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## **Circular economy practices in a developing economy: Barriers to be defeated**

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# Circular economy practices in a developing economy: Barriers to be defeated

## Abstract:

The present study attempts to identify the barriers against the adoption of Circular Economic (CE) in the food supply chain (FSC) in the context of a developing economy. A total of 18 significant barriers are identified via a detailed literature review and from expert opinions. The Fuzzy-Decision Making Trial and Evaluation Laboratory (Fuzzy-DEMATEL) method was applied to prioritize and categorize the barriers. Further, identified barriers were ranked to determine the bottlenecks in the transition from linear to the CE, and the cause-effect relationship was drawn. The findings reveal that lack of technology and innovation, lack of robust estimate about food waste, lack of supply chain (SC) design and optimization, and lack of economic benefits and high cost of investment are the most significant barriers impacting the adoption of CE. Unlike previous studies, this article shows that CE's biological cycle via technological interventions and innovation should be fostered as a source of reducing barriers to CE in FSC in a developing economy. This study is unique in building a theoretical foundation for identifying and prioritizing adoption barriers of CE in FSC using the Fuzzy-DEMATEL method. The findings will help decision-makers, managers, and government formulate the strategies/policies for effective implementation of CE in FSC.

**Keywords:** *Circular Economy; Sustainability; Food Supply Chain; Fuzzy-DEMATEL.*

## 1 Introduction

The Circular Economy (CE) approaches offer potential benefits to an organization via appropriate policies and opportunities to manage different products (Noya et al., 2017; Laso et al., 2018). Many countries and organizations are now focusing on CE approaches to effectively use resources to overcome unsustainable production and consumption systems (De Los Rios & Charnley, 2016). The CE is becoming a significant driving force for sustainability and a critical part of national, international and businesses policies (Stewart and Niero, 2018; Ghisellini et al., 2016; EC, 2015). It is estimated that the CE can lead to an economic benefit of around €1.8 trillion per year by 2030 (MCBE, 2016). The adoption of CE needs a proper framework and approaches and requires inclusive debate for its support to empower mechanisms in the value chain (De Mattos & de Albuquerque, 2018). However, the transition towards CE faces several barriers that disincentivize organizational actions towards CE. Lack of economic benefits and high economic uncertainty, for instance, are reasons for the ineffective development of CE in supply chains (SC) (Rizos et al., 2015; Dossa et al., 2020).

Earlier authors have identified barriers to the adoption of CE. For instance, Mangla et al. (2018a) identified a list of sixteen barriers for adopting circularity in the SC in developing economies and points out that financial and government regulations are the constraints for adopting CE for developing nations. Masi et al. (2018) and Tura et al. (2019) have identified a detailed list of barriers to adopting CE and categorized them into social, economic, institutional, infrastructural, technological, organizational, and SC dimensions. Farooque et al. (2019a) and Sharma et al. (2019) have done the initial works identifying and evaluating the CE transition barriers, particularly in the food supply chain (FSC). Their works state that lack of SC collaboration, lack of support, lack of knowledge, awareness, lack of policies and technologies are the most prominent barriers to adopt CE. On the other hand, Dossa et al. (2020) argue that financial aspects, particularly transactions with uncertainty, are barriers to adopting CE practices in FSC. It can be argued that there hasn't been a common finding concerning barriers to CE.

The extant literature review indicates the scarcity of work in the domain of FSC, particularly for a developing economy. Most of the works in this domain have addressed the SC sustainability, CE adoption, risks in FSC, primarily focusing on FSC and agricultural supply chains (ASC). (Sharma et al., 2019; Chauhan et al., 2019; Zhao et al., 2017; Yazdani et al., 2019; Mangla et al., 2018b; Ali et al., 2019; Khan et al., 2020; Rehman Khan et al., 2020; Khan et al., 2021). However, the studies related to CE adoption barriers, particularly in FSC in developing economies, need more in-depth investigation.

The food sector remains one of the critically important and relevant domains for embracing the CE. Food demand and consumption proliferate worldwide due to population growth, changing lifestyles, and evolving food habits (Yazdani et al., 2019). Due to the rapid population growth (~9 billion by 2050), there will be an increase in global food demand and consumption, posing significant stress on natural resources (Govindan and Hasanagic, 2018). Further, the food industry faces a trilemma of environmental pollution, food scarcity, and food wastage, which needs to be addressed by adopting a green recovery mechanism. It is projected that approximately 1/3 of the food wastage worldwide is through FSC, leading to loss of valuable natural resources (Gustavsson et al., 2011; HLPE, 2014; Cristóbal et al., 2018). India alone accounts for the loss of approximately 20-30 % of food products (Raut et al., 2019).

The food recovery by creating circular biological flows has a promising possibility of reducing excessive production quantities and food waste and adequately redistributing available food in FSC (Vlajic et al., 2018). To achieve waste reduction and green recovery, the way forward is to adopt CE in FSC.

The Indian economy faces a significant burden on natural resources and demand and supply (Raut et al., 2019). The risk will result in a loss of about half-a-trillion dollars' worth of India's GDP by the year 2030, which can be protected by adopting CE business models (FICCI, 2018). Developing nations need to identify the CE adoption barriers in FSC to boost the required transition from linear to CE. However, CE is comprehensive concept to implement, and there are challenges involved during the adoption of CE, which slows down organizational transition towards CE (Parida et al., 2019). Further, researchers have paid little attention to identifying adoption barriers against CE in FSC in the context of developing economies. To fill the literature gap, the present study tries to identify crucial barriers against CE adoption in FSC and analyze the cause-effect relationship. The study seeks to emphasis on the following research objectives:

RO1- To identify and prioritize adoption barriers for CE in FSC in a holistic way.

RO2- To broadly categorize the adoption barriers along with their cause-effect relationship.

RO3- To provide input to decision-makers/managers to overcome the identified adoption barriers against CE in FSC.

The study offers valuable insights about CE adoption barriers in FSC and helps the Indian food sector identify crucial CE transition barriers, facilitating them to shift towards CE gradually. The earlier works of Farooque et al. (2019a) and Sharma et al. (2019) shed light on barriers towards CE transition in FSC using the fuzzy-DEMATEL and Delphi approach. However, the works have some limitations, such as the list of barriers is not exhaustive, limitations during data collection, etc. The move towards CE cannot be achieved entirely without having a detailed understanding of the CE.

Considering the need for studies related to CE barriers, the present study provides an exhaustive list of significant adoption barriers for CE in FSC in the context of a developing economy. The identified barriers were categorized into different dimensions, as shown in Table 2. Further, the CE adoption barriers were prioritized using the fuzzy-DEMATEL method. This method is a fundamental approach with an amalgamation of fuzzy set theory, prioritized the cause-effect relationship barriers. A fuzzy-DEMATEL method is a preferred approach among decision-makers and describes the structural model for the relationship among different criteria and defines their strength. The present study also supports literature review, expert opinion, and case study in the domain of FSC, aiming to provide a substantial theoretical contribution by identifying adoption barriers against CE. The proposed work is one of the preliminary works performed to identify and prioritize the CE adoption barriers in the context of a developing economy.

The paper is structured where Section 2 highlights the review of literature and research gaps. Section 3 presents the research methodology. The case study and the Fuzzy-DEMATEL method is

described in Section 4. Section 5 includes the results as well as discussion. The managerial and policy implications are outlined in Section 6. At last, conclusion and future directions are depicted in Section 7.

## **2. Literature Review**

The CE distinguishes itself from the Linear Economy based on reusing and replacing the resources rather than consuming them. The CE philosophy is about decoupling economic activities based on the intake of limited resources and scheming waste out from the system (Ellen MacArthur Foundation 2019). The term ‘waste’ connotes differently from the traditional sense of junk; instead, it is underutilization of assets and resources (FICCI, 2018). However, organizations encounter different barriers during CE practices adoption (Kirchherr et al., 2018). The subsequent paragraphs highlight the critical connection between the CE adoption barriers and FSC.

There is ample literature that deals with the CE adoption barriers ranging from organizational to societal (Korhonen et al., 2018). Guldmann and Huulgaard (2020) and Tura et al., (2019) compared the CE barriers and highlight that barriers exist at the market, social, institutional, value chain, technological and informational, organizational, and employee levels. Particularly the hard barriers (technical and financial factors) and soft barriers (social, regulatory, or institutional) hampers organizational transition towards CE the most (De Jesus & Mendonça, 2018). The detailed literature review of Rizos et al. (2015) states that lack of financial and government support, CE legislation; environmental culture; information deficits; administrative burdens; technical skills, and expertise are among the significant CE barriers. The gamut of recent studies from several scholars found common barriers that correspond to CE are lack of environmental policies, rules, and regulations, lack of government support, lack of technical expertise and knowledge among organizations, lack of capabilities and skilled people, lack of financial capability and support, culture and social issues, technological issue (Govindan and Hasanagic, 2018; Masi et al., 2018; Mangla et al., 2018a; De Jesus & Mendonça, 2018; Garcés-Ayerbe et al., 2019; García-Quevedo et al., 2020).

