Received: 14 February 2022 | Revised: 31 May 2022 | Accepted: 14 June 2022

DOI: 10.1002/bse.3191

RESEARCH ARTICLE

Business Strategy and the Environment WILEY

# Circular economy adoption challenges in the food supply chain for sustainable development

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## Abstract

Food loss and waste are major issues in the food industry, and they affect all stages of the food supply chain (FSC). Food loss and waste are linked to environmental deterioration, economic loss, and an increase in hunger. Therefore, the food industry requires sustainable consumption and production (SCP) to reduce losses and waste. The circular economy (CE) concept has become a popular strategy for reducing food waste and boosting sustainability. Therefore, with efficient reverse logistics in the FSC, food producers can help achieve sustainable development goals (SDGs) like SCP and zero hunger. In literature, minimal research has been available in identifying the CE adoption challenges in FSC. This research identifies 15 critical challenges from the literature and discussion with the panel of experts. The relationship between the challenges has been established through an interpretive structural modeling (ISM) technique. The challenges were characterized in cause–effect according to their relational intensity obtained using the grey decision-making trial and evaluation laboratory (DEMATEL) technique. Grey's relational theory is applied in DEMATEL to minimize uncertainty and vagueness of the expert judgment. The findings of this study suggest that creating policy from the government, providing incentives, and strictly enforcing environmental regulations are the most critical challenge. Hence, by focusing on the above, the effective adoption of the CE principle is achieved. This result also suggests that by addressing the challenges of CE, corporate social responsibility (CSR) can be performed. This study provides some recommendations for the practitioners to adopt CE towards sustainable development targets.

**KEYWORDS**
circular economy, DEMATEL, food supply chain, Grey's relational theory, interpretive structural modeling, sustainable development goal (SDG)

## 1 | INTRODUCTION

A food supply chain (FSC) is a network that links consumers, farmers, and producers (Antonucci et al., 2019). Several parties (farmers, producers, distributors, warehouses, retailers, etc.) have collaborated in the FSC network to supply safe and secure food to customers (Dania et al., 2018). Several wastes are linked with changing raw food (produced by farmers) into processed food and reaching consumers (Béné et al., 2019; Gardas et al., 2018; Mourad, 2016). According to UNEP (2021), worldwide food waste in 2019 was roughly 931 million tons, with households, food service, and retail accounting for 61%, 26%, and 13%, respectively, resulting in 17% of total edible food waste. Food waste has negative consequences from a social standpoint and an ecological and economic standpoint. In the FSC, strong waste management must dispose of the minimum amount of wastage in landfills after ensuring the 3Rs' (reuse, recovery, recycle). Hence, a close-loop supply chain in FSC helps in the reduction of wastage. As a result, a circular idea maximizes the use of produced food and reduces global food waste.

Food waste is associated with massive greenhouse gas emissions, environmental impacts, biodiversity loss, and so on, (Corrado et al., 2019), so waste management is the key (UNEP, 2021). Food waste management is the major challenge for sustainable development, derived from the ineffective management of food surplus (Alae-Carew et al., 2019; Cicculo et al., 2021). To reduce food loss and wastage, Papargyropoulou et al. (2014) provide a hierarchy of food waste management, that is., prevention of food wastage, reuse, recycling recovery, and disposal; however, there is a significant gap in FSC for managing food waste. Vilariño et al. (2017) state food loss and waste reduction is an essential part of the circular economy (CE) and helps to achieve sustainable development goals (SDGs). Therefore, CE adoption in FSC is necessary to minimize wastage recycling and recovery. Thus, there is a lack of practical implications of CE in FSC because of several challenges (e.g., lack of govt regulation, lack of top management commitment). The CE principle is one such concept applied in the FSC for reducing food wastage (Kumar, Singh, & Kumar, 2021). From an FSC perspective, CE has rapidly converted a significant driving force behind SC sustainability in research and practice (Béné et al., 2019; Genovese et al., 2017). CE presents a new and advanced sustainability boundary in SC management (SCM) (Nasir et al., 2017). Some global SC leaders are adopting the CE features, including Apple, Coca-Cola, and Colgate-Palmolive (Farooque et al., 2019). The waste created in a linear supply chain is immediately transported to landfills, whereas CE has a zero-waste aim with negligible landfill waste (Bressanelli et al., 2019). Figure 1 depicts the distinction between linear and circular supply networks. To successfully adopt CE practice in FSC, firms need to understand and tackle critical challenges. Adopting CE in FSC has several advantages. It can utilize maximum value from the food, reduce wastage, and zero land disposal. Therefore, CE adoption in FSC is urgently required to support sustainable development targets like sustainable consumption and production (SCP) and zero hunger.

Reducing food waste leads to increased sustainability (Ghosh & Eriksson, 2019; Kumar, Raut, et al., 2021). Besides several advantages of CE adoption for sustainable development targets, it still faces challenges and obstacles in actual practice. FSC faces significant challenges while adopting CE practice; some of them are regulation (Mangla et al., 2018), lack of innovation in green packaging materials to protect food waste reduction (Kumar, Raut, et al., 2021), lack of circular design for food packaging, weak enforcement of the environmental policy, poor market responses for the recycled material, inadequate digital infrastructure, refurbished products, lack of government support, and so on (Mangla et al., 2018; Mogale et al., 2020; Kumar, Singh, & Kumar, 2021). Food wastage is directly reduced by improving food safety and quality and increasing sustainability. The CE can reduce wastage and environmental impact by reusing, remanufacturing, and recycling food products. Previous literature and UNEP (2021) highlight that FSC has significant room for reducing food waste, and CE has a key role in lowering wastage and achieving sustainable development. Towards SCP, CE helps to improve several sustainable development targets like; waste management (12.5.1), resource use (12.2), food loss and waste (12.3), chemical waste management (12.4), and sustainable public procurement (12.7).

This study mainly focuses on India because of the second largest country according to the population and seventh according to a geographical area. As the country's population increases, food is also required. On the other hand, India is the third-largest greenhouse gas contributing country, and the food sector contributes one-fourth of it approx. 26%. Around 67 million tons of edible food get wasted in India, valued at around 92,000 crores, which are enough to feed 12 crores of people (Kumar, Choubey, et al., 2021). Recently, food waste has been directly filled into the landfill without reusing, donation, or recovery. Therefore, the CE concept in the Indian FSC is urgently required to lower food wastage and build a robust waste management plan. To successfully adopt CE in Indian FSC deep investigation of CE adoption challenges and policy and recommendations is required to achieve SDGs. Indian FSC has the potential to adopt CE practice, but they face a few challenges which need to explore and planned accordingly, so the authors used Indian FSC as a case analysis.

Previous literature-inspired researchers by showing lacks of CE adoption in FSC, despite its clear advantage in waste reduction, new value generation, and sustainable development. Furthermore, Sharma et al. (2019) also study the CE challenges, but they do not focus on

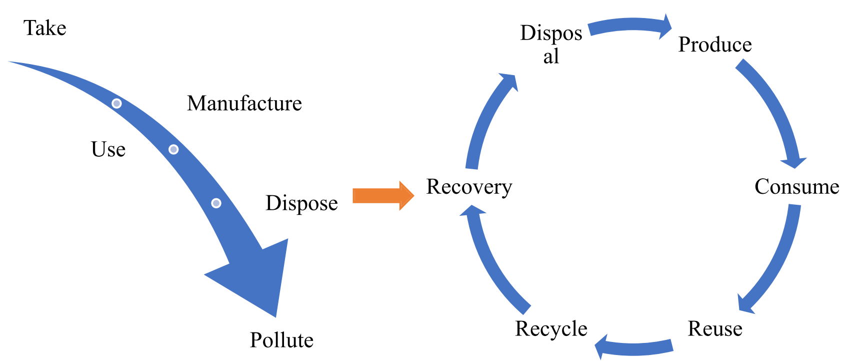



**FIGURE 1** Transition from linear supply chain to circular supply chain

sustainable development nor discuss the relationship's intensity and causal interaction. Herein, this research aims to identify the key challenges food industries face in the adoption of CE. The identified CE adoption challenges have been analyzed and investigated, along with the intensity of the relationship, the interrelationship among them. This study also provides insight to the FSC for sustainable development to achieve the SDGs. This study also contributes to the literature by providing clear guidance for practitioners via a detailed investigation of the challenges and implications for sustainable development. Findings obtained from the analysis of challenges practitioners clearly understand the critical challenges, interrelationship, and their causal relationship with the intensity. This paper proposes policies and implications for waste reduction and reaching SDGs such as SCP and zero hunger based on the analysis. Based on the gap in the literature and the aim of this study, the following research questions will be provided. Readers of this research article get answered to these research questions.

### 1.1 | Research questions

RQ1: What challenges does the Indian FSC face when adopting CE, and how do they help achieve sustainable development goals to ensure sustainable consumption and production?

RQ2: What are the CE adoption challenges' contextual interrelationship and hierarchical structure?

RQ3: What is the causal relationship and intensity of the CE challenges, and how does it help ensure sustainable consumption and production?

### 1.2 | Research objective

The following objectives are set to achieve in this study:

RO1: To explore the CE adoption challenges Indian FSC to ensure SCP.
RO2: To investigate the interrelationship and hierarchical structure for the CE adoption challenges in FSC.
RO3: To find the causal relationship with their intensity for the circular economy adoption challenges in the view of SCP.

This has several contributions to the research by focusing on the research objectives. First, it will show the contextual interrelationship among the critical CE adoption challenges and cluster them based on their causal relationship. Second, this research utilizes a two-phase multicriteria decision making (MCDM) based research methodology, interpretative structural modeling (ISM), and an integrated grey DEMATEL technique to fulfill the research aims. The ISM method examines the contextual interconnection of challenges and presents a hierarchical framework. Third, at the same time, the grey DEMATEL technique offers a causal relationship with the intensity of the challenges and categorizes them as cause-and-effect groups. The causal relationship gives clear insight into the issues of understanding criticality, which aids policymakers in making decisions. Fourth, based on the outcomes of this study, we provide policy recommendations for the FSC towards CE adoption and the achievement of SDGs such as SCP and zero hunger.

