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Key Enablers for Transitioning to Circular Supply Chains in Electronics: An ISM MICMAC Analysis

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Abstract

The implications of interconnected supply networks on product life, distribution, and production are significant. As businesses transition to a Circular Economy (CE), they embrace circular practices driven by the innovative nature of circular supply chain (CSC) models. However, adopting these models involves overcoming several barriers. This study delves into the factors that facilitate circular processes within businesses. Despite the growing interest, transitioning to CSCs can be challenging due to resource constraints and the complexities of implementation. In the literature review, we identified vital facilitators and further explored them with input from industry professionals. This investigation aims to analyze twelve notable facilitators and depict their interrelationships using ISM MICMAC Analysis. The results highlight the necessity of "Infrastructure for Circular Economy" (ICE), "Regulatory Policies and Government Support" (RPGS), and "Leadership Commitment and Strategies" (LCS) for the establishment of CSCs. These findings will be valuable insights for researchers and managers in the electronics industry pursuing circular processes within their business context.

Keywords: Circular Supply Chain, Electronics Industry, ISM, MICMAC Analysis, Key Enablers, Sustainable Supply Chain, Circular Economy.

1. Introduction

Businesses are reevaluating their supply chain management systems to lessen their environmental impact and protect natural resources [1]. According to Abdulai et al. (2024), Gift et al. (2023), Khandelwal and Barua (2020), and Patwa et al. (2021) [2]–[5], the current economic paradigm is referred to as "take, manufacture, and discard." In this situation, products are used and thrown away after their useful life. Despite being traditional, this model is still in use. There is a consensus among Ghisellini et al. (2018), Khan et al. (2024), and Sudhanshu Joshi and Barve (2023) [6]–[8] that the linear paradigm's contempt for social and environmental considerations is the root cause of waste and ecological problems. Many researchers conclude that Circular Supply Chains (CSCs) offer a superior approach. The Circular Economy (CE) idea brings together social, environmental, and economic issues to ensure a steady flow of raw materials and long-term financial stability. New research [9], [10] shows that CE is becoming increasingly popular as a potential way to solve environmental problems. Numerous researchers and practitioners are in favor of this recognition. CE is becoming significantly important, as shown by these findings. CE aims to improve resource security and recover natural wealth by improving biological and technical aspects. This is possible when organizations proactively embed a circular mindset in each segment of the supply network. This goal will be reached using new economic models and circular design methods. The most important thing is for everyone in the supply chain to think about processes circularly. This method includes recycling, remanufacturing, reusing, fixing, and restoring. CE also encourages using sustainable energy sources like solar, wind, and biomass throughout production [11], [12]. Feldman and coworkers' research from 2024 [13] shows that CE strongly promotes the use of materials that are good for the environment and the recovery of valuable resources. Numerous research studies on CE highlight the critical role of the supply chain. A study by Çıkmak and Kesici (2023) [14] says that CE supply networks create, share, and protect value in a very different way than standard linear supply lines. Suppipat and Hu (2022) [15] highlight that the design attributes of the product and the value it offers are two of the most important things to consider when deciding how things are done. Data from Dev et al. (2020) and Lahane and Kant (2023) [16], [17] show that both forward and backward flows need to be included in CSC applications. Zhang et al. (2021) [18] note that these processes should be integrated from the outset, encompassing the value statement and product design. Integrating forward and backward processes ensures that materials and products are continuously cycled through the supply chain, reducing waste and maximizing resource efficiency. The change

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from linear to CSCs must go smoothly. For loop closing to work as intended, methods and technologies that are made for circularity must be used [19]. Not only would this save money, but it would also make things more efficient. Organizations must deal with problems with the number, quality, and time of product returns to implement CE well. If enterprises do not look at CE from all angles, they might be unable to collect value effectively. CSCs use circular design principles to get companies to work together to get the most value from their products while making the least amount of trash [20], [21]. According to a research study conducted in 2020 by Khandelwal and Barua [2], circular approaches may be challenging to implement. Businesses focus on various "circular initiatives" to implement the CE fully. As discussed by Singh et al. (2023) [22], the acceptance of these initiatives is influenced by several different factors. Examples are implementing reverse transit infrastructure, circular business models, and top management commitment. This article aims to identify and evaluate the most critical variables that assist businesses in developing feasible CSC implementation plans. This article comprises nine sections: an introduction, a review of the literature on circular practices and critical enablers, study objectives, methods, data analysis, discussion and results, research implications, and, lastly, study limits and prospects for future research. The shift to CE practices in supply chains is crucial for addressing environmental sustainability. By adopting CSC principles, businesses aim to enhance resource efficiency, reduce waste, and promote sustainable production. This requires rethinking supply chain management and emphasizing the role of innovations, stakeholder commitment, and integrated strategies for effective implementation[23].