Along with the barriers mentioned above, other barriers derailing organizational transition towards CE include lack of SC integration, lack of support from top management, lack of circular design, lack of market availability (Lahane et al., 2020). The finding of Rizos et al. (2015) presents that the biggest reason for failure CE at the organizational level is high economic uncertainty. From the SC perspective, lack of network support, lack of skills, capabilities, and collaboration hampers the SC transition towards CE (Rizos et al., 2016). The work of Farooque et al. (2019a) states that the most important barrier for adoption of CE in FSC is lack of collaboration/support from SC actors followed by lack of environmental enforcement, regulations, and lack of pressure and preference

from market. However, the recent work of Jabbour et al. (2020) states that among all identified barriers, internal barriers related to poor communication and unclear roles of different departments derail the CE. Further, the weak environmental awareness and lack of green financial policy were crucial barriers for CE in the agriculture value chain (Xia and Ruan, 2020). Jaeger and Upadhyay (2020) found another set of barriers derailing CE implementation, such as quality issues, SC complexities, lack of coordination, lack of production and design, high investment costs, and disassembly of products.

It is essential to point out that the identified comprehensive list of CE transition barriers and arguments might not be exhaustive and may vary from organization to organization (Werning & Spinler, 2020). The extant literature on the CE barriers from earlier research shows that some common barriers span different dimensions, hampering CE's organizational transition. Few recent studies have also pointed out other barriers in an entirely different dimension. Despite growing efforts to understand CE barriers, there is further scope for a detailed understanding of the circumstances required for a CE, particularly when the concept interconnects with FSC. Additionally, identifying CE adoption barriers needs to focus on particular value chains for its effective implementation (Lahane et al., 2020).

The large body of literature on CE, notably in the diverse sectors and value chains, available elsewhere. However, the present work focuses on the relevant literature that is the intersection of the two themes: CE and the FSC. To study CE's adoption, particularly in FSC, researchers have widely used various tools and approaches. The review of these recent studies is presented in Table 1, highlighting the earlier published work using various techniques, tools, identified factors, research questions, and limitations for evaluation and selection.

**Table 1. Summary of studies in FSC and CE**

Sr. No.	Author and Year	Industry/ Sector	Country	Approach/ Method	Factors	Research questions/Research objectives	Limitations of study	Remark
1.	Kumar et al., 2021	Agriculture	India	Integrated ISM-ANP	Policy, government support and incentives, awareness etc	To explore CE and Industry 4.0 adoption barriers in ASC and develop contextual relationship among them.	The study was limited to ASC and need to further explore particularly to AFSC. The study lacks with case example support	The list of identified are not exhaustive barriers need strengthening particularly focusing AFSC.
2.	Krishnan et al., 2020	Food industry (Mango)	India	Life cycle assessment (LCA)	Technology aspects, i.e., operational efficiency, resource recovery, and environmental impacts.	To identify the presence of inefficiencies during FSC, i.e., mango production and consumption viz via impact assessment study	Lack of inventory, system boundary data during the LCA study, and the study's findings were generalized.	It is necessary to collect more information on barriers related to FSC, which were not identified and consider during the LCA study.
3.	Dossa et al., 2020	Wheat FSC	UK	Interpretivist qualitative research	Financial (i.e., transactions)	To identify the role of cost of transactions and uncertainty in the diffusion of CE practices	Lack of multiple case studies and the participants number was small.	For the better diffusion of CE in FSC it is important to initially investigate in detail the barriers for CE practices.
4.	Xia & Ruan, 2020	Agriculture	China	Grey-DEMATEL	Government; Farmers and Enterprises	To identifies key barriers for developing circular agriculture considering government, farmers, and the enterprise's dimension.	The study lacks a comparative analysis between the fuzzy and gray-DEMATEL.	The list of identified barriers considers only three dimensions. Further dimensions to identify barriers need investigation.
5.	Sharma et al., 2019	Dairy food industry	India	Delphi and interpretive structural modeling	Technology, policy and government, SC, knowledge, and awareness, etc.	To identify challenges for CE in FSC and the interaction among them	The use of the Delphi approach has certain limitations such as data collection, survey, time	The list of identified barriers is not exhaustive and is not categorized appropriately.
6.	Farooque et al., 2019b	Food industry	China	Fuzzy-DEMATEL	Financial and economic aspects, technology and	Illustrating CE in FSC, Framework development based on multiple	The study is more inclined towards the	A list of identified barriers is not



					expertise, organizational aspects, environmental rules and regulations, market and SC aspects	organizational theory, identification, and barriers analysis.	Chines context, and very few barriers were identified; no categorization of identified barriers	exhaustive. Hence, future research needs to expand the list of barriers.
7.	Principato et al., 2019	Pasta industry	Italy	Barilla company case study	Technology aspects such and production, cultivation, and milling, etc., Consumer consumption, retail, and market	The reasons for food losses and wastages during the FSC of pasta production and implementing the CE approach.	The study is related to pasta production, where food losses are limited.	Further study needs to be focused on FSC to frame the CE approach.
8.	Yazdani et al., 2019	Agriculture	Spain	MCDM	Factors related to flood risk such as climate, water, policy, urban system, etc.	To identify flood risk drivers in connection with agriculture SC and CE	Experts' weights and their relative effects were not taken into consideration.	Identified barriers are mostly related to agriculture flood risk. Further, studies need to focus on other appropriate tools.
9.	Secondi et al., 2019	Tomato sauce food industry	Italy	A theoretical and applied framework	Food losses during entire FSC of tomato sauce	To identify food loss and waste during the entire FSC and to use the CE approach	The theoretical and applied framework have some uncertainties.	Further studies are required in other FSC using an appropriate tool
10	Clark et al., 2019	food packaging industry	UK	A questionnaire-based study	Technology, stakeholders, financial, market, consumer, legislation	To study the challenges of the food packaging industry and technology transformation for the adoption of CE	The study was based on a survey, and opinions may be biased. The study was more inclined towards technology aspects for the adoption of CE.	There can be limitations on technology-based solutions for the adoption of CE. Further, studies are essential to explore barriers more holistically.
11	Mangla et al., 2018b	Agri-food industry	India	ISM-fuzzy DEMATEL	Government and regulatory body, stakeholders, SC, cost, and economic aspects.	To identify enablers, their relationship for the sustainability of FSC	The subjectivity of cause-effect relations, barriers in the entire FSC were not considered; some barriers may have less importance.	The identified list of barriers is not exhaustive. The superior approach needs to be used to determine the relationship between barriers.

12	Vlajic et al., 2018	Agri-fresh food industry	UK	Case studies and survey	The technology for recovery and its benefits, markets, the residual value of food products.	To understand drivers and critical elements in agriculture FSC for CE.	The study was limited to fresh FSC. The survey data collected may have biased scenarios.	The circularity in FSC differs from country to country because of policy, legislation, customer, trade, etc.
13	Cristóbal et al., 2018	Food industry	Italy	Integer linear programming (ILP) and LCA	The decision-maker, environmental and economic	To implement food waste prevention and management and avoiding negative environmental impacts,	The social dimension was not taken into consideration. The database was assumed considering the EU and the US.	The study was inclined towards a developed economy. The FSCs in emerging economies may have different scope.
14	Borrello et al., 2017	Food industry	Italy	Structured questioner-based survey	Knowledge, attitude, and concern of consumers for food waste reduction and circularity	To understand consumers' awareness and willingness for technology-based waste reduction and CE approach.	The case study was hypothetical, and the effectiveness, The feasibility of the design framework was not explored.	The entire FSC framework needs a more in-depth investigation. Detail studies on drivers and barriers for consumers choice
15	Noya et al., 2017	Pork food industry	Spain	LCA	Environmental impacts and ecoefficiency	To adopt CE framework in the Catalan pork industry	The study has not considered the entire value chain of pork production and consumption.	The entire FSC network and barriers need to explore.
16	Genovese et al., 2017	The cooking oil industry	UK	Hybrid LCA	GHG emissions, waste recovered, resource use, market dynamics, policy, and society.	To enhance the SC by aligning it with CE. The implication of CE	The use of a hybrid LCA model has some limitations in terms of inventory and system boundaries. The SC aspects of only waste cooking oil were considered	The entire FSC of the cooking oil sector needs to consider.
17	Borrello et al., 2016	Agri-food industry	Netherland	Linear-based framework	The regulatory framework, locations of firms, SC, consumer, technology, economic benefits.	To apply a CE framework in Agri-FSC.	The framework is conceptual.	The identified list of barriers is not exhaustive.

It is essential to identify barriers to adopting CE in FSC and categorization, prioritization, and establishing a relationship based on appropriate methodology. The existing literature has a lack of detailed information regarding CE adoption barriers in FSC and their categorization. Further, an appropriate/suitable method needs to prioritize the barriers and identify the relationship between them.

In the context of developing nations, CE studies are rare, and their priority varies. Therefore, CE adoption requires identifying a holistic list of barriers, their appropriate categorization, and their prioritization based on suitable methods for emerging economies like India.

The present work attempts to fill the gap by identifying barriers affecting the adoption of CE in FSC. The study is motivated by the lack of literature on CE in FSC and tries to build an exhaustive list of essential barriers against CE in FSC and their relationship. The study addresses the complexities in FSC by using the fuzzy DEMATEL method. The integrated Fuzzy DEMATEL method is an appropriate approach for complex decision-making. The method used matrix tools and fuzzy set theories to examine the complex scenario of decision-making.

