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Implementing circular economy practices in Indian SMEs: analysis of challenges with case study

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Abstract: The adoption of circular economy (CE) and its practices is still in a nascent stage in Indian SMEs, irrespective of various initiatives, policies, and transnational strategic partnerships. Existing research has outlined the benefits of CE adoption in Indian SMEs to achieve sustainable business performance in emerging markets. This paper has identified the challenges of CE in Indian SMEs. The fuzzy DEMATEL approach is used to prioritise the challenges of the CE in Indian SMEs. The robustness of model and expert's biases is checked by sensitivity analysis. The analysis shows that the lack of legislation and regulation, systemic nature of CE, multi and interdisciplinary nature of CE are

the top causing challenges. Similarly, the lack of affordable waste management techniques, non-availability of reverse logistics facilities and lack of in-house technological capabilities on CE are top effect challenges. Based on classification and prioritisation from fuzzy DEMATEL techniques, the organisations can form strategies and make a transformation toward circular practices. Observations from the case study state that internal technological facilities and training can also help in the journey of implementing CE practices. To get a practical insight into CE implementation, we have conducted a case study on windshield manufacturing organisation.

Keywords: linear economy; circular economy; CE; Indian small and medium enterprises; Industry 4.0; case study; India.

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Rakesh Kumar Phanden is a distinguished academician and researcher with a PhD from the National Institute of Technology Kurukshetra, India. He is actively involved in the scholarly community, participating in conference technical sessions and reviewing for SCIs and Scopus-indexed journals. He has played key roles in organising international conferences, including ICNDME 2014, FLAME 2020, FLUTE 2021, FLUTE 2023, FLAME 2022, and FLAME 2024. He is the author and editor of ten books and has edited nine special issues for Scopus and SCI-indexed journals. He also serves on the editorial boards of several journals. With 17 years of teaching experience, he has taught at private and government institutions in India and abroad. He has published over 100 papers at national and international levels.

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1 Introduction

The linear economy has endured from the start of civilisation and Industrialisation in Indian society. In a linear economy, the products are made from virgin materials and thrown away in nature after use. These practices pressure natural resources and have environmental, economic, and social impacts (Govindan, 2023; Kumar et al., 2023). Limitations of the linear economy and awareness of resource conservation have brought the attention of the government, non-government organisations and societies toward circular economy (CE) practices. CE focuses on creating an ecosystem of expanding product useful life by adopting practices of reducing, reusing, recycling, recovering, redesigning and remanufacturing (Govindan and Hasanagic, 2018; Fatimah et al., 2023). Various issues like population growth and change in human consumption have significantly grabbed the attention of various international organisations such as the European Union and the United Nations. Global economies are changing their focus from linear to CE. Practices of the CE provide an edge to achieving self-sustainability in materials and energy and lead a guiding path towards net-zero manufacturing (Kumar et al., 2023; Garg et al., 2021).

CE has evolved as a leading approach to support sustainability in recent years. Ellen MacArthur Foundation (2013) have defined CE as “An approach that provides multiple value creation mechanisms, which are decoupled from the consumption of finite resources”. The transition from linear to CE needs fundamental changes in the value chain. Alone in Europe, the business benefits linked with CE practices are estimated to be 1.8 trillion euros/year by 2030 (Ellen MacArthur Foundation, 2013). CE implementation has particular importance in manufacturing organisations due to their contribution to economies all over the globe (Blomsma et al., 2019). Kumar et al. (2023) observed that government policies and regulations on CE, consumer awareness and demand for CE products, economic incentives available for CE products, and new global business opportunities due to CE are the leading contributing factors for CE implementation. A reduction in energy and waste-related costs, the availability of infrastructure for CE practices, and an improvement in information-sharing transparency among supply chain members are the leading factors in the implementation of CE and sustainable practices (Kumar et al., 2023, 2024; Maurya et al., 2021).

Despite the interests and benefits of CE, manufacturing companies are facing challenges in implementing CE. It is being observed that CE is insignificantly implemented globally (Harris et al., 2021). Only 2%–5% of organisations have successfully implemented CE (Căuțișanu et al., 2018). Chen et al. (2021) has observed that a lack of knowledge on CE leads to failure during implementation. Compared to small and medium enterprises (SMEs) more prominent players find CE practices affordable. Considering the scarcity of virgin resources for developing economies, it is a significant challenge. CE focuses on the principles of reducing, reusing, repairing, or recycling (Kumar et al., 2023). Adopting CE practices is a futuristic approach, and the current study's findings will be a guide map for SMEs dealing with its adoption challenges. The findings demonstrate an absence of holistic research on CE implementation in Indian SMEs. For the successful implementation of CE and its practices, there is a need to find and analyse the challenges in its implementation path. Based on the above discussion, the objective of the present work is reflected in subsequent questions:

RQ1 What are the challenges while implementing CE and its practices in Indian SMEs?

RQ2 What potential causal relationships exist among the challenges of CE?

RQ3 To study the CE implementation case in an Indian manufacturing SME?

We have analysed the identified challenges of CE in Indian SMEs and studied implementation by case study. Further sections of the research paper are structured as follows: Section 2 includes a comprehensive literature review, Section 3 outlines the methodology, Section 4 presents the results of the fuzzy DEMATEL analysis, and Section 5 provides a detailed case study. Section 6 presents the conclusions, implications, and future research directions based on this study.

2 Literature review

CE has been recognised as a unifying concept capable of solving societal problems linked to environmental pollution and resource depletion. Its adoption is rapidly reforming manufacturing, production, consumption, and recycling across various segments of the economy (Kumar et al., 2023). CE creates a balance of industrial development and economic growth with the environment and human health through carbon footprint reduction. The framing of policies, regulatory measures, and administrative guidance on CE are required at the different levels of provinces, cities, industrial sectors, and industries (Govindan, 2023). The material flow analysis and life cycle assessment approaches have a high potential for assessing the long-term environmental implications of CE policy measures.

Transparency, monitoring, feedback, and the recognition of progress with rewards and penalties are enablers that can change the behaviour of producers and consumers towards CE. CE is an ideal approach to achieve sustainability globally with zero waste and decarbonisation (Kumar et al., 2023; Dutta et al., 2022). CE practices help in achieving the sustainable development goals (SDGs). CE mitigates the environmental concerns of SDG through the optimum utilisation of energy, materials, and waste reduction (Garg et al., 2021). SMEs are a significant contributor to India's GDP and exports, and CE practices are important in Indian SMEs. Developed economies have the privilege of finances and technologies to adopt sustainable practices compared to developing economies (Singh and Kumar, 2020).