Furthermore, this study provides opportunities for researchers and practitioners based on the challenges. In the later part of the study, Section 2 demonstrates the review of literature based on circular FSC. Section 3 represents the research methodology, while the application of the proposed method has been discussed in Section 4. Section 5 discusses the findings obtained from the analysis of results and the implications provided. Finally, in Section 6, the whole research is concluded along with the future direction.

## 2 | LITERATURE REVIEW

A comprehensive analysis is performed on the articles published on the Web of Science and Scopus. In addition, the latest articles were collected between 2016 and 2022 on circular supply chain implementation on FSC.

### 2.1 | Sustainable development and FSC

Food is one of the most critical requirements of human life, and the supply chain plays an essential role in providing food, whether it is unprocessed (vegetables, grains, fruits, etc.) or processed food from farmers/producers to consumers (Chkanikova & Sroufe, 2021; Wang et al., 2021). Feeding the world's rising population is the point of concern for the supply chain, and the FSC sees pressure to provide safe and secure food to all people (Bendinelli et al., 2020). In food production, processing, and huge distribution, food waste is associated, and the wastage of food raises several environmental, social, and economic concerns. Food wastage is associated with a large environmental impact that is directly dumped into the landfills without recovering and reusing. According to UN food waste, one-third of the produced edible food gets wasted, and around one-third of our population does not get food and sleeps without food. From the economic perspective, global food wastage spoils the global economy by $936 billion. Therefore, sustainable development in the FSC is an urgent requirement for reducing food wastage and feeding people. Because of the perishability and short shelf life of food products, there is a significant amount of waste at every stage of the supply chain, including harvesting, shipping, processing, and consumption (Balaji & Arshinder, 2016). Food losses and waste in FSC have a direct influence on biological deterioration, which leads to poverty and food insecurity, as well as the global economy; hence, recent FSC poses a considerable challenge to sustainable development (Ali et al., 2019; Arndt et al., 2020; Dey et al., 2020; Parmar et al., 2018; Sufiyan et al., 2019). As a result, decreasing food waste is essential for achieving SDG, SCP, and supporting zero hunger (Byerlee & Fanzo, 2019). Several researchers (Cicculло et al., 2021; Dey et al., 2020; Slorach et al., 2020; Teigiserova et al., 2020) investigate CE practices in the FSC, with food waste reduction as a primary driver of sustainable development. While, researchers (Belmonte-Ureña et al., 2021; Kayikci et al., 2022; Triguero et al., 2022) also utilized the CE pathway to the sustainable development. Nayal et al. (2022) show that using digital technology in the CE increases supply chain performance and helps in sustainable development. According to Bassi and Dias (2020), CE is more dedicated to achieving SDGs 12.

## 2.2 | CE and sustainable development

The CE plays an essential role in the sustainable development of the FSC, especially in SCP (SDG 12), Zero Hunger (SDG 2), and climate action (SDG 13), (Genovese et al., 2017; Virmani et al., 2022). The CE practice is not new in research, but it has recently gained attention due to the UN's goal for sustainable development (Geissdoerfer et al., 2018). Recovery, recycling, and reuse (3R) are the primary drivers of CE to extract value from waste and improve performance in all aspects of sustainability (Dey et al., 2020). With the CE practice, the product life cycle is improved by maximizing resource consumption and generating value when the product approaches the end of its useful life (Dev et al., 2020). In a circular supply chain, trash is not directly transferred to landfills; instead, it goes through a recovery phase to extract as much energy as feasible (Loizia et al., 2019; Peng & Pivato, 2019). In the CE practice, the concept of waste in the linear supply chain is removed by reusing and reproducing new value from the food waste (Sehnem et al., 2019). Dev et al. (2020) applied CE concept to recover energy from the urban waste. Rada et al. (2017) use the CE technique to recover energy from municipal solid waste. Loizia et al. (2019) generate energy by anaerobic digestion of food waste. Based on Industry 4.0 and CE, Dev et al. (2020) created a sustainable reverse SC performance framework. Yadav, Luthra, Jakhar, et al. (2020) developed a framework for reducing SC issues using Industry 4.0-based CE. Kazancoglu, Ekinci, et al. (2021) established a green supply chain performance evaluation methodology based on CE. Based on previous discussions, it is apparent that CE adoption in FSC would increase sustainable food consumption and production by not directly dumping into landfills and instead of turning into fertilizers or donating surplus food to the needy to reach zero hunger. Based on several kinds of literature (Dey et al., 2020; Kazancoglu, Sagnak, et al., 2021; Kazancoglu, Ekinci, et al., 2021), CE adoption has a positive impact on sustainable development as it reduces environmental impact and improves social wellbeing and economic growth.

### 2.2.1 | CE in FSC

The technical nutrients (e.g., plastics and packaging) in a circular FSC are designed to be reused, remanufactured, restored, and recycled substantially. Furthermore, collecting high-quality biological nutrients (e.g., organic materials) in such a way contribute to natural resources, either directly or after processing (De Angelis et al., 2018). The FSC is linked with significant waste, and numerous researchers (Ciccullo et al., 2021; Dev et al., 2020; Hebrok & Heidenstrøm, 2019; Lehtokunnas et al., 2020) have already used CE practices to reduce it. Genovese et al. (2017) conducted a life cycle study and discovered that CE practice improves the FSC's sustainability and benefits the environment. Meherishi et al. (2019) revealed that sustainable packaging in supply chain management aids in implementing CE practices. Jurgilevich et al. (2016) investigated the obstacles to using the notion of CE in the FSC. Principato et al. (2019) offered a case study on CE practices in the pasta production industry. They observed that pasta production is the most outstanding CE example because it accounts for just 2% of food loss and wastage throughout the life cycle. Blockchain (Nandi et al., 2021), Industry 4.0 (Mastos et al., 2021), Big data (Kazancoglu, Ozbiltekin Pala, et al., 2021), and other technologies, in conjunction with CE, increase FSC sustainability. Researchers (Nandi et al., 2020, 2021; Upadhyay et al., 2021) applied blockchain, big data, and other technology to enhance the CE practice in the era of Industry 4.0. Therefore, several researchers applied Blockchain technology to improve traceability (Demestichas et al., 2020; Hew et al., 2020; Zhang et al., 2021), food safety (George et al., 2019; Lin et al., 2019; Tripoli & Schmidhuber, 2020), and quality (George et al., 2019; Mondal et al., 2019). Principato et al. (2019) applied CE in pasta production to reduce food loss and wastage, while Ciccullo et al. (2021) in Agri-FSC.

### 2.2.2 | Challenges to the adoption of CE in the FSC

Apart from the advantages of adopting CE over the linear practice in FSC, it has some barriers to implement it in reality. Table 1 depicts the main feature of past recent studies on the identification and analysis of CE adoption challenges in FSC. Several studies (Farooque et al., 2019; Govindan & Hasanagic, 2018; Kumar, Mangla et al., 2018; Kumar, Singh, & Kumar, 2021; Raut, et al., 2021) highlighted challenges to CE adoption in the Food/Agri-FSC without showing their advantage to the sustainable development. According to Sharma et al. (2019), the most significant difficulty in emerging economies such as India, Bangladesh, and Pakistan is lack of government policy surrounding the adoption of CE. Kumar, Singh, and Kumar (2021) also reveal that inefficient waste management and recycling programs and lack of environmental regulations and sustainable policies pose obstacles. In addition, there was a shortage of information technology (IT) support and digital logistic infrastructure in emerging economies (Govindan & Hasanagic, 2018; Mangla et al., 2018). In the recent Industry 4.0 era, lack of technological capability is one of the challenges FSC faced in successfully adopting CE practice. An effective traceability system is required for CE adoption in FSC to trach the waste generated (Nandi et al., 2021). The FSC traceability is critical since it tracks food waste, food quality and safety, and transparency. However, establishing a traceability system is challenging (Govindan & Hasanagic, 2018; Sharma et al., 2019). It has been found that challenges are interrelated, with some acting as a cause/driver and others as an effect/driven. Therefore, it is vital to investigate and analyze challenges to

**TABLE 1** Features of past research on the CE challenges to FSC

| Source | Country | Objective | Tools and technique | Findings | Gap obtained |
|---|---|---|---|---|---|
| Farooque et al. (2019) | China | To identify barriers to the circular FSC barriers and reveals the cause-effect relationship. | Fuzzy DEMATEL | They develop a theoretical framework for the FSC barriers in China and explore causal relationships. | They did not connect findings with sustainable development and the contextual interrelationship. The study did not reveal the challenges of dependent, independent, linkage, and autonomous behavior. |
| Kumar, Raut, et al. (2021) | India | To identify I 4.0 and CE adoption berries in the agriculture supply chain. | ISM-ANP | I 4.0 and CE adoption barriers identification, contextual interrelationship among barriers and prioritization of barriers. | Study focuses on I 4.0 and CE adoption barriers but did not connect with sustainable development, and causal interaction is missing. |
| Liu et al. (2021) | China | To analyze the barriers to the SCP in Chinese FSC from CE perspective. | Fuzzy DEMATEL | They identify and analyze barriers to SCP in FSC through F-DEMATEL and discuss their effect on CE practice. | The contextual interrelationship and factor dependent, independent, linkage, and autonomous behavior barriers are missing in this study. |
| Sharma et al. (2019) | India | To identify and analyze CE driven sustainable FSC barriers. | ISM-MICMAC | The CE-driven sustainable FSC barriers have been identified and analyzed, their contextual interrelationship and level of importance. | This study did not revealed the causal interrelationship and the intensity of the interrelationship of barriers. |
| Govindan and Hasanagic (2018) | - | To identify drivers, practices, and barriers in supply chain management. | Systematic literature review | This study identifies drivers, practices, and barriers to CE adoption in supply chain management. | Analysis of the identified factors is required for getting deep insight and making policies. |
| Formentini et al. (2022) | | To identify and study the CE adoption barriers and enablers in soft wheat bread production. | Decision support tool | This study identifies CE adoption enablers and challenges for the soft wheat bread production chain. They provide a framework of food loss and waste reduction. | An in-depth investigation and analysis of the causal behavior and interrelationship of challenges are required. Also, results obtained from the study need to connect with sustainable development. |
| Ada et al. (2021) | Turkey | To identify and analyze CE barriers for FSC and provide an Industry 4.0 based solution | Literature review | This study identifies and analyzes CE adoption barriers in Turkish FSC and provides an Industry 4.0-based solution based on the literature support. | It needs to connect with sustainable development, and an in-depth analysis of challenges is required. |
| This study | India | To identify and analyze CE adoption challenges from the perspective of sustainable development. | ISM-grey-DEMATEL | Fifteen critical challenges are identified by the Indian food industry and academic experts. Challenges are in-depth investigated to reveal their contextual interrelationship with their intensity as well as they are grouped based on causal relationship into cause-and-effect. | |

understand their role and importance in developing CE practice to uncover new opportunities.