2. Literature review

According to published research, sustainable development and supply chain management experts and practitioners are increasingly interested in CEs. Recently, Patra et al. (2023), Herrador (2024), Mhatre et al. (2023), and Mondal et al. (2023) [21], [24]–[26] have studied various CE components and investigated the topic from multiple objectives. Responsible and effective resource exploitation is promoted by this supply chain management method. CE encourages reusing, recycling, and remanufacturing as alternatives to "take, make, dispose." This project aims to extend resource life and reduce waste. Supply chain practices encourage using durable, repairable products to reduce landfill waste. Energy conservation involves capturing and reusing wasted energy, thus lowering overall energy consumption. CE helps preserve the environment and support the ecosystem using renewable resources like solar and wind electricity. Using several methods, organizations can attain this goal. According to Dwivedi et al. (2023) and Parviziomran and Elliot (2024) [27], [28], these methods reduce trash production significantly. CE replaces "end-of-life" with resource extraction through disassembly, reuse, and recycling at various production, distribution, and consumption stages. This optimizes resource consumption. All these efforts have made The economy more ecologically friendly and sustainable. In their 2017 study, Kirchherr and colleagues [29] examined the CE from macro (cities, regions, and nations), meso (eco-industrial parks), and micro (specific commodities, firms, and customers) perspectives. Sustainable development aims to protect the environment, promote economic growth, and provide social fairness for future generations. Researchers Govindan and Hasanagic[30] conducted a literature review in 2018 to identify the essential concepts, approaches, and elements that impact organization CE acceptance. Lopes de Sousa Jabbour et al. (2019) [31] investigated how firms may implement CE practices. Researchers [32] investigated CSC management challenges in underdeveloped nations. Meanwhile, Demko-Rihter et al. (2023) [33] and Elia et al. (2017) [34] developed methods to assess system circularity and track CE operations. In CE's context, Dubey et al. (2019) [35] developed a method to examine how top management support and external limitations affect supplier relationship management implementation. The authors [36] used questionnaires and a thorough literature study to detect circular practices in their research. In the CE paradigm, Y. Kazancoglu and colleagues (2018) [37] developed a method for assessing supply chain sustainability. Researchers Chiappetta Jabbour and colleagues [38] have developed a mechanism to forecast individual and institutional lifespans till 2020. The final plan considered the roles of stakeholders, success metrics, and concerns about competitors' large-scale business models. India secured its position as the world's third-largest producer of electronic waste, a status underscored by the considerable volume of e-waste it generates annually. This phenomenon is vividly reflected in the analysis of global e-waste production, where the country's contribution is highlighted as both significant and concerning. Moreover, a comprehensive review of the data on this subject, when visualized through a word cloud as shown in Figure 1, emphasizes the scale and the specific types of e-waste predominantly produced. This graphical representation succinctly conveys the critical nature of the issue, underscoring the urgent need for effective management and recycling strategies to mitigate the environmental impact of this growing challenge.

Figure 1. Word Cloud

The sentiment analysis, which is a way of computationally identifying and organizing expressed ideas in the studied research articles about CSCs in electronics, revealed a polarity of 0.0845, implying a hopeful view of electronic sector circular supply networks as mentioned in Figure 2. The sentiment is not strongly positive or negative but leans towards positivity. The subjectivity, measured at 0.4112, suggests a balanced mix of objective and subjective content, providing factual content and personal insights or opinions. Overall, the summary sections provide a fair amount of information while including elements of interpretation and opinions. Given that the summary coversCSCs in electronics, the slight positive polarity might indicate a sense of optimism about the potential benefits and advancements in this area.

3. Drivers for CSCs

Many factors affect the implementation of CE. These include information accessibility, social norms, legal limits, supply chains, organizational structures, and financial systems [30]. These issues make long-term sustainability measures too expensive for enterprises. Businesses that use a CE model maximize resource usage and minimize waste [39], [40]. Renewable energy may help corporate entrepreneurship develop supplier chains. CE may save energy use and waste costs. CE can help a company grow and profit by generating new ideas and optimizing operations [41]. Social forces drove much of this transformation. Since restrictions are tightening and global markets are changing, businesses must rethink their approach. CE models can boost GDP, create jobs, and address social and economic challenges. Government controls on Limits, financial incentives, and subsidies can help mitigate the risks of adopting CE practices. Corporate Environmentalism underpins international standards like ISO 14001, which promote sustainable practices and values.CE and technology are linked. Sustainable technology and information-sharing platforms are being created to increase stakeholder participation and the CE. Supply chain management should reduce raw material use and stabilize resource costs. Product design should maximize value production, distribution, and retention to ensure CSCs. Enterprises can enhance their brand's reputation and competitive advantage by leveraging concepts related to the CE. The foundation of enterprises that adopt a CE model is built upon four essential elements: funding, infrastructure, legislation, and rational thinking. Businesses that actively participate in the CE and strive to minimize waste attract customers and receive favorable ratings. Financial resources are required to support the administration, training, and technological progress of CE. Products operating under a CE framework must effectively appeal to customers and yield a financial gain. Industry 4.0 technologies, such as the Internet of Things (IoT), cyber-physical systems (CPS), cloud computing, and robots, can facilitate the CE by enhancing operational efficiency and offering data-driven insights [42]. Cooperation and information sharing across the whole supply chain are advantageous for small and medium-sized enterprises (SMEs). Numerous small and medium-sized firms (SMEs) face obstacles such as scarce resources, constrained technology, and fierce competition. SMEs can apply CE practices by complying with legislative regulations, cooperating with supply chain partners, and offering incentives to customers. The main objective here is to ensure that CE features are appropriately aligned. Understanding and implementing these elements is crucial to achieve sustainable economic growth and fully utilize the advantages of the CE. Table 1 presents the list of critical enablers for CSC adoption.