Moreover, the method recognized crucial information about the cause-effect relationship and its importance. The methodology has been planned to identify the adoption barriers for CE in FSC across seven domains. The proposed method tries to integrate the fuzzy DEMATEL method to explain the problem of CE in FSC. The proposed methodology and an Indian case study from the FSC have been specified, and the outcomes are discussed in detail. Overall, this study attempts to relate CE in FSC for developing nations.

### **3 Proposed CE adoption barriers**

The section covers the extant literature on CE in FSC and tries to provide a systematic understanding of barriers against CE adoption in FSC, as shown in Table 2. Scientific databases like EBSCO, SCOPUS, and ProQuest were used to search the literature. The literature review for the proposed barrier is performed using Boolean search criteria. During the search, keywords like “Circular Economy (CE)”; “Food Supply Chain (FSC)”; “challenges”; “barriers”; “Sustainability” and combinations of terms in the abstract, keywords and title of the articles published in the English language were studied. Each article's theoretical viewpoint is explored and recorded along with abstract, method followed, results, discussion, and conclusions. Around 100 research papers and articles are collected, of which the most relevant 74 documents were chosen by browsing the title, keywords, abstract, method and conclusion. The articles were excluded were CE,

sustainability, challenges and barriers, food industry, and FSC were not the main topic, keywords, or headlines.

With the help of well-defined criteria, the organized literature was examined from 2009 to 2020. It is essential to mention that most of the research on CE has been done in recent years. All the research articles were illustrative of the information in the domain of CE in FSC. Further, all the identified barriers were systematically grouped into seven categories (Moktadir et al., 2018; Tura et al., 2019). The detailed literature review description on adoption barriers in the seven categories is specified in Table 2.

The earlier literature in the domain of FSC and CE provides insight into CE adoption barriers in developing economies. For instance, countries like India's financial and government regulations impede circularity in SC (Mangla et al., 2018a). The work of Sharma et al. (2019) further highlighted that lack of technology, innovation, lack of government policies, law, standard system, and lack of knowledge, awareness among consumer and supplier are the most critical barriers for effective adoption of CE in the food industry mainly in the Indian context. Krishnan et al., 2020 also highlighted that technology aspects hinder the adoption of CE in FSC.

Lack of consumer awareness, lack of emerging technologies and innovation, policies and law, lack of financial capability/funds to drive capital investments and R&D, lack of firm's awareness, and cross-sectoral collaboration among different stakeholders are few barriers obstructing the adoption of CE practices in India (Ellen Macarthur Foundation, 2016; FICCI, 2018). The recent work of Kumar et al. (2021) has identified a lack of policy, lack of support and incentives from government, lack of awareness as bottleneck for CE adoption in ASC. Thus, based on table 1, the extract literature review, data collected from questionnaires, and a detailed discussion with expert team, the list of CE adoption barriers hindering sustainable practices in FSC was contextualized in the developing economy.

**Table 2. Summary of proposed CE adoption barriers in the present study**

Category	Barriers	Summary of the barriers	Reference
Economic	Lack of financial capability (X1)	The food wastes need further processing/transformation before being reused; such changes are cost-intensive, i.e., R&D and infrastructure investment is required. Moreover, the assessment and feasibility of available technologies to support such transformation require a considerable investment. Even to justify such expenditure, it is essential to obtain high-value products from food waste during each stage of the SC, which is difficult at present.	Xue et al., 2010; Su et al., 2013; Mirabella et al., 2014; Ellen Macarthur Foundation, 2015b; Rizos et al., 2015; Ellen Macarthur Foundation, 2016; FICCI, 2018; Masi et al., 2018, Ormazabal et al., 2018; Jaeger and Upadhyay 2020
	Lack of economic benefits and high cost of investment (X2)	CE is a new and emerging business strategy. It is difficult for an organization to adopt it in the SC correct position to gain economic benefits. Additionally, new business models and recycled materials cost high to adopt CE with high financial ambiguity.	Su et al., 2013; Borrello et al., 2016; Rizos et al., 2015; Sauvé et al., 2016; Mangla et al., 2018a; De Jesus & Mendonça, 2018; Clark et al., 2019; Xia & Ruan, 2020; Dossa et al., 2020.
Technology and information	Lack of technology and innovation (X3)	A vast quantity of food waste is being generated by the food industry, which leads to economic and environmental loss. Such losses can be avoided via technological interventions and innovative, i.e., biorefinery, industrial symbiosis, eco-innovation, etc. The presence of technology and innovation solution is a prerequisite for the adoption of CE, which is one of the barriers.	Mirabella et al., 2014; Ellen Macarthur Foundation, 2016; Ghisellini, et al., 2016; Borrello et al., 2016; FICCI, 2018; De Jesus & Mendonça, 2018; Sharma et al., 2019; Clark et al., 2019; Krishnan et al., 2020
Supply chain (SC)	Lack of supply chain (SC) design and optimization (X4)	Appropriate close-loop supply system design reduces negative environmental impacts and allows a shift from traditional LE to CE. It is essential to have such designs specifically for the sustainability of the SC and for stakeholder's competitive benefits. Furthermore, food loss and wastage during production and different stages of the circular SC can be avoided by optimizing the reuse of these losses and wastages for other value-added applications.	Ghisellini et al., 2016; Principato et al., 2019; Jaeger and Upadhyay 2020
	Supply chain (SC) disruptions (X5)	Environmental disasters, i.e., floods, thunderstorms, hurricanes, disrupt the SC, which has a significant impact on industrial settings and communities. The consumer and food industry may face negative consequences due to such disruption in the supply and production of agricultural food products.	Heckmann et al., 2015; Yazdani et al., 2019
	Lack of quality in the circular product (X6)	Having a high-value product from food waste during each stage of the SC is essential for CE. Unfortunately, circular products fail to meet customer's standards and requirements, leading to a lower selling price, resulting in CE barriers.	Ghisellini et al., 2016; Lieder and Rashid, 2016
	Lack of packaging and cold chain (X7)	In developing countries, Most of the food is wasted due to a lack of proper packing and the absence of a cold chain facility during handling and transportation.	Joshi et al. 2009; Manzini and Accorsi 2013

Institutional	Lack of policies, law, and standard system (X8)	To have CE, attention, extensive efforts, and active measures must modify present standard systems, i.e., rules, standards, and policies. However, the current complex government structure, policy framework, and lack of legislative enforcement posed challenges for the CE transition.	Su et al., 2013; Rizos et al., 2015; Ellen Macarthur Foundation, 2016; Borrello et al., 2016; Urbinati et al. 2017; Ranta et al., 2018; FICCI, 2018 Mangla et al., 2018a; Farooque et al. 2019a; Sharma et al., 2019
	Lack of robust estimate about food waste (X9)	The detail and approximate estimate of food waste generation in the country as well as at the global level is lacking. Thus, lack of such crucial information and assessment becomes barriers to adopting policies and frameworks related to CE.	Corrado et al., 2017; Corrado & Sala, 2018
Social	Lack of awareness, knowledge in consumer and supplier (X10)	In developing countries, the losses associated with food waste are highly concentrated at the consumer level. Therefore, the role of consumers and suppliers is essential to make the transition from LE to CE. Moreover, their awareness and knowledge about recycling materials are particularly crucial for adopting CE in SC.	Xue et al., 2010; Ellen Macarthur Foundation, 2016; Borrello et al., 2017; FICCI, 2018; Farooque et al., 2019a; Sharma et al., 2019.
	Lack of Consumer perception (X11)	Irrespective of economic and environmental benefits, the consumer does not yet well accept CE-based products. Furthermore, CE-based business models fail to fulfill consumers' cultural, social, and psychological needs, resulting in the barrier to CE diffusion. Even the negative perception and behavior of consumer-related to circular product become barriers for adoption of CE	Borrello et al., 2016; Borrello et al., 2017; Kirchherr et al., 2018; Singh & Giacosa, 2019
	Lack of involvement and support from consumer and supplier (X12)	To ride the wave of CE requires active participation from consumers and suppliers. However, both are reluctant to have circular products and services due to elevated cost or quality issues. The advancement of both's is vital for improving the supply, use, and purchase of more sustainable products and services. Therefore, having CE initiatives require involvement and support from these external stakeholders.	Su et al., 2013; Rizos et al., 2015; Andrews, 2015; Rizos et al., 2016; Ghisellini et al., 2016; Farooque et al., 2019a; Singh and Giacosa, 2019.
	Lack of firm's awareness, behavior, collaboration, and leadership (X13)	Firm's awareness, practice, collaboration, and leadership are essential factors toward developing CE, but due to lack of time, low vision, and limited resources, organizations neglect CE priorities. Indeed, the firm's harmful behavior, lack of awareness, and leadership are some of the hurdles for accepting the CE framework. It is essential that internal stakeholders should be aware, have affirmative action, collaborate, and lead circularity in SC and put collaborative efforts.	Su et al., 2013; Liu and Bai, 2014; Rizos et al., 2016; Ellen Macarthur Foundation, 2016; FICCI, 2018; Ormazabal et al., 2018
	Lack of training and skills (X14)	Skills and training are required to make a strategic shift towards CE. Lack of skills and training affects the firm's interest in CE. Certainly, CE is an emerging concept, and to have a CE-based business model required a call to develop in-house or outsourced training and skills sets.	Liu and Bai 2014; Rizos et al., 2015; Rizos et al., 2016; García-Quevedo et al., 2020

Organizational	Lack of scalability and replicability of the business model (X15)	To embrace CE in the organization requires innovative business models, and such business models need to design, keeping in mind the aspects of scalability and replicability. These two aspects can contribute to economic margins, public-private funding, and the widespread of CE principles.	Schaltegger et al., 2016; Zucchella & Previtali, 2019
	Lack of CE Indicators (X16)	CE indicators are mostly disorganized and fragmented, making it difficult for the organization to communicate, report, and monitor the CE progress.	Jain et al., 2018; Howard et al., 2018
	Lack of Interface and network support (X17)	Lack of proper policies from government along with enterprise-market interfaces and network support are significant barriers to CE adoption. The push from government policy and pull from organization and market is insufficient at present, leading to CE's derailing.	Kuokkanen et al., 2016; Borrello et al., 2016; Singh and Giacosa, 2019; Lahane et al., 2020;
Environment	Lack of scope for Green-House Gas (GHG) emission reduction (X18)	FSC poses a particular challenge for climate change policies (i.e., higher GHG emissions), critical issues during food transport and distribution. To reduce such GHG emission during the entire FSC require radical changes.	Audsley et al., 2010

The barriers against CE adoption in the FSC were ranked, and the relationship was developed by the fuzzy DEMATEL method, which is described in the subsequent section.