Regardless of the enormous benefits of CE, its implementation is quite limited in manufacturing industries due to various reasons like uncertainties of finance, complexity of circular practices, absence of regulation and infrastructures (Bocken et al., 2018; Guldmann and Huulgaard, 2020). The lack of affordable waste management techniques and the high cost of CE practices and products make it difficult to get consumer perception favourable toward CE (Donner et al., 2021). Kumar et al. (2019) stressed contriving policies consulting all stakeholders and supply chain members. Lack of knowledge and training of managerial staff on CE is a big hindrance in implementing CE. Pathak and Endayilalu (2019) stated that investment in technology and training are key parameters of transformation from a linear to a CE.

Waste reduction with used product handling and asset analysis are key factors of CE implementation in manufacturing organisations. Industry 4.0 technologies enable both strategic and technology implementation decisions (Rizvi et al., 2023; Govindan, 2023). ‘market competition’, ‘cross-functional teams’ formation’, ‘focus on global standards’, ‘skilled workforce’, ‘consumer awareness on CE’ and ‘dedicated fund for CE’ are key factors of CE for the eco-friendly, innovative, flexible and e-waste management system (Bhattacharjee et al., 2023). CE-supportive regulations, changes in demand and consumption of products and synergies, and cooperation between stakeholders across the value chain are critical enablers in plastic circularity (Pollard et al., 2023). Product lifecycle, service-based models, circular design, reverse flows, awareness of consumers and users, and collaborations between SC members are key factors of CE adoption (Lisiecki et al., 2023). Management commitment and strategies for building a ‘Green image’, coordination with suppliers, technological upgrades, reverse supply chain practices, workforce skills and training, and customer awareness and demand for CE products are crucial factors in successfully adopting CE. ‘Government policy and regulation on CE’, ‘consumer awareness and demand for CE products’, ‘economic incentives available for CE products’, and ‘new global business opportunity due to CE’ have a higher out-degree influence on other factors of CE in Indian SMEs (Kumar et al., 2023).

Uncertainty on market demand and returns on investment in circular practices are critical challenges (Kumar et al., 2019; Ingemarsdotter et al., 2020). Technologies of Industry 4.0 like the internet of things (IoTs), Industry internet of things (IIoTs), cloud computing, cyber-physical system (CPS) and automation can help in CE data integrated practices (Kumar et al., 2021a; Govindan and Arampatzis, 2023; Chandrayan and Kumar, 2020). Digital technologies enable sustainable management and CE implementation. IoT helps in data collection, AI in predictive maintenance, big data analytics in demand forecasting, and blockchain technology for tracking product origins. The level or degree of digitalisation varies by size and type of company (Viles et al., 2022). Lack of coordination, collaboration and information sharing among Supply Chain members makes it difficult to adopt technological changes, especially in SMEs (Kumar et al., 2020; Singh and Kumar, 2020).

SMEs hesitate to share information due to competition and fear of loss of business (Singh and Kumar, 2020). Hopkinson et al. (2018) observed that the lack of technologies and standardisation of recycled materials are big challenges in adopting CE. The transformation from linear to circular also depends on consumer behavioural, social, and cultural background too (Kumar et al., 2023; Kirchherr et al., 2018; Donner et al., 2021). Government regulation and legislation on practices of CEs can help organisations in adopting it. On the other hand, frequently changing and non-favourable regulations can create hindrances in the implementation of CE too (Kazancoglu et al., 2021). Converting waste of one organisation into raw material of another is highly dependent on government regulations, which further helps in managing price fluctuation and volatility (Kumar et al., 2019). Uncertainty and geographical dispersion associated with reverse supply chain make its management more difficult and costlier hence products of CE become costlier too (Gupta et al., 2019). Sarja et al. (2020) examined the obstacles, ambivalences and catalysts involved in a business’s transition towards CE. The Challenges of CE implementation identified from the literature review are summarised in Table 1.

Table 1 Challenges of CE implementation in Indian SMEs

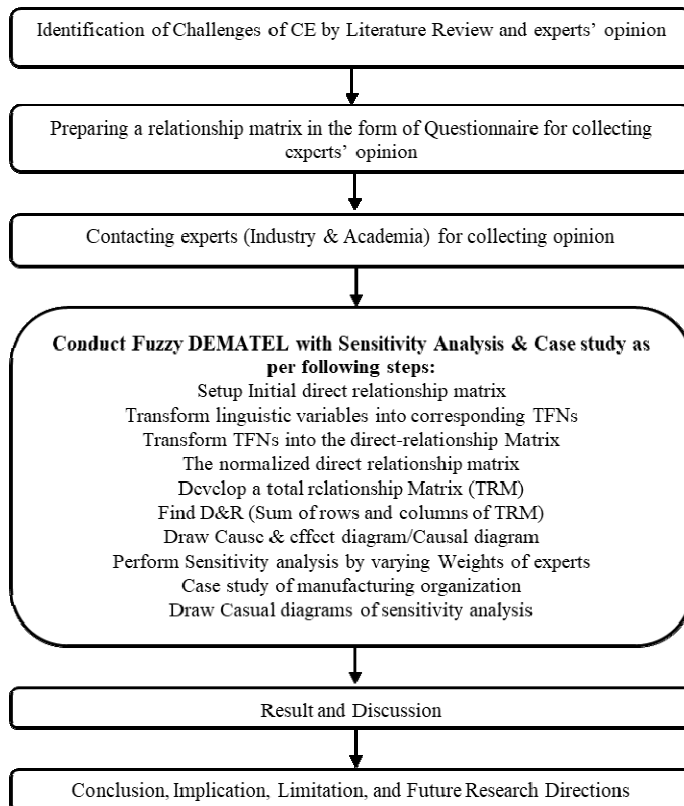
<i>S. no.</i>	<i>Challenges</i>	<i>References</i>
1	Systemic nature of CE/fundamental changes required in value chain	Bressanelli et al. (2018), Galvão et al. (2020), Kumar et al. (2023)
2	Multi and inter disciplinary nature of CE system	Bocken et al.(2018), Kjaer et al. (2019), Korhonen et al. (2018)
3	Lack of knowledge and expertise of SMEs on CE	Cantú et al. (2021), Kumar et al. (2021a), Kalar et al. (2021), Bocken and Geradts (2020)
4	Lack of motivation and participation from consumer/SC partners on CE	Jakhar et al. (2019), Jabbour et al. (2020), Winans et al. (2017)
5	Lack of in-house technological capabilities on CE	Tura et al. (2019), Donner and de Vries (2021)
6	Lack of coordination and collaboration between SC members	Rizos et al. (2016), Zucchella and Previtali (2019), Kumar et al. (2021a)
7	Non-availability of reverse logistics facilities	Gupta et al. (2019), Kumar et al.(2021b), Guldmann and Huulgaard (2020)
8	In sufficient market demand of CE products	Baxter et al. (2017), Hina et al. (2022)
9	High cost of CE practices and products	Linder and Williander (2017), Agyemang et al. (2019)
10	Lack of affordable waste management techniques	Donner et al. (2021), Kumar (2021), Bodar et al. (2018)
11	Lack of legislation and regulations on CE	Kazancoglu et al. (2021), Dutta et al. (2020), Patwa et al. (2021)
12	Lack of funds for circular practices (government support/internal funds/FDI on CE)	Linder and Williander (2017), Pathak and Endayilalu (2019)
13	Lack of skilled/trained workforce on CE	Pathak and Endayilalu (2019), Askary and Kumar (2020), Hina et al. (2022)
14	Lack of short-term returns/uncertainties of returns on CE	Burke et al. (2021), Rizos et al. (2016), Kumar et al. (2019)
15	Lack of awareness among consumers/SC members about CE practices and products	Kirchherr et al. (2018), Ranta et al.(2018), Kumar (2021), Kumar et al. (2023)
16	Lack of policies and strategies on CE	Ferasso et al.(2020), Kumar et al.(2019), Witjes and Lozano (2016), Bonsu (2020)