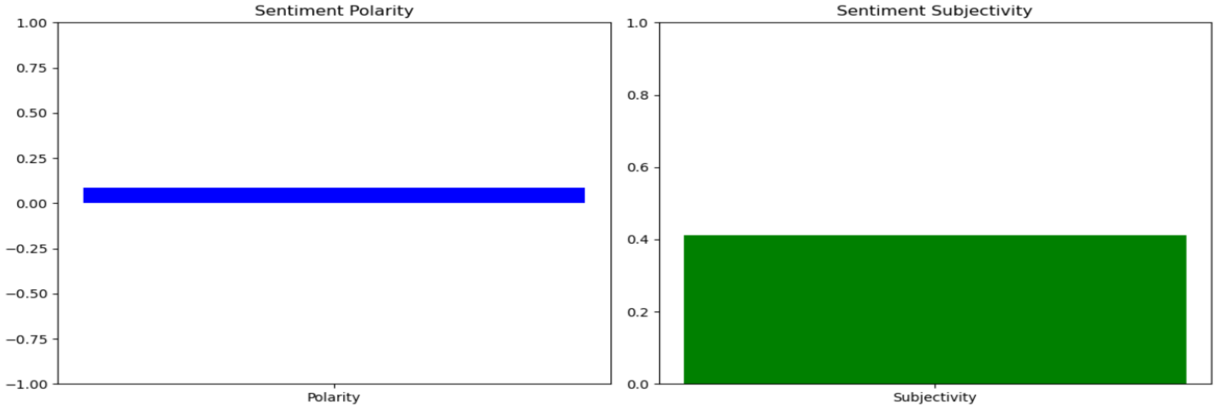

Figure 2. Sentiment Analysis- Polarity and Subjectivity

Table 1. List of Enablers

No.	Enabler	Description	References
1	Leadership Commitment and Strategies (LCS)	The senior executives are leading and implementing strategies to strengthen the CE.	[43]
2	Workforce Expertise and Skills (WES)	The workforce's proficiency and proficiency in CE methodologies and protocols.	[44]
3	Regulatory Policies and Government Support (RPGS)	The government encourages businesses to use CE ways and even encourages some of them to do so.	[45]
4	Consumer Knowledge and Demand (CKD)	The extent to which consumers are informed about and seek out CE products.	[46]
5	Innovative Materials and R&D Access (IMRDA)	CE technologies demand cutting-edge materials and research facilities.	[47]
6	Stakeholder Influence and Awareness (SIA)	The advocacy for a CE requires the knowledge and influence of various stakeholders.	[48][49]
7	Financial Incentives (FI)	Participating in a CE can lead to financial benefits and incentives.	[50]
8	Collaboration and Coordination in Supply Chain (CCSC)	To promote actions related to the CE, whether or not partners in the supply chain effectively collaborate and coordinate.	[51][52]
9	Infrastructure for Circular Economy (ICE)	There is a physical and technical infrastructure in place that can implement the principles of a CE.	[53]
10	Environmental Focus of Organizations (EFO)	The primary objectives of a firm are to achieve sustainability and promote environmental friendliness.	[54][55]
11	Technological Tools for Innovation (TTI)	Accessible technology is utilized to enhance CE activities.	[56][57]
12	Potential Business Opportunities (PBO)	How the CE may create new domestic and international economic opportunities.	[58][59]

4. Research methodology and model development using ISM

Researchers have used various Multi-Criteria Decision-Making (MCDM) techniques for effective decision-making[60]–[65]. In this paper, we apply Interpretive Structural Modelling (ISM) to identify and structure relationships among key factors, revealing their hierarchical interdependencies and supporting better decision-making. A popular scientific method, ISM, incorporates multiple components to create a complete and integrated variables model [66]. Researchers apply the ISM approach to assess the strength and direction of connected components. Academics extensively employ ISM to examine the relationships between the numerous elements of critical factors, according to many studies. Authors Kannan and Haq (2007) [67] iterate that ISM is exemplary in showing the interdependencies of the researched phenomena. In this study, ISM is employed to analyze the interrelations among the key enablers for transitioning to Circular Supply Chains (CSC) in the electronics industry. The next sections will explain the steps involved in developing the ISM model, starting from data collection to validation.

Data Collection: To gather qualitative data, detailed semi-structured interviews were conducted with experts from various segments of the electronics industry, including manufacturing, policy-making, and research institutes. Given the complexity of CSC practices, a purposive sampling method was employed to ensure that the participants had significant experience and expertise in the field. Interviews lasted 60 to 90 minutes and were conducted in person or via video conferencing. This approach provided rich insights into the practical challenges and opportunities for transitioning to CSC, which were crucial for developing a robust ISM model. Audio recordings of the interviews were transcribed verbatim for analysis.