## 2.3 | Modeling tools and techniques

Various MCDM tools and techniques were utilized in the literature to model a complex system's attributes/factors and challenges. ISM is a structural modeling technique applied to obtain a hierarchical model of the attributes (Kumar & Choubey, 2021; Mangla et al., 2018). Several researchers (Kamble et al., 2019; Kumar et al., 2020; Mangla et al., 2018; Mathiyazhagan et al., 2013; Nazam et al., 2020) applied ISM for modeling the barriers. DEMATEL is another MCDM technique used by researchers to obtain intensity for the relationship and cluster the factors into a cause-and-effect category. In the literature, some researchers also applied the DEMATEL methodology for modeling the barriers (Kouhizadeh et al., 2021; Kumar & Choubey, 2022; Sharma et al., 2019). While some applied ISM-based DEMATEL methodology multi-objective purpose (Kamble et al., 2019; Kumar et al., 2022; Mangla et al., 2018; Yadav et al., 2021; Yadav, Luthra, & Garg, 2020). Some other techniques are utilized, such as ISM-based ANP (Kumar et al., 2020; Nazam et al., 2020). It has been noted that researchers used predefined MCDM techniques without significant modification from a technical point of view; hence, this research also combines two MCDM techniques ISM and grey DEMATEL. The difference in the implementation of various tools and techniques is shown in Table 2.

## 2.4 | Findings from the literature

A review of previous research found that CE offers a high potential for reducing waste and attaining the goal of sustainable development. Because of a lack of waste management policies or practices, a lack of utilization of green products and wastage of valuable products throughout their life cycle, a lack of recycling and remanufacturing poor waste recovery, and final dumping to the planet, primary resources are aggressively used all over the world (Mangla et al., 2018). The change of FSC is essential to combat the greatest threat to the growth of sustainability. According to the UNEP (2021) assessment, FSC needs a significant improvement in waste reduction to meet the SDGs. Several nations (Japan, Australia, Germany, etc.) have already implemented the CSR effort in their FSC utilizing the CE approach (George et al., 2015). SDGs such as SCP, zero hunger, and life on land are easily possible using CE practices in FSC; there are still difficulties to overcome. Several research on CE adoption in FSC is available. However, few identify CE adoption issues in FSC for developing countries like India (Kumar, Raut, et al., 2021; Yadav, Luthra, Jakhar, et al., 2020). Researchers (Farooque et al., 2019; Sharma et al., 2019) also identify and analyze the CE challenges in the FSC, but they do not have prime focus on sustainable development in the FSC, especially on SDG 2 and SDG 12. Farooque et al. (2019) identify CE challenges in the context of China, while Sharma et al. (2019) study in the Indian context. In the investigation of CE challenges by

**TABLE 2** Difference among various modeling techniques

| | ISM-MICMAC | ISM-DEMATEL | ISM-ANP | DEMATEL-ANP | SEM |
|---|---|---|---|---|---|
| Purpose/objective | ISM–MICMAC reveals the contextual relations between driving and dependence power attributes. | The ISM-based DEMATEL uncovers the contextual relations and discriminates the attributes into cause-and-effect. | ISM-ANP gave a contextual relationship among attributes and also prioritized the attributes. | DEMATEL-ANP is utilized to cluster the attributes as well as prioritization. | SEM is mainly used for the hypothetical enhancement of the version; it needs a substantial sample range. |
| Input requirement | Interrelationship among factors in symbolic form. | Interrelationship among factors in symbolic form along with their intensity in linguistic scale. | Interrelationship among factors in symbolic form along with their weightage. | Interrelationship among factors in linguistic scale along with their weightage. | Large number of data set for factors and their corresponding items. |
| Output | Interrelationship hierarchy with their influence level and factor classification based on driving and dependence power. | Interrelationship hierarchy with their influence level with intensity of each relationship and factor classification-based prominence and relational score to cause and effect. | Interrelationship hierarchy with their influence level and factor ranking and their weight. | Factor classification-based prominence and relational score to cause and effect also factor weightage and rank. | To test hypothesis and factor relationship with their level of significance and development of theocratical model. |

Sharma et al. (2019), they do not reveal the intensity of the relationship and causal analysis. A thorough analysis of CE adoption issues is essential to make policy and identify natural obstacles that have the most significant impact. Analyzing challenge outcomes aids in the discovery of new opportunities in the context of sustainable development. The contextual examination of issues aids in developing policy and strategy for implementing CE practice and sustainable development (Kumar, Raut, et al., 2021; Mangla et al., 2018). As a result, this study used the ISM-Grey-DEMATEL technique to analyze the challenges to implementing CE in FSC and discuss their significance to sustainable development, especially SDG 2 and SDG 12. This research aims to provide a leveled hierarchical structural framework that establishes the contextual link between problems, prominence, and relational intensity.

## 3 | RESEARCH METHODOLOGY

This study has applied ISM and grey-DEMATEL to establish the relationship among the CE adoption challenges. This section of the study will elaborate on the methodology that has been shown in Figure 2. A two-phase integrated methodology is required based on the research questions and objectives. A two-phase ISM-Grey-DEMATEL-based research methodology has been adopted in this study. The advantage and features of applied techniques over others are depicted in Table 2. In the first phase, the CE adoption challenges for FSC have been identified and finalized through the expert's opinion. After that, contextual interrelationships were developed using the ISM approach. Finally, the grey-DEMATEL methodology has been applied in the second phase to cluster the challenges into cause and effect. Grey-DEMATEL also provides intensity for the relationship among all the challenges.

### 3.1 | Interpretive structural modelling- ISM

ISM is an eminent method presented by Warfield (1974) to establish the contextual interrelationship among the factors of a complex system and the hierarchical structure. Several researchers applied the ISM methodology for the relationship establishment on challenges in a different field, for example, for CE in Industry 4.0 adoption (Kumar, Singh, & Kumar, 2021), perishable FSC sustainability (Kumar et al., 2020), Internet of Things (IoT) adoption barriers (Kamble et al., 2019), and impediments of the sustainable FSC (Darbari

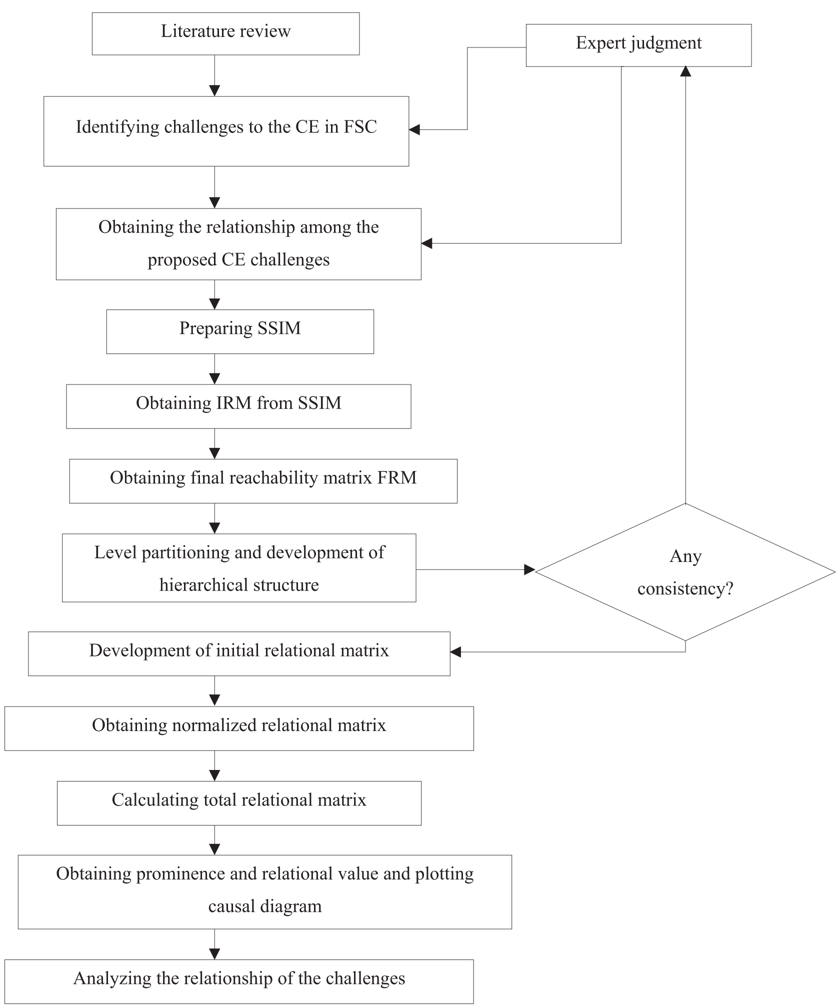



**FIGURE 2** Proposed research methodology

et al., 2018). The procedures of the ISM approach are explained below.

Step 1. Identification of CE adoption challenges for FSC

Literature was searched in Scopus, Scholar Google, and Web of Science with keywords of "circular FSC," "circular supply chain," "challenges to the Circular FSC," and "barriers to CE adoption in FSC." After an exhaustive study and suggestions from the experts, the 15 critical challenges to circular FSC were identified.

Step 2. Formation of structural self-interaction matrix—SSIM

A brainstorming season was performed with the experts (academics and industrial) of FSC to obtain the relationship among each pair of the CE challenges. As a result, a triangular relationship matrix contains relationship among each pair of the challenges was formulated using four alphabetical symbols (V, A, X, and O). The symbol V stands for challenge "i" will help to reach "j," A stands for "j" will help to reach "i," X stands for both challenges "i" and "j" will help each other, while O stands for neither "i" help nor "j."