3 Methodology

We have analysed the challenges of CE implementation using fuzzy decision-making trial and evaluation laboratory (DEMATEL) techniques. By this technique, the interrelationship among the challenges is developed, and influential challenges have been identified. The challenges have been classified into cause-and-effect groups and are graphically represented by the cause-effect diagram (Shakeri and Khalilzadeh, 2020). The sturdiness of fuzzy DEMATEL analysis is also checked by sensitivity analysis.

Furthermore, DEMATEL is an excellent and efficient tool for determining the interconnectedness of several components in a complicated system (Kumar et al., 2020). The DEMATEL approach, which incorporates the concept of fuzziness, enables the accommodation of uncertain or vague expert opinions and expressions, thereby facilitating more informed and accurate judgements in complex and ambiguous situations (Kumar et al., 2023). Ferdous et al. (2011) and Kumar et al. (2020) observed that DEMATEL is a preferred technique over AHP, TISM, ISM, or any MCDM techniques as it dissects challenges into the cause-and-effect group and highlights the severity of their effects also. The proposed technique is versatile, as it can effectively elucidate and explore the intricate cause-and-effect relationships among diverse challenges. Incorporating diverse factors into the analysis empowers managerial teams to develop and implement targeted strategies that effectively address these challenges. The survey questionnaire was administered to a panel of industry and academic experts, each with a minimum of eight to ten years of relevant managerial or research experience, to elicit their professional opinions on the complex interrelationships and interdependencies among the challenges under consideration. Utilising diverse modes of communication, the research team effectively engaged with academic and industrial experts from across different national states of India. Inclusion criteria for industrial experts comprised professionals with relevant managerial qualifications, while academic experts were required to possess a minimum doctoral degree qualification.

Figure 1 Methodology of study and fuzzy DEMATEL analysis



Before participating in the survey, the panel of experts was thoroughly briefed on the research's overarching goals and corresponding title. The survey questionnaire, designed to capture the informed perspectives of 50 specialists, with 25 individuals drawn from each of the industry and academia cohorts, was subsequently distributed to the panel. Out of the total panel of 50 experts, 30 individuals, including 17 from industry and 13 from academia, responded to the survey questionnaire. Further analysis was performed of 25 of the completed responses that met all the requisite criteria for inclusion. Figure 1 depicts a comprehensive flowchart that delineates the various stages of the methodology employed, wherein the complex challenges under consideration were quantitatively modelled utilising the fuzzy DEMATEL approach. The resulting causal diagram, thus developed, effectively captures the relative importance of each challenge. Subsequent sections provide an in-depth elaboration of the fuzzy DEMATEL methodology employed in the present study.

3.1 Initial direct-relation matrix

The initial step in the Fuzzy DEMATEL process, as illustrated in Table 2, involves establishing a direct relation matrix using linguistic variables. Design for these variables can be found in Table 3.

3.2 Convert linguistic variables to TFNs

The 2nd step of the fuzzy DEMATEL analysis converts linguistic variables in TFNs.

Table 2 Initial direct relation matrix of challenges

	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13	C14	C15	C16
C01	NI	VLI	VLI	NI	LI	VLI	LI	VLI	VHI	HI	NI	LI	VLI	VLI	NI	LI
C02	LI	NI	LI	VLI	LI	VLI	LI	NI	VHI	HI	NI	NI	HI	VLI	NI	LI
C03	NI	NI	NI	LI	HI	LI	LI	NI	LI	LI	NI	LI	VHI	NI	VHI	VHI
C04	NI	NI	VHI	NI	VHI	VHI	HI	HI	LI	VHI	LI	HI	VHI	HI	HI	VHI
C05	NI	NI	VHI	LI	NI	HI	LI	LI	HI	VHI	NI	VLI	VHI	LI	LI	HI
C06	NI	NI	VHI	HI	VHI	NI	VHI	LI	LI	HI	NI	HI	VHI	HI	VHI	VHI
C07	NI	NI	VLI	LI	VLI	VLI	NI	HI	HI	HI	NI	VLI	LI	LI	HI	HI
C08	NI	NI	LI	HI	HI	NI	VHI	NI	HI	HI	LI	HI	VHI	VHI	HI	VHI
C09	NI	NI	LI	HI	HI	NI	VHI	VHI	NI	HI	VLI	LI	VLI	HI	NI	HI
C10	NI	NI	NI	NI	VLI	NI	LI	VLI	VHI	NI	NI	VLI	NI	LI	NI	NI
C11	NI	NI	HI	HI	LI	VLI	VHI	HI	LI	HI	NI	LI	LI	LI	LI	VHI
C12	NI	NI	HI	LI	VHI	LI	HI	VLI	VLI	LI	NI	NI	VHI	VLI	HI	VHI
C13	VLI	VLI	VHI	HI	HI	LI	HI	VLI	HI	HI	NI	NI	NI	VLI	VHI	VHI
C14	NI	NI	NI	HI	LI	LI	LI	NI	HI	LI	VLI	HI	VLI	NI	NI	VHI
C15	NI	NI	VHI	HI	HI	HI	VHI	VLI	LI	LI	NI	LI	VHI	LI	NI	VHI
C16	NI	NI	HI	HI	VHI	VHI	VHI	VLI	LI	HI	VLI	HI	VHI	VLI	VHI	NI

