Circular Economy Adoption in the Electrical and Electronic Equipment Sector: A Framework for Firm-level Enablers and Levers

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Sandeep Sehgal

(FPMN2003)

Under the Guidance of

Dr. Shivani Bali

Dr. Ritika Gugnani

JAIPURIA INSTITUTE OF MANAGEMENT NOIDA, INDIA

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JAIPURIA INSTITUTE OF MANAGEMENT

THESIS CERTIFICATE

The Thesis entitled **"Circular Economy Adoption in the Electrical and Electronic Equipment Sector: A Framework for Firm-level Enablers and Levers"** submitted to the Jaipuria Institute of Management, Noida, in partial fulfilment of the requirements of the Fellow Program in Management, is based on my original work carried out under the guidance of Dr. Shivani Bali and Dr. Ritika Gugnani from July 2021 to December 2025.

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Date: 20-12-2025

(Signature)

Name of Research Scholar: Sandeep Sehgal

Enrollment No.: FPMN2003

Countersigned by Research Supervisor and Co-supervisor

Supervisor Name: Dr. Shivani Bali

Designation: Professor & Area Chair – Business Analytics

Jaipuria Institute of Management, Noida, Uttar Pradesh, India

Co-Supervisor Name: Dr. Ritika Gugnani

Designation: Professor & Dean Academics

Jaipuria Institute of Management, Noida, Uttar Pradesh, India

CERTIFICATE FROM GUIDE

It is certified that the work contained in the thesis titled **"Circular Economy Adoption in the Electrical and Electronic Equipment Sector: A Framework for Firm-level Enablers and Levers"**, submitted by **SANDEEP SEHGAL** (Enrolment No. FPMN2003) has been carried out under my/our supervision at Jaipuria Institute of Management, Noida, India, and that this work has not been submitted elsewhere for a degree.

Signature in Full of the Supervisor:

Shivani

(Signature)

Supervisor Name: Dr. Shivani Bali
Designation: Professor & Area Chair – Business Analytics
Jaipuria Institute of Management, Noida, Uttar Pradesh, India

Date: 20-12-2025

CERTIFICATE FROM CO-GUIDE

It is certified that the work contained in the thesis titled **"Circular Economy Adoption in the Electrical and Electronic Equipment Sector: A Framework for Firm-level Enablers and Levers"**, submitted by **SANDEEP SEHGAL** (Enrolment No. FPMN2003) has been carried out under my/our supervision at Jaipuria Institute of Management, Noida, India, and that this work has not been submitted elsewhere for a degree.

Signature in Full of the Co-Supervisor:

(Signature)

Co-Supervisor Name: Dr. Ritika Gugnani
Designation: Professor & Dean Academics
Jaipuria Institute of Management, Noida, Uttar Pradesh, India

Date: 20-12-2025

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"There is no happiness except in the realization that we have accomplished something"

Henry Ford

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Sandeep Sehgal
Enrollment No.: FPMN2003
Jaipuria Institute of Management, Noida

EXECUTIVE SUMMARY

Introduction

The progression in technology, revolution in designing new products, and convincing market strategies attracts customers to purchase electronic items frequently. This has led to an exponential rise of EEE waste (Prakash & Barua, 2016a). India ranks third in electronic-waste production in the world after China & USA. In the year 2022, India generated approximately 1.6 million tons of e-waste and is projected to reach 29 million tons by 2030 (Markets & Data, 2023). Hence, this raises critical sustainability and supply chain concerns, indicates a pressing need to implement circular economy (CE) strategies and involve all stakeholders in the electronic value chain (Bhattacharjee et al., 2023). In India, the large proportion of e-waste, is handled by unorganized and unregulated sector (Chowdhary V., 2025). They are not fully capable of effective extraction methods, hence lowering the recovery rates of high value parts. Secondly, the inadequate access to proper infrastructure for proper processing and recovery of e-waste, is hindering the development of large-scale e-waste sustainable CE value chain. Third, the country is grappling with a technology boom and a rise in electronic product consumption, generating significantly large volumes of e-waste (Chowdhary V., 2025).

To address the above challenges, the country's regulations and policy frameworks are evolving to encourage recycling enterprises. The key founding policy includes e-waste management rules, that introduced a mechanism such as extended producer responsibility (EPR) and requires an online registration and reporting for Electrical and Electronic Equipment (EEE) manufacturing companies (Bhadra & Mishra, 2021). Despite being the progressive framework in place, there still remain barriers in implementation and enforcement. The government continuous interventions are underway to provide financial incentives, and regulatory frameworks to businesses to encourage resource efficiency, eco-design and compliance with environmental and health standards (Bhattacharjee et al., 2023; Buttke et al., 2024). The electronic industries' shift towards CE adoption is nascent in developing economies (Bhattacharjee et al., 2023). However, this shift will contribute towards alignment with '*United Nations Sustainable Development Goals'*(SDGs). CE implementation in EEE industry brings environmental, social and economic prosperity (MacArthur, 2023).

Research Gaps

The research aims at addressing many critical gaps. First, it has been observed that the existing research in the area of CE adoption is fragmented. Most of the studies focused on generalized insights into the manufacturing industry (Coluccia et al., 2024; Masi et al., 2024; Vidal et al., 2024). Considering the potential of CE transition in the EEE sector, this is a notable gap to fill. Also, the amount of e-waste generation, regulatory intensity and proper disposal of EOL products, a sector specific investigation of CE adoption at a firm-level is essential.

Second, several studies in the existing literature have examined factors, enablers and barriers of CE transition (Khan et al., 2022; H. Lu et al., 2024), however, the literature has not consistently distinguished between the enablers and levers. The contextual factors, that is, enablers facilitate CE adoption, while the levers represent the actionable practices firms can deploy. While past studies have analysed multiple enablers, the role of levers has been comparatively neglected, and the interdependence amongst them, have received very less scholarly attention. This lack of conceptual clarity regarding importance and interdependence among enablers and levers, restricts the ability of the firms to effectively plan CE strategies.

Evolving paradigms such as Industry 5.0, innovation in product design, servitized business models, and sustainability integration have received little academic attention in the context of Indian EEE sector (Bressanelli et al., 2021; Santiago et al., 2025; Svensson-Hoglund et al., 2021a). Since, these paradigms plays an important role to sector's transition towards circularity, their incorporation into the existing framework remains underexplored, which is a notable research gap which this study will consider.

Lastly, the frameworks in existing literature are often limited to single decision-making techniques, sometimes fail to capture the complexity of CE adoption. while the traditional approaches are useful in providing insights, but they are inadequate for addressing multidimensional relationships amongst enablers and levers of CE adoption. A hybrid multi-criteria decision making (MCDM) framework involving ‘Delphi method’ and ‘Grey DEMATEL’ is proposed in this study. The proposed framework, remain underutilized, despite their potential to capture interdependencies and systematically rank the alternatives.

To conclude, the literature revels that while CE transition has gained momentum in the research community, there still remains critical gaps in sector-specific analysis, clarity between enablers and levers, and methodological rigor. Hence, the thesis seeks to bridge these gaps by developing a comprehensive framework for accessing the enablers and levers of CE transition in the EEE sector.

Research Methodology

First, a systematic literature review (SLR) was meticulously undertaken in Chapter two of the thesis. The review involves gaining an in-depth understanding of firm-level CE adoption, and has led to the identification of the research gaps and the motivation for conducting this research, which is, identification and analysis of critical enablers and levers of CE transition in the EEE sector. To address this a hybrid multi-criteria decision-making framework based on Delphi method and Grey DEMATEL technique is proposed.

A Delphi-method was adopted where the industry experts were engaged to validate and finalize the critical enablers and levers. Further, Grey DEMATEL method was applied to examine the priority and the cause-and-effect relationships among the identified enablers and levers. This multi-phase approach ensured both theoretical rigor and practical relevance in facilitating a strategic and actionable transition toward achieving resilient and sustainable supply chains for the future through the adoption of circular practices.

Data Analysis & Discussions

The study aims at identifying the enablers and levers of CE adoption specific to EEE sector. The top three critical factors of CE transition are Industry 5.0, circular product design, and consumer & society, followed by circular supply chain and government intervention. The findings also revealed that government intervention and Industry 5.0 are the two top cause group enablers of CE adoption, whereas the two prominent effect group levers are financial investment followed by competence & skill set building of the workforce. The findings bring important implications for practitioners and policymakers, offering them the roadmap to prioritize the enablers and levers based on their rank and association. Hence, the proposed framework guides them in creating a strategic plan for effective CE transition to achieve the resilient supply chains of the future.

Conclusion

This thesis proposed a hybrid methodological decision-making framework for advancing towards CE adoption in the Indian EEE sector. The exponential rise in e-waste poses a significant challenge for its management. Hence, the EEE sector is recognized as a high-priority sector for CE transition. The key objective of CE transition is to deliver economic, environmental and social benefit through the circular flow of resources. Integrating CE practices into business has a substantial impact on the entire value chain by reducing waste production, enhancing resource efficiency, and promoting sustainability-focused collaboration among stakeholders. This thesis has tried to make sincere efforts in applying multi-criteria decision-making techniques to the area of circular economy adoption through the lens of enablers and levers. This research provides valuable information for academician, practitioners and policy makers.

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LIST OF ABBREVIATIONS

AHP	:	Analytic Hierarchy Process
ANP	:	Analytic Network Process
BGIR	:	Building a ‘Green Image’ Reputation
C	:	Competition
CBM	:	Circular Business Models
CE	:	Circular Economy
CEBM	:	Circular Economy Business Models
CEBMI	:	Circular Economy Business Models Innovations
CPD	:	Circular Product Design
CS	:	Consumer & Society
CSB	:	Competence & Skill-set Building
CSC	:	Circular Supply Chain
DEMATEL	:	Decision-making Trial and Evaluation Laboratory
EEE	:	Electrical and Electronic Equipment
EOL	:	End-of-Life
E-waste	:	Electronic-Waste
E-WOM	:	Electronic – Word of Mouth
FI	:	Financial Investment
GI	:	Government Intervention
I4.0	:	Industry 4.0
I5.0	:	Industry 5.0
IN	:	Innovation
IoT	:	Internet of Things
IRM	:	Initial Relation Matrix
ISM	:	Interpretive Structural Modelling
LLC	:	Long Life Cycle
MCDM	:	Multi-Criteria Decision Making

PCB	:	Printed Circuit Boards
PSS	:	Product Service System
RPRM	:	Rising Prices of Raw Materials
RQ	:	Research Question
SBM	:	Servitized Business Models
SC	:	Supply Chain
SCP	:	Sustainable and Cleaner Production
SD	:	System Dynamics
SDG	:	Sustainable Development Goals
SLR	:	Systematic Literature Review
TPB	:	Theory of Planned Behavior
TISM	:	Total Interpretive Structural Modelling
UEEE	:	Used Electrical and Electronic Equipment
UN	:	United Nations
WEEE	:	Waste Electrical and Electronic Equipment
WPCB	:	Waste Printed Circuit Boards
EPR	:	Extended Producer Responsibility
SLR	:	Systematic Literature Review

CHAPTER – 1

INTRODUCTION

This chapter aims at introducing the thesis by outlining the rationale for conducting the research study on the topic "Circular Economy Adoption in the Electrical and Electronic Equipment Sector: A Framework for Firm-level Enablers and Levers". The chapter is organized into different sections: circular economy (CE) adoption in EEE sector, the problem statement, research gaps, research objectives & questions, finally, the scope and contribution of the study. These sections lay a foundation of the research study and provide a brief overview of the entire research work. Finally, the last section presents a brief overview of the thesis's overall structure spread across the different chapters. For this research study, the author has used the two terms 'CE transition' and 'CE adoption' interchangeably, both conveying the same meaning as transition is possible only with the adoption of CE practices.

1.1 Circular Economy

Since commodity producers currently face severe limitations owing to a shortage of natural resources and unmatched ecosystem depletion, present economic situations demand a fundamentally diverse method to the implementation of economic activity. Nowadays, a unique development paradigm is essential to guarantee sustainable development, which presupposes environmental safety, economic growth, and an improvement in the standard of living for the populace.

In today's era, CE adoption is more of a need than a choice. CE eradicates waste by using it as a renewed source of materials that, ideally, will increase the value of the newly manufactured product. (Tambovceva and Jelna, 2017). The resources, when used effectively, can be assessed in line with the principles of circular economy. This concept brings harmony comparable to nature. Achieving this requires several key attributes, such as adaptability, innovation, agility and innovation.

For fresh economic growth, the CE implementation can have considerable positive impact on the global economy, environment and society. The circular economy envisions a shift from the existing model of production and consumption, based on "end-of-life (EOL)" principles, to the new model (Hanulakova, and Ferdinand, 2018). In all stages of manufacturing, distribution, and consumption, the new model seeks to reduce resource consumption by recycling and reusing diverse goods and materials. Since CE is linked to several of the 17 'Sustainable Development Goals (SDGS)' recognized by the United Nations, circular strategies endeavors to accomplish SDGs.