Step 3. Transformation of SSIM into initial reachability matrix—IRM

The symbols used in SSIM are converted into numerical binary digit. Symbols were converted through some rules, if the cell value in SSIM is V then the entry at (i,j) is replaced by 1, and the (j,i) is replaced by 0. If the cell value in SSIM is A then the entry value at (i,j) is replaced by 0, and (j,i) is replaced by 1. If SSIM entry value is X then entry values at (i,j) and (j,i) both are replaced by 1 while if SSIM entry value is O then entry values at (i,j) and (j,i) both are replaced by 0. After transforming all the symbols of SSIM into a binary digit, the new matrix is known as IRM.

Step 4. Applying transitivity operation to obtain FRM

The FRM is obtained by applying a transitivity check on the IRM. In transitivity, the operation was applied to eliminate the inference which arises due to several indirect relations. The transitivity check performed if "k" is related to "l" and "l" is related to "m" then "k" and "m" are also related, and if the entry value is zero, it is replaced by 1.

Step 5. Level partitioning and formation of hierarchical structure

Level partitioning has been performed by matching the reachability set (RS) and antecedent set (AS) with the intersection set (IS). Here, RS for factor A is the entry set of factors influenced by factor A while AS of factor A is the entry set of those factors that drive factor A. While IS is the intersection entry of the RS and AS. In level partitioning, the value in RS and IS is found same; in that case, the corresponding attributes (challenges) are out as the first level. The factors (Challenges) selected as first-level are removed from the further iteration for obtaining the next-level factor. The same iteration of matching RS and IS is performed till the last challenges are selected. Then, the challenges selected at the first level are placed at the top of the hierarchy, the last selected challenges are placed at the bottom of the hierarchy, and linkage direction is shown from bottom to top in the hierarchy to obtain an interrelationship hierarchy.

### 3.1.1 | Limitation of ISM

In the ISM approach, the relationship among the pair of attributes was represented by the binary digit; that is, the binary number is used to correspond to the appropriate model in ISM; that is, one means for relationship exists and for not in a relationship. While this does not happen to consider an equal weight for all relationships in the actual scenario, this needs to incorporate the intensity for each pair of the attributes in terms of very high to very low (Bhosale & Kant, 2016). Therefore, this study incorporates the DEMATEL methodology supporting grey theory to handle the vagueness of the expert's opinion. DEMATEL is a technique that takes the input of relationships among attributes in terms of the intensity of the relationship.

## 3.2 | Grey DEMATEL

DEMATEL is a prominent tool used for analyzing causal interaction among the factors. This study applies DEMATEL to classify the challenges into the cause-and-effect category. In support of DEMATEL, we applied grey relation theory. The grey relation theory helps overcome the vagueness in the expert's judgment. Several researchers (Fu et al., 2012; Garg, 2021; Sahu et al., 2018; Sangari et al., 2020) previously applied the grey relation theory in support of DEMATEL for the same. The procedure for applying grey DEMATEL is explained as follows.

Step 1. Formulation of initial relation matrix.

The initial relation matrix is formulated by getting an expert's opinion on the final reachability matrix of ISM. The expert panel provides their opinion on each pair's relationship intensity of the challenges in terms of grey linguistic terms. A five-point grey linguistic term 0–4 was used where 0 denotes no influence and 4 denotes very high influence. Then, the grey linguistic variables are transformed into the numerical digit between 0 and 1, and transformation rules for a linguistic variable into a grey number (lower and upper number) are shown in Table 3. The initial relation matrix is obtained after converting each linguistic variable into a grey number.

**TABLE 3** Grey linguistic terms

| "No" | "VL" | "L" | "H" | "VH" |
|---|---|---|---|---|
| 0 | 0 | 0.25 | 0.5 | 0.75 |
| 0 | 0.25 | 0.5 | 0.75 | 1 |

Step 2. Obtaining normalized relational matrix N

The crisp normalized matrix is obtained by applying the normalization of the grey initial relation matrix. For example, a grey number's lower and upper value $\left(\underline{\otimes} x_{ij}^{l}, \overline{\otimes} x_{ij}^{l}\right)$ is 1st normalized using Equation (1).

$$\begin{gathered}\underline{\otimes}\dot{x}_{ij} = \left(\underline{\otimes}\check{X}_{ij} - \min_j \underline{\otimes}\check{X}_{ij}\right)/\Delta_{\min}^{\max}, \\ \overline{\otimes}\dot{x}_{ij} = \left(\overline{\otimes}\check{X}_{ij} - \min_j \overline{\otimes}\check{X}_{ij}\right)/\Delta_{\min}^{\max} \\ \text{Where } \Delta_{\min}^{\max} = \max_j \overline{\otimes}\check{X}_{ij} - \min_j \underline{\otimes}\check{X}_{ij}\end{gathered} \tag{1}$$

After normalization of grey numbers, the total normalized crisp value is computed using Equation (2).

$$C_{ij} = \left(\frac{\left(\underline{\otimes}\dot{X}_{ij}\left(1-\underline{\otimes}\dot{X}_{ij}\right) + \left(\overline{\otimes}\dot{X}_{ij} \times \overline{\otimes}\dot{X}_{ij}\right)\right)}{\left(1-\underline{\otimes}\dot{X}_{ij} + \overline{\otimes}\dot{X}_{ij}\right)}\right) \tag{2}$$

For obtaining the final crisp matrix C, Equation (3) is used.

$$\begin{gathered}C = \left[C_{ij}^{*}\right] \\ \text{Where } C_{ij}^{*} = \left(\min \underline{\otimes}\dot{x}_{ij} + \left(C_{ij} \times \Delta_{\min}^{\max}\right)\right)\end{gathered} \tag{3}$$

The Normalized crisp, direct relation matrix N, is determined using the equation.

$$\begin{gathered}N = C \times L \\ \text{Where } L = \frac{1}{\max 1 \le i \le l \sum_{j}^{l} x_{ij}}\end{gathered} \tag{4}$$

Step 3. Calculation of total relation matrix T

After the computation of "crisp normalized relation matrix N," the "total relation matrix T" is computed using Equation (5).

$$T = N \times (I - N)^{-1} \tag{5}$$

*where I denotes identity matrix.*

Step 4. Obtaining prominence and relational value and plotting causal diagram

First, R and C were calculated to denote row and column sum for computing prominence and relational vector. The R and C were calculated using Equation (6).

$$\begin{gathered}R = \left[\sum_{j=1}^{n} t_{ij}\right]_{n \times 1}, \text{ and} \\ C = \left[\sum_{i=1}^{n} t_{ij}\right]_{1 \times n}\end{gathered} \tag{6}$$

After the computation of R and C, the prominence vector (R + C) and relation vector (R − C) were calculated. The prominence vector provides the importance value, while the relation vector is utilized to cluster the attributes into the cause-and-effect category.

# 4 | CASE ILLUSTRATION AND RESULT ANALYSIS

## 4.1 | Case study

The UNEP (2021) reported that a significant amount of food is wasted in India, and globally, around 931 million tons of food are wasted. While India is a populous country, food wastage is a crime. As earlier said, the CE is not only minimizing wastage; it also reduces environmental pollution. Also, it is directly related to the environmental burden.

So, this study focuses on identifying the challenges faced by the Indian FSC while adopting the CE practice. Experts from various food organizations in India were consulted to achieve the study's desired objectives. Five food organizations agreed to participate and gave their feedback ten organizations.

## 4.2 | Identified challenges to circular FSC

A team of 15 experts, seven from the organization and eight from academia, participated; after their valuable feedback, the 15 challenges to CE adoption in Indian FSC have been identified. After a comprehensive literature search on various platforms and discussion with experts, the 15 challenges of circular FSC adoption are proposed for further analysis. Proposed challenges with detailed descriptions have been shown in Table 4.

## 4.3 | Application of ISM approach

The ISM is applied as per the earlier discussed procedure. First, the challenges were identified, and the relationship among each set pair of challenges was obtained from a panel of five experts. Then, based on the discussion held in the panel, a conclusive contextual relationship, the SSIM matrix, was generated, shown in Table 5.

After obtaining the SSIM matrix, the symbols were converted into the binary digit (0 and 1) known as the initial relation matrix and shown in Table 6.

Transitivity operation is performed on the IRM to obtain the final reachability matrix shown in Table 7. Next, the driving power and

**TABLE 4** Challenges to CE adoption in FSC and description

| Challenges to the circular food supply chain | Discerption | Author |
|---|---|---|
| Lack of CE policies from government—CE1 | Lack of government policies for product recycling, reuse, and remanufacturing are barriers to adopting CE in FSC. | Farooque et al. (2019); Sharma et al. (2019) |
| Lack of environmental regulations and enforcement—CE2 | Lack of environmental laws and enforcement is a barrier to environmentally friendly practices like CE sustainability adoption in FSC. | |
| Poor utilization of traceable systems—CE3 | Traceability improves organizations to decrease wastage to retain financial and ecological sustainability. | Govindan and Hasanagic (2018); Mangla et al. (2018); Farooque et al. (2019) |
| Lack of innovative materials for food packaging to enable food waste reduction—CE4 | There is a lack of innovative green packaging material that helps achieve CE. | Farooque et al. (2019); Sharma et al. (2019) |
| Poor logistics and IT infrastructure—CE5 | Logistics and infrastructure are the important part of the supply chain, so poor logistic performance is the barrier to the circular FSC. | Experts |
| Lack of a standard system and performance indicators for measuring CE in SC—CE6 | There is a lack of standard performance indicators available for assessing the circulatory index for the supply chain. | Govindan and Hasanagic (2018) |
| Lack of recycling and waste management policies—CE7 | Government policies regarding the recycling of food wastage, either commodity or packaging. Government policies may exert pressure on SC in recycling and decomposing the waste. | Govindan and Hasanagic (2018); Mangla et al. (2018) |
| Lack of incentive schemes by government for CE adoption—CE8 | In order to implement a new initiative, businesses need incentives from the government for proper functioning. | Kumar, Singh, and Kumar (2021); Mangla et al. (2018) |
| Lack of circular design aspect—CE9 | Foods are not designed for circular business models. However, a circular design helps re-engineer, remanufacture, and recycle. | Experts |
| Lack of acceptance from top management—CE10 | The commitment of the top management is the barrier to the CE or any new initiative in business. | Govindan and Hasanagic (2018); Mangla et al. (2018) |
| Technological limitations by tracking recycled materials—CE11 | There is a lack of a tracking system for correctly tracing recycled material. Proper tracking of recyclable material is advantageous for the circular initiative in SC. | Farooque et al. (2019); Giudice et al. (2020); Sharma et al. (2019) |
| Poor technological evolution for reuse, recovery remanufacturing, and reengineering—CE12 | For achieving CE recovery, reuse, re-engineering, and remanufacturing of the product are most important. | Farooque et al. (2019); Kumar, Raut, et al. (2021) |
| Poor market response for recycled, refurbished products—CE13 | Business is only for sailing the goods, so the market response to refurbishing recycled products is the challenge in CE adoption. | Govindan and Hasanagic (2018); Mangla et al. (2018) |
| Lack of financial capability for long-term CE goals—CE14 | Any new business initiative needs substantial financial resources, so the financial capability is the challenge for CE adoption. | Experts |
| Poor corporate social responsibility (CSR)—CE15 | Food organizations should be accountable for sustaining suitable environmental and safety standards for their foods. However, food organizations also lack effective partnerships and alliances with their suppliers. | Sharma et al. (2019) |

dependence power for all the challenges were computed in Table 7. After receiving the final reachability matrix level, partitioning is performed to get the level of importance; in this study, challenges were clustered into 10 levels, shown in Table 8.