Table 3 Linguistic terms and triangular fuzzy numbers

<i>Linguistic terms</i>	<i>Influence score</i>	<i>Triangular fuzzy numbers (TFNs)</i>
No influence	0	(0, 0, 0.25)
Very low influence	1	(0, 0.25, 0.50)
Low influence	2	(0.25, 0.50, 0.75)
High influence	3	(0.50, 0.75, 1)
Very high influence	4	(0.75, 1, 1)

3.3 Convert TFNs to direct-relation matrix F .

This step applied transforming fuzzy data into crisp scores (CFCS) method to calculate triangular fuzzy number. CFCS defuzzification method can give a better crisp value for fuzzy numbers compared to other existing methods and consists of five steps (Mirmousa and Dehnavi, 2016). As per chronological stages of CFCS, direct relation matrix ' F ' was framed.

Step 1 Normalisation

$$xa_{1ij}^k = \frac{(a_{1ij}^k - \min a_{1ij}^k)}{\Delta_{\min}^{\max}} \quad (1)$$

$$xa_{2ij}^k = \frac{(a_{2ij}^k - \min a_{2ij}^k)}{\Delta_{\min}^{\max}} \quad (2)$$

$$xa_{3ij}^k = \frac{(a_{3ij}^k - \min a_{3ij}^k)}{\Delta_{\min}^{\max}} \quad (3)$$

where $\Delta_{\min}^{\max} = \max r_{ij}^n - \min l_{ij}^n$.

Step 2 Compute right (rs) and left (ls) normalised values

$$xls_{ij}^k = \frac{xa_{2ij}^k}{(1 + xa_{2ij}^k - xa_{1ij}^k)} \quad (4)$$

$$xls_{ij}^k = \frac{xa_{3ij}^k}{(1 + xa_{3ij}^k - xa_{2ij}^k)} \quad (5)$$

Step 3 Compute total normalised crisp values

$$x_{ij}^k = \frac{[xls_{ij}^k (1 - xls_{ij}^k) + xrs_{ij}^k \times xrs_{ij}^k]}{(1 - xls_{ij}^k - xrs_{ij}^k)} \quad (6)$$

Step 4 Compute crisp values

$$\omega_{ij}^k = \min a_{ij}^n + x_{ij}^n \times \Delta_{\min}^{\max} \quad (7)$$

Step 5 Combine crisp values to get direct-relation-matrix

$$\omega_{ij}^k = 1 / k \times (\omega_{ij}^1 + \omega_{ij}^2 + \dots + \omega_{ij}^k) \quad (8)$$

Upon computing crisp values for all 25 answers through the application of equations presented in 1st to 4th step, a direct-relation-matrix ' F ' is formulated as outlined (refer Table 4), following prescribed formulation provided in 5th step.

3.4 Setup normalised direct-relation-matrix

This step involves obtaining a normalised direct-relation matrix ' S ' by applying the following equation:

$$S = P \times F$$

$$P = \frac{1}{\max_{1 \leq i \leq n} \sum_j^n a^{ij}} \quad (9)$$

3.5 Setup total-relation-matrix

The total-relation matrix ' M ' is obtained by applying the following equation, as shown in Table 5.

$$M = S \times (I - S)^{-1} \quad (10)$$

where ' I ' represents the identity-matrix, which has the same number of rows and columns as matrix ' S '.

3.6 Find R and D

Calculate the sum of rows in the total relation matrix as ' R ' and the sum of columns as ' D '.

$$R = \left[\sum_{j=1}^n t_{ij} \right]_{1 \times n} \quad (11)$$

$$D = \left[\sum_{j=1}^n t_{ij} \right]_{n \times 1} \quad (12)$$

3.7 Find $R+D$ and $D-R$

Calculate $R+D$ and $D-R$ for mapping cause and effect plot, as indicated in Table 6.

Table 4 Direct-relation-matrix ‘F’ of challenges

	C01	C02	C03	C04	C05	C06	C07	C08	C09	C10	C11	C12	C13	C14	C15	C16
C01	0	0.450104	0.32868	0.348913	0.445455	0.454865	0.32868	0.211905	0.966667	0.57164	0	0.57164	0.32868	0.32868	0	0.445455
C02	0.375	0	0.445455	0.211905	0.445455	0.211905	0.445455	0	0.966667	0.57164	0	0.105952	0.57164	0.211905	0.105952	0.32868
C03	0	0	0	0.57164	0.832246	0.445455	0.445455	0.222727	0.57164	0.57164	0.103365	0.445455	0.966667	0.105952	0.966667	0.966667
C04	0	0	0.966667	0	0.966667	0.966667	0.697826	0.57164	0.57164	0.832246	0.32658	0.697826	0.966667	0.57164	0.832246	0.966667
C05	0	0	0.832246	0.32868	0	0.697826	0.445455	0.445455	0.697826	0.706061	0	0.211905	0.832246	0.32868	0.445455	0.697826
C06	0	0	0.832246	0.832246	0.832246	0	0.832246	0.445455	0.57164	0.697826	0	0.57164	0.832246	0.57164	0.966667	0.966667
C07	0	0	0.32868	0.445455	0.211905	0.32868	0	0.697826	0.697826	0.697826	0	0.211905	0.445455	0.32868	0.57164	0.57164
C08	0	0	0.706061	0.832246	0.832246	0.348913	0.832246	0	0.697826	0.697826	0.446429	0.57164	0.966667	0.966667	0.697826	0.966667
C09	0	0	0.57164	0.697826	0.697826	0.222727	0.966667	0.966667	0	0.697826	0.206731	0.57164	0.32868	0.832246	0.222727	0.697826
C10	0	0	0.222727	0.348913	0.454865	0.222727	0.57164	0.32868	0.966667	0	0.103365	0.32868	0.105952	0.445455	0.105952	0.348913
C11	0	0	0.832246	0.832246	0.57164	0.454865	0.966667	0.697826	0.445455	0.57164	0	0.57164	0.57164	0.445455	0.706061	0.966667
C12	0	0	0.697826	0.57164	0.966667	0.57164	0.697826	0.211905	0.32868	0.445455	0	0	0.966667	0.211905	0.57164	0.966667
C13	0.086218	0.10119	0.966667	0.697826	0.697826	0.57164	0.697826	0.211905	0.697826	0.697826	0	0.105952	0	0.32868	0.966667	0.832246
C14	0	0	0.105952	0.697826	0.445455	0.445455	0.445455	0	0.697826	0.445455	0.206731	0.57164	0.454865	0	0.222727	0.966667
C15	0	0	0.966667	0.832246	0.697826	0.697826	0.832246	0.589286	0.445455	0.445455	0.103365	0.57164	0.966667	0.445455	0	0.966667
C16	0	0	0.832246	0.697826	0.832246	0.966667	0.832246	0.211905	0.445455	0.697826	0.206731	0.57164	0.966667	0.211905	0.966667	0