The foundation of CE is regenerative production, which is often known by different names, such as, 'closed-loop economy', 'green economy', 'bio economy', or 'non-waste economy'. The strategy is driven by three, core principles, eliminate waste', circulate products and materials at their highest rate', and 'regenerate nature' (MacArthur, 2015). This approach aims to replace the idea of 'End-of-Life (EOL)' with the transition towards more sustainable and resilient value chains.

The practitioners and policy makers throughout the globe are continuously looking beyond the linear 'take, make, trash' model of development in order to tactically shift toward a long-term plan. Research from the Ellen MacArthur Foundation and other organizations has demonstrated the potential of the circular economy, a theory that 'lessens resource dependence and increases wealth' (MacArthur, 2015). A circular economy offers an enormous prospect to help address pressing global challenges like 'land degradation, biodiversity loss', and the 'climate catastrophe' while also directly generating economic benefits for households, businesses, and communities.

1.2 Circular Economy Adoption in EEE Sector

The progression in technology, revolution in designing new products, and convincing market strategies attract customers to purchase electronic items frequently. This has led to an exponential rise in Electrical and Electronic Equipment (EEE) waste (Prakash & Barua, 2016a). India ranks third in electronic-waste production in the world after China & USA. In the year 2022, India generated approximately 1.6 million tons of e-waste and is projected to reach 29 million tons by 2030 (Markets & Data, 2023). This surge in growth is primarily due to increase in mobile phone manufacturing and assembly operations (Chowdhary V., 2025). Hence, this raises critical sustainability and supply chain concerns, indicates a pressing need to implement circular economy (CE) strategies and involve all stakeholders in the electronic value chain (Bhattacharjee et al., 2023).

In India, the large proportion of e-waste, is handled by unorganized and unregulated sector. They are not fully capable of effective extraction methods, hence lowering the recovery rates of high value parts. Secondly, the inadequate access to proper infrastructure for proper processing and recovery of e-waste, is hindering the development of large-scale e-waste sustainable CE value chain. Third, the country is grappling with a technology boom and a rise in electronic product consumption, generating significantly large volumes of e-waste (Chowdhary V., 2025).

To address the above challenges, the country's regulations and policy frameworks are evolving to encourage recycling enterprises. The key founding policy includes e-waste management rules, that introduced a mechanism such as extended producer responsibility (EPR) and requires an online registration and reporting for Electrical and Electronic Equipment (EEE) manufacturing companies (Bhadra & Mishra, 2021). Despite being the progressive framework in place, there still remain barriers in implementation and enforcement. The government continuous interventions are underway to provide financial incentives, and regulatory frameworks to businesses to encourage resource efficiency, eco-design and compliance with environmental and health standards (Bhattacharjee et al., 2023; Buttke et al., 2024).

The electronic industries' shift towards CE adoption is nascent in developing economies (Bhattacharjee et al., 2023). However, this shift will contribute towards alignment with '*United Nations Sustainable Development Goals'*(SDGs). CE adoption will accelerate progress across several SDGs, for example, '*SDG 7*: Affordable and clean energy'; '*SDG 9*: Industry innovation and infrastructure'; '*SDG 12*: Responsible consumption and production'; and '*SDG 13*: Climate action'. The alignment with these goals ensures operationalization through enforceable mechanism through supplier engagement, innovative business model, product design and innovation (Bhattacharjee et al., 2023).

CE implementation in EEE industry brings environmental, social and economic prosperity (MacArthur, 2023). From environmental viewpoint, CE implementation supports compliance with current regulations, improve resource efficiency and promote sustainability throughout the business value chain. Socially, CE adoption promotes workers' health & safety, develop their innovation skills through reskilling and upskilling programs. Social impact of CE adoption also brings strong brand reputation for a firm. Finally, economic benefits of CE adoption results in reduction of operational cost, improving product and process efficiency (Zoka & Korez Vide, 2025). Despite such huge benefits, the adoption of such paradigm in developing countries is still limited to a few pioneering firms, and the majority of value chain actors face implementation challenges with respect to ecosystem, design strategies and the business models. This gap underlines the need for systematic research and decision-making frameworks that can guide firms, suppliers and policymakers in translating CE principles into measurable actions.

1.3 Problem Statement

The EEE sector is recognized as one of the high-priority sectors for CE adoption as this multi-billion-dollar industry is a primary contributor to global e-waste problem (Rittershaus et al., 2025). The sector is frequently criticised for quick product launches, disregard for resource scarcity and continuation of unsustainable production and consumption patterns. This has led to limited integration of CE principles into operational practices which continue to restrict its sustainability potential. Suppliers, as key value chain actors in the ecosystem, often lack competence, technological readiness, and collaborative orientation essential for circular transition (Rizos & Bryhn, 2022). Given the critical need for sustainable practices and the potential benefits of CE, there is a growing body of research calling for a deeper understanding of firm level CE transition with the lens of '*enablers* and *levers*'. Although, many studies have identified *enablers* and barriers of CE adoption, but the *levers* of CE transition have received limited scholarly attention (Bressanelli et al., 2021). *Levers* refer to as 'important building blocks of CE transition as they are the tools and practices which firms implement to encourage CE practices', whereas *enablers* are 'the contextual force that makes it easier to implement *levers* into the processes'.

Since leading global firms are experimenting with industry 5.0 technologies (Santiago et al., 2025), circular product design (Svensson-Hoglund et al., 2021a) and servitized business models (Bressanelli et al., 2021) to enhance sustainability, such practices are largely underexplored in the Indian EEE sector. Consequently, electronic companies face increasing pressure to strategically prepare for the recovery and disposal of End-of-Life (EOL) products, they lack structured methodology and decision-support framework to implement CE strategies effectively. Therefore, the key problems this thesis addresses are as follows:

1. To understand CE transition at a firm-level in Indian EEE sector.
2. To determine the vital *enablers* & *levers* of CE transition in Indian EEE sector.

1.4 Research Gaps

The research aims at addressing many critical gaps. First, it has been observed that the existing research in the area of CE adoption is fragmented. Most of the studies focused on generalized insights into the manufacturing industry (Coluccia et al., 2024; Masi et al., 2024; Vidal et al., 2024). Seeing the potential of circular economy transition in the EEE industry, this is a notable gap to fill. Also, the amount of e-waste generation, regulatory intensity and proper disposal of EOL products, a sector specific investigation of CE adoption at a firm-level is essential.

Second, several studies in the existing literature have examined factors, *enablers* and barriers of CE transition (Khan et al., 2022; H. Lu et al., 2024), however, the literature has not consistently distinguished between the *enablers* and *levers*. The contextual factors, that is, *enablers* facilitate CE adoption, while the *levers* represent the actionable practices firms can deploy. While past studies have analysed multiple *enablers*, the role of *levers* has been comparatively neglected, and the interdependence amongst them have received very less scholarly attention. This lack of conceptual clarity regarding importance and interdependence among *enablers* and *levers*, restricts the ability of the firms to effectively plan CE strategies.

Evolving paradigms such as Industry 5.0, innovation in product design, servitized business models, and sustainability integration have received little academic attention in the context of Indian EEE sector (Bressanelli et al., 2021; Santiago et al., 2025; Svensson-Hoglund et al., 2021a). Since, these paradigms play an important role to sector's transition towards circularity, their incorporation into the existing framework remains underexplored, which is a notable research gap which this study will consider.

Lastly, the frameworks in existing literature are often limited to single decision-making techniques, sometimes fail to capture the complexity of CE adoption. while the traditional approaches are useful in providing insights, but they are inadequate for addressing multidimensional relationships amongst *enablers* and *levers* of CE adoption. A hybrid multi-criteria decision making (MCDM) framework involving 'Delphi method' and 'Grey Decision-making Trial and Evaluation Laboratory (DEMATEL)' is proposed in this study. The proposed framework, remain underutilized, despite their potential to capture interdependencies and systematically rank the alternatives.

In summary, the extant literature indicates that while CE adoption has gained attention in the research community, there still remain crucial gaps in industry-specific analysis, clarity between *enablers* and *levers*, and methodological rigor. Therefore, the thesis endeavors to bridge these gaps by formulating a comprehensive framework for analyzing the *enablers* and *levers* of CE transition in the EEE sector.

1.5 Research Objectives and Questions

Based on the above research gaps, this study seeks to extend the understanding of firm-level CE adoption in EEE sector. The overarching aim is to develop integrated framework that address both the evaluation of *enablers* and *levers* of CE adoption, and their interrelationship amongst them which helps in smooth transition from traditional to circular economy adoption.

1.5.1 Research Objectives

1. To understand the firm level CE transition in EEE sector.
2. To identify and analyze the critical *enablers* and *levers* of CE transition in the EEE sector
3. To develop a comprehensive framework for ranking and measuring interrelationships amongst the *enablers* and *levers*.
4. To highlight managerial, societal, and policy implications of CE transition at a firm level, contributing to the achievement of sustainable and resilient supply chains of future.

1.5.2 Research Questions

Based on the above objectives, the thesis seeks to answer the following questions:

RQ1: *'How does CE transition take place at a firm level?'*

RQ2: *'What is the role of ecosystem in implementing CE into practice?'*

RQ3: *'What are the electronic industry's most common CE models & strategies?'*

RQ4: *'What gaps are there in extant literature in CE adoption?'*

RQ5: *'What are the potential enablers and levers of CE adoption in the EEE sector that promote resilient and sustainable supply chains for the future?'*

RQ6: *'What enablers and levers are essential in driving CE adoption in the EEE sector, which promotes resilient and sustainable supply chains for the future?'*

RQ7: *'How do the essential enablers and levers influence each other regarding cause-and-effect relationships?'*

RQ8: *'What are the managerial, social and policy implications of CE adoption at a firm level?'*

1.6 Scope and Contribution of the Study

The scope of the work done in the thesis is confined to the study of firm-level CE transition in the EEE sector, with a special focus on Indian context. The primary focus is on India owing to increase in the manufacturing of electronic products, escalating e-waste challenges, and evolving regulatory landscape.

The research draws its basis from a Systematic Literature Review (SLR) of 94 peer-reviewed papers, three major themes of CE adoption were derived – 'Ecosystem', 'Design Strategies' and 'Circular Economy Business Models (CEBM)'. From these themes, two specific research gaps were identified to shape the scope of this thesis:

- The absence of comprehensive framework for evaluating *enablers* and *levers*
- The lack of sector-specific, circularity-oriented framework for CE transition

The research is limited to EEE sector and does not include other manufacturing industries. It considers firms and suppliers operating in India. By narrowing the scope in this way, the thesis ensures depth of analysis in the above two underexplored yet vital aspects of CE adoption, while proposing framework that are academically rigorous and practically relevant.

1.7 Organization of the Thesis

The thesis is organized into five chapters. Given below are the brief compositions of the chapters:

Chapter 1: Introduction

This is an introductory chapter and provides the context of the study by providing the background and outlining the need for conducting the research. The chapter presents the context and the significance of CE adoption in EEE sector. A systematic approach is followed to set out the context by including the topics in an order given as - problem statement, research gaps, research objectives and questions, and finally scope and contribution of the research study.

Chapter 2: Literature Review

This chapter aims to understand circular economy adoption at a firm-level by addressing research questions *one to four*. To this a systematic literature review (SLR) was conducted by reviewing a corpus of 94 peer-reviewed papers. After thorough analysis, three major themes of CE adoption were extracted – 'ecosystem', 'design strategies', and 'circular economy business models'. Further, the sub-themes were also extracted to have a thorough understanding of the firm-level CE adoption in the EEE industry. The chapter then proposes the research gaps and research questions under each theme for future research. For this thesis, a research gap identified under ecosystem theme is chosen, which is, "*Despite extensive literature on enablers and* *barriers to CE adoption at the firm level, there remains limited research on identifying and evaluating specific levers, such as tools, practices and mechanisms that the firm can employ to effectively facilitate and enhance CE adoption*". Further chapters in the thesis focus on addressing this research gap.

Chapter 3: Research Methodology

Chapter 3 discusses the research design, data collection, sample selection & design, and decision-making framework employed in the study. It details the rationale for employing hybrid multi-criteria decision making (MCDM) framework involving Delphi method and Grey DEMATEL technique, for evaluating *enablers* and *levers* of CE adoption. The steps to apply Grey-DEMATEL technique are also presented in this chapter. Finally, the chapter presents the potential list of *enablers* and *levers* of CE adoption using secondary research and a Delphi method. Hence, this answers research question *five* of the study.

Chapter 4: Data Analysis & Discussion

In this chapter the proposed MCDM method is applied to identify enabling factors of CE adoption with a lens of *enablers* and *levers*. The Grey-DEMATEL technique was utilized to understand the importance and inter-relationship among *enablers* and *levers*. This chapter focuses on answering research questions *six* to *eight*. The discussion on the findings obtained from data analysis is also deliberated in this chapter along with the theoretical, practical and social implications. This chapter contributes a novel, practical framework for accelerating circular economy transition within the EEE sector and advancing the development of resilient and sustainable supply chains of the future.

Chapter 5: Conclusion, Limitations and Directions for Future Research

Finally, chapter 5 concludes the study's findings by highlighting the concluding remarks. It also outlines limitations of the study and proposes directions for future research, particularly in the areas of emerging digital technologies, servitized business models and sustainable innovations to enable circularity.