Data Analysis: Thematic analysis was employed to analyze the interview data. Initial codes were generated, and themes were identified through an iterative reading and re-reading of the transcripts. This thematic analysis laid the foundation for determining the key enablers for CSC transition. By categorizing and mapping these themes, the ISM methodology was applied to examine the interdependencies between the enablers. In this way, the qualitative data directly informed the construction of the ISM model, ensuring that the final model reflects both the theoretical framework and expert opinion.

5. Delphi Method for Validation

To ensure the validity and reliability of the identified enablers and their interrelationships, the Delphi method was incorporated into the research process[68]. The Delphi method is a structured, multi-stage process that gathers expert feedback through multiple rounds of questioning, aiming to achieve a consensus on a specific issue. In this study, two rounds of the Delphi method were conducted with the same group of six experts, providing them with an opportunity to refine and validate the findings derived from the ISM analysis.

- **First Round:**

In the first round of the Delphi process, the initial list of key enablers, derived from thematic analysis and ISM modeling, was presented to the experts. They were asked to evaluate the relevance, importance, and clarity of each enabler and suggest modifications or additional enablers if necessary. The feedback gathered in this round was instrumental in refining the model, as it allowed for the identification of any gaps or discrepancies in the initial ISM framework.

- **Second Round:**

After incorporating the feedback from the first round, a revised version of the ISM model was presented to the same group of experts in the second round. This round aimed to confirm the modifications and achieve consensus on the final list of enablers and their relationships. At this stage, experts provided further insights to fine-tune the interdependencies among the enablers, ensuring that the model reflected a comprehensive understanding of the CSC transition process.

The Delphi process was key to validating the ISM model, as it provided a systematic approach to refining the constructs based on expert opinion.By ensuring multiple rounds of review, the final model achieved a high level of credibility and consensus among industry professionals.

Figure 3 shows the ISM model-generating procedure.

The table 2 below lists business experts who have consented to the study and offered feedback. The study included more experts representing a diverse cross-section of the industry and other stakeholders to enhance the robustness of the findings. Five highly qualified team members are from well-known Indian electronics manicuring organizations. One scholar from a well-known Indian research institute worked on this project. This person has worked with several different MCDM approaches. Further study concentrated on the application of ISM methodology.

Table 2. Expert's Profile

Expert	Position	Experience	Type of industry
1	Operations Manager	12	Electronics
2	Deputy Manager (SCM)	16	Automotive
3	Research Scholar (Circular Economy domain)	4.5	Research Institute
4	Senior Design Engineer	8.5	Electronics
5	Lead Engineer (Projects)	8	Automotive
6	Production Engineer	5.5	Electronics

The structural self-interaction matrix (SSIM) shown in Table 3 below depicts the contextual link among the twelve critical enablers investigated in this study based on comments from experts in the field. The four symbols show the enabling factors' correlation directions. Factor i affects factor *j* but not the other way around, represented by V. An equation or mathematical statement is expressed by the expression (i→ j). If a one-way link exists betweenvariables j and i, no mutual consequences will exist. The phrasing "(*j*→i)" applies denoted by A. Whenever variables i and j interact and affect other variables (i→ j and *j*→i), it is denoted by X. Symbol O is used when factors j and i have no relationship and do not affect each other.