After the level partitioning, the hierarchical structure of the challenges was constructed, shown in Figure 3. Poor CSR (CE15) is selected at the first level—placed at the top of the hierarchy. Therefore, the challenge poor CSR (CE15) is influenced by all the challenges placed below it so far; it was the least influential challenge. At the same time, the lack of CE policies from the government (CE1) is selected at the last level and placed at the bottom of the hierarchy. So, CE1 is the most influential challenge faced by the Indian FSC adopting the CE practice.

The lack of a standard system and performance indicators for measuring CE in SC (CE6) is placed at the 9th level of the hierarchy. In contrast, the lack of recycling and waste management policies (CE7) and poor logistics and IT infrastructure (CE5) are selected at the 8th level. The government's lack of incentive schemes for CE adoption (CE8) is placed at the 7th level in the hierarchy. In contrast, poor utilization of the traceability system (CE3) and the lack of environmental

**TABLE 5** SSIM for CE challenges

| | CE1 | CE2 | CE3 | CE4 | CE5 | CE6 | CE7 | CE8 | CE9 | CE10 | CE11 | CE12 | CE13 | CE14 | CE15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CE1 | X | V | O | V | O | V | X | V | V | V | V | V | O | O | V |
| CE2 | | X | O | V | O | A | A | O | V | V | V | V | O | O | V |
| CE3 | | | X | O | A | O | O | A | O | O | V | V | O | V | V |
| CE4 | | | | X | O | O | O | A | V | V | O | V | V | V | V |
| CE5 | | | | | X | O | O | V | O | O | V | O | O | O | V |
| CE6 | | | | | | X | V | O | V | V | V | O | O | O | O |
| CE7 | | | | | | | X | V | V | V | V | V | O | O | V |
| CE8 | | | | | | | | X | V | V | O | V | O | V | V |
| CE9 | | | | | | | | | X | O | A | V | V | O | V |
| CE10 | | | | | | | | | | X | O | V | V | O | V |
| CE11 | | | | | | | | | | | X | V | O | O | V |
| CE12 | | | | | | | | | | | | X | V | O | V |
| CE13 | | | | | | | | | | | | | X | V | V |
| CE14 | | | | | | | | | | | | | | X | V |
| CE15 | | | | | | | | | | | | | | | X |

**TABLE 6** IRM for CE challenges

| | CE1 | CE2 | CE3 | CE4 | CE5 | CE6 | CE7 | CE8 | CE9 | CE10 | CE11 | CE12 | CE13 | CE14 | CE15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CE1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| CE2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| CE3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 |
| CE4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| CE5 | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| CE6 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| CE7 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| CE8 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 |
| CE9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 |
| CE10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 |
| CE11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 |
| CE12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 |
| CE13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |
| CE14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| CE15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

regulations and enforcement (CE2) are placed at the 6th level of the hierarchy. Finally, the lack of innovative materials for food packaging to enable food waste reduction (CE4) and Technological limitations by tracking recycled materials (CE11) are selected at the 5th level.

In contrast, Lack of Acceptance from Top management (CE10) and Lack of Circular Design Aspect (CE9) are placed at the 4th level of the hierarchy. Poor market response for recycled, refurbished products (CE13) and Lack of financial capability for long-term CE goals (CE14) are placed at the 2nd level. In contrast, Poor technological evolution for reuse, recovery remanufacturing, and reengineering (CE12) is placed at 3rd level in the hierarchy.

### 4.3.1 | MICMAC analysis

MICMAC analysis is performed to cluster the challenges. MICMAC utilizes the result from the final reachability matrix. First, each attribute's driving power and dependence power were calculated by row and column summation for MICMAC analysis. Then, driving and dependence power was plotted to get the MICMAC graph. The challenges were clustered into four quadrants, namely; first, the autonomous cluster placed at the lower-left corner of the graph (which has low driving and dependence power), the second cluster is the dependence cluster placed at the lower right corner (which has high

**TABLE 7** Total reachability matrix for CE challenges

| | CE1 | CE2 | CE3 | CE4 | CE5 | CE6 | CE7 | CE8 | CE9 | CE10 | CE11 | CE12 | CE13 | CE14 | CE15 | Drv. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CE1 | 1 | 1 | 1* | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1* | 1 | 14 |
| CE2 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1* | 1* | 1 | 9 |
| CE3 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1* | 0 | 1 | 1 | 1* | 1 | 1 | 7 |
| CE4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 7 |
| CE5 | 0 | 0 | 1 | 1* | 1 | 0 | 0 | 1 | 1* | 1* | 1 | 1* | 0 | 1* | 1 | 10 |
| CE6 | 0 | 1 | 0 | 1* | 0 | 1 | 1 | 1* | 1 | 1 | 1 | 1* | 1* | 0 | 1* | 11 |
| CE7 | 0 | 1 | 1* | 1* | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1* | 1 | 12 |
| CE8 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1* | 1 | 1* | 1 | 1 | 10 |
| CE9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 1 | 4 |
| CE10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 4 |
| CE11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1* | 0 | 1 | 5 |
| CE12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 3 |
| CE13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 2 |
| CE14 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| CE15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Dep. | 1 | 4 | 5 | 7 | 1 | 2 | 3 | 5 | 10 | 8 | 8 | 12 | 12 | 8 | 15 | |

*Note*: 1* denotes transitivity relation.

**TABLE 8** Level partitioning of CE challenges

| | | Antecedent set | Reachability set | Intersection set |
|---|---|---|---|---|
| 1st | CE15 | 15 | 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15 | 15 |
| 2nd | CE13 | 13 | 1,2,3,4,6,7,8,9,10,11,12,13 | 13 |
| 2nd | CE14 | 14 | 1,2,3,4,5,7,8,14 | 14 |
| 3rd | CE12 | 12 | 12 | 12 |
| 4th | CE9 | 9 | 9 | 9 |
| 4th | CE10 | 10 | 10 | 10 |
| 5th | CE4 | 4 | 1,2,4,5,6,7,8, | 4 |
| 5th | CE11 | 11 | 11 | 11 |
| 6th | CE2 | 2 | 1,2,6,7, | 2 |
| 6th | CE3 | 3 | 1.3.5.7.8. | 3 |
| 7th | CE8 | 8 | 1,5,6,7,8, | 8 |
| 8th | CE5 | 5 | 5 | 5 |
| 8th | CE7 | 7 | 1,6,7, | 7 |
| 9th | CE6 | 6 | 1,6 | 6 |
| 10th | CE1 | 1 | 1 | 1 |

dependence and low driving power), the third cluster is linkage cluster placed at the upper left corner of the MICMAC plot (has higher dependence and driving power), and the fourth cluster is independent cluster placed at upper left corner (has higher driving but lower dependence power). The MICMAC plot is shown in Figure 4. In this study, seven challenges (CE15, CE13, CE12, CE9, CE10, CE14, CE11) are placed at the dependence cluster, while the other seven are placed at the independent cluster. There were no challenges has been found in the autonomous and linkage cluster.

### 4.4 | Application of Grey DEMATEL methodology

Grey DEMATEL methodology has been applied based on the procedures discussed in the earlier section. Based on the findings of the ISM analysis, the panel of experts was asked to assign the intensity to the relationship among each pair of the challenge to form an initial relational matrix. Based on the outcomes from the experts, the initial relation matrix is developed and shown in Table A1. After converting linguistic variables into grey numbers, the grey initial relation matrix

