglawey, A., Cabral-Pinto, M., Son, C. T., Krishnan, S., & Khan, N. A. (2021). Understanding the impacts of the COVID-19 pandemic on sustainable agri-food system and agroecosystem decarbonization nexus: A review. *Journal of Cleaner Production*, *318*, 128451.

Agarwal, S., Tyagi, M., & Garg, R. K. (2021). Conception of circular economy obstacles in context of supply chain: A case of rubber industry. *International Journal of Productivity and Performance Management*, in press.

Aksoy, H. K., & Gupta, S. M. (2018). Improving remanufacturing systems decisions by bayesian approach. *International Journal of Industrial Engineering*, *25*(3), 316–334.

Alavi, B., Tavana, M., & Mina, H. (2021). A dynamic decision support system for sustainable supplier selection in circular economy. *Sustainable Production and Consumption*, *27*, 905–920.

Ali, S. S., Paksoy, T., Torğul, B., & Kaur, R. (2020). Reverse logistics optimization of an industrial air conditioner manufacturing company for designing sustainable supply chain: A fuzzy hybrid multi-criteria decision-making approach. *Wireless Networks*, *26*(8), 5759–5782.

Alshemari, A., Breen, L., Quinn, G., & Sivarajah, U. (2020). Can we create a circular pharmaceutical supply chain (CPSC) to reduce medicines waste? *Pharmacy*, *8*(4), 221.

Ambekar, S., Roy, D., Hiray, A., Prakash, A., & Patyal, V. S. (2021). Barriers to adoption of reverse logistics: A case of construction, real estate, infrastructure and project (CRIP) sectors. *Engineering, Construction and Architectural Management*, *29*(7), 2878–2902.

Arena, M., Azzone, G., Grecchi, M., & Piantoni, G. (2021). How can the waste management sector contribute to overcoming barriers to the circular economy? *Sustainable Development*, *29*(6), 1062–1071.

Ayati, M. S., Shekarian, E., Majava, J., & Wæhrens, B. V. (2022). Toward a circular supply chain: Understanding barriers from the perspective of recovery approaches. *Journal of Cleaner Production*, *359*, 131775.

Bals, L., & Tate, W. L. (2018). Sustainable supply chain design in social businesses: Advancing the theory of supply chain. *Journal of Business Logistics*, *39*(1), 57–79.

Banasik, A., Kanellopoulos, A., Claassen, G. D. H., Bloemhof-Ruwaard, J. M., & van der Vorst, J. G. (2017). Closing loops in agricultural supply chains using multi-objective optimization: A case study of an industrial mushroom supply chain. *International Journal of Production Economics*, *183*, 409–420.

Batista, L., Gong, Y., Pereira, S., Jia, F., & Bittar, A. (2019). Circular supply chains in emerging economies–a comparative study of packaging recovery ecosystems in China and Brazil. *International Journal of Production Research*, *57*(23), 7248–7268.

Bet, B., Kas, J., Truijens, D., Lee, S.V.D., Broere, J., Leising, E., Nuninga, T., Bose, P., Ravensberg, E.V., Francesco, E.D. and Wang, Y. (2018). Barriers and best practices for the circular economy. Retrieved from http://hdl.handle.net/1765/105039

Blok, V., Wesselink, R., Studynka, O., & Kemp, R. (2015). Encouraging sustainability in the workplace: A survey on the pro-environmental behaviour of university employees. *Journal of Cleaner Production*, *106*, 55–67.

Blomsma, F., & Brennan, G. (2017). The emergence of circular economy: A new framing around prolonging resource productivity. *Journal of Industrial Ecology*, *21*(3), 603–614.

Bracquené, E., Dewulf, W., & Duflou, J. R. (2020). Measuring the performance of more circular complex product supply chains. *Resources, Conservation and Recycling*, *154*, 104608.