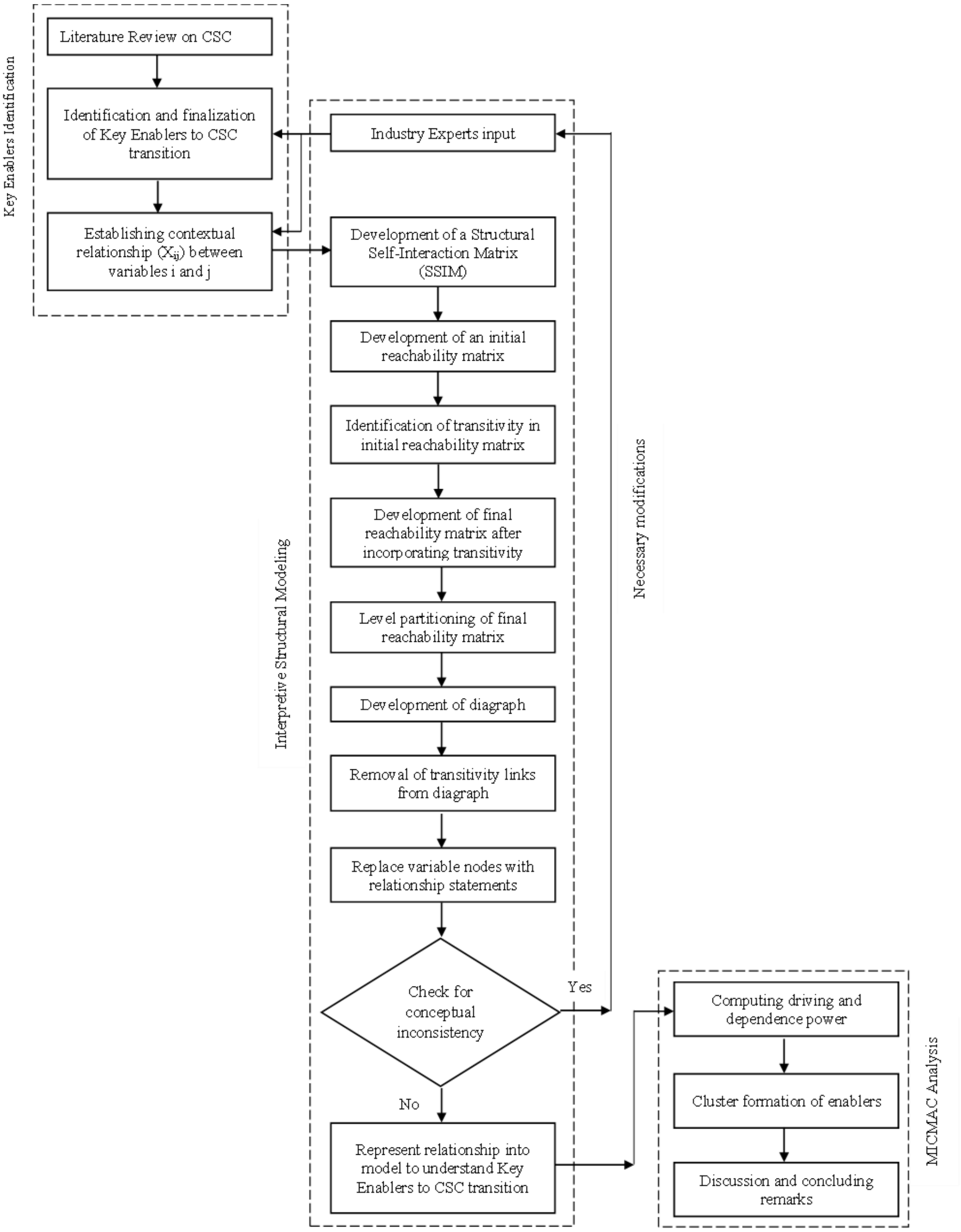

Figure 3. ISM MICMAC procedure[69]

Table 3. Structural self-interaction matrix (SSIM)

CRFs	SIA	TTI	EFO	ICE	CCSC	FI	PBO	IMRDA	WES	RPGS	CKD	LCS
LCS	V	V	V	V	V	V	V	V	O	A	O	-
CKD	A	V	X	A	X	V	A	X	V	A	-	
RPGS	V	V	V	X	V	V	V	V	V	-		
WES	A	O	A	A	A	A	A	A	-			
IMRDA	X	O	A	A	V	V	A	-				
PBO	V	O	V	A	V	V	-					
FI	A	A	A	A	A	-						
CCSC	A	X	V	A	-							
ICE	V	V	V	-								
EFO	X	V	-									
TTI	V	-										
SIA	-											

The reachability matrix in Table 4 was formulated using SSIM. Table 5 improved it by analyzing variable changes as per transitivity. After this stage of the ISM process, the SSIM becomes a binary matrix. Guidelines were used to turn SSIM into a fundamental reachability matrix. When the SSIM point (i→ j) is V, the first reachability matrix item for (i→ j) is recorded as 1, whereas the entry for (*j*→i) is preserved as 0. If the SSIM is (i→ j), it is reported as A. In the initial reachability matrix, item (i→ j) is assigned a value of 0, and (*j*→i) is modified to 1. The (i→ j) SSIM location will be allocated X, and the initial reachability matrix entries for (*j*→i) and (i→ j) will be preserved with 1. If the SSIM point corresponding to (i→ j) is O, the values of (i→ j) and (*j*→i) in the initial reachability matrix will be set to zero. If " i " is linked to "j" and "j" is related to "k," then "i" is always linked to "k." This is "transitivity." The final reachability matrix is created when transitivity is introduced.

Once transitivity is added to the ultimate reachability matrix, the drive power (DrP) and dependability power (DeP) are found by adding the binary numbers in the rows and columns of the matrix. DrP is looked at in descending order to rank the critical factors under study. These DrP and DeP are put in the next step of the ISM model, which is level splitting. The final reachability matrix is examined to find the predecessor set and enabling factors reachability [70]. The reachability set (R_i) for a particular enabler comprises the factor itself and other factors that it may impact, whereas the antecedent set (A_i) contains the factor itself and other elements that may influence it. The next step is to find the overlap set, which is shown by IS = R_i ∩ A_i, by looking for numbers that are similar in both sets. The ISM model's top level was given the number 1 to ensure that the reachability and intersection sets were equal. Once level 1 was found, the element was taken out of the equation for further net steps, and the process was repeated for each of the other components. Refer to tables 6–10.