Table 5 Total relation matrix M of challenges

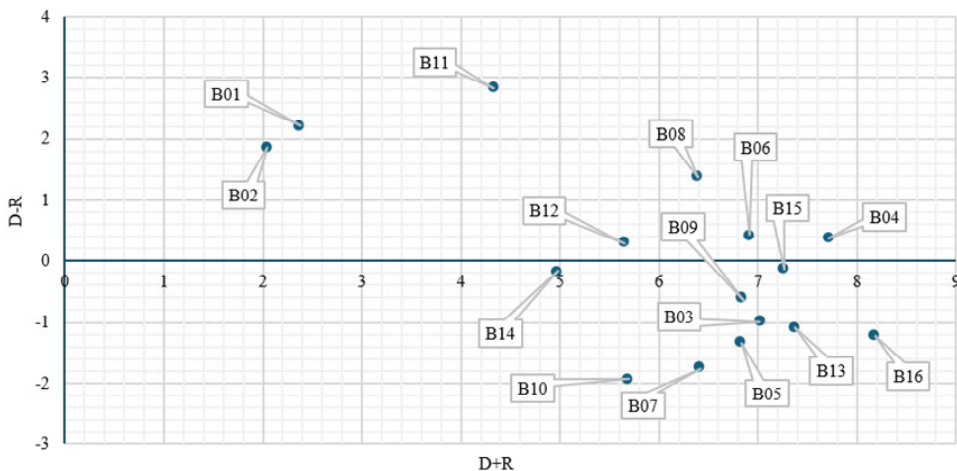
	$C01$	$C02$	$C03$	$C04$	$C05$	$C06$	$C07$	$C08$	$C09$	$C10$	$C11$	$C12$	$C13$	$C14$	$C15$	$C16$
$C01$	0.003369	0.047315	0.174623	0.164817	0.190944	0.159477	0.179824	0.113014	0.227027	0.193166	0.027439	0.151225	0.182389	0.126587	0.132527	0.210457
$C02$	0.039439	0.003614	0.163485	0.131947	0.166617	0.118632	0.167848	0.080987	0.208323	0.172958	0.022787	0.091921	0.179433	0.101105	0.122015	0.173108
$C03$	0.002708	0.003161	0.199903	0.232539	0.277115	0.205068	0.241361	0.145516	0.229318	0.238199	0.04619	0.17036	0.298316	0.134077	0.276446	0.317544
$C04$	0.003337	0.003895	0.352852	0.239203	0.35581	0.303734	0.330207	0.217273	0.289762	0.323333	0.079769	0.23779	0.367568	0.219242	0.326489	0.396366
$C05$	0.002405	0.002807	0.255785	0.195236	0.180941	0.209511	0.223256	0.15433	0.227503	0.234514	0.034112	0.138174	0.264943	0.145771	0.211903	0.273255
$C06$	0.002991	0.003492	0.315427	0.29335	0.318104	0.194811	0.316346	0.190739	0.267318	0.288125	0.045181	0.210097	0.3295	0.203331	0.314064	0.366519
$C07$	0.001818	0.002122	0.181431	0.181322	0.174284	0.153063	0.153984	0.162333	0.202705	0.207738	0.031057	0.121887	0.20026	0.131533	0.194131	0.229652
$C08$	0.00321	0.003747	0.316126	0.306951	0.330848	0.239179	0.331138	0.156635	0.291735	0.301153	0.09086	0.219884	0.353602	0.249504	0.301086	0.383492
$C09$	0.002213	0.002584	0.251007	0.248603	0.26825	0.184924	0.292677	0.216699	0.182904	0.255369	0.06057	0.187898	0.243824	0.208528	0.209389	0.300874
$C10$	0.001238	0.001444	0.140069	0.14413	0.165292	0.118263	0.178018	0.111721	0.200617	0.114641	0.034449	0.113018	0.136317	0.123296	0.121094	0.174769
$C11$	0.002734	0.003192	0.310424	0.29019	0.289416	0.233668	0.32526	0.212416	0.250494	0.272274	0.044825	0.208291	0.301216	0.189666	0.28742	0.361851
$C12$	0.002691	0.003142	0.262002	0.229072	0.286389	0.214708	0.259687	0.141017	0.205687	0.22507	0.035184	0.124615	0.296464	0.140445	0.240132	0.314739
$C13$	0.011024	0.012868	0.293014	0.249845	0.270836	0.220228	0.270083	0.150006	0.249476	0.256744	0.038639	0.145724	0.214315	0.160007	0.280922	0.313429
$C14$	0.001873	0.002186	0.167118	0.206899	0.200608	0.171318	0.200904	0.099547	0.204042	0.189043	0.04944	0.157723	0.20628	0.097889	0.167978	0.270129
$C15$	0.003049	0.00356	0.321935	0.287849	0.30031	0.255189	0.309717	0.198804	0.249351	0.259838	0.053727	0.205368	0.335915	0.187259	0.221433	0.359727
$C16$	0.002982	0.00348	0.305384	0.270373	0.305732	0.273967	0.304662	0.163366	0.244897	0.276822	0.060208	0.200821	0.328448	0.16221	0.304536	0.263075