Chen, J., Wang, H., & Zhong, R. Y. (2021). A supply chain disruption recovery strategy considering product change under COVID-19. *Journal of Manufacturing Systems*, *60*, 920–927.

Chen, L. Y., & Wang, T. C. (2009). Optimizing partners' choice in IS/IT outsourcing projects: The strategic decision of fuzzy VIKOR. *International Journal of Production Economics*, *120*(1), 233–242.

Chinnici, G., Zarbà, C., Hamam, M., Pecorino, B., & D'Amico, M. (2019). A model of circular economy of citrus industry. *International Multidisciplinary Scientific GeoConference: SGEM*, *19*(4.2), 19–26.

Ciulli, F., Kolk, A., & Boe-Lillegraven, S. (2020). Circularity brokers: Digital platform organizations and waste recovery in food supply chains. *Journal of Business Ethics*, *167*(2), 299–331.

Coderoni, S., & Perito, M. A. (2020). Sustainable consumption in the circular economy. An analysis of consumers' purchase intentions for waste-to-value food. *Journal of Cleaner Production*, *252*, 119870.

Diabat, A., & Jebali, A. (2021). Multi-product and multi-period closed loop supply chain network design under take-back legislation. *International Journal of Production Economics*, *231*, 107879.

Dorr, E., Koegler, M., Gabrielle, B., & Aubry, C. (2021). Life cycle assessment of a circular, urban mushroom farm. *Journal of Cleaner Production*, *288*, 125668.

Dulia, E. F., Ali, S. M., Garshasbi, M., & Kabir, G. (2021). Admitting risks towards circular economy practices and strategies: An empirical test from supply chain perspective. *Journal of Cleaner Production*, *317*, 128420.

Dwivedi, A., & Madaan, J. (2020). A hybrid approach for modeling the key performance indicators of information facilitated product recovery system. *Journal of Modelling in Management*, *15*(3), 933–965.

Dwivedi, A., Madaan, J., Santibanez Gonzalez, E. D. R., & Moktadir, M. A. (2022). A two-phase approach to efficiently support product recovery systems in a circular economy context. *Management Decision*, *60*(7), 2060–2091.

Farooque, M., Zhang, A., & Liu, Y. (2019). Barriers to circular food supply chains in China. *Supply Chain Management*, *24*(5), 677–696.

Garrido-Hidalgo, C., Ramirez, F. J., Olivares, T., & Roda-Sanchez, L. (2020). The adoption of internet of things in a circular supply chain framework for the recovery of WEEE: The case of lithium-ion electric vehicle battery packs. *Waste Management*, *103*, 32–44.

Geissdoerfer, M., Savaget, P., Bocken, N. M., & Hultink, E. J. (2017). The Circular Economy–A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768.

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11–32.

Ghosh, S. K. (2020). *Circular economy: global perspective*. Springer.

Govindan, K., & Hasanagic, M. (2018). A systematic review on drivers, barriers, and practices towards circular economy: A supply chain perspective. *International Journal of Production Research*, *56*(1–2), 278–311.

Hvass, K., & Pedersen, E. R. G. (2019). Toward circular economy of fashion: Experiences from a brand's product take-back initiative. *Journal of Fashion Marketing and Management*, *23*(3), 345–365.

Ishigaki, A., Yamada, T., & Gupta, S. M. (2017). Design of a closed-loop supply chain with stochastic product returns. *International Journal of Automation Technology*, *11*(4), 563–571.

Jambeck, J., Hardesty, B. D., Brooks, A. L., Friend, T., Teleki, K., Fabres, J., Beaudoin, Y., Bamba, A., Francis, J., Ribbink, A. J., & Baleta, T. (2018). Challenges and emerging solutions to the land-based plastic waste issue in Africa. *Marine Policy*, *96*, 256–263.

Jiang, Y., Zhao, Y., Dong, M., & Han, S. (2019). Sustainable supply chain network design with carbon footprint consideration: A case study in China. *Mathematical Problems in Engineering*, *19*, 1–19.