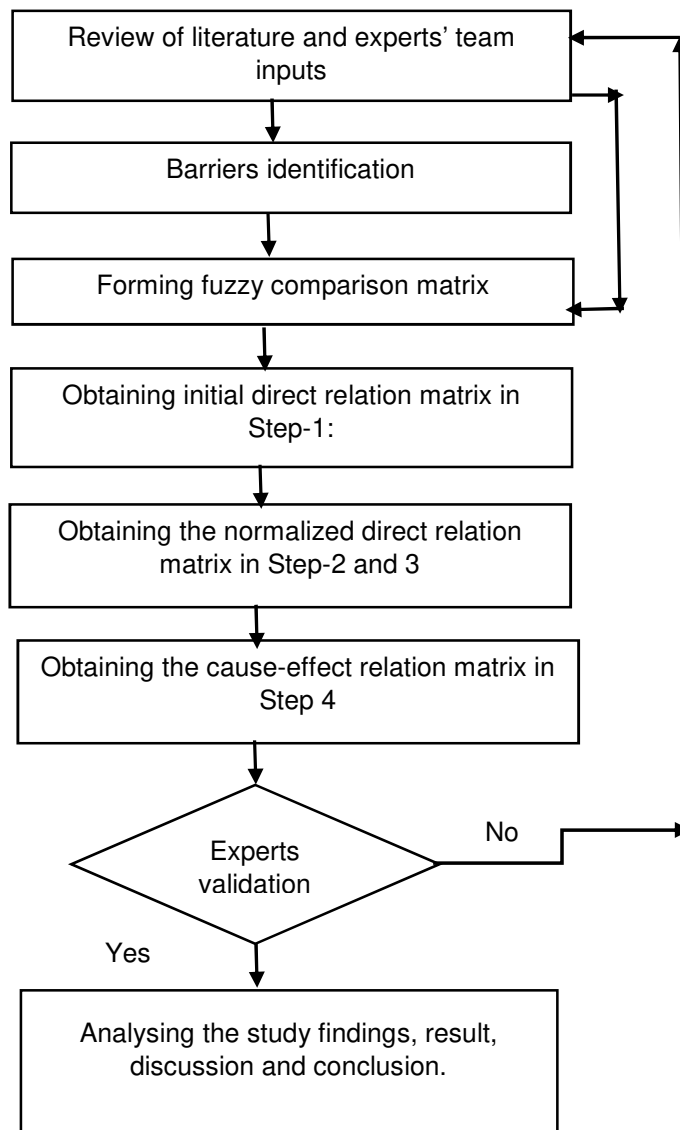
## **4 Research Methodology**

### **4.1 Working of Fuzzy DEMATEL method/approach.**

To solve the people-centric complex problems, the Fuzzy-DEMATEL method is most preferred compared to conventional quantification methods. The real-world problems comprise of fuzziness, uncertainty, and making a corporate decision in uncertain environments. The Fuzzy-DEMATEL method is ideal. The fuzzy DEMATEL method is further essential for studying multidimensional decision-making problems in policies, organizations, and SC. In uncertain scenarios where multi-criteria evaluation is required, the fuzzy DEMATEL method is frequently used. This method has gained widespread attention in recent times because of its practical application in visualizing the complicated cause-effect relationship with graphs and matrices (Farooque et al., 2019b).

Experts' consultation, their inputs, and a detail literature review were performed to identify the CE adoption barriers, experts' consultation. During the detailed literature review, various scientific databases i.e. EBSCO, ProQuest, and SCOPUS are used to search the literature, as highlighted in section 3. The expert inputs were taken from 20 expert professionals working in academia, industry, management, and consulting sector. On the basis of a detailed literature review as well as experts' team inputs, the eighteen CE barriers were identified. After identifying the barriers, the fuzzy DEMATEL method was applied. During the fuzzy DEMATEL method, a direct relation matrix was first obtained (Step 1) from the expert team inputs. The expert team provided their input values on a linguistic comparison scale. After that, a normalized direct relation matrix (Step-2 and 3) was obtained, for which the direct relation matrix A was the base. Later, the cause-effect relation matrix and casual diagram (Step 4) was developed, showing the outcome of a cause-effect relationship, their ranks, and the weights of essential factors. The fuzzy-DEMATEL method findings were then finalized from expert team inputs. Finally, the study findings were analyzed in the result, discussion, conclusion section, and managerial and policymaking implications were proposed. The Figure 1 depicts the brief about research methodology.





**Figure 1:** Research methodology

It is a common characteristic among multi-criteria decision-making techniques that expert input is primarily qualitative criteria expressed linguistically. These linguistic expressions are based on expertise and relevant experience, which are not exact or crisp and become difficult to quantify and compute. In such cases, the theory of fuzzy set can be used to analyze uncertain conceptions linked with human-centric subjective judgment. According to the logic of fuzzy set, each value among 1 and 0 shows partial truth, and  $[0,1]$  corresponds to crisp or exact binary logic. The different equations involved in the fuzzy set method are highlighted in the following section, along with notation and assumptions.

Assume that  $Z$  is the discourse universe, i.e.,  $Z = \{z_1, z_2, z_3, \dots, z_n\}$ ;

The set of fuzzy  $\check{O}$  of  $Z$  is order pairs set

i.e.  $\{(z_1, f_{\check{O}}(z_1)), (z_2, f_{\check{O}}(z_2)), (z_n, f_{\check{O}}(z_n))\}$ ; where,  $f_{\check{O}}: Z \rightarrow (0,1)$ , is the

membership function of  $\check{O}$  and  $f_{\check{O}}(z_i)$  is the degree of membership of  $z_i$  in  $\check{O}$ .

1. In the case where  $Z$  is not a finite or countable set and is continuous, the set of fuzzy  $\check{O}$  is expressed as  $\check{O} = f_{\check{O}}^{(z_i)} / (z)$ ; where;  $z \in Z$

2. In case when  $Z$  is a finite or countable set, then the fuzzy set  $\check{O}$  is shown as,

$$\check{O} = \sum_i f_{\check{O}}^{(z_i)} / (z), \text{ where } z_i \in Z$$

3. A fuzzy set  $\check{O}$  of the universe of discourse  $Z$  is normal, if its function of membership,  $f_{\check{O}}(z)$  satisfies  $\max f_{\check{O}}(z) = 1$

4. In case a fuzzy number is a fuzzy subset in the discourse universe  $Z$ , which is not convex but normal as well.

5. In case the fuzzy  $\alpha$ -cut  $\check{O}_\alpha$  and strong  $\alpha$ -cut  $\check{O}_{\alpha+}$  of the fuzzy set  $\check{O}$  in the universe of discourse, then  $Z$  is specified as shown in eq. 1

$$\left. \begin{aligned} \check{O}_\alpha &= \{z_i | f_{\check{O}}(z_i) \geq \alpha, z_i \in Z\} \text{ where } \alpha \in [0,1] \\ \check{O}_{\alpha+} &= \{z_i | f_{\check{O}}(z) \geq \alpha, z_i \in Z\} \text{ where } \alpha \in [0,1] \end{aligned} \right\} \text{ (eq. 1)}$$

6. In case a set of fuzzy  $\check{O}$  of a  $Z$ , i.e., the universe of discourse is convex if and only if every  $\check{O}_\alpha$  is convex, that is  $\check{O}_\alpha$  is a closed interval of  $R$ , then an eq. 2 can be written as,

$$\check{O}_\alpha = [L1(\alpha), L2(\alpha)]; \text{ where, } \alpha \in [0,1] \quad \text{eq. 2}$$

7. In case a Triangular Fuzzy Number (TFN) is a triplet, i.e.,  $(a_1, a_2, a_3)$ , then the membership function of the fuzzy number  $\check{O}$  can be written as specified in Eq. 3

$$f_{\check{O}}(Z) = \left\{ \begin{array}{l} 0, z < a_1 \\ \frac{(z-a_1)}{a_2-a_1}, a_1 \leq z \leq a_2, \\ \frac{(a_3-z)}{a_3-a_2}, a_2 \leq z \leq a_3, \\ 0, z > a_3 \end{array} \right\} \quad \text{(eq. 3)}$$