1.8 Summary

This chapter served as the thesis overview. An extensive discussion on the area of research in CE adoption is presented. The chapter elucidates the need for CE transition at a firm level with the lens of *enablers* and *levers*, hence contributing to the realization of sustainable and resilient supply chains of future. The chapter further discusses the scope and contribution of the study by emphasizing its practical relevance and theoretical rigor. The last section of the chapter provides a concise overview of the thesis overall structure.

Following this, the next chapter will provide a literature review relevant to CE transition at a firm level.

CHAPTER – 2

LITERATURE REVIEW[1]

This chapter presents a systematic review of literature relating to circular economy transition in electronic industry. The chapter examines the current CE models and strategies and practices prevailing in the EEE industry ecosystem. To achieve this, a comprehensive literature study is carried out. From the collection of 94 research papers, three major themes of CE transition at the firm level were extracted: ecosystem (n=42), design strategies (n=32), and circular economy business models (n=20). Further, every theme was further classified into different sub-themes. Finally, by performing a thorough content analysis of the chosen works, a profound understanding is acquired about the fundamental discussions in the field that are relevant and applicable to the electronics industry.

2.1 Introduction

Businesses and nations worldwide are favouring strategic long-term growth over a linear growth model (Mallick et al., 2023a). Using the recovery processes of reuse, repair, remanufacture, and recycling, the circular economy (CE) is a sustainable strategy for recirculating items (Gupta, Kumar, Kusi-Sarpong, et al., 2021). To eliminate waste, it emphasizes on making better goods, materials, processes, and business models. In addition to benefiting people, companies, and communities economically, a circular economy presents a significant chance to address urgent global issues, including biodiversity loss, climate catastrophe, and land degradation (Awan et al., 2021; Bhatia et al., 2020).

This chapter is based on the following research paper:
Sehgal, S., Gugnani, R., & Bali, S. (2025). Navigating circular economy transition at a firm level: a systematic literature review of the electronic industry. *International Journal of System Assurance Engineering and Management*. https://doi.org/10.1007/s13198-025-02948-5

Research on circular economies focusses on three main areas: helping businesses implement circular processes at the micro, macro, and intermediate levels; influencing societal and economic dynamics and discussing experiences of industrial symbiosis respectively (Merli et al., 2018). One aspect of CE that generates much debate is the concept of closed loops. Biological loops are closely aligned with the environment and ecology, while technological closed loops are more connected to manufacturing operations (Homrich et al., 2018). Circular economy business models must maximize value while using minimal resources (Foroozanfar et al., 2022). The CE system incorporates various concepts, including spaceman economy (Boulding, 1966), industrial ecology (Graedel & Allenby, 1995), C2C (cradle-to-cradle) (Braungart & McDonough, 2009), and waste prevention (Yano & Sakai, 2016). Separating circularity from circular strategies can quickly solve the problem of different conceptualizations by scholars (Zotti & Bigano, 2019). Circular economy adopters must rethink their value offerings and create cost-effective, productive, and business-performing value chains (Rashid et al., 2013). Government initiatives and business strategies could potentially reconcile conflicting stakeholder agendas to promote the adoption of CE (Lieder & Rashid, 2016).

Technology, product development, and persuasive marketing are driving customers to buy new electronics, increasing e-waste exponentially (Prakash & Barua, 2016b). Globally, electronic waste production increases by 2.6 million tonnes per year, with plans to reach 82 million tonnes by 2030—a further 33% increase from 2022 (Cornelis et al., 2024). Many nations face challenges in managing electronic waste. EEE companies must strategically plan for the appropriate recovery and disposal of electronic goods after the EOL stage. In many countries, the informal sector bears primary responsibility for e-waste management. The sector lacks adequate collection, logistics, and infrastructure support to ensure efficient disposal of electronic waste and recycling. Thus, a circular economy could significantly reduce electronic waste.

The issues above serve as the impetus for examining and categorizing the work conducted in circular economy literature. The current study focuses on CE models in the electronic industry. While review papers focus on generalizing circular economy model strategies and implementations, very few discuss the specific industry. Different industries are at different levels of CE implementation; therefore, a generalized framework may not fit all industries and suggest industry-specific requirements.

Circular business models help electronics companies produce value by using fewer resources and extending product and part life. A circular economy uses products until they can be reused, refurbished, or remanufactured, unlike a linear economy. Adoption of CE strategies offers several benefits to the electronics sector, such as better handling and managing of end-of-life equipment and its precious materials. Second, alignment with sustainable development goals (SDGs), which address challenges like resource depletion, exploitation, pollution, and labour rights. Third, this also helps reduce carbon emissions by practicing reuse, recycling, and remanufacturing strategies. The transformation of linear business models into circular ones can be accomplished by going through the stages of "closing, narrowing, slowing, and cleaning loops" (Anthesis, 2021).

This chapter aims to understand the implementation of circular practices across the EEE ecosystem based on circular strategies and business models. This analysis is accomplished by conducting a systematic literature review. The following research questions are formulated.

RQ1: '*How does CE transition take place at a firm level?*'

RQ2: '*What is the role of ecosystem in implementing CE into practice?'*

RQ3: '*What are the electronic industry's most common CE models & strategies?'*

RQ4: '*What gaps are there in existing research, and how can they be filled?'*

The RQs we seek to address require a broad and exploratory approach to the well-known digital database Scopus. Hence, we refined congruent literature to get a pertinent collection of 94 research pieces that span 14 years. After carefully selecting and evaluating the material at various stages, we comprehensively examined the strategies and models applicable to CE.

More research is required to sufficiently understand how industry conditions and individual firms' specific circular business models influence outcomes in the circular economy. The identification and analysis of various CEBM approaches designed to aid businesses in the transition to a CE were essential in addressing this initial gap. These approaches focus on achieving "slowed, closed, or narrowed resource loops" (Brändström et al., 2024). These approaches are customized to match the unique characteristics of each firm or sector and the value it delivers to its end consumers. Through a comprehensive examination of the available literature, the authors were able to pin down the shortcomings in prior studies. By performing a thorough content analysis of the chosen studies, we acquired a profound understanding of the fundamental deliberations in the field which are relevant and applicable to the electronics industry (Sehgal, Gugnani, et al., 2025).

2.2 Methods

The chapter aims at reviewing existing literature on CE transition in EEE industry through SLR approach (Sehgal, Gugnani, et al., 2025). First, the pre-existing literature was surveyed to see what has been revealed about this phenomenon. These details allowed for an examination of the electronic industry's use of circular economy integration for mitigating the consequences of resource scarcity. This research improves our understanding of resource scarcity in the electronics industry and offers novel solutions to this problem through its primary contribution: the creation of new insights that provide a significant platform for advancing towards CE transition.

In the process of carrying out this systematic literature review, we looked through the database Scopus for earlier versions of systematic literature reviews that had been published there. The search terms adopted were (TITLE-ABS-KEY ("Circular Economy") OR TITLE-ABS-KEY ("circular Economy" OR "Circular Econom*" OR "circular economy*" OR "CE principle*" OR "bio economy*"OR "circular design*" OR "circular business*" OR "Circular Econom*" OR "Industry 4.0" OR "INDUSTRY 5.0" OR "Industrie 4.0" OR "Fourth Industrial Revolution" AND "Electronics Industry" OR "EEE" OR "Electricals and electronic equipment" OR "Consumer Electronics" OR "Electron* Industry" OR "WEEE" OR "Consumer Electronic Device*" OR "Electronic consumer product*" OR "Home appliances OR "Home electrical appliance"

We looked through the Scopus databases, which are widely acknowledged to be the most comprehensive and have the broadest coverage of journals. It was on 31 December 2024 that the search was conducted, and 785 entries were recorded. Further restrictions were imposed by applying restrictions rule limiting our articles to final for publication and choosing subject area as business and Management and limiting language to English by putting up commands AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SUBJAREA , "BUSI")) AND (LIMIT-TO (LANGUAGE , "English").The final entries selected were 94.

After thoroughly examining each paper, several categories of analysis were created to organize the most critical findings from previously published research on the circular economy transition in the global electronics industry. The empirical data that was examined for this research gave rise to the exploring notions that were suggested. They indicate the significance, requirement, and usefulness of interconnected, related, and collaborative solutions for achieving a thriving circular economy. Confirming these premises by doing more research in various geographical settings for the electronics industry can provide actionable insights that may contribute to the development of the circular economy.

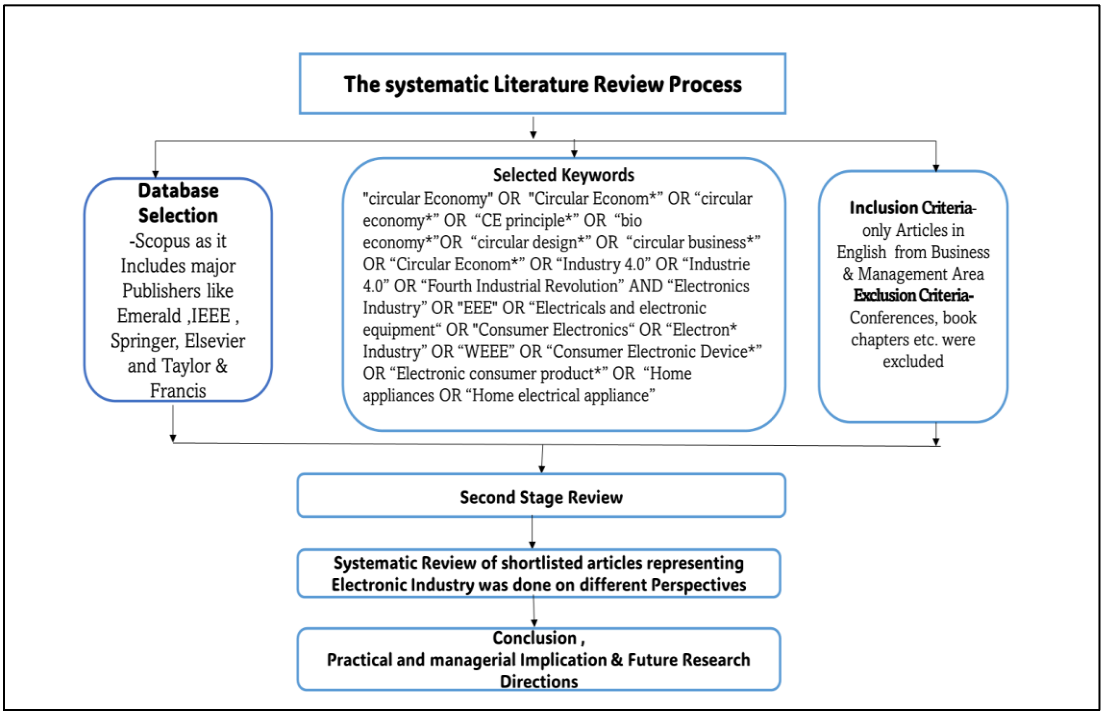

Figure 2.1: Systematic Literature Review Process (Authors' Compilation)

2.2.1 Research Profiling

To understand the broad range of concepts covered for circular economy transition in electronics industry, 94 papers from journals were arranged. The selected articles were published by various outlets. Most of the papers were found to have been published in prestigious journals such as Journal of Cleaner Production, International Journal of Production Research, Technological Forecasting and Social Change, Business Strategy and the Environment, International Journal of Production Economics and many more.

The annual distribution of the number of papers published from 2010 to 2024 was selected (Figure 2.2). Following that, all the articles were thoroughly read, and articles related to the electronics industry were shortlisted to comprehend the implementation of CE in the industry. This trend indicates that published articles have increased significantly in recent years because of increased interest in adopting a circular economy.

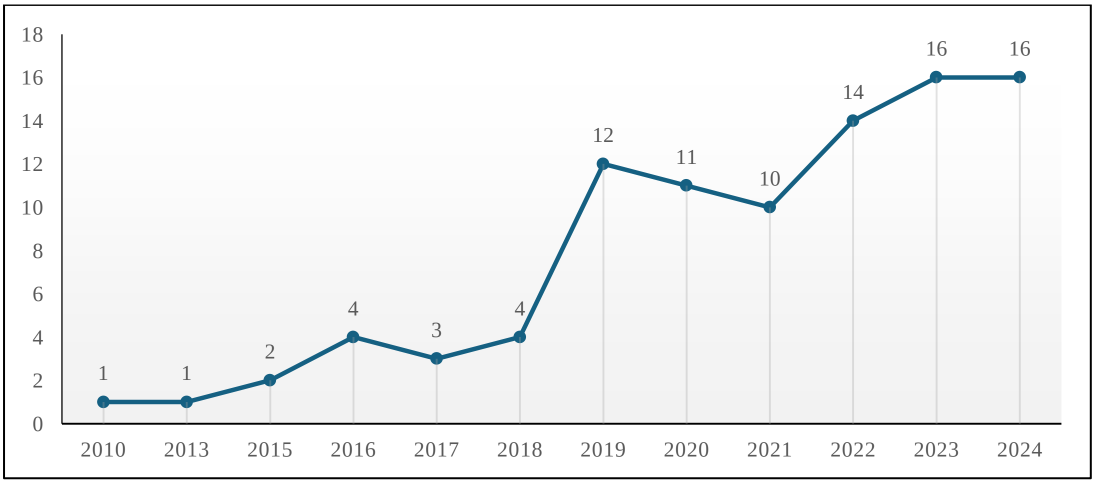

Figure 2.2: Year-wise Distribution of Publications (Authors' Compilation)

2.3 Thematic Foci

The research aimed to identify strategies that enable the electronics sector to progress towards CE transition and to examine the current CE models and strategies prevailing in the electronics industry ecosystem. To achieve this objective, we thoroughly examined the corpus of developed congruent research, as explained in the previous section. Consequently, two author team members individually analyzed the selected studies to comprehend and extract the main talks. These discussions were then used to develop strategies and models for the electronics sector. We addressed the conflicts amongst coders by engaging in conversations and arbitration with other members of the author team, albeit the number of disagreements was minimal. We recruited two subject area experts to examine the overall categorization of the elements into strategies and models, the same as how we shortlisted congruent research. To enhance the clarity and precision of the story, we used the traditional method of organizing the material into themes based on their respective focus areas. Each was further divided into different sub-themes and explained in the following discussion.