**FIGURE 3** The hierarchical structure of CE challenges

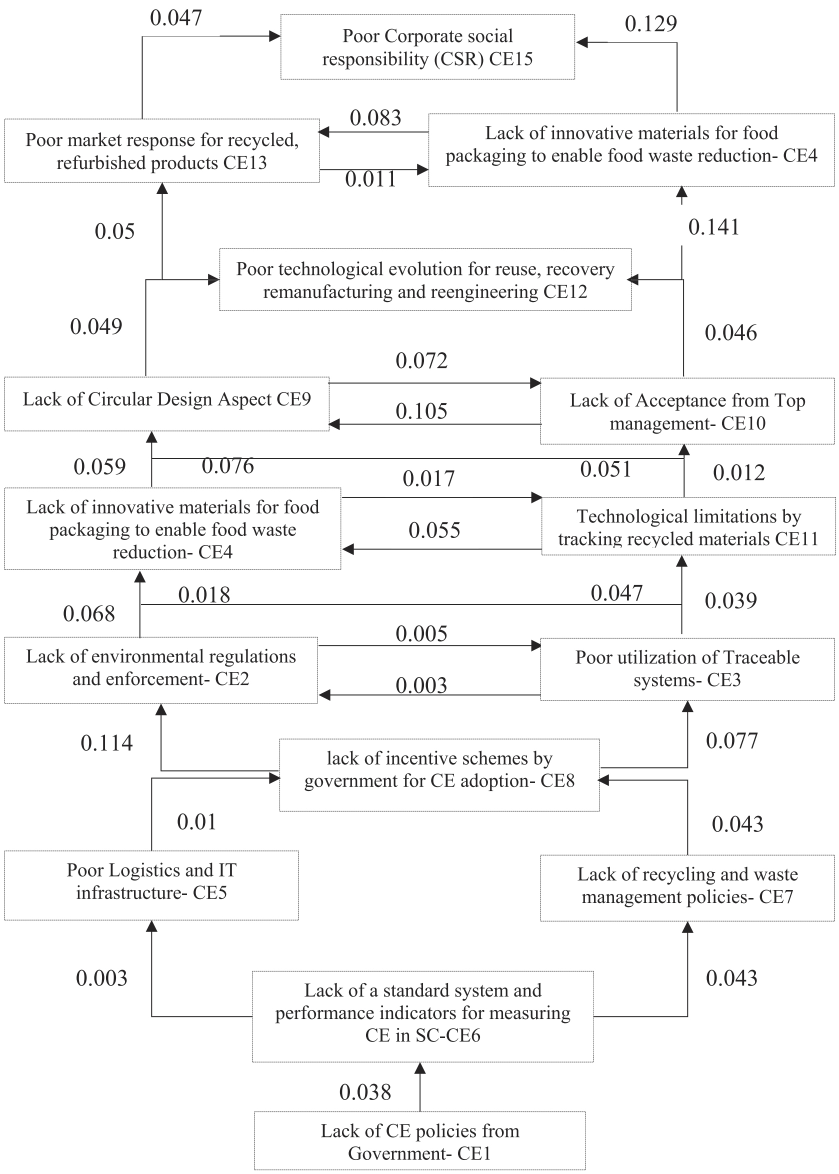
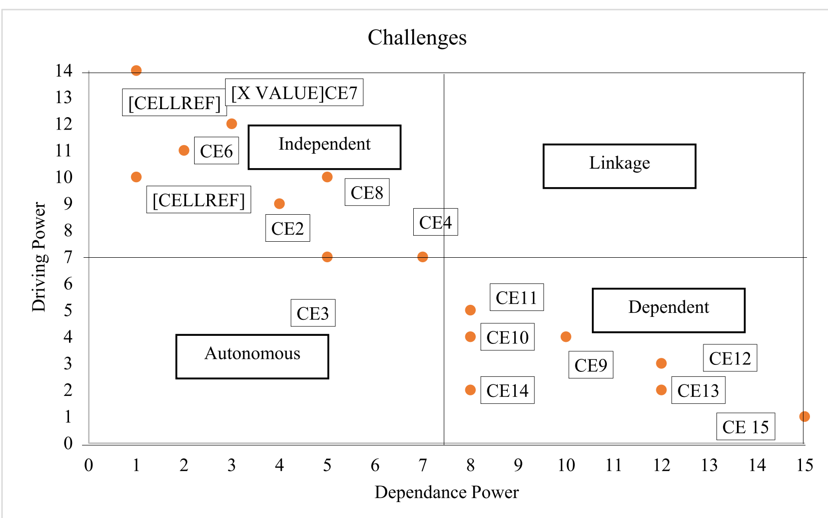



**FIGURE 4** MICMAC plot for CE challenges



was obtained. The grey initial relation matrix is normalized using Equation (4) to get a crisp normalized relation matrix shown in Table A2. The total relation matrix T was obtained using Equation (5) and shown in Table A3. The sum of row and column is computed to get the R and C vector and then the prominence vector (R + C) and relational vector (R − C) were computed in Table 9. The prominence and relational vector are then plotted in a graph, and the causal plot is shown in Figure 5.

The causal plot shown in Figure 5 is utilized to cluster the challenges into the cause-and-effect challenges. Poor CSR CE15 has the highest prominence value (1.623) and has the lowest relational value (−1.40). Seven challenges, respectively CE1, CE2, CE5, CE6, CE7, CE8, and CE14, are grouped in the causal group, except these, all are clustered in the effect group.

## 5 | DISCUSSIONS AND IMPLICATIONS

### 5.1 | Discussions

This study utilizes the ISM approach to establish the contextual relationship among the challenges and the hierarchical structure that shows the interdependency of the challenges and level of influence. Also, the MICMAC analysis is employed to cluster the challenges into the four-group based on their interdependency (driving and dependence) values. Findings reveal challenges such as lack of CE policies from the government, lack of environmental regulations and enforcement, Poor Logistics and IT infrastructure, lack of a standard system for performance indicators for measuring CE in SC, lack of recycling and waste management policies, and lack of incentive schemes by government for CE adoption are grouped as independent challenges.

Whereas, Poor utilization of Traceable systems and the lack of innovative materials for food packaging to enable food waste reduction are placed at the boundary of the independent and autonomous cluster. DEMATEL methodology reveals these two challenges placed at the boundary in ISM; while in DEMATEL, their relational score is negative and very low (−0.02 and −0.16) also it placed at 5th and 6th level in the hierarchy. So, due to significantly less relational value, their significance in CE adoption and suggestion from experts, and support from literature Gedam et al. (2021), these two challenges are selected as causal challenges and considered independent challenges. So, these challenges act as driving forces that push the whole system and are critical in the CE adoption. Challenges placed in the independent cluster of MICMAC analysis are general drivers/causal challenges (Mangla et al., 2018). Therefore, the grey-DEMATEL show that CE1, CE2, CE5, CE6, CE7, and CE8 are found at the causal challenges have a positive relational (R − C) score. On the other hand, challenges characterized as causal challenges should be placed at the bottom level of the ISM hierarchy. From the hierarchy of this study, the above challenges were placed at the bottom of the hierarchy such that CE1 at 10th, CE2 at 6th, CE5 at 8th, CE6 at 9th, CE7 at 8th, and CE8 at 7th.

The seven challenges, Lack of Circular Design Aspect; Lack of Acceptance from Top management; Technological limitations by

**TABLE 9** Prominence and relational vector for CE challenges

| | CE15 | CE1 | CE8 | CE12 | CE4 | CE9 | CE2 | CE7 | CE10 | CE11 | CE13 | CE6 | CE3 | CE5 | CE14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D | 0.11 | 1.223 | 1.228 | 0.405 | 0.641 | 0.453 | 0.793 | 0.969 | 0.423 | 0.49 | 0.211 | 0.779 | 0.308 | 0.484 | 0.319 |
| R | 1.513 | 0.397 | 0.299 | 1.119 | 0.804 | 0.981 | 0.524 | 0.296 | 0.687 | 0.562 | 0.78 | 0.098 | 0.326 | 0.148 | 0.302 |
| D + R | 1.623 | 1.62 | 1.526 | 1.524 | 1.445 | 1.435 | 1.317 | 1.265 | 1.11 | 1.053 | 0.991 | 0.877 | 0.634 | 0.632 | 0.622 |
| D-R | −1.403 | 0.826 | 0.929 | −0.714 | −0.163 | −0.528 | 0.268 | 0.673 | −0.264 | −0.072 | −0.569 | 0.681 | −0.019 | 0.336 | 0.017 |
| Group | E | C | C | E | E | E | C | C | E | E | E | C | E | C | C |

*Note*: C: Cause, E: Effect.

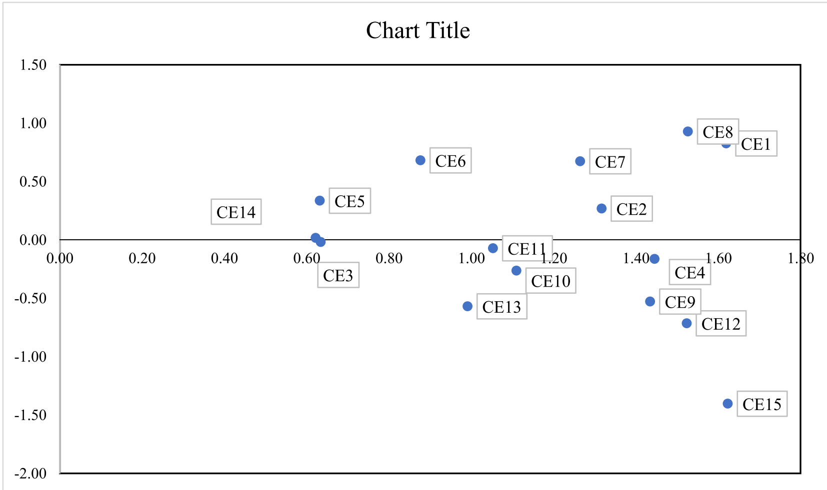



**FIGURE 5** Causal plot for CE challenges

tracking recycled materials; Poor technological evolution for reuse, recovery remanufacturing, and reengineering; poor market response for recycled, refurbished products; Lack of financial capability for long-term CE goals; and Poor CSR, were grouped in the dependent cluster, so these challenges are at the driven stage. Generally, the challenges placed in the dependence cluster are not more critical. Therefore, they should be categorized in the effect category in DEMATEL and placed at the top level of the hierarchy. So, the findings of the DEMATEL study show that challenges (CE9, CE10, CE11, CE12, CE13, and CE15) have a negative relational score and are categorized in the effect category. While lack of financial capability for long-term CE goals has a low positive relational score of 0.02 but is placed at the 2nd level of the hierarchy, this is also considered in the effect category.

Based on the above discussion, readers may answer the first two questions: what challenges an FSC faces in adopting CE; second, readers also understand the level of importance and causal classification. In further discussion, readers will see how those challenges influence each other and support achieving sustainable development targets like SCP and zero hunger. Lack of CE policies from the government is placed at the bottom of the hierarchy; therefore, it is a critical challenge for the system; this is also in line with (Kazancoglu, Sagnak, et al., 2021; Kumar, Singh, & Kumar, 2021). So, it is urgently required that government should make policy and ensure strict implementation of CE practice in the FSC. Many FSCs implement CE practices through the government initiative that help reduce wastage. The policy from the government provides standard system and performance indicators for evaluating circularity performance in FSC to help decision-makers and practitioners in CE adoption (Govindan & Hasanagic, 2018).