Table 6 Cause and effect classification of challenges of CE

	<i>D</i>	<i>R</i>	<i>D+R</i>	<i>D-R</i>	<i>Ranking (D+R)</i>	<i>Ranking (D-R)</i>
C01	2.284201	0.087082	2.371283	2.197119	15	2
C02	1.944218	0.102609	2.046827	1.84161	16	3
C03	3.017855	4.010584	7.028439	-0.99273	5	11
C04	4.046629	3.672327	7.718956	0.374302	2	6
C05	2.754445	4.081529	6.835975	-1.32708	8	14
C06	3.659397	3.255739	6.915136	0.403658	6	5
C07	2.329319	4.084972	6.414291	-1.75565	9	15
C08	3.87915	2.514402	6.393551	1.364748	10	4
C09	3.116312	3.731159	6.847471	-0.61485	7	10
C10	1.878374	3.808986	5.68736	-1.93061	11	16
C11	3.583339	0.754438	4.337776	2.828901	14	1
C12	2.981045	2.684797	5.665842	0.296248	12	7
C13	3.137159	4.23879	7.37595	-1.10163	3	12
C14	2.392977	2.580449	4.973426	-0.18747	13	9
C15	3.553031	3.711565	7.264596	-0.15853	4	8
C16	3.470962	4.708986	8.179948	-1.23802	1	13

3.8 Causal diagram

In accordance with the graphical representation presented in Figure 2, the ultimate stage of the analysis involves the depiction of a causal diagram. This involves the utilisation of the horizontal axis, whereby the degree of a central role ($D+R$) is represented. Additionally, the vertical axis is utilised to symbolise degree of relation ($D-R$).

Figure 2 Cause and effect diagram of challenges (see online version for colours)

4 Results and discussion

Within this section, the paper has presented and analysed outcomes acquired through fuzzy-DEMATEL approach. As previously detailed within the methodology (refer to Tables 5 and 6), summation of rows is denoted by D , whilst R represents the summation of columns. It is essential to recognise that $D+R$ indicates the interdependence among the various challenges, whereas $D-R$ signifies the causal and effectual nature of the association. Specifically, positive values resulting from the $D-R$ calculation are deemed to belong to the cause group of challenges, whereas negative values are assigned to the effect group of challenges. Notably, the cause group of enablers has a substantial and multifaceted impact on the adoption of CE practices in Indian organisations, with the remaining challenges being categorised as belonging to the effect group. For each of the identified challenges, values of ' $D+R$ ' and ' $D-R$ ' have been computed.

Ultimately, the challenges that have been identified are examined and ranked in order of priority by means of a C&E chart (refer to Figure 2). Notably, the ' $D-R$ ' value can provide insight into the controllability of various issues impacting the adoption of CE practices. Variables that exhibit a positive value of ' $D-R$ ' are commonly referred to as 'impressiveness factors'. This is because their overall influence on other factors (D) is greater than the influence they receive from other factors (R). The influencing factors identified in this analysis are considered to be the underlying causes and are generally regarded as more amenable to control since they are impacted less significantly by other factors. It follows that a higher value of ($D+R$) indicates a greater degree of interconnectedness among the elements, with the element in question occupying a more central role in the overall system. Additionally, $D+R$ is indicative of the relative importance of the various challenges that have been identified.

As evidenced by Table 6 and Figure 2, the factor denoted as 'C16' (namely, 'lack of policies and strategies on CE (in SMEs)') has attained the highest value of ($D+R$), equates to 8.17. Thus, the observation suggests that this particular factor possessed greatest connection along with other identified challenges as well as, it is important for successful implementation of CE practices. The ($D-R$) value for 'C16' is -1.23802 , and its relative position within effect group indicates about its poor impact by the other challenges related to the other members of the effect cluster, refer to the Figure 2 and Table 6 for details. Further, finding of studies state that, 'C04' 'Lack of motivation and participation from consumer/SC partners on CE', 'C13' 'Lack of skilled/trained workforce on CE', 'C15' 'Lack of awareness among consumers/SC members about CE practices and products', and 'C03' 'Lack of knowledge and expertise of SMEs on CE' are the four other most influential challenges impacting the CE adoption in SMEs.

Further, on based of $D-R$ values, challenges have been classified in the cause (+ve value) and effect (-ve value) group. 'C11' 'Lack of legislation and regulation on CE', 'C01' 'Systemic nature of CE', 'C02' 'Multi and inter disciplinary nature of CE system', 'C08' 'In sufficient market demand of CE products' and 'C04' 'Lack of motivation and participation of consumers/SC chain partners' are the top five causing challenges. Similarly, 'C10' 'Lack of affordable waste management techniques', 'C07' 'Non-availability of reverse logistics facilities', 'C05' 'Lack of in-house technological capabilities on CE', 'C16' 'Lack of policies and strategies on CE' and 'C13' 'Lack of skilled/trained workforce on CE' are top five effect group challenge. The collective impact of a set of challenges exhibits the highest degree of influence among other factors, thereby rendering it a critical area for policy intervention. As such, policymakers should

prioritise managing this influential factor as it substantially impacts diverse areas of concern. Table 6 shows the classification of all challenges in the cause-and-effect group of challenges.

4.1 Sensitivity analysis

To check the robustness of the technique model authors has done sensitivity analysis. The bias of expert's opinion can be identified by sensitivity analysis (Kumar et al., 2020). The implementation of this strategy facilitates the methodological generalisation of the proposed system. In the present investigation, the authors have employed the technique of expert weight variation, as outlined by Biswas and Gupta (2019). The authors conducted an overall analysis wherein they considered four distinct cases. In case 1, the first expert was allocated a weightage of 40%, which was comparatively higher than that assigned to the other experts, i.e., 20% weightage each. Analogously, in cases 2, 3, and 4, the second, third, and fourth experts were respectively assigned a higher weightage of 40%, while the weightage of the remaining experts was maintained at 20% (refer to Table 7). Cause and effect variation of challenges is shown in Table 8. The results obtained show no considerable variation and confirm the proposed model's hardness.