The flow of themes extraction from the corpus is as follows: From the corpus of 94 papers, first, we extracted three broad themes of CE adoption at the firm level: ecosystem (n=42), design strategies (n=32) and circular economy business models (n=20). Further, we did a thorough analysis of the papers following in each of the three themes. For every theme, the papers were then further classified into different sub-themes. This will help in proving an overview of how firms view and implement CE into their business operations.

2.3.1 Circular Economy at Firm Level

The concept of CE transition at the firm level is increasingly being adopted by organizations aiming to promote sustainability, reduce waste and enhance resource efficiency. After analyzing the research papers, the authors found three broad themes of CE transition: ecosystem, design strategies and circular economy business models, which are crucial at the firm level. In other words, at the firm level, CE is viewed as a comprehensive approach to achieving sustainability that involves creating an ecosystem that promotes strategic collaborations, innovate design strategies and introduce novel business models to promote circularity. Figure 2.3 shows the firm level view of circular economy.

Figure 2.3: Circular Economy at Firm Level (Authors' Compilation)

An ecosystem is integral in implementing CE into practice as it interconnects customers, promotes enforcement of laws & regulations and enhances value chain efficiency. Engaging customers promotes sustainable consumption, product returns, and recycling awareness. Compliance with regulations fosters a supportive regulatory environment. Finally, the value chain collaboration in the ecosystem promotes waste reduction, resource efficiency and business sustainability.

Businesses must make two critical strategic decisions when implementing circularity: innovation and resource strategies (Bocken & Ritala, 2022). Companies need to determine if they should enhance the circularity of their business models through firm-driven inner processes, partnerships involving external stakeholders, or both. The second critical strategic decision businesses must make when implementing CE business models is whether to pursue which resource strategy - 'narrowing, slowing', or 'closing resource loops' (Bocken et al., 2016). Narrowing the loop results in better designs and manufacturing processes capable of using fewer resources (energy, water, and material) and reduce packaging. The linear economy uses this method to save money and resources. Reusing material after it has been used to create a product is known as a closed loop. Extending a product's lifespan is about slowing the loop so that it retains its best value for an extended period. The three approaches mentioned above work well together. One example is making a product with cleaner methods (thereby narrowing the loop), recycled materials (there by closing the loop), and materials and services that last a long time (thereby slowing the loop) (Bocken and Ritala, 2022). A business plan that completes the cycle might follow slowing loops, such as repurposing materials from a discounted high-quality product to generate new value. Various approaches to circularity, which involve different paths and are influenced by the unique characteristics of firms, have been developed for helping companies in moving towards circular economy.

Adopting circular business models (CBM) at the firm level is critical for transitioning to CE, but organizations pursuing such initiatives face several challenges that impede their success. Although several research on impediments to the CE have been conducted, there still needs to be more knowledge on how firm-specific criteria, such as industry circumstances and the kind of CEBM used, influence outcomes. To close the said gap, the authors demonstrate various CEBM methods that are developed to support firms in their transition to a circular economy, which is tailored to the nature of their business and the value they offer to their end consumers (Henry et al.,2020).

The objective of the chapter is to derive the underline themes of CE transition. To this end, the detailed analysis of the papers on each of three themes of CE transition is discussed in the subsequent section.

2.3.1.1 Ecosystem

A review of literature revealed that the shortlisted studies on ecosystem perspective have primarily explored four key aspects that can be categorized into different sub-themes: (a) consumers, (b) enablers & barriers, (c) policy landscape, and (d) role of value chain actors.

(a) **Consumers:** A literature survey found that the nominated studies on ecosystems enabling firm-level CE adoption to have investigated the role of consumers in CE transition. For example, Atlason et al., (2017) investigated end-users' perception towards EoL scenarios of electronic products. Their findings suggest that users' preferences largely align with the concept of CE, and women consumers are willing to pay a premium price for environmentally friendly e-products. Taking the discussion forward, Singhal et al., (2019) carried out a systematic literature review to investigate factors related to purchase intention (PI) of consumers towards remanufactured products and revealed that subjective norm and attitude have strong positive impact on PI whereas perceived risk has negative impact on the PI. It was also suggested that the consumers who buy remanufactured automotive products are more environmentally conscious than those who buy electronic products. Consumer choices about whether to purchase new, eco-friendly products that meet CE standards significantly impact CE development. Given that the next generation will make the purchases, this is critical. The readiness of university students to purchase ecolabelled smartphones indicated that factors like household income, parents' education, and age positively impacted their willingness to pay the specified price (Bigerna et al., 2021). Another study by Bigliardi et al., (2022) found that environmental knowledge and green perceived value are strong predictors of 'green purchase intention'. Consumers can help SME manufacturers achieve their sustainability goals by responsibly returning e-waste. The consumer's "immediate Return Intention (IRI)"of used products plays a vital role in determining their willingness to engage (Kamal et al., 2022). The study also discovered a strong connection between a consumer's ability to obtain and evaluate environmental information about products and return quality, which includes knowledge of product returns. Another study by Bernardes et al., (2024) investigated the role of end-users for guaranteeing the effectiveness of We reverse logistic chains for achieving CE. Koide et al., (2023) compared new, used, refurbished, and subscription products and identified four consumer segments, listed in decreasing order: brand-new stubborn (51%), balanced decision-makers (25%), price-sensitive (13%), and subscription-prone (12%). Subscription or refurbished models are preferred over reuse for older circular products. It was also found that various business models 'cannibalised', for example, subscription systems reducing reused product sales. Jabbour et al., (2023) examined students' attitude towards buying electronic products, with a special focus on notebooks, smartphones and television, and their openness towards circular practices. The study revealed that the greatest market share for electronic segment is for new products with reliability and quality being the important factors of buying decisions. Secondly, the study also highlighted that awareness of students for circular premium was low. Consumers' behaviour towards disposal, collection & recycling of lithium-ions batteries was studied by Mathew et al. in 2023. Newaz & Appolloni, (2024) investigated progression of behavioral research on e-waste management to gain understanding on the evolution on WEEE domain and highlighted that theory of planned behavior (TPB) is extensively used in CE behavioral research. The behavioral intentions of millennials with respect to e-waste, research was conducted by Sharma et al., (2024), with the findings that e-WOM have a significant impact on the millennials. The research in consumer domain highlighted that end users are an important link for ensuring the effectiveness of WEEE in achieving circularity in reverse logistics chain (Bernardes et al., 2024; Vighnesh et al., 2024).

To summarize, while a lot of past research focused on lack of consumers' awareness towards EoL scenarios of electronic products, there is a disconnect between manufacturers' environmental intention and consumers' behavior at the end of product's life.

(b) ***Enablers* & Barriers:** To determine potential barriers to transition to CEBM, Werning & Spinler, (2020) did a firm level study, a few of the barriers were organizational resistivity, financial resources, cultural resistance to change. The authors' suggested to elevate transition, the firms must consider a shift towards Product-Service System (PSS) and reverse logistics. A lack of recyclability is a characteristic of product design, as items are frequently not engineered to be readily recycled, resulting in higher recycling expenses and posing challenges in metal recovery (Aminoff & Sundqvist-Andberg, 2021). Several problems impede the deployment and distribution of novel closed-loop solutions, delaying the transition to CE. Cultural attitudes and factors limit WEEE by treating it as cheap waste rather than a resource with valuable materials. Bressanelli et al., (2021) discussed and reviewed the *enablers*, *levers*, and benefits of CE adoption in the EEE sector. A study by Kumar et al., (2022) investigated *enablers* for developing sustainable WEEE management policy in emerging economies by capturing multi-stakeholders' perspective. Their study highlighted research development capabilities, digitization, and use of green & cleaner technologies are the significant causal *enablers*. Barriers, *enablers* and policy insights into the implementation of CEBM are investigated in research conducted by Rizos & Bryhn, (2022) using a multi-case study approach. Their findings show that despite the policy in place there are lot of gaps which need attention, for example, lack of rules for transparency, weak enforcement of legislation rules and lack of CE standards. Further, (Bhattacharjee et al., 2023) examined the Critical success factors (CSFs) of CE transition for implementing better e-waste management system.

Putting it succinctly, the reviewed studies discuss the *enablers* and barriers of CE adoption at firm level, while how to measure benefits from *enablers* and overcome barriers has not been explored much. Moreover, the research on *levers*, such as tools and practices of CE adoption is also lacking in the extant literature.

(c) **Policy Landscape:** A study by Gu et al., (2017) investigated about the government support to WEEE fund system. This pool of fund systems is critical in establishment of sustainable fund operations. Lu & Weng, (2018) discussed the evolution of Industry 5.0 i.e. smart manufacturing technology and technology roadmap involving formulation of government policy to support this technical transition. Mazahir et al., (2019) measured the success of e-waste legislation by mapping product characteristics with a policy in context to product reuse. McMahon et al., (2019) assessed re-use, preparation for re-use, and related legislation on e-waste management. Ibitz, (2020) researched on the implementation of comprehensive waste management policy framework to overcome the challenges and harness the benefits of CE transition. Quality labelling schemes for reused and remanufactured ICT equipment have been proposed by Gåvertsson et al., (2020) to build consumers' confidence in the quality of the reused products. Svensson-Hoglund et al., (2021) reviewed the policy landscape for repair of consumer electronics for EU and US repair markets. Franz & Silva, (2022) suggested aligning generation, management, and legislation of WEEE with cleaner production, eco-design and reverse logistics for improved execution. Jakubelskas et al., (2022) explored circular economy development in the Baltic States. Cheshmeh et al., (2023) highlighted about the legal framework for UEEE and WEEE to help reduce risk of waste and most effective way to achieve SDGs. Amicarelli et al., (2023) developed a standardized method to measure the circularity of processes in organization.

To summarize, despite the policy in place there are lot of gaps which need attention of researchers and policy makers, for example, lack of rules for transparency, weak enforcement of legislation rules and lack of CE standards.

(d) **Role of Value Chain Actors:** Collaboration across the value chain within the ecosystem encourages significant waste reduction and enhances resource efficiency. This cooperative approach not only minimizes environmental impact but also strengthens long-term sustainability by optimizing resource use and reducing operational waste. CE adopters must rethink their value offerings and create cost-effective, productive, and business-performing value chains (Park et al., 2010; Rashid et al., 2013). Implementation of extended producer responsibility (EPR) System involving multiple stakeholders within the value chain is discussed in literature by (Richter & Koppejan, 2016). They also discussed the successful and challenging factors of such systems. Further, Flygansvær et al., (2018) studied the influence of inter-firm culture and collaborations on social, ecological & economic performance of supply chain. Flygansvær et al., (2019) also studied entrepreneurial ecosystem, i.e. their involvement in recycling of electronic products to achieve sustainable CE. Agrawal & Singh, (2020) examined the relationship between outsourcing benefits and TBL based performance of reverse supply chain. Brito et al., (2022) accessed the chain of EEE and its waste within the product chain and its interaction with CE. A framework for transitioning the part of business to remanufacturing is presented by (Vogt Duberg et al., 2020). The study also highlighted the role of factors and actors involved in this transition. Marques & Manzanares, (2023) discussed a framework based on social network metrics to access the circularity in supply chain. Hidalgo-Carvajal & Carrasco-Gallego, (2022) studied inclusion of Informal recycling sector for managing WEEE in the closed loop supply chain. Thapa et al., (2023) proposed an actionable solution towards achieving sustainable and circular used EEE and waste-value chain.

Hence, we can conclude that the reviewed studies on ecosystem highlighted the importance of collaboration across the value chain within the ecosystem, however, a few research studies emphasize on the impact of collaboration for achieving long term sustainability goals which can be the focus of the future studies.

2.3.1.2 Design Strategies

Design strategies within CE focus on creating products and systems with the intention of reducing waste, increasing resource efficiency, and ensuring that the products can be reused, repaired, remanufactured, or recycled at the end of their lifecycle. After reviewing the past literature, it is observed that the qualified studies on design strategies can be categorized under two sub-themes (a) Slowing the loop (b) Closing the loop.