Jin, R., Li, B., Zhou, T., Wanatowski, D., & Piroozfar, P. (2017). An empirical study of perceptions towards construction and demolition waste recycling and reuse in China. *Resources, Conservation and Recycling*, *126*, 86–98.

John, S. T., Sridharan, R., & Kumar, P. R. (2018). Reverse logistics network design: A case of mobile phones and digital cameras. *The International Journal of Advanced Manufacturing Technology*, *94*(1), 615–631.

Jonkutė, G., & Staniškis, J. K. (2016). Realising sustainable consumption and production in companies: The Ssstainable and Responsible Company (SURESCOM) model. *Journal of Cleaner Production*, *138*, 170–180.

Jukic, N., & Nicholas, J. (2010, June). A framework for requirement collection and definition process for data warehousing projects. In *Proceedings of the ITI 2010, 32nd International Conference on Information Technology Interfaces* (pp. 187–192). IEEE.

Julianelli, V., Caiado, R. G. G., Scavarda, L. F., & Cruz, S. P. D. M. F. (2020). Interplay between reverse logistics and circular economy: Critical success factors-based taxonomy and framework. *Resources, Conservation and Recycling*, *158*, 104784.

Kane, G. M., Bakker, C. A., & Balkenende, A. R. (2018). Towards design strategies for circular medical products. *Resources, Conservation and Recycling*, *135*, 38–47.

Kashiwagi, Y., Todo, Y., & Matous, P. (2018). International propagation of economic shocks through global supply chains. *WINPEC Working Paper Series*, *1810*, 1–16.

Kazancoglu, I., Kazancoglu, Y., Kahraman, A., Yarimoglu, E., & Soni, G. (2022). Investigating barriers to circular supply chain in the textile industry from Stakeholders' perspective. *International Journal of Logistics Research and Applications*, *25*(4–5), 521–548.

Kazancoglu, I., Kazancoglu, Y., Yarimoglu, E., & Kahraman, A. (2020). A conceptual framework for barriers of circular supply chains for sustainability in the textile industry. *Sustainable Development*, *28*(5), 1477–1492.

Kazancoglu, I., Sagnak, M., Kumar Mangla, S., & Kazancoglu, Y. (2021). Circular economy and the policy: A framework for improving the corporate environmental management in supply chains. *Business Strategy and the Environment*, *30*(1), 590–608.

Kongar, E., Haznedaroglu, E., Abdelghany, O., & Bahtiyar, M. O. (2015). A novel IT infrastructure for reverse logistics operations of end-of-life pharmaceutical products. *Information Technology and Management*, *16*(1), 51–65.

Kumar, A., Moktadir, M. A., Khan, S. A. R., Garza-Reyes, J. A., Tyagi, M., & Kazançoğlu, Y. (2020). Behavioral factors on the adoption of sustainable supply chain practices. *Resources, Conservation and Recycling*, *158*, 104818.

Kushwaha, S., Chan, F. T., Chakraborty, K., & Pratap, S. (2022). Collection and remanufacturing channels selection under a product take-back regulation with remanufacturing target. *International Journal of Production Research*, *60*(24), 7384–7410.

Kusumowardani, N., Tjahjono, B., Lazell, J., Bek, D., Theodorakopoulos, N., Andrikopoulos, P., & Priadi, C. R. (2022). A circular capability framework to address food waste and losses in the agri-food supply chain: The antecedents, principles and outcomes of circular economy. *Journal of Business Research*, *142*, 17–31.

Lacity, M. C., Willcocks, L. P., & Rottman, J. W. (2008). Global outsourcing of back office services: Lessons, trends, and enduring challenges. *Strategic Outsourcing: An International Journal*, *1*(1), 13–34.

Lahane, S., & Kant, R. (2021a). A hybrid Pythagorean fuzzy AHP–CoCoSo framework to rank the performance outcomes of circular supply chain due to adoption of its enablers. *Waste Management*, *130*, 48–60.