Table 7 Weight allocation of specialists for sensitivity test of challenges

	<i>Expert-1</i>	<i>Expert-2</i>	<i>Expert-3</i>	<i>Expert-4</i>
Test-1	0.4	0.2	0.2	0.2
Test-2	0.2	0.4	0.2	0.2
Test-3	0.2	0.2	0.4	0.2
Test-4	0.2	0.2	0.2	0.4

Table 8 Ranking of challenges on the basis of sensitivity test

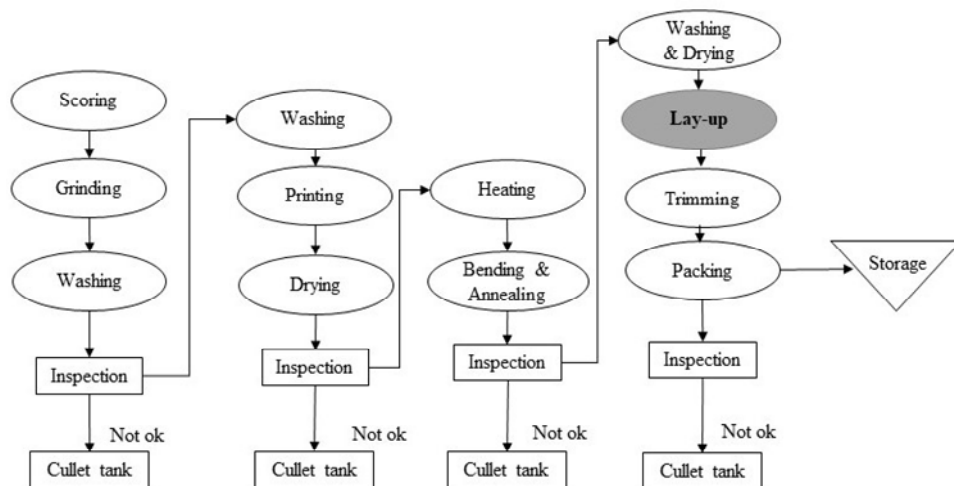
	<i>Original</i>	<i>Test-1</i>	<i>Test-2</i>	<i>Test-3</i>	<i>Test-4</i>
C01	2	2	2	2	2
C02	3	3	3	3	3
C03	11	11	13	10	12
C04	6	6	5	6	6
C05	14	14	14	12	14
C06	5	7	6	5	5
C07	15	15	15	15	15
C08	4	4	4	4	4
C09	10	10	11	11	10
C10	16	16	16	16	16
C11	1	1	1	1	1
C12	7	5	7	7	7
C13	12	12	10	13	11
C14	9	9	9	9	8
C15	8	8	8	8	9
C16	13	13	12	14	13

5 Case study

In Section 4, authors have analysed the challenges of CE implementation by the Fuzzy DEMATEL techniques and observed that there are many challenges in the transformation from linear to CE. Authors have conducted a case study to understand the practical implication of finding and analysis. The present case study has been conducted in an automotive glass manufacturing unit of XYZ Pvt. Ltd. Case organisation has manufacturing facilities in Faridabad, Haryana to produce laminated windshield, backlite, rear quarter glass and door glass, front door glass and vent glass. Case organisation is an ancillary of an automobile company established in 1987 with seven manufacturing units across India. The case organisation is a medium-scale glass production firm with a capacity of 2.5 million sets of glasses annually with a manpower of 1845. The case organisation has 70% market share of glass manufacturing for passenger vehicles, LCV/MHCV goods carrier (trucks), LCV/MHCV goods carrier (buses), OFF highway and metro coaches in India.

Case organisation has an employee strength of 125. All manufactured products are sold to its consumers with the parent company's brand name. The laminated windshield glass (LWG) manufacturing process has been explained in the flow chart shown in Figure 1. Authors have studied the processes of LWG manufacturing and observed excessive water usage. This unit consumes 78 kilo litres of water per day in various processes. The flow diagram of glass manufacturing process is illustrated in Figure 1.

Figure 3 Process flow of LWG manufacturing



In the case organisation, to solve the problem of excessive water usage in LWG manufacturing process, authors conducted a systematic case study using PDCA cycle. Steps of case study are as follows:

Step 1 Identification of problem

While discussing the concepts of CE with internal experts and middle management of case organisation, authors identified the issue of excessive water usage in LWG manufacturing process. To adopt the practices of CE in water

usage, authors identified 51 problems by brainstorming in which all possible areas and processes of water consumption in the plant was listed and categorised as (A) problems that can be solved by departmental expertise, (B) problems that can be solved with the help of other department and (C) problems which can be solved with the help of outside technical experts (Top management permission required). Category B possessed 30 problems. Category A had 20 and category C possessed only one problem. Thus, category B was selected.

Step 2 Selection of problem

Here, the nominal group technique (NGT) was used to select the problems which were numbered greater than 20 in NGT. Thus, two problems were selected:

- 1 machine breakdown reduction due to DM water
- 2 soft water consumption optimisation.

Based on the data collected from January 2022 to July 2022, the average machine breakdown due to DM water shortage was 80 minutes and the soft water consumption in mopping and toilets stations was 17.2-kilo litres per day, for the first and second problems, respectively.

Step 3 Define the problem

The machine stoppage period due to a shortage of DM water is termed the 'DM water breakdown time'. However, the layup machine can be stopped for either reason such as a fault in the water pump supply, uncontrolled outlet parameters, low flow rate of DM water and any other plant breakdown. In the present case study, two layup machines require a continuous DM water supply in the washing zone to wash bend glass with highly pure water to eliminate delamination or water spot. Soft water optimisation refers to the reduction in soft water consumption quantity by checking its requirement and usage corresponding to its application. Soft water is used for pre-processing including grinding and drilling, cooling towers and air washers. Due to low scaling capabilities, it is more suitable where water continuously recalculated within close circuits. It is produced by passing raw water through a softener unit where hardness causes ions to get trapped in resin. Due to the treatment process, it is more costly than raw water. In this case study, the soft water distribution in toilet and mopping activities was targeted, since it was increasing the soft water consumption and daily running cost due to the high generation cost of soft water.

Step 4 Analysis: 4W (what, when, who and where) 2H (how and how much) Analysis was conducted for the defined problems.

Step 5 Identification of causes

There were ten problems identified for machine breakdown due to DM water shortage and based on NGT (having a value greater than 20), the identified causes were:

- 1 DM Water shortage at the machine during mixed bed (MB) 1 and 2 regenerations
- 2 MB 1 and 2 feed pumps are not working correctly
- 3 MB 3 water distributor broke up, frequently.

There were ten problems identified for soft water shortage and based on NGT (having a value greater than 20) the identified cause was unwanted consumption of soft water to toilets and mopping station.

Table 9 4W (what, when, who and where) 2H (how and how much) analysis

<i>4W and 2H sheets</i>					
<i>Meeting agenda</i>	<i>(1)</i>	<i>To decrease layup machine breakdown due to DM water</i>			
	<i>(2)</i>	<i>Soft water consumption</i>			
<i>Members</i>	<i>A, B, C, D, E</i>				
<i>What</i>	<i>When</i>	<i>Who</i>	<i>Where</i>	<i>How</i>	<i>How much</i>
What is the problem?	When It occurs?	Who reported it?	Where problem lies?	How this occurred?	How much it occurs/day?
Machine breakdown due to DM water	During DM water supply	Operator	DM plant	?	3–4 times monthly
Soft water shortage	During soft water supply	Operator	Softener unit	?	2–3 times daily

Step 6 Validation of causes

Gemba visits were used to validate causes for ten identified potential causes.