(a) **Slowing the Loop** refers to extending the lifespan of the products which can be achieved by designing products that are more durable, easier to repair or upgraded. Further slowing the resource loop is divided into two broad sub-themes – (a.1) design for durability and (a.2) design for product life extension.

(a.1) **Design for Durability:** In the extant literature the study by (Bundgaard & Huulgaard, 2019) highlighted that Luxury products offered by Bang & Olufsen supports design for durability through their high-quality, long-life span, extended warranties, and robust repair and service schemes. Bracquené et al., (2021) in their work discussed how improved repair strategies can increase the durability of washing machines and hence contribute to achieving sustainability.

(a.2) **Design for Product Life Extension:** At the outset, (Coughlan et al., 2018) discussed a design strategy to access the feasibility of extending product life by repurposing end-of-life notebook computers into thin client computers by reusing the key components. Messmann et al., (2019) analyzed potential for the preparation for reuse of WEEE to realize economic and ecological benefits. The influence of consumer behaviour in the context of repair of electrical devices was investigated by Brusselaers et al., (2020). Ali et al., (2021) examined creative reuse opportunities that add value to matrix trays and prevent their landfilling. Repair friendly designs and consumer awareness are important to extend product lifetimes and minimize ecological footprints (Sandez et al, 2024).

To summarize, for slowing the loop the selected papers focused on the extended warranty, reuse, repurposing and repair strategies for durability and product life extension. Although slowing the loop is cost and resource effective solution for CE transition, however, less studies were found in the literature, thus indicating the future scope of research in this area.

(b) **Closing the Resource Loop** refers to creating a circular supply chain where EOL products are collected, recycled, and reused as raw materials for new products. The studies on closing the loop are discussed under two categories which form two sub-themes of our research study. They are (b.1) design for disassembly and (b.2) design for recycling

(b.1) **Design for Disassembly:** The studies included in the review explored design strategies that facilitate easy disassembly of products enabling the reuse of components. The process of bioleaching is becoming a promising technology for recovery of valuable metals from e-waste, hence contributing to a transition to CE with environmentally friendly approach (Villares et al., 2016). The process of dismantling and recovery of electrochemical copper from waste printed circuit boards (PCB) is researched by (Cocchiara et al., 2019). Continuing with PCB, the process of disassembly of the PCB and permanent magnets from the hard disk is explored by (Talens Peiró et al., 2020). Bai et al., (2022) highlighted through their research that autonomous disassembly of e-waste is the advanced I4.0 technology for accomplishing the goals of social sustainability through CE practices. Eco-design and design for CE are frequently used sustainable design approaches, thereby minimizing the resource utilization, which is the key idea behind dematerialization is the finding of the study conducted by Suppipat & Hu, (2022). Lastly, a novel framework on 'design for circular disassembly' is proposed by Formentini & Ramanujan, (2023) to support CE transition.

(b.2) **Design for Recycling:** The reviewed studies under this strategy highlighted the importance of selecting materials and designing products to ensure effective and efficient recycling at the end of their lifecycle (Diani et al., 2019; Schepler et al., 2024). Moving on, past studies have confirmed that EEE industry looks forward to achieving closed loop system as the future design strategies. However, to achieve this goal, past research discussed various challenges in designing sustainable EEE products (Laurenti et al., 2015). In the pursuit of resource efficiency and environmentally friendly product design, Sommerhuber et al., (2016) explored the potential use of recycled WEEE plastics and particleboards in the making of wood plastic composites (WPC). A study to estimate the amount of e-waste recovered and associated with its greenhouse impact is highlighted in a study conducted by Unger et al., (2017). A similar study was conducted by Islam & Iyer-Raniga, (2023) to evaluates the potentially available recycle resources and their revenue generation. The recovery of materials from e-waste for reuse in creating a closed-loop system is widely discussed design strategy in the reviewed papers under the sub-theme of design for recycling (H. Chen et al., 2021; Kohlbeck et al., 2023; Mahmoudi et al., 2021; Martin et al., 2020). Finally, research by (W. C. Chen & Rau, 2023) proposed a framework that aims to consider the pathway of closing the loop through product innovation. Emphasizing recycled plastics from e-waste can effectively deal with resource crisis and environmental pollution, Sun et al., (2024) highlighted that recycling of WEEE plastics will lead to 10 metric carbon reduction by 2050. Govindan et al., (2024) found through their study that usage of IoT in circular supply chain network leads to an increase in consumer willingness to return e-waste. (Pesce et al., 2024), in their work, authors discussed strategic choices for successful remanufacturing approaches.

Drawing upon these findings, the research has demonstrated significant progress in implementing closed-loop strategies; however, several critical gaps remain. For instance, the reviewed studies predominantly emphasize the recyclability of parts/components at EoL stage, while future research should prioritize incorporating recycling considerations into the product design phase. This integration will play a pivotal role in advancing sustainability.

2.3.1.3 Circular Economy Business Models (CEBM)

The shortlisted studies acknowledge that CEBM aims at business operations and revenue generation within a circular economy. It is focused on how businesses operate, generate value and maintain a closed loop system. The review indicated three themes for CEBM in electronic industry: (a) Product-service-system (PSS) Model (b) Resource recovery models (c) Innovation models.

(a) **Product-service-system Model:** The importance of EEE manufacturers lies in their ability to enhance value through various means such as repair, refurbishment, reuse, remanufacturing, and recycling. By embracing a CE approach and implementing a Product-Service-System, manufacturers can maximize value from the initial sale of EEE products and generate consistent income streams. Increasing consumer engagement in PSS related to the circular economy (CE) is crucial. Assessing customers' unmet demands allows for the identification of potential innovation opportunities for new product-service systems (PSS), which can then be used to create customer-centric value propositions and drive the adoption of customer experience strategies. Similarly, in Brazil, the PSS model was investigated as a use-oriented solution that attempts to provide drinking water to customers by leasing water filters (Sousa-Zomer & Cauchick Miguel, 2018). In addition, scholars also highlighted that shifting from product-oriented to PSS-based business models can help increase the circularity of resource flows thereby improving organizations' competitiveness (Hankammer et al., 2019). Creating sustainable PSS involves the reduction of material intensity and providing incentives for the entire supply chain to follow suit. However, the PSS providers in the equipment industry are facing challenges when implementing Industry 4.0 technologies. One of the major challenges is how to collect and analyze the operational data from varied sources (Wang et al., 2020). To overcome the challenge and provide innovative equipment management services to the customers an artificial intelligence-based model resulted in predictive identification of faults and preventive maintenance was proposed (Pourranjbar & Shokouhyar, 2023).

To summarize, the implementation of PSS models in CE adoption has contributed to reducing material intensity and incentivizing sustainable practices across supply chain (Bressanelli et al., 2024). However, future research should focus on integrating recycling considerations into product design, optimizing data management for Industry 4.0 and addressing barriers to improve circularity and sustainability. These efforts will enhance the long-term impact of PSS on supply chain sustainability.

(b) **Resource Recovery Models:** An innovative economic model proposed by Cucchiella et al., (2016) to identify the presence of profitability within the recovery process of automotive Waste Printed Circuit Boards (WPCB). A multi-objective model is proposed to help regulators develop efficient recovery targets, to deliver desirable economic and environmental outcomes for collective product take back system (Chen et al., 2019). Novel digital twin based WEEE recovery system to assist manufacturing/ remanufacturing from design to recovery was proposed by (Wang & Wang, 2019). To ensure the right sourcing strategy for recycling material, three strategic models proposed by Ndubisi et al. (2020) were compared based on the transactional cost. Circular EEE System Dynamics (SD) Model to facilitate CE transition was conceptualized based on the idea of Industrial Ecology (IE) and sustainability transitions (Guzzo et al., 2021) for optimal recovery option. product recovery in CE for short life cycle (SLC) vs. long life cycle (LLC) electronic returns (Choudhary et al., 2022). A strategic framework is proposed to find the critical factors impacting remanufacturing in India to achieve sustainable and economic development (V. Sharma et al., 2024). Another study conducted in 2024 by (Torrubia et al.) demonstrated that utilizing green hydrogen in recycling copper from secondary sources significantly reduces carbon emissions by 93-97% when compared to primary productions.

(c) **Innovation Models:** Extending the lifespan of electronic products is crucial for a circular supply chain because it lowers the demand for new, resource-intensive products and promotes resource efficiency and conservation. Glöser-Chahoud et al., (2021) highlighted the need for more research on how hibernation – where electronic products are unused but not sold off. The researchers introduced a dynamic cascade stock and flow model to simulate various usage and storage stages of these products. EEE manufacturers play a crucial role in adding value through processes like repair, refurbishment, reuse, remanufacturing, and recycling. In the electronic industry, where technological advancements are frequent and competition is fierce, the circular economy business model innovation (CEBMI) framework guides companies to implement CE practices throughout the innovation process. A study conducted by Pollard et al., (2021) proposed a five layered CEBMI framework that includes: business strategy, CEBM architecture, CEBM challenges & opportunities, policy & regulations for EEE sector and circularity indicators which can minimize expenses related to raw materials, energy, and waste management. Another study by He et al., (2024) highlights the role of product innovation in optimizing e-waste management, showing how innovative design, combined with stricter collection targets and reuse policies, can enhance the effectiveness of take-back regulations for sustainable recycling. The year 2024 presents a series of insightful papers that collectively demonstrate the transformative potential of industry 4.0 in positioning the electronic industry as a frontrunner in CE adoption (Morovati Sharifabadi et al., 2024). These works highlight how advanced digital technologies are reshaping operational practices to achieve sustainable outcomes (Karuppiah et al., 2024). By optimizing reverse logistics and material recovery, particularly through data-driven approaches, the industry can significantly reduce e-waste and enhance resource efficiency (Tseng et al., 2024). Furthermore, the integration of Quality 4.0 principles ensures seamless refurbishment, remanufacturing and reintegration of products into supply chains, fostering closed-loop systems (Talaie et al., 2024).

Future studies could focus more on the development and integration of collaborative and innovation-driven frameworks to enhance CEBM adoption.

2.4 Discussion

We formulated four research questions to define the aim of our investigation (Sehgal, Gugnani, et al., 2025). To address research questions RQ1 to RQ3 we extensively reviewed and analyzed the existing literature. RQ1 focused on CE transition of electronic industry at a level of a firm, further RQ2 and RQ3 focused on the three views of CE transition – ecosystem, design strategies and circular economy business models. More precisely, we ran a comprehensive search procedure on the well-known digital database Scopus. Afterwards, we refined the congruent literature to get a pertinent collection of 94 pieces of research that spanned 14 years. After carefully selecting and evaluating the material at various stages, we comprehensively examined the ecosystem, strategies and models applicable to CE, thoroughly discussed in the previous section and summarized through a visual presented in Figure 2.4.

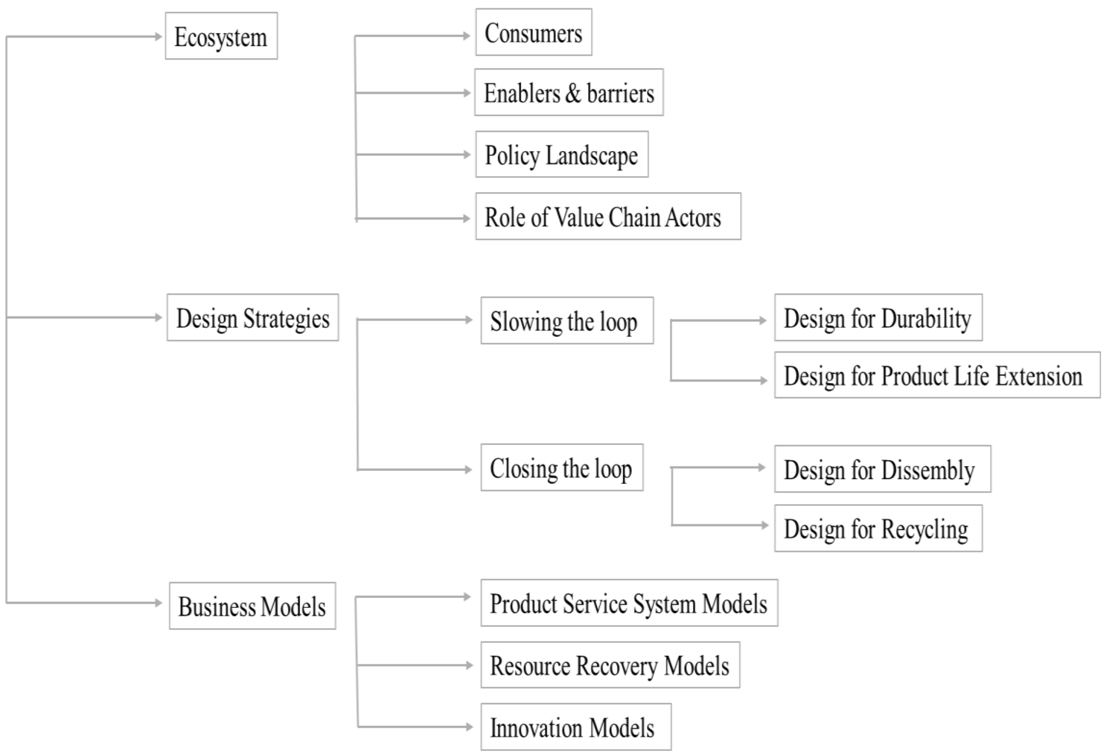

Figure 2.4: Circular Economy at Firm Level – Themes & Sub-themes (Authors' Compilation)

To address RQ4, we conducted a thorough analysis of the existing literature and made a deliberate effort to identify the shortcomings of previous research. Through our comprehensive content analysis of the selected works, we gained a deep understanding of the essential discussions in the field. The obtained understanding also assisted us in developing a discerning perspective on the existing evidence, allowing us to pinpoint areas of deficiency and propose necessary future study endeavors. To ensure clarity and consistency with the narrative in our systematic literature review (SLR) so far, we have consistently used the ecosystem, strategies and CEBM lens to classify gaps and identify new research topics, as shown in Table 2.1. To ensure the relevance of this research, the identified gaps and proposed research questions were presented to five industry experts and five academic experts. The feedback was overwhelmingly positive, with the experts acknowledging that this work could greatly assist practitioners in their journey towards circular economy transition. The experts also discussed the research and practical implications of the literature review conducted and some of the key points are discussed below:

1. This SLR presents the broader view of CE adoption at firm level through the lens of ecosystem, design strategies and CEBM, hence serves as a guide for future researchers as a central point of reference.
2. Different industries are at different levels of CE implementation; therefore, a generalized framework may not fit all industries and suggest industry-specific requirements. Hence, the review is important reference for future researchers heading to do research in EEE sector.