Table 4. Initial Reachability Matrix

CRFs	LCS	CKD	RPGS	WES	IMRDA	PBO	FI	CCSC	ICE	EFO	TTI	SIA
LCS	1	0	0	0	1	1	1	1	1	1	1	1
CKD	0	1	0	1	1	0	1	1	0	1	1	0
RPGS	1	1	1	1	1	1	1	1	1	1	1	1
WES	0	0	0	1	0	0	0	0	0	0	0	0
IMRDA	0	1	0	1	1	0	1	1	0	0	0	1
PBO	0	1	0	1	1	1	1	1	0	1	0	1
FI	0	0	0	1	0	0	1	0	0	0	0	0
CCSC	0	1	0	1	0	0	1	1	0	1	1	0
ICE	0	1	1	1	1	1	1	1	1	1	1	1
EFO	0	1	0	1	1	0	1	0	0	1	1	1
TTI	0	0	0	0	0	0	1	1	0	0	1	1
SIA	0	1	0	1	1	0	1	1	0	1	0	1

Table 5. Final Reachability Matrix

CRFs	LCS	CKD	RPGS	WES	IMRDA	PBO	FI	CCSC	ICE	EFO	TTI	SIA
LCS	1	1*	1*	1*	1	1	1	1	1	1	1	1
CKD	0	1	0	1	1	0	1	1	0	1	1	1*
RPGS	1	1	1	1	1	1	1	1	1	1	1	1
WES	0	0	0	1	0	0	0	0	0	0	0	0
IMRDA	0	1	0	1	1	0	1	1	0	1*	1*	1
PBO	0	1	0	1	1	1	1	1	0	1	1*	1
FI	0	0	0	1	0	0	1	0	0	0	0	0
CCSC	0	1	0	1	1*	0	1	1	0	1	1	1*
ICE	1*	1	1	1	1	1	1	1	1	1	1	1
EFO	0	1	0	1	1	0	1	1*	0	1	1	1
TTI	0	1*	0	1*	1*	0	1	1	0	1*	1	1
SIA	0	1	0	1	1	0	1	1	0	1	1*	1

Note: * Values after incorporating the transitivity

Table 6. Level partition—Iteration I

Enablers	**Reachability Set (R_i)**	**Antecedent Set (A_i)**	**Intersection Set IS=($R_i \cap A_i$)**	**Level**
LCS	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 3, 9	1, 3, 9	
CKD	2, 4, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	
RPGS	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 3, 9	1, 3, 9	
WES	4	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	4	1
IMRDA	2, 4, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	
PBO	2, 4, 5, 6, 7, 8, 10, 11, 12	1, 3, 6, 9	6	
FI	4, 7	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12	7	
CCSC	2, 4, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	
ICE	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	1, 3, 9	1, 3, 9	
EFO	2, 4, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	
TTI	2, 4, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	
SIA	2, 4, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	

Table 7. Level partition—Iteration II

Enablers	**Reachability Set (R_i)**	**Antecedent Set (A_i)**	**Intersection Set $IS=(R_i \cap A_i)$**	**Level**
LCS	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12	1, 3, 9	1, 3, 9	
CKD	2, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	
RPGS	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12	1, 3, 9	1, 3, 9	
WES		1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12		1
IMRDA	2, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	
PBO	2, 5, 6, 7, 8, 10, 11, 12	1, 3, 6, 9	6	
FI	7	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12	7	2
CCSC	2, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	
ICE	1, 2, 3, 5, 6, 7, 8, 9, 10, 11, 12	1, 3, 9	1, 3, 9	
EFO	2, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	
TTI	2, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	
SIA	2, 5, 7, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	

Table 8. Level partition—Iteration III

Enablers	**Reachability Set (R_i)**	**Antecedent Set (A_i)**	**Intersection Set $IS=(R_i \cap A_i)$**	**Level**
LCS	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	1, 3, 9	1, 3, 9	
CKD	2, 5, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	3
RPGS	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	1, 3, 9	1, 3, 9	
WES		1, 2, 3, 5, 6, 8, 9, 10, 11, 12		1
IMRDA	2, 5, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	3
PBO	2, 5, 6, 8, 10, 11, 12	1, 3, 6, 9	6	
FI		1, 2, 3, 5, 6, 8, 9, 10, 11, 12		2
CCSC	2, 5, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	3
ICE	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	1, 3, 9	1, 3, 9	
EFO	2, 5, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	3
TTI	2, 5, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	3
SIA	2, 5, 8, 10, 11, 12	1, 2, 3, 5, 6, 8, 9, 10, 11, 12	2, 5, 8, 10, 11, 12	3

Table 9. Level partition—Iteration IV

Enablers	**Reachability Set (R_i)**	**Antecedent Set (A_i)**	**Intersection Set $IS=(R_i \cap A_i)$**	**Level**
LCS	1, 3, 6, 9	1, 3, 9	1, 3, 9	
CKD		1, 3, 6, 9		3
RPGS	1, 3, 6, 9	1, 3, 9	1, 3, 9	
WES		1, 3, 6, 9		1
IMRDA		1, 3, 6, 9		3
PBO	6	1, 3, 6, 9	6	4
FI		1, 3, 6, 9		2
CCSC		1, 3, 6, 9		3
ICE	1, 3, 6, 9	1, 3, 9	1, 3, 9	
EFO		1, 3, 6, 9		3
TTI		1, 3, 6, 9		3
SIA		1, 3, 6, 9		3

Table 10. Level partition—Iteration V

Enablers	**Reachability Set (R_i)**	**Antecedent Set (A_i)**	**Intersection Set $IS=(R_i \cap A_i)$**	**Level**
LCS	1, 3, 9	1, 3, 9	1, 3, 9	5
CKD		1, 3, 9		3
RPGS	1, 3, 9	1, 3, 9	1, 3, 9	5
WES		1, 3, 9		1
IMRDA		1, 3, 9		3
PBO		1, 3, 9		4
FI		1, 3, 9		2
CCSC		1, 3, 9		3
ICE	1, 3, 9	1, 3, 9	1, 3, 9	5
EFO		1, 3, 9		3
TTI		1, 3, 9		3
SIA		1, 3, 9		3

Table 11 shows a conical matrix of all crucial components at the same level.