8. In case if  $\check{O}$  and  $\check{P}$  are two TFN parameterized by the triplet, i.e.,  $(c_1, c_2, c_3)$  and  $(d_1, d_2, d_3)$ , then the operational laws of these two TFNs can be written as specified in Eq. 4

$$\check{O}(+) \check{P} = (c_1, c_2, c_3) (+) (d_1, d_2, d_3) = (c_1 + d_1, c_2 + d_2, c_3 + d_3)$$

$$\check{O}(-) \check{P} = (c_1, c_2, c_3) (-) (d_1, d_2, d_3) = (c_1 - d_1, c_2 - d_2, c_3 - d_3)$$

$$\begin{aligned} \check{O}(\times)P \sim &= (c_1, c_2, c_3) (\times)(d_1, d_2, d_3) = (c_1 \times d_1, c_2 \times d_2, c_3 \times d_3) \\ \check{O}(\div)P \sim &= (c_1, c_2, c_3) (\div)(d_1, d_2, d_3) = (c_1 \div d_1, c_2 \div d_2, c_3 \div d_3) \end{aligned} \quad \left. \vphantom{\begin{aligned} \check{O}(\times)P \sim \\ \check{O}(\div)P \sim \end{aligned}} \right\} \text{(eq. 4)}$$

Where;  $c_1, c_2, c_3$  are real numbers and  $c_1 \leq c_2 \leq c_3$

For a group decision, it is vital to have the desired solution. The process of reaching the desired solution and agreement depends on the inputs and reactions of different individuals; only then can a good decision be made. Thus, to deal with the study's ambiguity, fuzzy aggregation is essential, which comprises de-fuzzification. The de-fuzzification process is vital as decisions and judgments are human-centric based on fuzzy linguistic variables, which are fuzzy numbers. The de-fuzzification method selects precise elements from the output of fuzzy set and then translates these fuzzy numbers to exact crisp score. Thus, to calculate the left and right score by fuzzy minimum and maximum, a overall score calculated as weighted average as per the membership functions is required.

Let's assume,  $\hat{w}_{ij}^k = (a_{1ij}^k, a_{2ij}^k, a_{3ij}^k)$ , where the degree of  $i^{\text{th}}$  criteria affects the  $j^{\text{th}}$  criteria, and the questionnaires of fuzzy are  $k$  ( $k = 1, 2, 3, 4, \dots, k$ ).

Now normalization can be written as specified in Eq. 5

$$\begin{aligned} za_{1ij}^k &= (a_{1ij}^k - \min a_{1ij}^k) / \Delta_{min}^{max} \\ za_{2ij}^k &= (a_{2ij}^k - \min a_{2ij}^k) / \Delta_{min}^{max} \\ za_{3ij}^k &= (a_{3ij}^k - \min a_{3ij}^k) / \Delta_{min}^{max} \end{aligned} \quad \left. \vphantom{\begin{aligned} za_{1ij}^k \\ za_{2ij}^k \\ za_{3ij}^k \end{aligned}} \right\} \text{(eq. 5)}$$

Where;  $\Delta_{min}^{max} = \max r_{ij}^n - \min l_{ij}^n$

The calculated left (ls) and right (rs) normalized values can be written as specified in Eq. 6

$$\begin{aligned} zls_{ij}^k &= za_{2ij}^k / (1 + za_{2ij}^k - za_{1ij}^k) \\ zrs_{ij}^k &= za_{3ij}^k / (1 + za_{3ij}^k - za_{2ij}^k) \end{aligned} \quad \left. \vphantom{\begin{aligned} zls_{ij}^k \\ zrs_{ij}^k \end{aligned}} \right\} \text{(eq. 6)}$$

The calculated total normalized exact crisp values can be written as specified in Eq. 7

$$z_{ij}^k = [zls_{ij}^k (1 - zls_{ij}^k) + zrs_{ij}^k \times zls_{ij}^n / (1 - zls_{ij}^k + zrs_{ij}^k)] \quad \text{(eq. 7)}$$

The calculated total normalized exact crisp values can be written as specified in Eq. 8

$$\hat{w}_{ij}^k = \min a_{ij}^n + z_{ij}^n \Delta_{min}^{max} \quad \text{(eq. 8)}$$

The integrated exact crisp values of  $k$  respondents having a different opinion can be written as specified in Eq. 9

$$\hat{w}_{ij}^k = 1/k (\hat{w}_{ij}^1 + \hat{w}_{ij}^2 + \dots + \hat{w}_{ij}^k) \quad \text{(eq. 9)}$$

Furthermore, to understand the relationship between the element system and to solve complex system problems, the DEMATEL method was used. The method is based on graph theory, allowing an analysis of the complex issue and solving them by visualization. The process adopts a structural modeling approach taking the direct graph form, i.e., a casual-effect diagram. The casual-effect diagram highlights the interdependence relationship and values influential effects among different factors. The visual relationship helps analyze all elements and factors categorized into effect group and casual group.

Assume that system consists of a set of different elements, i.e.,  $D = (d_1, d_2, d_3, \dots, d_n)$

The particular group and pairwise relation are considered for mathematical modeling relationships. The different steps during the DEMATEL method are specified below.

**Step 1** - To create a direct relation matrix, a measurement of the relationship among criteria is needed. The linguistic comparison scale was designed into five levels as a (1) no influence; (2) moderately low influence; (3) moderately high influence; (4) strong influence; (5) very strong influence.

Further, (A) which is initial direct relation matrix is a  $n \times n$  matrix developed from a comparison of pairs, where  $T_{ij}$  represented the degree where the  $i$  criteria affects the  $j$  criteria, i.e.,  $T = [t_{ij}]_{n \times n}$

**Step 2**- The direct relation matrix A is the foundation to obtain the normalized direct relation matrix (I). The matrix I can be created with the help of Eq. 10 and 11.

$$S = k \times A \quad (\text{eq. 10})$$

$$\text{Where, } k = \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^n a_{ij}} \quad (\text{eq. 11})$$

**Step 3**- To attain the total relation matrix (I), the normalized direct relation matrix S is initially obtained, and the matrix (I) is indicated as the identity matrix. The matrix (I) is obtained as specified in Eq. 12

$$T = Z(I - Z) - 1 \quad (\text{eq. 12})$$

**Step 4**- To obtain a casual diagram, the addition of rows and columns are individually specified as vectors U and V in the matrix (I). An effect and casual diagram can be acquired by mapping the U+V and U-V datasets. The U+V, a horizontal axis vector, is obtained by adding U+V, which shows the importance of criteria. The U-V denotes a vertical axis vector obtained by deducting U from V. If U-V is positive, then it is a group criterion of the cause group, and if U-V is negative, then it is a group criteria of the effect group. The equation related to the causal diagram is specified in eq. 13, 14, 15.

$$T = [t_{ij}]_{n \times n}, \quad i, j = 1, 2, 3, \dots, n \quad (\text{eq. 13})$$

$$U = [\sum_{i=1}^n t_{ij}]_{1 \times n} = [t_j]_{n \times 1} \quad (\text{eq. 14})$$

$$V = [\sum_{j=1}^n t_{ij}]_{1 \times n} = [t_j]_{n \times 1} \quad (\text{eq. 15})$$

**Step 5-** To obtain a matrix of inner dependence, the addition of every total relation matrix column should be equal to 1 via method of normalization after that, the matrix of inner dependence can be obtained.

The different stages involved during the DEMATEL method because of the ambiguity are presented in the next section.

**Stage 1 (Decision goals identification)** – During this stage, all the important information is collected to assess the disadvantages and advantages of decision goals. Further, the monitoring of the result is also done to confirm decision goals. This stage is vital to form different expert panels from group information to achieve desired goals.

**Stage 2 (Survey instrument and evaluation criteria development)** – This stage is essential to create a set of criteria for assessment. The created set of criteria has a complex nature due to the relationship among different clusters of criteria. The proposed method is relevant to obtain the structural model and segregating the criteria into effect and cause groups for evaluation.

**Stage 3 (Use and interpretation of linguistic information)** – To convert fuzzy numbers into exact crisp scores, the use of linguistic information is essential. By applying eq. 5 to 9, the fuzzy assessments can be de-fuzzified and combined into exact crisp values i.e.  $\hat{w}_{ij}^k$ .

**Stage 4 (Analysis of criteria into effect and causal diagram)** – The exact crisp values are obtained from the initial direct relation matrix. Eq. 10 can be used to obtain the normalized direct relation matrix. Eq. 11 to 15 give the effect and causal diagram.

## 4.2 Applying the Fuzzy-DEMATEL method to rank adoption barriers of CE to FSC

In the present study, CE in FSC was taken from a small-scale food industry project in Mumbai, Maharashtra, India. The small-scale XYZ food industry was established in 1995 and had operations in Mumbai city with around 1000. XYZ Food Industries is engaged in offering a wide range of food products and leading manufacturers and distributors. The industry deals with the supply of different food products and has its active business in and around Mumbai city. The case industry is also keen to improve their business performance by adopting the CE in their FSC. The case industry aims to provide updated knowledge and information about CE in the FSC in Mumbai city. Mumbai city is the financial capital of India and is a highly populated island city. However, due to tremendous economic growth and urbanization, the city needs a continuous

supply of resources, posing a threat to the surrounding environment and facing a shortage of food supply during the too wet rainy season.