The details are presented in Table 1 (Sr. no. 1 to 3 is for machine breakdown due to DM water shortage and Sr. no. 4 is for soft water shortage).

Table 10 Gemba visits to validate causes

<i>Sr. no.</i>	<i>Potential cause</i>	<i>Gemba visits</i>
1	DM water shortage at the machine during MB-1 and 2 regenerations	There is no valve to separate both MB outlet water
2	MB 1 and 2 feed pumps are not working properly	New pumps are required since the exiting pumps are obsolete and spare parts were not available
3	MB-3 water distributor broken up frequently	Feed pump start-stop frequently in auto mode due to jerks coming in the distributor
4	Unwanted consumption of soft water to toilets and mopping station	New pumps are required since the exiting pumps are obsolete and spare parts were not available

Steps 7 and 8 Root cause analysis, data analysis and developing solution:

Root cause analysis, data analysis and solution have been discussed in Table 11.

Table 11 Root cause analysis, data analysis and developing solution

<i>Potential causes</i>	<i>Root cause</i>	<i>Counter measure and solution</i>
Sr. no. 1 of Table 10	Design weakness	Provided one separate diaphragm valve in the outlet water line of both pumps so that now we can use one pump for water supply and one for regeneration of standby MB unit.
Sr. no. 2 of Table 10	Pumps were obsolete from the market due to the ageing factor	Replaced old pumps with new energy-efficient pumps and saved 20 KW/day, payback time of these pumps is 2.2 years
Sr. no. 3 of Table 10	Process weakness	Replaced PVC water distributor with SS316 distributor so that now it will sustain jerks.
Sr. no. 4 of Table 10	We were not aware of using soft water in toilets and mopping stations.	Fixed a separate water pipeline to identified points to provide raw water in place of soft water.

Step 9 Foreseeing possible resistance

Foreseeing possible resistance (layup machine breakdown due to DM water shortage).

Step 10 Trial implementation: trial result after completion of all solution. All Trial was found OK and effective with respect to the raised problem.

Table 12 Identified resistance and action taken

<i>S. no.</i>	<i>Identified resistance</i>	<i>Action taken to overcome the resistance</i>
1	Difficulties access while installing a diaphragm valve between both pumps' outlet line due to continuous running of feed pump	We have discussed with production team to plan and provide 60 min stoppage of m/c
2	Difficulties access while standby pump started for regeneration when another feed pump running for DM water supply to m/c	We have discussed with electrical team and they have modified panel as per our requirement so that now we can run one pump in auto for m/c and one pump manual for regeneration
3	Difficulties access while replacing MB-3 water distributor because we need to open MB and requirement of layup-4 stoppage	We have discussed with production team to plan and provide 30 min stoppage of m/c
4	Difficulties access while fixing a new water pipeline throughout the plant	We have discussed with project team to fixing the pipelines from suitable area because we need to fix it during running plant
5	Difficulties access due to long distance pipelines because of water transfer to different locations throughout the plant	We have made require modification in water distribution system in which we have installed new overhead tank at new DOJO building to cover area

Step 11 Regular implementation

After the successful trial result, regular implementation was established for all regeneration practices from August 2022. Colour tagging was applied for all old

and new water pipelines so that anyone can understand what type of water passing through it and use it as applicable for process.

Table 13 Trial implementation

<i>S. no.</i>	<i>Solutions</i>	<i>Month</i>	<i>Result</i>
1	To provide diaphragm valve in MB feed pump outlet line between both pumps	May-22	OK
2	To replace soft water pipelines with new raw water pipelines	May-22	OK
3	New MB feed pump flow and pressure required for layup machine	June-22	OK
4	Replacement of MB-3 water distributor	June-22	OK

Step 12 Follow-up and review

- 1 misuse of soft water
- 2 breakdown due to DM water shortage have been eliminated.

The tangible benefits are as follows:

- a After elimination of lay m/c breakdown due to DM

Glass saving / month = 225

Per glass avg. cost = 2,500 Rupees

Annual saving = $225 * 12 * 2500 = 6,750,000$ Rupees

- b After replacement for old pump with new energy efficient pumps

Per day energy saving = 20 KW unit price for 1 KW = 8 Rupees

Total per day saving = $20 * 8 = 160$ Rupee annual saving

= $160 * 365 = 58,400$ Rupees

- c After replacement of soft water line with raw water line

Soft water cons./ day = 17.2 Kl unit price for soft water = 18 Rs / Kl

Total per day saving = $17.2 * 18 = 309$ Rupees annual saving = $309 * 365$

= 112,785 Rupees

6 Conclusions, implication, and future research directions

Adopting CE concepts is the need of hour. Manufacturing SMEs face many challenges in implementing CE concepts. In this study authors have analysed the challenges of CE implementation in manufacturing organisations. From fuzzy DEMATEL analysis authors observed that challenges like lack of legislation and regulations on CE (C11), systemic nature of CE/fundamental changes required in value chain (C01) and multi & inter disciplinary nature of CE system (C02), In sufficient market demand of CE products (C08) and lack of motivation and participation from consumer/SC partners on CE (C04) are top five causing challenges. These challenges have a high influence on other

challenges. Similarly, authors observed that lack of affordable waste management techniques (C10), non-availability of reverse logistics facilities (C07) and lack of in-house technological capabilities on CE (C05), lack of policies and strategies on CE (C16) and lack of skilled/trained workforce on CE (C13) are top five effect group challenges. It implies that effect group challenges have a high influence from other challenges. To have a more practical viewpoint on implementation of CE practices in manufacturing industry, authors conducted a case study in a laminated wind glass manufacturing organisation. From case study authors observed that finding of fuzzy DEMATEL analysis are found relatable and validated in case study. During case study authors found that challenges like C01, C02, and C05 are found equally challenging in case organisation. To implement practices of CE authors observed that skills and training of workforce on CE, multi and inter disciplinary nature of CE system are highly important to cope with. In case organisations authors reduced the water usage and implemented practices leads to saving of costs. Findings of current study have high implications both for industries and academia. Observation of current study will help manufacturing organisation in planning strategies for implementing CE practices. Academia will get new initiative for learning and working in similar areas of research.

Disclaimer

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Data availability statement

Detailed data will be provided on demand.

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