Along with the government policy regarding CE, another major challenge may be resolved by making a recycling and waste management policy (Cicculo et al., 2021). With recycling and waste management policy and strict enforcement of policies, FSCs must modify their supply chain infrastructure. Hence, another challenge for FSC is building efficient logistics and IT infrastructure to implement CE practice in FSC (Raut et al., 2019). Therefore, to improve the logistic infrastructure in FSC, Feng et al. (2020) and Tijan et al. (2019) recommended implementing blockchain technology. The government should provide incentives and funds for industries to quickly set up a recycling and recovery plant in their business (Kumar, Raut, et al., 2021). The government also enforces the FSC practitioners to follow the environmental regulation because the lack of environmental regulation is linked with various environmental issues and badly affects biodiversity (Farooque et al., 2019).

The poor traceability system utilization is another challenge that leads to poor food quality, poor transparency, and mismanagement of food wastage (Jagtap & Rahimifard, 2019). Food quality has the greatest impact on food waste, which is improved by increasing velocity and transparency in the logistic system. Hence, the proper utilization of the traceability system within the FSC improves circularity within FSC (Kazancoglu, Ekinci, et al., 2021). So, by utilizing Blockchain (Nandi et al., 2020, 2021), big data (Kazancoglu, Ozbiltekin Pala, et al., 2021), and many technologies, traceability within FSC is improved. The application of Blockchain, RFID, and Bigdata improves the traceability within FSC that helps tackle the challenges in tracking and tracing recycled material. Thus, using advanced technologies, the SDG indicator 12.A.1 environmentally sound technologies may be improved, and it helps achieve SCP. Therefore, incorporating the above challenges, FSC adds the highest impact on sustainable development targets like climate action, SCP, and zero hunger. Sawe et al. (2021) propose that CE adoption would entail a set of real value creation processes that can have a favorable effect on increasing productivity and, as a result, competitiveness. CE concepts have improved sustainability through food loss prevention and profit optimization with the right approach to reverse supply chain organization.

Another challenge for CE adoption in FSC is the lack of innovative green packaging material: poor technological evolution for reuse, recovery remanufacturing, and reengineering. There is a lack of innovation in green packaging and circular material; therefore, food industries must make circular product designs for reuse, remanufacturing, and recycling, leading to an improved circulatory index (Govindan & Hasanagic, 2018). With the handling of this challenge, FSC improves its performance in several indicators of SCP like (resource use 12.231 and 12.2.2 and sustainable public procurement 12.7). Sustainable business (SDG indicator 1.6.1) and SCP policies (SDG indicator 12.1) improve major CE adoption challenges like the poor response from the market for the refurbished product and lack of top management acceptance. Due to poor CSR in FSC, the CE practice is affected, but the poor CSR is the main challenge minimized by tackling other challenges related to awareness, government policy, and so on (Genovese et al., 2017).

## 5.2 | Implications for the practitioners

This study has several implications for the practitioners and policymakers for sustainable development through the CE adoption. This section presents implications for practitioners. Food waste reduction is the biggest challenge for the food sector from a social, economic, and environmental perspective. The CE has the caliber to do so. Logistics infrastructure and food quality have an important role in reducing food waste. The product's design must be carried out in order for it to be reprocessed, reused, recycled, and recovered from waste, if feasible, leading to an increase in the economy and biodiversity, as well as the achievement of SDGs such as SCP and zero hunger (Batista et al., 2018).

Furthermore, new technologies like blockchain, IoT, and AI offer many cold chain logistics applications. These technologies can improve visibility, tracing, and tracking throughout the FSC. As a result, perishability-focused logistics infrastructure design should be prioritized (Kumar et al., 2020). Another significant concern is poor quality control; therefore, attempts to improve quality are critical (Kazancoglu, Sagnak, et al., 2021). The 4 R CE strategy includes remanufacturing, recycling, recovery, and reuse and helps FSC improve the circular movement of food products and minimize waste generated (Mangla et al., 2018). Furthermore, the adoption of CE in FSC leads to saving in the form of resources, the economy, and employment generation; these savings add to boost the sustainability of the FSC (Yadav, Luthra, Jakhar, et al., 2020). According to Kazancoglu, Sagnak, et al. (2021), reverse logistics activities in an FSC have benefited green performance evaluation through food waste reduction and environmental damage. Therefore, FSC must utilize effective reverse logistic infrastructure by advanced digital technologies.

## 5.3 | Implications for the policy and recommendations for sustainable development

Therefore, based on the findings of this study, strategies and policies for practitioners, policymakers, and stakeholders of FSC have been recommended for the adoption of the CE principal. The proposed policies and strategies for CE adoption will aid in the achievement of SDGs such as SCP and zero hunger, among others. This study also provides the contextual interrelationship among the challenges using ISM's prominent tool. Furthermore, by applying DEMATEL, the cause effect interaction and their prominence and relational intensity are provided for each challenge. Finally, by analyzing the findings, some recommendations have been provided for planning and making strategies for CE adoption in FSC. This study suggests that the challenges found at the independent cluster in the MICMAC plot are generally strategic oriented and help in building strategy. Also, the independent indicators are usually at the bottom level and essential for adopting CE in FSC. Therefore, for the formation of a short-term strategy for the CE adoption, practitioners and policymakers should focus on Lack of CE policies from the Government, Lack of a standard system for performance indicators for measuring CE in SC, Poor Logistics and IT infrastructure, Lack of recycling and waste management policies, and Lack of incentive schemes by the government for CE adoption because this is the strategic oriented challenges and placed at the bottom of the hierarchy. Government policies for recycling and waste management help achieve SDG 12, that is, SCP and SDG indicators SCP policies (SDG 12.1.1).

Food manufacturing firms should regularly monitor hazardous waste generation per capita and treatment. It helps achieve SDG 12 by improving the SDG indicator chemical and waste management (SDG 12.4.1 and SDG 12.4.2). Kumar, Raut, et al. (2021) also analyzed that the CE policy from the government and incentives for those who want to adopt CE practice in their business will help a lot in CE adoption (Kazancoglu, Sagnak, et al., 2021). Restructuring the logistic system into reverse logistics with new technologies like blockchain, IoT, and AI avoids logistics and IT infrastructure challenges and provides visible, traceable, and reliable logistics (Ethirajan et al., 2021; Khan et al., 2021). FSC's lack of logistics and cold chain infrastructure leads to food wastage, especially perishable food. Therefore, the government provides an incentive to build sufficient cold chain infrastructure. India needed urgent focus on clod chain infrastructure, including refrigerated carriers, cold storage facilities, and packhouse to minimize wastage and improve food quality. In the FSC, a new approach to food product design, green packaging, effective waste management, and efficient production processes is necessary (Ciccullo et al., 2021; Kornher & Kalkuhl, 2019). Policies and their strict enforcement for waste management, recycling, and recovery are also urgently needed from the government to avoid the mismanagement of food (Kazancoglu, Sagnak, et al., 2021).

The dependent challenges are performance-oriented, generally placed at the top of the hierarchy and useful in enhancing performance. For long-term strategic development for CE adoption, practitioners should focus on Poor CSR, Poor market response for recycled, refurbished products, Poor technological evolution for reuse, recovery remanufacturing and reengineering, Lack of Circular Design Aspect, Lack of innovative materials for food packaging to enable food waste reduction, and Technological limitations by tracking recycled materials to effective adoption of CE. By focusing on the above challenges, the productivity or circularity of the SC has improved and the sustainability of the SC. For tracing and tracking food products to deliver high-quality products and services, the application in FSC is recommended. In the food industry, packaging and processing stages are recommended to use green packaging material, avoid plastic packaging, and encourage recyclable packaging. In the FSC, food wastage must go through the recovery stage before dumping to recover possible valuable energy like biomass or convert it into fertilizers.

## 6 | CONCLUSION AND FUTURE DIRECTION

The progressive demand for food is due to rapid population growth, subsequent food wastage, and resource depletion. FSC must adopt the CE to decrease food waste and maximize resource use. FSC contributes to sustainable development by reducing food loss and waste and maximizing resource usage through 3Rs' recovery, reuse, and recycling. Recovery and recycling play a vital part in supporting SDGs such as sustainable production and consumption while reducing food waste and loss aids in attaining zero hunger. Some big players, including Apple, Coca-Cola, and Colgate-Palmolive, have already adopted the CE principle and got a tremendous advantage in reducing wastage, minimizing the utilization of primary resources, and building sustainability. While FSC still has faced several challenges in adopting CE in their FSC in actual practice.

This study identified 15 critical challenges of CE from literature as well as discussion with experts. An MCDM technique ISM-grey DEMATEL has been utilized to analyze the challenges to the CE adoption in FSC. The findings of this study include the contextual relationship among challenges, hierarchical structure with the level of importance for each challenge, cause–effect cartelization of the challenge, and their prominence and relation intensity have been obtained and discussed. The findings of this study are helpful for the practitioners and policymakers of FSC in adopting CE.

This study reveals that the government requires developing a short-term strategy by building a CE adoption policy and providing incentives to the FSC players. The challenges CE policies from Government (CE1) have been placed at the bottom of the hierarchy 10th level, so this is most important for CE adoption and falls in the independent cluster of MICMAC analysis to be strategic oriented. Hence, strict enforcement of CE policies is required to implement CE practices to achieve SDGs. So, poor CSR is characterized as a practical challenge with a maximum relational intensity of $-1.4$. On the other hand, poor CSR (CE15) has been placed at the top of the hierarchy and 1st level, so it is highly dependent on all the challenges; therefore, for the long-term strategic planning by improving all the challenges, CSR will automatic achieved, and supply chain become sustainable. It is advised that FSCs use digital technology to increase visibility and traceability. Before dumping food waste, FSC has recommended using reverse logistics in their supply chain to recover valuable energy from it. Before dumping food waste, it must have been transformed into suitable fertilizers or biomass—these suggestions aid FSC in meeting its goal of SCP.