3. The research gaps and the questions for each of the three views: ecosystem, design strategies and CEBM, are presented separately. Through consolidation of the research gaps and future directions can significantly enhance the growing body of literature on the CE transition, which is still in the process of evolving.

4. In terms of adopting strategies, most of the literature has focused on closed-loop strategies and ignored the impact of slow-loop strategies, which are equally crucial in creating positive solutions. However, it also came to light that durability and refurbishment are preferred over re-use in the electronics industry. Establishing an effective sourcing strategy (manufacturing vs. contracting vs. purchasing) for recycled material is critical for supply chains and corporate sustainability.

5. It has been discovered that, in terms of circular economy, the business models used in the electronics industry are product oriented. PSS principles are classified into three types: product-oriented, use-oriented, and results-oriented. By adopting a circular strategy and developing a product-service system, businesses may maximize the value of the original sale of E&E products while also generating consistent income. As a result, circular economy business models based on circularity adoption should prioritize two primary dimensions: implementing the circularity concept in value propositions to customers, how customers interact with suppliers, and reorganizing internal activities.

Table 2.1: Research Gaps and Proposed Research Questions

View & Themes	**Gaps**	**Proposed Research Questions**
View: Ecosystem **Themes:** (a) Consumers (b) *Enablers* & Barriers (c) Policy Landscape (d) Role of Value Chain Actors	**GAP1:** While a lot of research is done in the area of lack of consumers' awareness towards EoL scenarios of electronic products, however, there is a disconnect between manufacturers' environmental intention and consumers' behavior at the end of product's life. **GAP2:** Despite extensive literature on *enablers* & barriers to CE adoption at the firm level, there remains limited research on identifying & evaluating specific *levers*, such as tools, practices & mechanisms, that organizational can employ to effectively facilitate & enhance CE adoption. **GAP3:** Despite the policy in place there are lot of gaps which need attention, for example, lack of rules for transparency, weak enforcement of legislation rules and lack of CE standards **GAP4:** While many studies in the extant literature highlighted the importance of collaboration across the value chain within the ecosystem, however a few research emphasize on the impact of collaboration for achieving long term sustainability goals	**RQ1:** How to ensure that consumers will handle EEE products as intended by the manufacturer? **RQ2:** How to effectively influence and educate consumers to align their disposal behavior with CE principles? **RQ3:** How to build consumers' confidence for reused products? **RQ4:** How research development capabilities, digitization, and use of green & cleaner technologies can support tracking of product lifecycle, improve recycling efficiency and facilitate remanufacturing process? **RQ5**: What are the key *enablers* and *levers* of CE adoption in the EEE sector that promote resilient & sustainable supply chains of future? **RQ6:** How to develop a robust framework for measuring the effectiveness and compliance of the policies & regulation related to CE transition? **RQ7:** What are the regulations and laws for the health risks of personnel involved in managing EEE waste? **RQ8:** How to implement a nationwide reverse logistics system for EEE and to regulate this process through various routes available e.g. sectorial agreement, term of commitment or regulation? **RQ9:** How can multi-stakeholders be involved in the value chain to overcome the barriers like cost, technological or regulatory? **RQ10:** How inter-firm culture and collaboration fosters social, ecological and economic performance in managing nationwide e-waste? **RQ11:** How to design effective EPR policies to incentivize producers to take responsibility for the entire lifecycle of the products? **RQ12:** What role can public-private partnerships play in fostering CE adoption through industry 4.0 technologies? **RQ13:** How does the integration of Industry 5.0 technologies enhance the efficiency & effectiveness of CE practices in sustainable reverse supply chains?

View & Themes	Gaps	Proposed Research Questions
View: Design Strategies **Themes:** (a) Slowing the Loop (b) Closing the Loop	**GAP1:** Although slowing the resource loops is cost and resource effective solution towards CE transition, however less attention has been paid by the researchers & practitioners on this front **GAP2:** Despite significant progress in implementing closed resource loop strategies, several research gaps still exist that need to be addressed for more efficient CE implementation **GAP3:** The current research focuses on the recyclability of the individual components after EoL, while research is needed to integrate recycling considerations into the early design phase of the products	**RQ1:** How product design using the slow loop strategies can be made cost efficient and at the same time attractive to consumers? **RQ2:** Which products can be promoted at a national level with the approach of slowing the loop via reuse/repair, remanufacture, and repurposing? **RQ3:** Can standardization of components and materials enhance the remanufacturing efficiency of electronic products? **RQ4:** How to innovate product designs that are easy to dissemble without sacrificing product performance and consumer appeal? **RQ5:** Are the environmental impacts of preparing WEEE for reuse balanced by the benefits of avoiding the purchase of a new product? **RQ6:** How to bring innovations in advanced sorting and separation technologies to increase material recovery rate? **RQ7:** How can closed loop strategy be made financially sustainable? **RQ8:** What recovery option is the most practical for a returned long life cycle product in the electrical and electronic equipment (EEE) industry? **RQ9:** What is the utility of incorporating frameworks like the Eco-cost/Value Ratio (EVR) in life cycle assessment (LCA) investigations? **RQ10:** Which specific policy measures are most effective in encouraging the closure of resource loops? **RQ11:** Can the implementation of processes for the recovery of rare earth elements (REEs) mitigate the risks associated with REE supply and provide environmental and societal benefits? **RQ12:** What design strategies can enhance product recyclability and overcome challenges in material recovery by engineering products for easier disassembly and material separation?
View: Circular Economy Business Models	**GAP1:** While there is lot of discussion about PSS models in the literature and its benefits, however there is scarcity of literature about implementing PSS model within established organizational framework and how these	**RQ1:** What are the potential limitations and disadvantages associated with a product-service system (PSS) business model for electronics and electrical (E&E) manufacturers, such as the challenges involved in implementing and expanding this model within established organizational

View & Themes	Gaps	Proposed Research Questions
Themes: (a) Product-service-system Model (b) Resource Recovery Models (c) Innovation Models	models impact the entire value chain. **GAP2:** Less attention has been given to resource recovery models and innovation models of CEBM in comparison to PSS models. **GAP3:** While different CEBM models are proposed in the literature, however, there is a gap in understanding how specific policies impact the adoption of CEBMs	frameworks? **RQ2:** What challenges do PSS providers face when integrating Industry 4.0 technologies throughout the lifecycle of the product? **RQ3:** How to measure and track resource recovery using CEBM frameworks and methodology? **RQ4:** What are the other alternative methodologies available other than digital twins and Industry 4.0 *enablers* in enhancing the sustainability of WEEE remanufacturing? **RQ5:** How to foster the culture of collaborative circular business models through innovative frameworks? **RQ6:** How do policies related to waste management, recycling standards, eco-design products influence business decisions and encourage innovation in CEBM adoption? **RQ7:** How can one effectively mitigate apprehensions regarding the ecological consequences resulting from the amplified remanufacturing of WEEE, specifically about waste handling and disposal through resource recovery models? **RQ8:** What measurable impact does the adoption of CEBM, supported by Industry 4.0, have on reducing environmental footprints in the electronics industry? **RQ9:** What innovative frameworks or models can effectively integrate Industry 5.0 technologies with circular economy principles to optimize reverse logistics performance?

2.5 Summary

This chapter examined the pertinent literature sourced from a vast reservoir of information from the fields of CE adoption in EEE sector. The review highlighted that the Companies in the EEE sector can achieve firm level CE transition through a collaborative ecosystem inter-connected through strategic relationships, product design strategies with the intention of waste reduction and enhancing resource recovery and lastly implementing CEBM models to improve business operations and increase revenue generation. CE transitions bring significant benefits; however, the process may bring several challenges. Given the intricate and comprehensive nature of effort required for CE transition, the review focused on the CE systematic identification of the themes of CE transition at the firm level and then extracting the research sub-themes from the identified themes.

Further, in the subsequent chapters, the author researched GAP2 (refer Table 2.1), from the ecosystem theme, which is **“**Despite extensive literature on enablers & barriers to CE adoption at the firm level, there remains limited research on identifying & evaluating specific *levers*, such as tools, practices & mechanisms, that organizational can employ to effectively facilitate & enhance CE adoption.”. To this gap this thesis answers the proposed research question “RQ5 (refer Table 2.1): What are the key *enablers* and *levers* of CE adoption in the EEE sector that promote resilient & sustainable supply chains of future?”

CHAPTER – 3

RESEARCH METHODOLOGY[2]

3.1 Introduction

The research focuses on the adoption of circular economy (CE) practices within the Electrical and Electronic Equipment (EEE) sector in India. Given the sector's critical role in the face of environmental and regulatory pressures, as well as concerns about resource efficiency, a systematic literature review was meticulously undertaken in the previous Chapter. The review involves gaining an in-depth understanding of firm-level CE adoption, which enables the identification of prevailing themes, gaps, and proposed research questions The SLR has led to the identification of the methodology of the proposed research objective, which is, identification and analysis of critical enablers and levers of CE transition in the EEE sector. To address this a hybrid multi-criteria decision-making framework based on Delphi method and Grey DEMATEL technique is proposed. Hence, the main goal of this chapter is to present and justify the chosen research methodology for this study.

3.2 Research Design

The research was carried out in three phases to systematically identify, validate, and analyze the enablers and levers of CE adoption. Phase one involves identification of potential enablers and levers for the adoption of CE practices. Then, in phase two, a Delphi-method was adopted where the industry experts were engaged to validate and finalize the critical enablers and levers. This step ensured that the criteria considered

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This chapter is based on the following research paper:

Sehgal, S., Bali, S., Gunasekaran, A., Roy, M. H., & Gugnani, R. (2025). Leveraging Circular Economy Transition to Achieve Resilient and Sustainable Supply Chains of the Future: A study of EEE Industry. *Sustainable Futures*, *10*, 101053. https://doi.org/10.1016/j.sftr.2025.101053 in the study were based on academic research while also reflecting the realities of the Indian EEE industry. Finally, in the last phase, grey DEMATEL method was applied to examine priority and the cause-and-effect relationships among the identified enablers and levers. This multi-phase approach ensured both theoretical rigor and practical relevance in facilitating a strategic and actionable transition toward achieving resilient and sustainable supply chains for the future through the adoption of circular practices. The conceptual framework used to conduct the study is presented in Figure 3.1

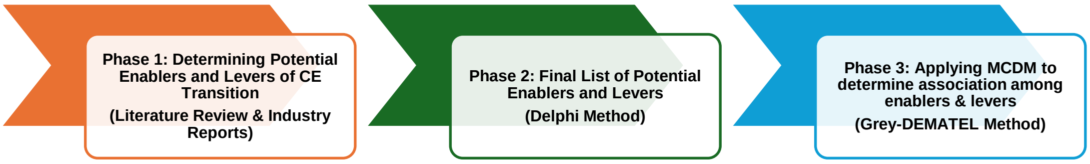

Figure 3.1: Conceptual Framework

3.3 Data Collection

Both secondary and primary sources of data were utilized to achieve the study's objective. Phase one involves secondary data collection, primarily through an extensive review of scholarly literature and industry reports relevant to the CE and EEE sector. Through expert consultation, the potential list of enablers and levers was finalized in the second phase of the research. Primary data was collected using a survey questionnaire through expert participation. The survey questionnaire comprises thirteen factors (six enablers and seven levers) and was circulated among experts with the aim of understanding their assessment about successful implementation of CE in the EEE sector. Finally, in Stage 3, the identified enablers and levers have been used in applying the grey DEMATEL technique. In addition, the questionnaire gathered demographic details, including age, experience, and designation, of the respondents.