Due to commitments towards sustainability and regularity requirements, the industry is keen to adopt CE practices and interested in adopting CE practices in their FSC. The XYZ industry is interested in applying the findings from the Fuzzy-DEMATEL method. The case industry also helped to identify barriers and rank them to aid decision-makers in adopting CE in FSC. The required details for applying the Fuzzy-DEMATEL method were collected from the team. The team consists of 20 expert professionals (from academia and industry, management, and consulting) who have expertise and experience in FSC. The details of the expert team and their demographic aspects are shown in Table 3.

Table 3: The demographic details of 20 expert professionals.

<b>Demographic variables</b>	<b>Specifications and details</b>			
Gender (Female (F); Male (M))	M	M	M	M and F
Age (Average)	35+	37+	35+	40+
Educational background	MTech and MBA	MBA	MTech	PhD
Professional experience	Experience of more than 8 years	Experience of more than 7 years	Experience of more than 5 years	10 years of experience
Domain	Industry	Management	Consulting	Academia
Numbers of experts	6	5	5	4

The initial direct relation matrix for the measurement of the relationship among criteria is depicted in Table 4.

**Table 4: Initial matrix**

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18
X1	0.00	1.67	2.67	2.33	2.67	3.33	3.67	3.67	3.67	3.67	4.00	3.33	3.33	2.00	3.67	4.00	3.33	3.33
X2	1.33	0.00	2.33	1.67	2.67	1.67	2.33	3.67	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	4.33	1.67
X3	2.33	2.33	0.00	2.33	2.33	1.67	2.67	3.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	1.67
X4	2.00	2.67	2.00	0.00	2.33	2.33	2.33	3.67	2.33	3.33	4.67	4.67	4.67	4.67	3.33	4.67	4.67	2.33
X5	1.67	2.67	1.33	2.33	0.00	2.67	2.33	3.67	2.33	3.33	4.67	4.67	4.67	4.67	3.33	4.67	4.67	2.67
X6	1.33	3.33	1.33	2.67	2.33	0.00	2.33	3.67	2.67	2.67	4.67	4.67	4.67	4.67	2.67	4.67	4.67	0.00
X7	1.33	2.00	1.67	1.67	2.33	2.33	0.00	3.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.67	2.33
X8	3.33	2.00	1.33	1.33	2.33	2.33	2.33	0.00	1.67	2.00	4.67	4.67	4.67	4.67	2.00	4.67	4.67	2.33
X9	3.67	1.00	2.33	1.33	2.33	3.00	2.33	2.33	0.00	4.33	4.67	4.67	4.67	4.67	4.33	4.67	4.67	3.00
X10	1.00	1.33	3.00	2.33	1.33	2.67	2.33	1.00	2.33	0.00	4.67	4.67	4.67	4.67	0.00	4.67	4.67	2.67
X11	1.67	1.67	2.33	2.33	1.33	2.67	3.33	1.00	2.67	3.33	0.00	4.67	4.67	4.67	3.33	0.00	4.67	2.67
X12	1.33	2.33	3.33	1.67	1.67	2.67	2.67	1.00	3.33	2.67	5.00	0.00	4.67	4.67	2.67	5.00	0.00	2.67
X13	1.33	3.33	2.33	2.33	3.00	2.33	1.67	1.67	1.67	4.00	4.67	4.67	0.00	1.00	4.00	4.67	4.67	2.33
X14	1.00	1.33	2.33	2.33	2.33	2.33	2.33	3.00	1.67	2.67	3.00	4.67	3.33	0.00	2.67	3.00	4.67	2.33
X15	0.00	1.67	2.67	2.33	2.67	3.33	3.67	3.67	3.67	3.67	4.00	3.33	3.33	2.00	0.00	4.00	3.33	3.33
X16	1.33	0.00	2.33	1.67	2.67	1.67	2.33	3.67	4.33	4.33	4.33	4.33	4.33	4.33	4.33	0.00	4.33	1.67
X17	2.33	2.33	0.00	2.33	2.33	1.67	2.67	3.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	4.67	0.00	1.67
X18	2.00	2.67	2.00	0.00	2.33	2.33	2.33	3.67	2.33	3.33	4.67	4.67	4.67	4.67	3.33	4.67	4.67	0.00

The normalized direct relation matrix can be obtained using Equation 10, 11, and 12, as shown in Table 5.

**Table 5- The normalized direct relation matrix**

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18
X1	1.00	-0.03	-0.04	-0.04	-0.04	-0.05	-0.06	-0.06	-0.06	-0.06	-0.07	-0.05	-0.05	-0.03	-0.06	-0.07	-0.05	-0.05
X2	-0.02	1.00	-0.04	-0.03	-0.04	-0.03	-0.04	-0.06	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.03
X3	-0.04	-0.04	1.00	-0.04	-0.04	-0.03	-0.04	-0.06	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.03
X4	-0.03	-0.04	-0.03	1.00	-0.04	-0.04	-0.04	-0.06	-0.04	-0.05	-0.08	-0.08	-0.08	-0.08	-0.05	-0.08	-0.08	-0.04
X5	-0.03	-0.04	-0.02	-0.04	1.00	-0.04	-0.04	-0.06	-0.04	-0.05	-0.08	-0.08	-0.08	-0.08	-0.05	-0.08	-0.08	-0.04
X6	-0.02	-0.05	-0.02	-0.04	-0.04	1.00	-0.04	-0.06	-0.04	-0.04	-0.08	-0.08	-0.08	-0.08	-0.04	-0.08	-0.08	0.00
X7	-0.02	-0.03	-0.03	-0.03	-0.04	-0.04	1.00	-0.06	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
X8	-0.05	-0.03	-0.02	-0.02	-0.04	-0.04	-0.04	1.00	-0.03	-0.03	-0.08	-0.08	-0.08	-0.08	-0.03	-0.08	-0.08	-0.04
X9	-0.06	-0.02	-0.04	-0.02	-0.04	-0.05	-0.04	-0.04	1.00	-0.07	-0.08	-0.08	-0.08	-0.08	-0.07	-0.08	-0.08	-0.05
X10	-0.02	-0.02	-0.05	-0.04	-0.02	-0.04	-0.04	-0.02	-0.04	1.00	-0.08	-0.08	-0.08	-0.08	0.00	-0.08	-0.08	-0.04
X11	-0.03	-0.03	-0.04	-0.04	-0.02	-0.04	-0.05	-0.02	-0.04	-0.05	1.00	-0.08	-0.08	-0.08	-0.05	0.00	-0.08	-0.04
X12	-0.02	-0.04	-0.05	-0.03	-0.03	-0.04	-0.04	-0.02	-0.05	-0.04	-0.08	1.00	-0.08	-0.08	-0.04	-0.08	0.00	-0.04
X13	-0.02	-0.05	-0.04	-0.04	-0.05	-0.04	-0.03	-0.03	-0.03	-0.07	-0.08	-0.08	1.00	-0.02	-0.07	-0.08	-0.08	-0.04
X14	-0.02	-0.02	-0.04	-0.04	-0.04	-0.04	-0.04	-0.05	-0.03	-0.04	-0.05	-0.08	-0.05	1.00	-0.04	-0.05	-0.08	-0.04
X15	0.00	-0.03	-0.04	-0.04	-0.04	-0.05	-0.06	-0.06	-0.06	-0.06	-0.07	-0.05	-0.05	-0.03	1.00	-0.07	-0.05	-0.05
X16	-0.02	0.00	-0.04	-0.03	-0.04	-0.03	-0.04	-0.06	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	-0.07	1.00	-0.07	-0.03
X17	-0.04	-0.04	0.00	-0.04	-0.04	-0.03	-0.04	-0.06	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	1.00	-0.03
X18	-0.03	-0.04	-0.03	0.00	-0.04	-0.04	-0.04	-0.06	-0.04	-0.05	-0.08	-0.08	-0.08	-0.08	-0.05	-0.08	-0.08	1.00



The cause-effect relation matrix and casual diagram (Figure 2) can be obtained using Equation 13, 14, 15, as shown in Table 6.