Lahane, S., & Kant, R. (2021b). Evaluation and ranking of solutions to mitigate circular supply chain risks. *Sustainable Production and Consumption*, *27*, 753–773.

Lahane, S., Prajapati, H., & Kant, R. (2021). Emergence of circular economy research: A systematic literature review. *Management of Environmental Quality*, *32*(3), 575–595.

Levering, R., & Vos, B. (2019). Organizational drivers and barriers to circular supply chain operations. In *Operations management and sustainability* (pp. 43–66). Palgrave Macmillan.

Lewandowski, M. (2016). Designing the business models for circular economy—Towards the conceptual framework. *Sustainability*, *8*(1), 43.

Li, B., Chen, W., Xu, C., & Hou, P. (2018). Impacts of government subsidies for environmental-friendly products in a dual-channel supply chain. *Journal of Cleaner Production*, *171*, 1558–1576.

Lieder, M., & Rashid, A. (2016). Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *Journal of Cleaner Production*, *115*, 36–51.

Linder, M., Sarasini, S., & van Loon, P. (2017). A metric for quantifying product-level circularity. *Journal of Industrial Ecology*, *21*(3), 545–558.

Liu, H. C., Liu, L., Liu, N., & Mao, L. X. (2012). Risk evaluation in failure mode and effects analysis with extended VIKOR method under fuzzy environment. *Expert Systems with Applications*, *39*(17), 12926–12934.

Liu, Y., Wood, L. C., Venkatesh, V. G., Zhang, A., & Farooque, M. (2021). Barriers to sustainable food consumption and production in China: A fuzzy DEMATEL analysis from a circular economy perspective. *Sustainable Production and Consumption*, *28*, 1114–1129.

Loomba, A. P., & Nakashima, K. (2012). Enhancing value in reverse supply chains by sorting before product recovery. *Production Planning & Control*, *23*(2–3), 205–215.

Ma, H., Li, X., & Liu, Y. (2020). Multi-period multi-scenario optimal design for closed-loop supply chain network of hazardous products with consideration of facility expansion. *Soft Computing*, *24*(4), 2769–2780.

Madaan, J., Kumar, P., & Chan, F. T. (2012). Decision and information interoperability for improving performance of product recovery systems. *Decision Support Systems*, *53*(3), 448–457.

Mangla, S. K., Börühan, G., Ersoy, P., Kazancoglu, Y., & Song, M. (2021). Impact of information hiding on circular food supply chains in business-to-business context. *Journal of Business Research*, *135*, 1–18.

Mangla, S. K., Luthra, S., Mishra, N., Singh, A., Rana, N. P., Dora, M., & Dwivedi, Y. (2018). Barriers to effective circular supply chain management in a developing country context. *Production Planning & Control*, *29*(6), 551–569.

Mardani, A., Zavadskas, E. K., Govindan, K., Amat Senin, A., & Jusoh, A. (2016). VIKOR technique: A systematic review of the state of the art literature on methodologies and applications. *Sustainability*, *8*(1), 37.

Mishra, J. L., Hopkinson, P. G., & Tidridge, G. (2018). Value creation from circular economy-led closed loop supply chains: A case study of fast-moving consumer goods. *Production Planning & Control*, *29*(6), 509–521.

Nag, U., Sharma, S. K., & Govindan, K. (2021). Investigating drivers of circular supply chain with product-service system in automotive firms of an emerging economy. *Journal of Cleaner Production*, *319*, 128629.

Nandi, S., Sarkis, J., Hervani, A. A., & Helms, M. M. (2021). Redesigning supply chains using blockchain-enabled circular economy and COVID-19 experiences. *Sustainable Production and Consumption*, *27*, 10–22.

Narimissa, O., Kangarani-Farahani, A., & Molla-Alizadeh-Zavardehi, S. (2020). Drivers and barriers for implementation and improvement of Sustainable Supply Chain Management. *Sustainable Development*, *28*(1), 247–258.