Table 11. Conical Matrix

Variables	WES	FI	CKD	IMRDA	CCSC	EFO	TTI	SIA	PBO	LCS	RPGS	ICE	Dependence Power	Level
WES	1	0	0	0	0	0	0	0	0	0	0	0	1	1
FI	1	1	0	0	0	0	0	0	0	0	0	0	2	2
CKD	0	1	1	1	1	1	1	1*	0	0	0	0	8	3
IMRDA	0	1	1	1	1	1*	1*	1	0	0	0	0	8	3
CCSC	0	1	1	1*	1	1	1	1*	0	0	0	0	8	3
EFO	0	1	1	1	1*	1	1	1	0	0	0	0	8	3
TTI	0	1	1*	1*	1	1*	1	1	0	0	0	0	8	3
SIA	0	1	1	1	1	1	1*	1	0	0	0	0	8	3
PBO	0	0	1	1	1	1	1*	1	1	0	0	0	9	4
LCS	0	0	0	0	0	0	0	0	1	1	1*	1	12	5
RPGS	0	0	0	0	0	0	0	0	1	1	1	1	12	5
ICE	0	0	0	0	0	0	0	0	1	1*	1	1	12	5
Dependence Power	12	11	10	10	10	10	10	10	4	3	3	3		
Level	1	2	3	3	3	3	3	3	4	5	5	5		

The construction of an ISM model from a conical matrix is accomplished through arrows and nodes. The diagram and the ISM model are shown in Figures 4 and 5, respectively. A hierarchical model of key enablers is shown here, along with visualizations of the links between the various enablers and the CSC transition.

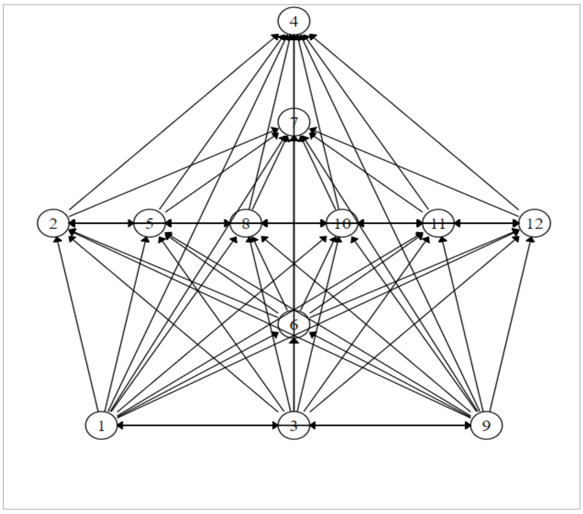

Figure 4. ISM Digraph

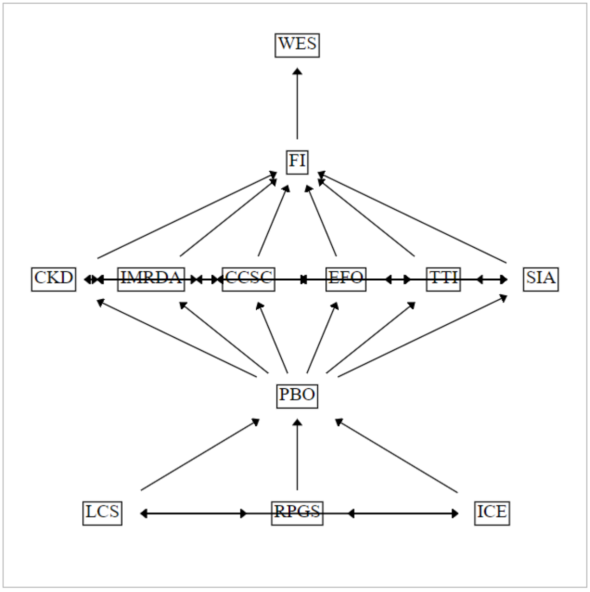

Figure 5. Final ISM model

6. Critical Factors Classification using MICMAC Analysis

Many researchers use MICMAC analysis, a matrix of cross-impact multiplications applied to classification, to determine what factors drive and depend on critical variables under investigation. Using the DrP and DeP numbers of each key enabler, figure 6 shows that four groups were made: autonomous, dependent, linking, and independent.