**Table 6 Cause-effect relationship matrix**

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	U-V	U+V	
X1	0.15	0.20	0.23	0.21	0.24	0.27	0.29	0.30	0.32	0.37	0.44	0.43	0.42	0.38	0.34	0.41	0.40	0.26	2.64	<b>8.72</b>	cause
X2	0.18	0.18	0.23	0.21	0.25	0.25	0.27	0.31	0.34	0.39	0.46	0.46	0.45	0.42	0.36	0.43	0.43	0.24	2.27	<b>8.89</b>	cause
X3	0.20	0.23	0.21	0.24	0.26	0.27	0.30	0.33	0.37	0.42	0.49	0.50	0.49	0.46	0.39	0.46	0.46	0.26	2.49	<b>9.36</b>	cause
X4	0.19	0.22	0.23	0.18	0.25	0.26	0.27	0.31	0.31	0.37	0.46	0.47	0.46	0.43	0.35	0.43	0.43	0.25	2.29	<b>8.92</b>	cause
X5	0.18	0.22	0.22	0.22	0.21	0.26	0.27	0.31	0.31	0.37	0.46	0.46	0.45	0.43	0.35	0.43	0.43	0.25	1.74	<b>8.87</b>	cause
X6	0.17	0.22	0.21	0.22	0.23	0.21	0.26	0.29	0.30	0.34	0.44	0.44	0.43	0.41	0.32	0.41	0.41	0.20	1.15	<b>8.54</b>	cause
X7	0.14	0.17	0.17	0.16	0.19	0.20	0.18	0.25	0.24	0.28	0.33	0.33	0.33	0.31	0.26	0.31	0.31	0.19	-0.25	<b>7.40</b>	effect
X8	0.19	0.20	0.20	0.19	0.23	0.24	0.25	0.23	0.27	0.32	0.42	0.43	0.42	0.39	0.30	0.40	0.40	0.23	0.28	<b>8.33</b>	cause
X9	0.21	0.20	0.24	0.21	0.25	0.28	0.28	0.30	0.28	0.39	0.47	0.47	0.47	0.44	0.37	0.44	0.44	0.27	0.67	<b>9.04</b>	cause
X10	0.15	0.18	0.21	0.19	0.20	0.23	0.24	0.23	0.27	0.27	0.41	0.41	0.40	0.38	0.26	0.38	0.38	0.22	-1.22	<b>8.05</b>	effect
X11	0.16	0.18	0.20	0.19	0.20	0.23	0.25	0.23	0.27	0.32	0.33	0.40	0.39	0.37	0.30	0.30	0.37	0.22	-2.74	<b>7.94</b>	effect
X12	0.15	0.19	0.22	0.18	0.20	0.23	0.24	0.23	0.28	0.31	0.40	0.33	0.40	0.37	0.29	0.38	0.31	0.22	-2.75	<b>7.98</b>	effect
X13	0.16	0.21	0.21	0.20	0.23	0.23	0.24	0.25	0.27	0.35	0.42	0.42	0.34	0.34	0.33	0.39	0.39	0.23	-2.30	<b>8.27</b>	effect
X14	0.14	0.17	0.19	0.18	0.21	0.22	0.23	0.25	0.25	0.30	0.36	0.39	0.36	0.29	0.28	0.34	0.36	0.21	-2.27	<b>7.77</b>	effect
X15	0.14	0.19	0.22	0.20	0.23	0.25	0.27	0.29	0.30	0.34	0.42	0.41	0.40	0.36	0.27	0.39	0.38	0.24	-0.53	<b>8.34</b>	effect
X16	0.16	0.17	0.22	0.20	0.23	0.23	0.25	0.29	0.32	0.36	0.43	0.43	0.42	0.40	0.34	0.33	0.40	0.22	-1.67	<b>8.44</b>	effect
X17	0.19	0.22	0.20	0.22	0.24	0.25	0.28	0.31	0.34	0.39	0.46	0.46	0.45	0.42	0.36	0.43	0.36	0.24	-1.27	<b>8.84</b>	effect
X18	0.18	0.22	0.22	0.18	0.24	0.25	0.26	0.30	0.30	0.36	0.45	0.45	0.44	0.41	0.34	0.42	0.42	0.20	1.47	<b>8.66</b>	cause

Table 6 shows the outcome of a cause-effect relationship, their ranks, and the weights of essential factors. The factor U+V denotes cause factors, whereas U-V denotes the effect factors. After values were established via analysis, the critical cause and effect factors were identified. As shown in Figure 2 from U+V and U-V datasets, the cause-effect diagram was plotted, helping solve complex decision-making problems. By identifying the position and importance of individual factors in the entire FSC, the study can explore the factors with a significant impact on FSC; based on this, a gradual shift towards CE can be planned.

The inner dependency matrix can be obtained by adding the total relation matrix, as shown in Table 7. During this matrix generation, the highest prominences were considered. The coefficient matrix is shown in Table 7. The cut-off value for the same is  $\alpha = 0.30$ .

**Table 7: Inner dependency matrix**

$\alpha = 0.30$																			
	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15	X16	X17	X18	
X1								0.30	0.32	0.37	0.44	0.43	0.42	0.38	0.34	0.41	0.40		
X2								0.31	0.34	0.39	0.46	0.46	0.45	0.42	0.36	0.43	0.43		
X3							0.30	0.33	0.37	0.42	0.49	0.50	0.49	0.46	0.39	0.46	0.46		
X4								0.31	0.31	0.37	0.46	0.47	0.46	0.43	0.35	0.43	0.43		
X5								0.31	0.31	0.37	0.46	0.46	0.45	0.43	0.35	0.43	0.43		
X6									0.30	0.34	0.44	0.44	0.43	0.41	0.32	0.41	0.41		
X7											0.33	0.33	0.33	0.31		0.31	0.31		
X8										0.32	0.42	0.43	0.42	0.39	0.30	0.40	0.40		
X9										0.39	0.47	0.47	0.47	0.44	0.37	0.44	0.44		
X10											0.41	0.41	0.40	0.38		0.38	0.38		
X11										0.32	0.33	0.40	0.39	0.37	0.30	0.30	0.37		
X12										0.31	0.40	0.33	0.40	0.37		0.38	0.31		
X13										0.35	0.42	0.42	0.34	0.34	0.33	0.39	0.39		
X14										0.30	0.36	0.39	0.36	0.29		0.34	0.36		
X15									0.30	0.34	0.42	0.41	0.40	0.36		0.39	0.38		

X16									0.32	0.36	0.43	0.43	0.42	0.40	0.34	0.33	0.40	
X17								0.31	0.34	0.39	0.46	0.46	0.45	0.42	0.36	0.43	0.36	
X18								0.30	0.30	0.36	0.45	0.45	0.44	0.41	0.34	0.42	0.42	

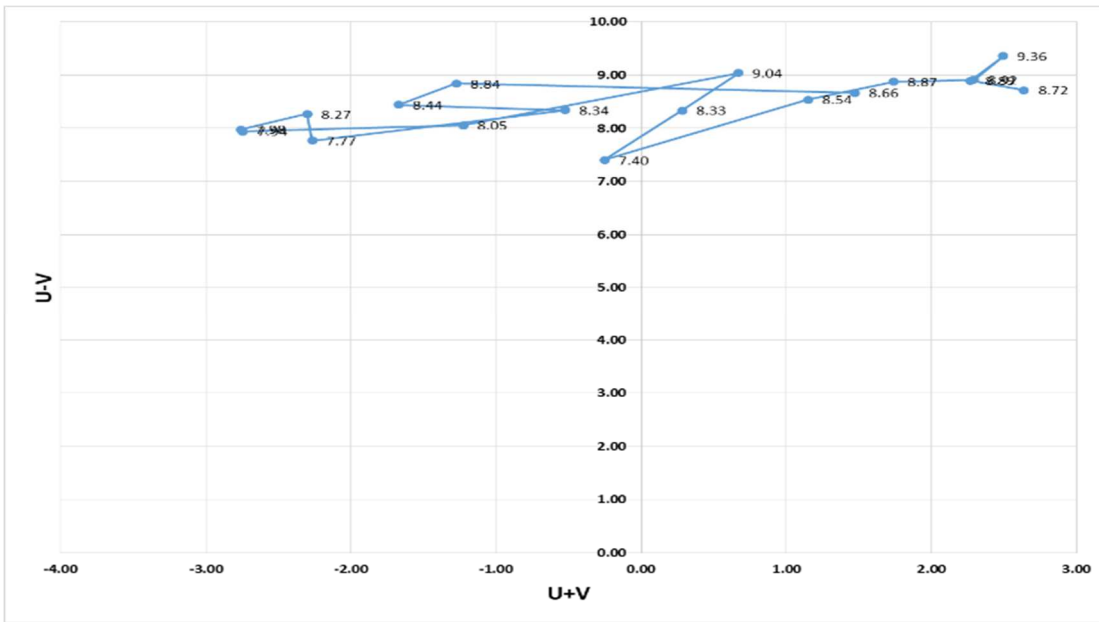


Figure 3. The cause-effect diagram for various weights of experts

## 5. Result and Discussion

The fuzzy DEMATEL method showed the ranking and cause-effect relationship among the identified barriers (as shown in Table 5). The study provided a theoretical framework for CE adoption barriers in FSC, based on a literature review validated by experienced experts' inputs. The study reveals that lack of technology and innovation (X3 “9.36”), lack of robust estimate about food waste (X9 “9.04”), lack of supply chain (SC) design and optimization (X4 “8.92”), and lack of economic benefits and high cost of investment (X2 “8.89”) are four critical barriers against adoption of CE in FSC. It is crucial to focus on causal factors as these factors significantly influence the whole system, and their performance may affect the overall CE objectives.

Amongst the cause factors, lack of financial capability (X1 “8.72”) followed by lack of technology and innovation (X3 “9.36”), lack of supply chain (SC) design and optimization (X4 “8.92”), lack of economic benefits and high cost of investment (X2 “8.89”) had the highest U+V score. This highlights that a lack of financial capability (X1 “8.72”) affects CE in FSC significantly. The earlier works of Rizos et al. (2015), Rizos et al. (2016), and Dossa, et al. (2020) also point that financial aspects and economic uncertainty significantly affect the adoption of CE in FSC. The emphasis needs to be provided on the barriers mentioned above to adopt CE in developing nations (Ellen Macarthur Foundation, 2015b; Rizos et al., 2015).