### 6.1 | Limitations of the study and future research direction

This study has several limitations. First, this study focuses on the Indian FSC, and the result may or may not be generalized to other countries. However, it may be very helpful for developing nations. As the responses were obtained very strictly and carefully on each aspect of FSC and CE, some minor variation in the qualitative judgmental study is there. Second, the relationship obtained from ISM and the intensity provided from DEMATEL is purely based on the opinion of experts; hence, some modification is possible. In future, identification of circular FSC performance indicators and circulatory index framework may be constructed to extend the findings of this study. A structural modeling technique may be applied to validate the relationship obtained statically. In the future, researchers may find the interaction of Industry 4.0 technology to mitigate the challenges of CE and support the SDGs.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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**How to cite this article:** Kumar, M., Raut, R. D., Jagtap, S., & Choubey, V. K. (2022). Circular economy adoption challenges in the food supply chain for sustainable development. *Business Strategy and the Environment*, 1–23. https://doi.org/10.1002/bse.3191

## APPENDIX A.

**TABLE A1** Initial relational matrix

| | CE1 | CE2 | CE3 | CE4 | CE5 | CE6 | CE7 | CE8 | CE9 | CE10 | CE11 | CE12 | CE13 | CE14 | CE15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CE1 | NO | H | VL | H | NO | L | H | H | VH | VH | H | VH | L | VL | VH |
| CE2 | H | NO | NO | L | NO | VL | NO | VL | H | H | L | VH | L | VL | VH |
| CE3 | NO | NO | NO | VL | VL | NO | VL | NO | VL | VL | L | H | VL | L | H |
| CE4 | NO | H | NO | NO | VL | NO | VL | NO | L | L | VL | H | H | L | VH |
| CE5 | NO | NO | H | VL | NO | VL | NO | VL | L | VL | H | H | VL | L | H |
| CE6 | L | H | NO | VL | NO | NO | L | VL | H | H | H | H | L | VL | H |
| CE7 | VL | H | H | H | NO | NO | NO | L | H | H | H | VH | L | VL | VH |
| CE8 | H | NO | H | H | H | NO | L | NO | H | H | VL | H | H | H | VH |
| CE9 | VL | VL | NO | H | VL | VL | NO | VL | NO | VL | NO | L | H | VL | H |
| CE10 | NO | NO | NO | NO | VL | VL | VL | NO | VH | NO | L | L | H | VL | H |
| CE11 | NO | VL | L | L | NO | NO | NO | L | H | NO | NO | H | L | NO | H |
| CE12 | VL | VL | NO | NO | VL | VL | NO | VL | VL | VL | NO | NO | L | VL | H |
| CE13 | NO | VL | VL | VL | NO | NO | VL | L | L | NO | VL | VL | NO | NO | L |
| CE14 | VL | NO | NO | NO | VL | VL | NO | VL | VL | NO | L | L | NO | NO | L |
| CE15 | NO | NO | VL | NO | VL | NO | VL | NO | VL | NO | VL | NO | VL | VL | NO |

**TABLE A2** Normalized crisp relational matrix

| | CE1 | CE2 | CE3 | CE4 | CE5 | CE6 | CE7 | CE8 | CE9 | CE10 | CE11 | CE12 | CE13 | CE14 | CE15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CE1 | 0 | 0.065 | 0.005 | 0.065 | 0 | 0.035 | 0.065 | 0.065 | 0.095 | 0.095 | 0.065 | 0.095 | 0.035 | 0.005 | 0.095 |
| CE2 | 0.065 | 0 | 0 | 0.035 | 0 | 0.005 | 0 | 0.005 | 0.095 | 0.065 | 0.035 | 0.095 | 0.035 | 0.005 | 0.095 |
| CE3 | 0 | 0 | 0 | 0.005 | 0.005 | 0 | 0.005 | 0 | 0.005 | 0.005 | 0.035 | 0.065 | 0.005 | 0.035 | 0.065 |
| CE4 | 0.035 | 0.065 | 0 | 0 | 0.005 | 0 | 0.005 | 0 | 0.035 | 0.035 | 0.005 | 0.065 | 0.065 | 0.035 | 0.095 |
| CE5 | 0 | 0 | 0.065 | 0.005 | 0 | 0.005 | 0 | 0.005 | 0.035 | 0.005 | 0.065 | 0.065 | 0.005 | 0.035 | 0.065 |
| CE6 | 0.035 | 0.065 | 0 | 0.005 | 0 | 0 | 0.035 | 0.005 | 0.065 | 0.065 | 0.065 | 0.065 | 0.035 | 0.005 | 0.065 |
| CE7 | 0.005 | 0.065 | 0.065 | 0.065 | 0 | 0 | 0 | 0.035 | 0.065 | 0.065 | 0.065 | 0.095 | 0.035 | 0.005 | 0.095 |
| CE8 | 0.065 | 0.095 | 0.065 | 0.065 | 0.065 | 0 | 0.035 | 0 | 0.065 | 0.065 | 0.005 | 0.065 | 0.065 | 0.065 | 0.095 |
| CE9 | 0.005 | 0.005 | 0 | 0.065 | 0.005 | 0.005 | 0 | 0.005 | 0 | 0.065 | 0 | 0.035 | 0.065 | 0.005 | 0.065 |
| CE10 | 0 | 0 | 0 | 0 | 0.005 | 0.005 | 0.005 | 0 | 0.095 | 0 | 0.035 | 0.035 | 0.065 | 0.005 | 0.065 |
| CE11 | 0 | 0.005 | 0.035 | 0.035 | 0 | 0 | 0 | 0.035 | 0.065 | 0 | 0 | 0.065 | 0.035 | 0 | 0.065 |
| CE12 | 0.005 | 0.005 | 0 | 0.135 | 0.005 | 0.005 | 0 | 0.005 | 0.005 | 0.005 | 0 | 0 | 0.035 | 0.005 | 0.065 |
| CE13 | 0 | 0.005 | 0.005 | 0.002143 | 0 | 0 | 0.005 | 0.035 | 0.035 | 0 | 0.005 | 0.005 | 0 | 0 | 0.035 |
| CE14 | 0.065 | 0 | 0 | 0 | 0.005 | 0.005 | 0 | 0.005 | 0.005 | 0 | 0.035 | 0.035 | 0 | 0 | 0.035 |
| CE15 | 0 | 0 | 0.005 | 0 | 0.005 | 0 | 0.035 | 0 | 0.005 | 0 | 0.005 | 0 | 0.005 | 0.005 | 0 |

**TABLE A3** Total relational matrix

| | CE1 | CE2 | CE3 | CE4 | CE5 | CE6 | CE7 | CE8 | CE9 | CE10 | CE11 | CE12 | CE13 | CE14 | CE15 | D |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CE1 | 0.019 | 0.091 | 0.02 | 0.112 | 0.009 | 0.038 | 0.078 | 0.077 | 0.145 | 0.13 | 0.086 | 0.146 | 0.082 | 0.019 | 0.172 | 1.223 |
| CE2 | 0.072 | 0.014 | 0.005 | 0.068 | 0.004 | 0.009 | 0.012 | 0.015 | 0.123 | 0.086 | 0.047 | 0.122 | 0.064 | 0.012 | 0.141 | 0.793 |
| CE3 | 0.004 | 0.003 | 0.003 | 0.018 | 0.006 | 0.001 | 0.008 | 0.003 | 0.012 | 0.008 | 0.039 | 0.073 | 0.013 | 0.037 | 0.079 | 0.308 |
| CE4 | 0.045 | 0.073 | 0.004 | 0.023 | 0.007 | 0.003 | 0.014 | 0.008 | 0.059 | 0.051 | 0.017 | 0.087 | 0.083 | 0.039 | 0.129 | 0.641 |
| CE5 | 0.005 | 0.005 | 0.069 | 0.023 | 0.002 | 0.006 | 0.005 | 0.01 | 0.046 | 0.012 | 0.071 | 0.082 | 0.018 | 0.04 | 0.09 | 0.484 |
| CE6 | 0.044 | 0.077 | 0.008 | 0.037 | 0.003 | 0.003 | 0.043 | 0.016 | 0.099 | 0.087 | 0.079 | 0.097 | 0.063 | 0.011 | 0.113 | 0.779 |
| CE7 | 0.019 | 0.08 | 0.073 | 0.1 | 0.006 | 0.003 | 0.01 | 0.043 | 0.099 | 0.087 | 0.078 | 0.132 | 0.069 | 0.017 | 0.153 | 0.969 |
| CE8 | 0.084 | 0.114 | 0.077 | 0.104 | 0.07 | 0.006 | 0.049 | 0.014 | 0.112 | 0.097 | 0.033 | 0.119 | 0.102 | 0.078 | 0.169 | 1.228 |
| CE9 | 0.01 | 0.013 | 0.003 | 0.075 | 0.007 | 0.006 | 0.005 | 0.009 | 0.017 | 0.072 | 0.007 | 0.049 | 0.08 | 0.01 | 0.089 | 0.453 |
| CE10 | 0.003 | 0.004 | 0.004 | 0.016 | 0.007 | 0.006 | 0.009 | 0.005 | 0.105 | 0.009 | 0.038 | 0.046 | 0.078 | 0.008 | 0.085 | 0.423 |
| CE11 | 0.007 | 0.014 | 0.039 | 0.055 | 0.004 | 0.001 | 0.006 | 0.039 | 0.076 | 0.012 | 0.005 | 0.08 | 0.051 | 0.007 | 0.093 | 0.49 |
| CE12 | 0.013 | 0.017 | 0.002 | 0.141 | 0.007 | 0.006 | 0.005 | 0.008 | 0.018 | 0.015 | 0.005 | 0.016 | 0.05 | 0.012 | 0.089 | 0.405 |
| CE13 | 0.004 | 0.01 | 0.009 | 0.011 | 0.003 | 0.001 | 0.008 | 0.036 | 0.042 | 0.007 | 0.008 | 0.013 | 0.008 | 0.004 | 0.047 | 0.211 |
| CE14 | 0.068 | 0.008 | 0.004 | 0.016 | 0.007 | 0.008 | 0.007 | 0.012 | 0.019 | 0.011 | 0.042 | 0.05 | 0.01 | 0.003 | 0.055 | 0.319 |
| CE15 | 0.001 | 0.003 | 0.008 | 0.004 | 0.005 | 0 | 0.036 | 0.002 | 0.01 | 0.004 | 0.009 | 0.006 | 0.008 | 0.006 | 0.008 | 0.11 |
| R | 0.397 | 0.524 | 0.326 | 0.804 | 0.148 | 0.098 | 0.296 | 0.299 | 0.981 | 0.687 | 0.562 | 1.119 | 0.78 | 0.302 | 1.513 | |