Phase 1: Determining Potential Enablers and Levers of CE Transition

A comprehensive review of present literature and the industry reports were assessed to systematically identify potential enablers and levers facilitating the CE transition in the EEE sector. Peer-reviewed research articles were sourced from Scopus database, to ensure the inclusion of high-quality and reliable studies. Further, industry reports and practitioner documents focused on CE transition in the EEE sector were also reviewed to capture emerging trends and industry practices (MacArthur, 2023; Rada Michael, 2018; Research and Markets, 2024; Tiseo Ian, 2023).

The keywords used for determining the potential list of enablers and levers are presented in Table 3.1:

Table 3.1: Keyword search in Scopus Database

"circular economy" OR "CE" OR "circular business models" OR "circular supply chain" OR "closed-loop supply chain"
AND
"electronic waste" OR "Electricals and electronic equipment" OR "e-waste" OR "EEE" OR "WEEE" AND "enablers" OR "levers" OR "success factors"

Studies were nominated based on their relevance to CE adoption practices and their focus on practical implementations of enablers and levers in organizations. The search process shortlisted 29 articles and four industry reports. Two authors independently conducted a full-text review of these articles to extract potential enablers and levers. The authors used the traditional method of organizing material into themes, which, in our case, are enablers and levers. Following a detailed analysis of all the themes, the authors could select five potential enablers and seven levers of CE adoption discussed in Table 3.3 and 3.4.

3.4 Sample Selection and Sample Design

Given the objective of identifying and validating the potential enablers and levers of CE adoption in the Electrical, Electronic Equipment (EEE) sector, a non-probability purposive sampling design was employed. This approach is appropriate when the research requires input from individuals with specialized knowledge and experience in a specific domain, rather than a statistically representative population. The phase 2 of the research discusses in detail the sample selection and design to finalize the potential list of Enablers and levers.

Phase 2: Final List of Potential Enablers and Levers

Phase 2 addresses Research Question 5 (RQ5) by validating and finalizing the list of potential enablers and levers for CE adoption in the EEE sector. A panel of industry experts was engaged in to ensure contextual relevance and practical applicability of the shortlisted enablers and levers obtained during Phase 1. Delphi method was employed, involving iterative rounds of expert feedback and controlled discussions to reach a consensus on the most relevant enablers and levers. A total of *seventeen* experts from the EEE industry participated. Previous studies (Bali et al., 2023a; Yadav & Barve, 2018) indicate that panel of 15-20 experts are sufficient to produce reliable and meaningful insights, particularly when participants have relevant domain expertise.

Experts were carefully chosen using purposive sampling technique. The following criteria for selection were considered: (i) must have experience of working in the EEE sector; (ii) a minimum of five years of industry experience is mandatory; (iii) demonstrable understanding of CE or related sustainability initiatives.

The average experience of the participants was 18.6 years, which lies within the range of 8 to 24 years. This reflects a high level of sectoral expertise. The experts' profile including designation, years of experience, and department are presented in Table 3.2.

Table 3.2: Profile of Respondents

Expert	Designation	Years of Experience	Department
Exp1	Head	26	Manufacturing Operation
Exp2	General Manager	21	Supply Chain Management
Exp3	Deputy General Manager	8	Supply Chain Management
Exp4	Team Leader	8	Operations
Exp5	Head	39	Operations
Exp6	General Manager	18	Circular Economy
Exp7	Head	24	Business Excellence
Exp8	General Manager	20	Marketing
Exp9	Head	18	Manufacturing Technology
Exp10	Deputy Manager	7	Production
Exp11	Managing Director	22	Human Resources
Exp12	Head	18	Brand & Marcom
Exp13	Head	11	Human Resources
Exp14	General Manager	18	Supply Chain Management
Exp15	Vice President	20	Business Development
Exp16	Head	17	Quality Control
Exp17	Manager	22	Production & Operations

A structured consultation process using the Delphi method was utilized. The initial list of enablers and levers identified in Phase 1 was presented to the experts. Through multiple rounds of discussion and observation, the panel thoroughly assessed the relevance, clarity, and completeness of these enablers and levers. Following these discussions, the experts suggested adding "competition" as a new enabler, emphasizing its importance in fostering circular economy (CE) adoption through market forces and peer influence. The finalized list now includes six enablers and seven levers, serving as the foundation for further analysis and model creation. The expert panel collectively acknowledged the significance of this collaborative approach, aimed at ensuring that the audience feels involved and assured in the research process and its findings. Additionally, these enablers and levers are anticipated to play a crucial role in developing resilient supply chains and supporting wider initiatives for a sustainable future by enhancing resource efficiency, operational flexibility, and long-term value generation, refer Figure 3.2.

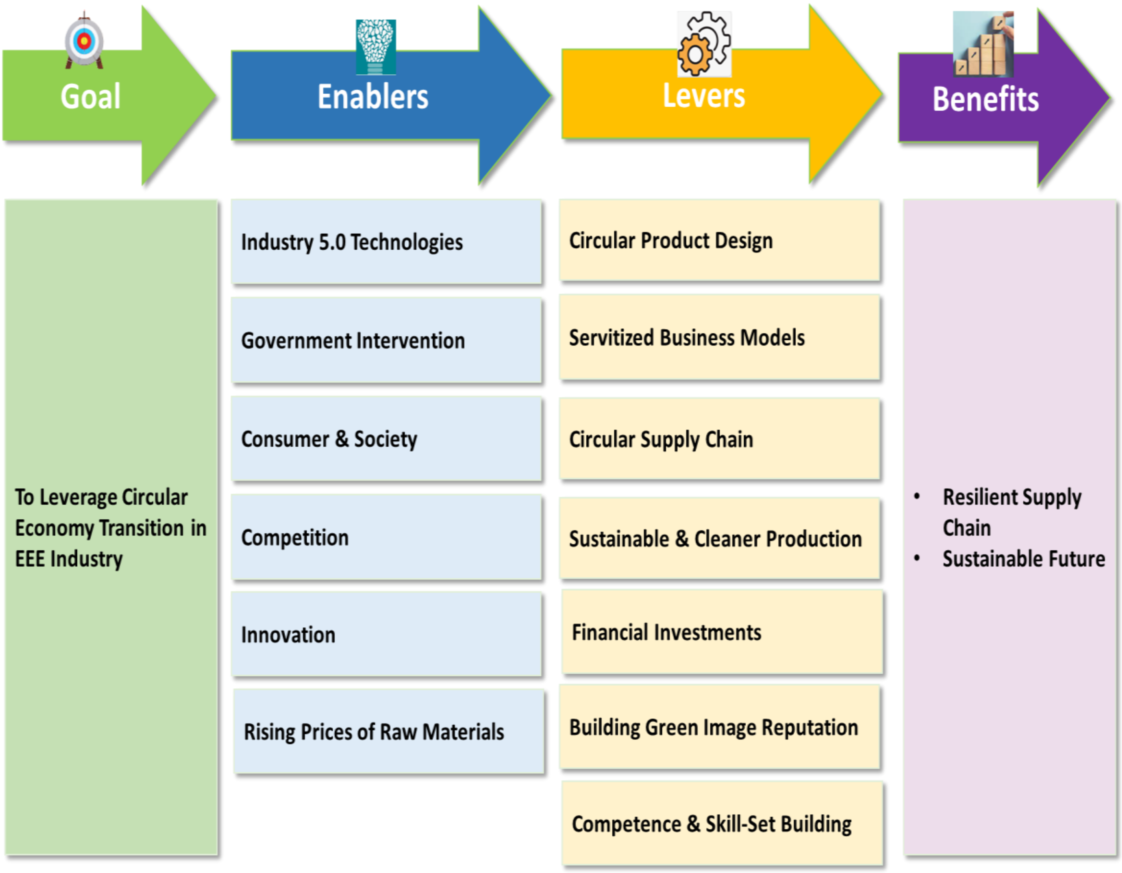

Figure 3.2: Final List of Enablers & Levers with the Study Objective (Authors' Compilation)

Table 3.3: Description of *Enablers*

Enablers	**Code**	**Description**	**References**
Industry 5.0 Technologies (I5.0)	E1	They are enabling technologies centered around three interrelated essential values: human-centricity, sustainability, and resilience'. These technologies are the Internet of Everything (IoE), collaborated robots, big data analytics, artificial intelligence and blockchain.	(Santiago et al., 2025); (Kazancoglu et al., 2023); (Dwivedi et al., 2023); (Turner et al., 2022)
Government Intervention (GI)	E2	Government intervention can enable CE implementation by enforcing regulations and laws, setting global standards, and providing financial support.	(Bressanelli et al., 2021); (Ikram & Sadki, 2024); (Svensson-Hoglund et al., 2021b); (Buttke et al., 2024); (Ho et al., 2021)
Consumer & Society (CS)	E3	Rising societal consciousness of environmental protection and climate change concerns has changed consumer demand. Hence, consumers and society can enable firms to adopt CE.	(Rizos & Bryhn, 2022); (Bhattacharjee et al., 2023); (Mallick et al., 2023b); (Ho et al., 2021); (Awaysheh et al., 2023)
Competition (C)	E4	Competition can enable firms to adopt CE-led practices to achieve resilience and be competitive with global competitors.	Expert Opinion
Innovation (IN)	E5	The CE implementation process can enable firms to think of innovative ideas related to product/processes to enhance circularity in the existing supply chain.	(Nakandala et al., 2023)
Rising Prices of Raw Materials (RPRM)	E6	Rising prices of virgin materials can enable CE adoption, leading to significant cost reductions leading to reduction in the supply chain cost.	(Ho et al., 2021)

Table 3.4: Description of *Levers*

Levers	**Code**	**Description**	**References**
Circular Product Design (CPD)	L1	It refers to designing a product to keep the product/ components/ parts at the maximum utility and value through the complete life cycle. Various circular product designs include design for durability & lifespan prolongation, design for ease of maintenance & repair, and design for disassembly, reassembly, and recycling.	(Bressanelli et al., 2021); (Svensson-Hoglund et al., 2021b)
Servitized Business Models (SBM)	L2	Servitized business models involve a move away from conventional approaches to selling products towards focusing on providing services to customers to maintain ongoing relationships. These models may take different forms, such as product-oriented, which includes services like after-sales support, maintenance, and repairs, and user-oriented models, such as leasing and sharing.	(Bressanelli et al., 2020, 2021); (Ingemarsdotter et al., 2020)

Levers	Code	Description	References
Circular Supply Chain (CSC)	L3	Companies can leverage circular supply chains using diverse strategies such as enhancing the effectiveness of the forward supply chain, establishing alliances for collaborations within the supply chain, and advocating the adoption of reverse logistics.	(Werner-Lewandowska et al., 2025); (Bag & Kumar Mangla, 2025); (Santiago et al., 2025) ; (MacArthur, 2023); (Ratsimandresy & Miemczyk, 2024); (Vidal et al., 2024)
Sustainable and Cleaner Production (SCP)	L4	SCP involves manufacturing of products and services by utilizing practices that do not harm the environment within the constraints of minimizing energy use and conserving natural resources.	(Khan et al., 2022); (Kumar et al., 2022b); (Gupta, Kumar, & Wasan, 2021); (Mahroof et al., 2024)
Financial Investments (FI)	L5	The progress towards a CE transition requires high financial investment initially; however, in the long run, this will help businesses achieve substantial cost savings while improving their operational processes through greater resource efficiency.	(Khan et al., 2022); (Mallick et al., 2023b); (MacArthur, 2023)
Building a 'Green Image' Reputation (BGIR)	L6	An organization with an image of a 'green brand' is regarded positively and trusted by environmentally friendly customers. To establish a 'green image' reputation, a company must incorporate environmentally friendly practices into its production processes, differentiating itself from competitors.	(Kumar et al., 2022b); (Jauhari et al., 2025) ;(M. Sharma et al., 2020); (Cheng et al., 2023); (Sheykhan et al., 2024);
Competence & Skill-set Building (CSB)	L7	This pertains to training supply chain & operations professionals with the necessary skill sets to facilitate a smooth shift from a linear to a circular economy. The skill set and competencies include training in industry technologies, sustainable design, waste minimization, recycling, etc.	(Rizos & Bryhn, 2022); (Bhattacharjee et al., 2023); (M. Sharma et al., 2020); (Alvim et al., 2024)

3.5 Multi-Criteria Decision-Making Technique

This section discusses the MCDM technique, Grey DEMATEL, used to prioritize and build relationships among the enablers and levers, so constituting Phase 3 of the research study.

Phase 3: Grey DEMATEL Method

The Grey-DEMATEL method was utilized to establish the hierarchy and the interrelationship among the enablers and levers. This MCDM method enables the analysis of complex interrelationships among factors by recognizing and mapping their causal relationships. DEMATEL technique categorizes factors into cause-and-effect groups, thereby providing deep insights into their relative influence within the system. Further, grey systems theory is integrated with the DEMATEL method to capture imprecise and vague human judgments, resulting in applying a comprehensive, unified technique. Microsoft Excel 365 tool was employed to solve Grey DEMATEL technique. The DEMATEL method analyzes factors and helps us understand the causal relationship among the factors (Bali et al., 2023b; Sehgal, Bali, et al., 2025; Yadav & Barve, 2018).