Furthermore, the subsequent higher positive U-V score, along with the highest U+V score for X3, implies that X3 has a high potential to improve CE in FSC (Ghisellini et al., 2016; De

Jesus & Mendonça, 2018). The U and V scores of X3 also point to a significant influence of X3 on other parameters. The relative S and R scores of different parameters are comparatively less than X3. Further, the received impact by X3 from other parameters is also relatively significantly less.

The lack of interphase and network support (X17 “8.84”), lack of CE indicators (X16 “8.44”), lack of scalability and replicability (X15 “8.34”), and lack of firms’ awareness, behavior, collaboration, and leadership (X13 “8.27”) were considered as essential barriers in the effect group. These effect group barriers tend to get influenced by other barriers due to the negative scores (U-V). The negative score highlights that the influential impact (U) of these activities is lower compared to influenced impact (V). The effect group is unsuitable for consideration as essential factors as they get easily influenced by the other factors. Nevertheless, it is advantageous to discuss the effect group that may help explore other factors' features. Among the identified effect group factors, X17 is a highly essential adoption barrier for CE in FSC (Kuokkanen et al., 2016).

It should be noted that, the U+V score indicates the relative importance of barriers in U+V ranking. X3 contributes the highest score, followed by X9, X17, and X16. Hence, it is essential to consider all the mentioned barriers for CE adoption in FSC, explicitly focusing on CE technology and innovation. Generally, it is essential to consider both U+V and U-V for cause-effect relationships and prioritize the barriers. Thus, the study has demonstrated four significant adoption barriers in the cause-and-effect group and their priority ranking for adopting CE in FSC. The findings of the study have been portrayed in the cause-effect diagram, as shown in Figure 3.

There are two specific studies, Farooque et al. (2019a) and Sharma et al. (2019), that related barriers to CE and FSC in developing economies, China and India, respectively, and each of them has found different results. Farooque et al. (2019a) checked the causal-effect relationships between eight barriers and lack of market pressure, and weak environmental regulations were identified as key barriers. In contrast, Sharma et al. (2019) analyzed the interaction among eleven challenges towards CE. The conclusion was that lack of technology and techniques is a driven barrier. Food organizations are required to use superior technologies, but such technologies demand high investments.

The finding of the study partly coincides with previous studies related to CE adoption barriers. For instance, Xue et al. (2010); Mangla et al. (2018a) and Masi et al. (2018) refer to lack of financial capability, government regulations; lack of practices, and lack of awareness among consumers as are main CE barriers. The works of Borrello et al. (2016) and Clark et al. (2019) point out lack of technology, innovation, lack of economic benefits, lack of law and legislation,

lack of acceptance among consumers, unintended environmental consequences, lack of reverse logistics management as crucial barriers for adoption of CE in ASC.

Further, in manufacturing and Small and Medium-Sized enterprises (SMEs), the barriers exist at the employee level, value chain, market, and institutional level (Guldmann and Huulgaard, 2020). The findings of Rizos et al. (2016) and Lahane et al. (2020) identify lack of financial capital/resources, lack of environmental regulations/laws, lack of SC integration, lack of support from top management, lack of information and knowledge, lack of available market for remanufactured products, lack of circular design aspects, lack of technology & innovation, lack of traceability in SC, lack of information about CE benefits, lack of government support and legislation as are the barriers which derail CE adoption in the manufacturing industry and SMEs. Some of the barriers hampering organizations to adopt a CE in SC, particularly in the manufacturing industry, include lack of government financial support, lack of technical capabilities, lack of skilled people and product quality, lack of governance, lack of reverse logistics, lack of society and consumer awareness. (Govindan and Hasanagic 2018; Werning and Spinler, 2020)

However, the finding of the recent study does not coincide with the earlier findings. Xia and Ruan, (2020) specified that the lack of awareness about environment and lack of green financial policy are crucial barriers for CE in the agriculture value chain. Further, hesitant company culture, lack of interest and awareness from consumer and firms are few pressing CE barriers (Liu and Bai, 2014; Kirchherr et al., 2018; Singh and Giacosa, 2019). In SMEs and manufacturing industry, lack of administrative processes, lack of regulations, standards or practices, lack of technical capabilities and skills, lack of human capital are common barriers derail the adoption of CE (Ormazabal et al., 2018; Garcés-Ayerbe et al., 2019; García-Quevedo et al., 2020). The study of Urbinati et al. (2017) and Ranta et al. (2018) point out that lack of organization support, for example, policies and regulations as crucial CE barriers. Further, the recent work of Jaeger and Upadhyay (2020), Jabbour et al. (2020) and Chhimwal et al. (2021) states that not only financial capability and regulations, but lack of CE quality, lack of coordination, lack of design, production, disassembly of products, lack of communication, lack of preference to reused, refurbished product, SC complexities and lack of clear roles of different departments derail the CE the most.

Thus, this article extends the current knowledge of barriers to CE in FSC in a developing economy by testing causal-effect relationships among 18 barriers, a higher number of barriers than similar studies. Further, the article provided through discussion on proposed barriers and compared and contrasted them with previous studies.

It was found that lack of technology and innovation (X3) is the crucial barrier to be tackled.

## **6 Managerial Contributions and Policymaking Implications**

The present study yields prescient insights and makes a significant theoretical contribution to CE in FSC. The study identifies different barriers, their ranking, and their inter-relationship for adopting CE in FSC. The findings show that there are 18 barriers categorized in the cause-effect group. It is crucial to give attention to the cause of group factors because of their subsequent influence on the effect of group factors. It is worth mentioning that factors belonging to cause group are tough to adopt, whereas factors belonging to effect group are easy to apply (Lin, 2013).

The study highlights that decision-makers and managers need to pay attention to lack of technology and innovation (X3), lack of robust estimate about food waste (X9), lack of supply chain (SC) design and optimization (X4), and lack of economic benefits and high cost of investment (X2) against adoption of CE in FSC. The results reveal that X3 is the most critical influencing factor.

The significant factors that can affect CE adoption in FSC are X1, X3, and X4. Hence, decision-makers and managers need to stress improving financial capability, R&D focus, and appropriate supply chain (SC) designs (Ellen Macarthur Foundation, 2015b; Rizos et al., 2015; De Jesus & Mendonça, 2018).

As stated earlier, CE's adoption is a cost-intensive affair, and firms find it difficult to spend on as-yet experimental services/products (X1). Thus, managers and decision-makers should explore public institution supports and government subsidies to finance CE activities. Also, decision-makers and managers can explore the opportunities from sustainability collaborations, eco-industrial parks, biorefinery or resource valorization, eco-innovations, adoption of cleaner technologies, etc. to develop in-house resources (Aranda-Usón et al., 2019). Additionally, the decision-makers need to develop a strategy for reusing and recovering already used products and waste estimation. Product design, such as consideration of eco-design for packing the food (biodegradable packaging), minimization of packaging, waste minimization, and sustainability collaboration activities, can be attempted by decision-makers (Lin, 2013).

The study also highlighted critical aspects of the adoption of CE in FSC. Government bodies such as the Department of Science and Technology (DST), NITI Ayog, Environment, Forest and Climate Change (MoEF&C) Ministry etc., can play a significant role in formulating CE policy initiatives related to the adoption of CE. Government agencies can develop draft policies, rules, indicators, and regulations for pushing CE initiatives. Attention must be paid to the

policy-based initiative in the agriculture and food sector from government and policymakers to progress toward a CE. Further, existing policy measure can be tailored with focus on technological innovation, CE subsidies, tax benefits, etc., for progress toward CE. In developing economies like India, it is critically important to have support from urban local bodies, governance structure, supporting policies for technology, innovation, CE business models, and awareness among stakeholders of FSC to adopt CE approaches.

Though the government is aware of the CE benefits, substantial efforts in terms of the law, policy, and regulation need augmentation. The EU and China's emerging regulatory steps for the adoption of CE have already started. In the same way, developing nations such as India need extensive efforts to make CE a reality.

## **7 Conclusions**

The present study provides a comprehensive list of 18 barriers against CE and categorization into seven different aspects through expert opinion and detailed literature review. The research analyzes and prioritizes barriers in the FSC by fuzzy DEMATEL approach along with the cause-effect relationship. Expert professional inputs and a case study were used to verify the fuzzy DEMATEL method's results.

This article extends the current knowledge of barriers to CE in FSC in a developing economy by testing causal-effect relationships among 18 barriers, a higher number of barriers than similar studies. It was found that lack of technology and innovation (X3) is the crucial barrier to be tackled. Additionally, financial capability (X1), economic benefits and investment (X2), lack of robust estimate about food waste (X9), and supply chain (SC) design and optimization (X4) are the top four barriers among cause groups.

The food industry generates a vast quantity of food waste, and such losses can be avoided via technological interventions and innovation, i.e., biorefinery, industrial symbiosis, eco-innovation, etc. The presence of technology and innovative solution is a prerequisite for CE's adaptability and development, one of the barriers. Therefore, different from previous studies, this article shows that CE's biological cycle via technological interventions and innovation should be fostered as a source of reducing barriers to CE in FSC in a developing economy.

Concisely, identified barriers for CE adoption could be a crucial information source for both government and managers/decision-makers of the organization. However, further research can aim to explore the domain of Industry 4.0, i.e. big data analytics, block-chain technology, Internet of things (IoT) etc. to have transparent and sustainable FSC. Even different business



models, extended producer responsibility (EPR), industrial symbiosis, etc., can be discovered in detail for long-term economic benefits by adopting CE.

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