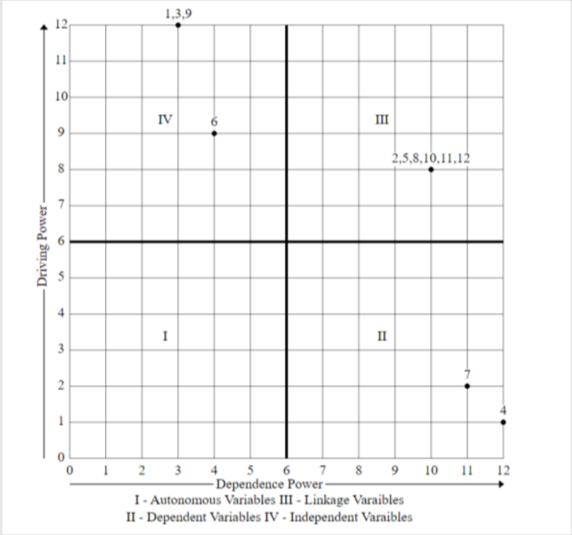

Figure 6. Critical factors classification using MICMAC analysis

7. Discussion

The electronics sector is rapidly evolving towards sustainability through the adoption of CSCs. This transition, however, is influenced by a complex array of enablers, each playing a crucial role in the process. This research identifies and analyzes twelve key enablers, structuring them into a hierarchical model using the ISM methodology. At the foundational level of the ISM model, we find enablers such as "Leadership Commitment and Strategies (LCS)," "Regulatory Policies and Government Support (RPGS)," and "Infrastructure for Circular Economy (ICE)." These enablers affect the entire system because of their low reliance power and tremendous driving power. Properly implementing these enablers is critical to the functioning of the CSCs. Any changes or upgrades made to these places will impact the supply chain. CKD stands for "Consumer Knowledge and Demand," IMRDA stands for "Innovative Materials and R&D Access," "CCSC" stands for "Collaboration and Coordination in Supply Chain," EFO represents the "Environmental Focus of Organizations," TTI stands for "Technological Tools for Innovation," whereas SIA for "Stakeholder Influence and Awareness." As we rise, these facilitators serve as both reactors and influencers. These enablers' driving and dependent strengths will impact and influence changes in other areas. Because these intermediary facilitators are interdependent, managing them is critical; integrated solutions considering supply chain consequences are required. The ranking is topped by "Workforce Expertise and Skills (WES)" and "Financial Incentives (FI)." The enablers have low driving power but high dependency power. They're at the top. Other model elements have a substantial impact on these facilitators. Enablers must be proficient at the fundamental and intermediate levels to do these duties. Given this reliance, a solid foundation that can sustain and nurture these high-level components is essential. The MICMAC analysis helps us understand enablers by categorizing them based on their driving and reliance powers. This study demonstrates that essential enablers are critical, and mid-level elements are interconnected. This research also identifies specific strategic objectives. Understanding the hierarchical structure and enabling linkages gives supply chain managers a wealth of knowledge. Managers can develop more successful and comprehensive plans by focusing on core enablers and recognizing mid-level enabler dynamics. These solutions will improve the efficiency and circularity of the industrial electronics supply chain, thereby contributing to achieving sustainability goals. This study discovered that CSC management necessitates nuance. Practitioners must address each enabler's features and responsibilities in the ISM model to ensure resilient and sustainable supply chain processes. This approach enables a more direct and precise way of addressing the challenging shift towards circularity.

8. Managerial implications

This study on electrical device supply chain circularity has substantial managerial implications. The management of supply chains involves a large number of facilitators. Parties, organizational structure, administration, judicial effectiveness, client familiarity, and specialist resources are all factors that might impact a case's outcome. Managers who thoroughly understand the project's components and structure can make more environmentally beneficial decisions. Managers can concentrate on crucial areas to overcome challenges and capture opportunities when they have strategic support. ISM initially presented the strategy paradigm. This all-encompassing technique establishes reliable circular supply networks and aids in formulating judgments on circularity over the long term. These discoveries will motivate scholars and organizations to investigate comparable frameworks in other domains, improving global sustainability.

9. Conclusion

This study determined the critical success factors for circularizing supply chains for electrical devices. This study revealed a relationship between these facilitators and a hierarchical model. This strategy improves supply chain management and minimizes interruptions. Twelve key enablers were identified after a thorough review of the literature and talks with subject matter experts. The use of the ISM approach resulted in the creation a hierarchical model that improves our comprehension of the interactions between various components by highlighting their relative influence. The MICMAC research identified numerous facilitators based on their driving and dependent power, providing insight into their benefits and drawbacks. This rigorous technique helps with strategic decision-making and implementing a circular electronics supply chain.

Limitations and future scope:

There are constraints to this research. Firstly, the generalizability of the findings is limited due to the specific number of experts and factors examined. The results may not apply to every field or geographical location. A broader, more diverse sample may reveal more complex issues and critical factors. Additionally, the study focused solely on the Indian electrical goods industry. Future research should examine other locations and sectors to gather more comprehensive data. Future research should also explore conducting similar studies in different regions and industries to compare and contrast the key enablers of CSCs, expanding the sample size and diversity of industry professionals involved in the research to enhance the robustness and applicability of the findings, investigating the interaction of critical components in specific sectors through advanced modeling techniques to derive strategies for improved performance and decision-making, evaluating the impact of specific circular practices on company growth and competitiveness to provide actionable insights for businesses aiming to transition to a CE, and incorporating longitudinal studies to observe the evolution and long-term effects of implementing CSC practices. By addressing these areas, future research can build on the findings of this study, providing a more comprehensive understanding of the key enablers for transitioning to CSCs in electronics and other sectors.

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