Nasir, M. H. A., Genovese, A., Acquaye, A. A., Koh, S. C. L., & Yamoah, F. (2017). Comparing linear and circular supply chains: A case study from the construction industry. *International Journal of Production Economics*, *183*, 443–457.

Ngammuangtueng, P., Jakrawatana, N., & Gheewala, S. H. (2020). Nexus Resources efficiency assessment and management towards transition to sustainable bioeconomy in Thailand. *Resources, Conservation and Recycling*, *160*, 104945.

Nikolaou, I. E., & Tsagarakis, K. P. (2021). An introduction to circular economy and sustainability: Some existing lessons and future directions. *Sustainable Production and Consumption*, *28*, 600–609.

Opricovic, S. (1998). Multicriteria optimization of civil engineering systems. *Faculty of Civil Engineering, Belgrade*, *2*(1), 5–21.

Opricovic, S. (2011). Fuzzy VIKOR with an application to water resources planning. *Expert Systems with Applications*, *38*(10), 12983–12990.

Orji, I. J., U-Dominic, C. M., & Okwara, U. K. (2022). Exploring the determinants in circular supply chain implementation in the Nigerian manufacturing industry. *Sustainable Production and Consumption*, *29*, 761–776.

Ozkan-Ozen, Y. D., Kazancoglu, Y., & Mangla, S. K. (2020). Synchronized barriers for circular supply chains in industry 3.5/industry 4.0 transition for sustainable resource management. *Resources, Conservation and Recycling*, *161*, 104986.

Pan, S. Y., Du, M. A., Huang, I. T., Liu, I. H., Chang, E. E., & Chiang, P. C. (2015). Strategies on implementation of waste-to-energy (WTE) supply chain for circular economy system: A review. *Journal of Cleaner Production*, *108*, 409–421.

Pant, K., Yadav, V. S., & Singh, A. R. (2021). Design of multi-tier multi-time horizon closed-loop supply chain network with sustainability under uncertain environment for Indian paper industry. *International Journal of Sustainable Engineering*, *14*(2), 107–122.

Parsa, M., Nookabadi, A. S., Atan, Z., & Malekian, Y. (2020). An optimal inventory policy for a multi-echelon closed-loop supply chain of post-consumer recycled content products. *Operational Research*, *22*(3), 1887–1938.

Patil, A., Madaan, J., Shardeo, V., Charan, P., & Dwivedi, A. (2021). Material convergence issue in the pharmaceutical supply chain during a disease outbreak. *The International Journal of Logistics Management*, *33*(3), 955–996.

Patwa, N., Sivarajah, U., Seetharaman, A., Sarkar, S., Maiti, K., & Hingorani, K. (2021). Towards a circular economy: An emerging economies context. *Journal of Business Research*, *122*, 725–735.

Pedram, A., Yusoff, N. B., Udoncy, O. E., Mahat, A. B., Pedram, P., & Babalola, A. (2017). Integrated forward and reverse supply chain: A tire case study. *Waste Management*, *60*, 460–470.

Prahinski, C., & Kocabasoglu, C. (2006). Empirical research opportunities in reverse supply chains. *Omega*, *34*(6), 519–532.

Prakash, S., Wijayasundara, M., Pathirana, P. N., & Law, K. (2021). Derisking resource recovery value chains for a circular economy–Accounting for supply and demand variations in recycled aggregate concrete. *Resources, Conservation and Recycling*, *168*, 105312.

Prosman, E. J., & Sacchi, R. (2018). New environmental supplier selection criteria for circular supply chains: Lessons from a consequential LCA study on waste recovery. *Journal of Cleaner Production*, *172*, 2782–2792.

Raghuram, P., & Harisankar, G. (2021). Modelling and assessment of the impact of supply disruption and cost of recovery using system dynamics approach. *International Journal of Industrial and Systems Engineering*, *38*(4), 432–449.

Reike, D., Vermeulen, W. J., & Witjes, S. (2018). The circular economy: New or refurbished as CE 3.0? —exploring controversies in the conceptualization of the circular economy through a focus on history and resource value retention options. *Resources, Conservation and Recycling*, *135*, 246–264.

Rizos, V., Behrens, A., van der Gaast, W., Hofman, E., Ioannou, A., Kafyeke, T., Flamos, A., Rinaldi, R., Papadelis, S., Hirschnitz-Garbers, M., & Topi, C. (2016). Implementation of circular economy business models by small and medium-sized enterprises: Barriers and enablers. *Sustainability (Switzerland)*, *8*(11), 1212.

Robles, I., Durkin, A., & Guo, M. (2021). Stochastic optimisation of organic waste-to-resource value chain. *Environmental Pollution*, *273*, 116435.

Salim, H., Stewart, R. A., Sahin, O., Sagstad, B., & Dudley, M. (2021). R3SOLVE: A Serious Game to Support End-of-Life Rooftop Solar Panel Waste Management. *Sustainability*, *13*(22), 12418.

Sandvik, I. M., & Stubbs, W. (2019). Circular fashion supply chain through textile-to-textile recycling. *Journal of Fashion Marketing and Management*, *23*(3), 366–381.

Sarkodie, S. A., & Owusu, P. A. (2021). Impact of COVID-19 pandemic on waste management. *Environment, Development and Sustainability*, *23*(5), 7951–7960.

Selma, K., Ilyès, B., Ladjel, B., Eric, S., Stéphane, J., & Michael, B. (2012). Ontology-based structured web data warehouses for sustainable interoperability: Requirement modeling, design methodology and tool. *Computers in Industry*, *63*(8), 799–812.

Shaharudin, M. R., Zailani, S., & Tan, K. C. (2015). Barriers to product returns and recovery management in a developing country: Investigation using multiple methods. *Journal of Cleaner Production*, *96*, 220–232.

Shahparvari, S., Chhetri, P., Chan, C., & Asefi, H. (2018). Modular recycling supply chain under uncertainty: A robust optimisation approach. *The International Journal of Advanced Manufacturing Technology*, *96*(1), 915–934.

Sharma, H. B., Vanapalli, K. R., Cheela, V. S., Ranjan, V. P., Jaglan, A. K., Dubey, B., Goel, S., & Bhattacharya, J. (2020). Challenges, opportunities, and innovations for effective solid waste management during and post COVID-19 pandemic. *Resources, Conservation and Recycling*, *162*, 105052.

Shemshadi, A., Shirazi, H., Toreihi, M., & Tarokh, M. J. (2011). A fuzzy VIKOR method for supplierselection based on entropy measure for objective weighting. *Expert Systems with Applications*, *38*(10), 12160–12167.

Sinha, E. (2021). Circular economy—A way forward to sustainable development: Identifying conceptual overlaps and contingency factors at the microlevel. *Sustainable Development*, *30*(4), 771–783.

Suchek, N., Fernandes, C. I., Kraus, S., Filser, M., & Sjögrén, H. (2021). Innovation and the circular economy: A systematic literature review. *Business Strategy and the Environment*, *30*(8), 3686–3702.

Sudusinghe, J. I., & Seuring, S. (2021). Supply chain collaboration and sustainability performance in circular economy: A systematic literature review. *International Journal of Production Economics*, *245*, 108402.

Sunarsih, S., Pamurti, R. D., Khabibah, S., & Hadiyanto, H. (2020). Analysis of priority scale for watershed reforestation using trapezoidal fuzzy VIKOR method: A case study in Semarang, Central Java Indonesia. *Symmetry*, *12*(4), 507.

Taghikhah, F., Voinov, A., & Shukla, N. (2019). Extending the supply chain to address sustainability. *Journal of Cleaner Production*, *229*, 652–666.

Tan, J., Tan, F. J., & Ramakrishna, S. (2022). Transitioning to a Circular Economy: A Systematic Review of Its Drivers and Barriers. *Sustainability*, *14*(3), 1757.

Tansel, B. (2017). From electronic consumer products to e-wastes: Global outlook, waste quantities, recycling challenges. *Environment International*, *98*, 35–45.

Trivedi, R. H., Patel, J. D., & Savalia, J. R. (2015). Pro-environmental behaviour, locus of control and willingness to pay for environmental friendly products. *Marketing Intelligence & Planning*, *33*(1), 67–89.

Tseng, M. L., Ha, H. M., Tran, T. P. T., Bui, T. D., Chen, C. C., & Lin, C. W. (2022). Building a data-driven circular supply chain hierarchical structure: Resource recovery implementation drives circular business strategy. *Business Strategy and the Environment*, *31*(5), 2082–2106.

Vahabzadeh, A. H., Asiaei, A., & Zailani, S. (2015). Green decision-making model in reverse logistics using FUZZY-VIKOR method. *Resources, Conservation and Recycling*, *103*, 125–138.

Van Fan, Y., Jiang, P., Klemeš, J. J., Liew, P. Y., & Lee, C. T. (2021). Integrated regional waste management to minimise the environmental footprints in circular economy transition. *Resources, Conservation and Recycling*, *168*, 105292.

van Loon, P., & Van Wassenhove, L. N. (2020). Transition to the circular economy: The story of four case companies. *International Journal of Production Research*, *58*(11), 3415–3422.

Vermunt, D. A., Negro, S. O., Verweij, P. A., Kuppens, D. V., & Hekkert, M. P. (2019). Exploring barriers to implementing different circular business models. *Journal of Cleaner Production*, *222*, 891–902.

Wang, H., Pan, X., & He, S. (2019). A new interval type-2 fuzzy VIKOR method for multi-attribute decision making. *International Journal of Fuzzy Systems*, *21*(1), 145–156.

Wang, X., Zhang, C., & Zhang, Z. (2019). Pollution haven or porter? The impact of environmental regulation on location choices of pollution-intensive firms in China. *Journal of Environmental Management*, *248*, 109248.

Waqas, M., Dong, Q. L., Ahmad, N., Zhu, Y., & Nadeem, M. (2018). Critical barriers to implementation of reverse logistics in the manufacturing industry: A case study of a developing country. *Sustainability*, *10*(11), 4202.

Webster, K. (2013). What might we say about a circular economy? Some temptations to avoid if possible. *World Futures*, *69*(7–8), 542–554.

Wong, D. T., & Ngai, E. W. (2021). Economic, organizational, and environmental capabilities for business sustainability competence: Findings from case studies in the fashion business. *Journal of Business Research*, *126*, 440–471.

Yang, M., Smart, P., Kumar, M., Jolly, M., & Evans, S. (2018). Product-service systems business models for circular supply chains. *Production Planning & Control*, *29*(6), 498–508.

Yazdani, M., & Graeml, F. R. (2014). VIKOR and its Applications. *International Journal of Strategic Decision Sciences*, *5*(2), 56–83.

Yu, H., & Solvang, W. D. (2018). Incorporating flexible capacity in the planning of a multi-product multi-echelon sustainable reverse logistics network under uncertainty. *Journal of Cleaner Production*, *198*, 285–303.

Zhang, A., Wang, J. X., Farooque, M., Wang, Y., & Choi, T. M. (2021). Multi-dimensional circular supply chain management: A comparative review of the state-of-the-art practices and research. *Transportation Research Part E: Logistics and Transportation Review*, *155*, 102509.

How to cite this article: Agrawal, D., Dwivedi, A., Patil, A., & Paul, S. K. (2023). Impediments of product recovery in circular supply chains: Implications for sustainable development. *Sustainable Development*, *31*(3), 1618–1637. https://doi.org/10.1002/sd.2472