The steps to apply Grey-DEMATEL method are presented below:

<u>Step 1</u>: Let there be a total of n drivers (*enablers* and *levers*) of CE adoption, and a total of m respondents were chosen for the expert panel. Each respondent, k, was asked to assess the degree of influence of an enabler/ lever (i) on the other enabler/ lever (j) on an integer scale ranging from 0 to 4, where 0 indicates 'no influence' and four 'very high influence' (Rajesh & Ravi, 2015). The k Initial Relation Matrices (IRM) were obtained based on the degree of influence the experts.

<u>Step 2</u>: The 'grey relation matrices' were computed by converting the integer scale rating into associated grey scales with the upper and lower values.

$$\otimes g_{ij}^{k} = \left(\underline{\otimes}\, g_{ij}^{k}, \overline{\otimes}\, g_{ij}^{k}\right) \tag{3.1}$$

where $1 \leq k \leq m;\ 1 \leq i \leq n;\ 1 \leq j \leq n$

The m grey initial relation matrices are obtained based on grey values and are represented as $[\otimes g_{ij}^{1}], [\otimes g_{ij}^{2}], \dots \dots, [\otimes g_{ij}^{m}]$

The grey scales used to represent the integer values are defined in Table 3.5.

Step 3: The average grey relation matrix, $[\otimes\tilde{g}_{ij}]$, is computed from m grey relation matrices as follows,

$$\otimes\tilde{g}_{ij} = \left(\frac{\sum_k \underline{\otimes} g_{ij}^k}{m}, \frac{\sum_k \overline{\otimes} g_{ij}^k}{m}\right) \quad (3.2)$$

Table 3.5: Integer values and their associated grey scales

Linguistic Terms	Integer Values	Grey Scales
No influence	0	(0, 0.1)
Very low	1	(0.1, 0.3)
Low	2	(0.2, 0.5)
High	3	(0.6, 0.9)
Very high	4	(0.9, 1)

Step 4: The modified CFCS method having a three-step process is then employed to transform the grey values into crisp values. The steps are shown below:

I. Normalizing grey value

$$\underline{\otimes}\dot{g}_{ij} = \left(\underline{\otimes}\tilde{g}_{ij} - {}^{min}_{j}\underline{\otimes}\tilde{g}_{ij}\right)/\triangle_{min}^{max} \quad (3.3)$$

where $\underline{\otimes}\dot{g}_{ij}$ denotes the 'normalized lower limit value of the grey number $\otimes\tilde{g}_{ij}$'

$$\overline{\otimes}\dot{g}_{ij} = \left(\overline{\otimes}\tilde{g}_{ij} - {}^{min}_{j}\overline{\otimes}\,\tilde{g}_{ij}\right)/\triangle_{min}^{max} \quad (3.4)$$

Where $\overline{\otimes}\dot{g}_{ij}$ denotes the 'normalized upper limit value of the grey number $\otimes\tilde{g}_{ij}$'

$$\triangle_{min}^{max} = {}^{max}_{j}\underline{\otimes}\tilde{g}_{ij} - {}^{min}_{j}\underline{\otimes}\tilde{g}_{ij} \quad (3.5)$$

II. Compute total normalized crisp value

$$z_{ij} = \frac{\left(\left(\underline{\otimes}\dot{g}_{ij}(1-\underline{\otimes}\dot{g}_{ij})\right)+\left(\overline{\otimes}\dot{g}_{ij} \times \overline{\otimes}\dot{g}_{ij}\right)\right)}{\left(1-\underline{\otimes}\dot{g}_{ij}+\overline{\otimes}\dot{g}_{ij}\right)} \quad (3.6)$$

III. Determine the final crisp value

$$z_{ij}^{*} = (min\otimes\tilde{g}_{ij} + \left(z_{ij} \times \triangle_{min}^{max}\right) \text{ and,} \quad (3.7)$$

$$Z = \left[z_{ij}^*\right] \tag{3.8}$$

Step 5: The normalized crisp relation matrix, R, is found by calculating S, computed by taking product of the average relation matrix Z and S.

$$S = \frac{1}{\max_{1\leq i\leq n}\sum_{j=1}^{n} z_{ij}^*} \tag{3.9}$$

$$R = Z \times S \tag{3.10}$$

where each element of matrix R lies between $0\ and\ 1$

Step 6: The 'total-relation matrix T' is obtained as follows:

$$T = R \times (I - R)^{-1} \tag{3.11}$$

where I denotes an identity matrix.

Step 7: The cause-and-effect parameters are obtained in step 7. The elements of the 'total relation matrix T' are denoted by t_{ij}. Let r_i denote the sum of ith row elements in matrix T; we conclude that r_i represents both direct and indirect effects given by enabler/lever i towards the other *enablers/levers*. c_j denotes the sum of elements of column j of matrix T, c_j summarizes both direct and indirect effects received by enabler/lever j from other *enablers/levers*.

$$r_i = \sum_{j=1}^{n} t_{ij},\ i = 1,2,..,n \tag{3.12}$$

$$c_j = \sum_{i=1}^{n} t_{ij},\ j = 1,2,..,n \tag{3.13}$$

When $i = j$, the sum $(r_i + c_j)$ signifies the total influence given and received by enabler/ lever i in the whole system. On other hand, $(r_i - c_j)$ determines the net effect that the enabler/lever i contributes to the entire system. A 'positive' value indicates that enabler/lever i is the net cause, whereas a 'negative' value signifies that enabler/lever i is the net effect.

Step 8: A threshold value is set to plot a digraph. Information about how one enabler or lever affects the other is represented by the elements of the total relation matrix T. A threshold value is set to avoid the insignificant effects and is computed by finding the mean of all the elements of matrix T (Rajesh & Ravi, 2015).

The author has used Microsoft Excel to solve the Grey-DEMATEL method discussed above.

3.6 Summary

This chapter outlined the research methodology adopted to examine the *enablers* and *levers* of CE adoption in the Indian EEE sector. By establishing this methodological foundation, the chapter provides a systematic approach to transition from theory to empirical analysis. The next chapter presents the detailed analysis of *enablers* and *levers* of CE adoption.

CHAPTER – 4

DATA ANALYSIS & DISCUSSION

The substantial rise in the scale of electronic waste is a considerable concern for electrical and electronic equipment (EEE) manufacturers. Transition to circular economy is a strategic move to combat the challenge of e-waste generation. Traditional supply chains (SC) and operations were designed to support linear 'take-make-waste' models. To successfully transition to CE and achieve a resilient supply chain in the future with sustainable operations, organizations will have to reconsider their current business models, product designs, and supply chains. While previous studies have identified enabling factors for CE transition, limited research has examined it through the combined lens of enablers and levers. Therefore, this chapter addresses this gap by focusing on research objectives two and three and answers RQ5-RQ8 posed in the introduction chapter.

4.1 Introduction

Circular Economy (CE) has gained traction over the past decade due to the rapidly changing climate, the diminution of natural resources, and growing social and environmental pressures (Agnusdei et al., 2022; Bressanelli et al., 2021; Khan et al., 2022). CE has replaced the End-of-life (EOL) concept with the closed-loop system as a regenerative system (Masi et al., 2024). While CE principles are gaining traction, many industries still rely on linear economy models, prioritizing value creation through virgin materials (Rizos & Bryhn, 2022). As we transition from a linear "take, make, waste" model, CE provides businesses with the chance to rethink and redesign

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This chapter is based on the following research paper:

Sehgal, S., Bali, S., Gunasekaran, A., Roy, M. H., & Gugnani, R. (2025). Leveraging Circular Economy Transition to Achieve Resilient and Sustainable Supply Chains of the Future: A study of EEE Industry. *Sustainable Futures*, *10*, 101053. https://doi.org/10.1016/j.sftr.2025.101053 their supply chains (Ikram & Sroufe, 2025), enabling them to meet sustainability goals (Ikram & Sadki, 2024), lower costs, and reduce greenhouse gas emissions.

The past literature discusses the drivers and challenges of CE transition (Khan et al., 2022; Mallick et al., 2023b), (H. Lu et al., 2024). However, these studies were not sector-specific but generally focused on the manufacturing industry. Considering the potential of CE transition in the EEE sector, this is a substantial gap to fill. Identifying CE drivers with the lens of *enablers* and *levers* is crucial, as it aids organizations and practitioners in effectively transitioning towards circular economy models. *Enablers* and *levers* are the two critical building blocks of CE transition; *levers* refer to tools and practices that organizations can utilize to promote CE adoption, while *enablers* are the conditional and contextual aspects that make it easier to implement *levers*. Although prior studies have identified various *enablers* supporting the transition towards circular economy practices, the role of *levers* has received comparatively limited scholarly attention. Furthermore, the interactions between *levers* and *enablers*, as well as the interdependencies among different *levers*, have been marginally explored or neglected mainly within the extant literature (Bressanelli et al., 2021), (Rizos & Bryhn, 2022), (Bhattacharjee et al., 2023), (Werner-Lewandowska et al., 2025). The existing research gaps and the evolving supply chain practices serve as the motivation for this study.

This study addresses the research gap by systematically investigating the *enablers* and *levers* of CE and examining their relationships within organizational supply chain contexts using the Grey-DEMATEL method. Therefore, the novelty of this work lies in identifying the relationship and hierarchy of importance of CE *enablers* and *levers* for achieving resilient and sustainable supply chains in the EEE sector, which, as per authors' knowledge, is under-represented in the extant literature. The EEE sector has been purposefully chosen for this study due to its substantial contribution to global e-waste generation. Secondly, rapid technological innovations and short product lifecycles provide significant opportunities for implementing CE practices. India is selected as the geographical scope of this study due to its rapidly growing electronics market and critical challenges associated with e-waste management. Secondly, India is the third-largest source of e-waste generation in the world. The nation is facing difficulties in managing the growing issue of e-waste. Lastly, India is at a nascent stage of CE transition, which presents great potential for implementation. Based on the research gaps, our study attempts to answer the following three research questions:

RQ5: *'What are the potential enablers and levers of CE adoption in the EEE sector that promote resilient and sustainable supply chains for the future?'*

RQ6: *'What enablers and levers are essential in driving CE adoption in the EEE sector, which promotes resilient and sustainable supply chains for the future?'*

RQ7: *'How do the essential enablers and levers influence each other regarding cause-and-effect relationships?'*

RQ8: *'What are the managerial, social and policy implications of CE adoption at a firm level?'*

The chapter seeks answers to the above RQs in the three phases discussed in the methodology section. The potential list of *enablers* and *levers* was identified in the first phase by conducting a structured literature review. Then, in the subsequent phase, the *enablers* and *levers* were finalized after rounds of discussions with industry experts using the Delphi technique. In the third Phase, the Grey-DEMATEL method was employed to determine the hierarchy and the interrelationship among the *enablers* and *levers*. The DEMATEL method facilitates the analysis of complex interrelationships among factors by identifying and mapping their causal relationships. DEMATEL offers a distinct advantage compared to other techniques by categorizing factors into cause-and-effect groups, thereby providing deeper insights into their relative influence within the system. Further, we have integrated grey systems theory with the DEMATEL method to capture imprecise and vague human judgments, resulting in a comprehensive, unified technique. In the previous research, the DEMATEL method was used to identify successful factors of CE adoption, but not many were specific to the EEE industry. For example, (Tushar et al., 2023) employed this technique in the hospital sector to drive sustainable healthcare service management. Although focused on the EEE sector, another recent study by (Werner-Lewandowska et al., 2025), applied this technique to determine *enablers* and barriers for building a circular supply chain (CSC). Their study focused on one aspect of CSC, which is remanufacturing, and studied *enablers* but lacked discussion on *levers* for building CSC. Hence, this study adopts a pragmatic philosophical stance, and context-driven inquiry to generate actionable insights into the complex challenge of CE adoption. This helps broaden the understanding of the benefits of CE transition to accomplish a goal of achieving a resilient supply chain and sustainable operations.

4.2 Data Analysis

A multi-criteria decision-making (MCDM) method is employed to investigate the study. Among the well-known MCDM methods are the Analytic Hierarchy Process

(AHP), the Analytic Network Process (ANP), Interpretive Structural Modelling (ISM), Total Interpretive Structural Modelling (TISM), and DEMATEL. AHP ranks the factors (Dožić et al., 2023), whereas ANP assesses ranking, identifies relationships amongst the factors, and manages consistency (Chowdhury et al., 2023). However, ANP applicability is limited due to its intricate methodology (Mangla et al., 2018). ISM and TISM have certain limitations in providing structural relationships among criteria and cannot measure and assess the strength of the relationship. The DEMATEL method analyzes factors and helps us understand the causal relationship among the factors (Bali et al., 2023b; Yadav & Barve, 2018). Hence, this method surpasses the above-stated methods and categorizes the components into the cause-and-effect group. One of the limitations of the DEMATEL method is its inability to capture imprecise and vague human judgments. This limitation can be addressed by integrating grey systems theory with the DEMATEL method, resulting in a comprehensive, unified method. Several studies during the past decade used the grey-DEMATEL method. Rajesh & Ravi (Rajesh & Ravi, 2015) incorporated the method to discover the significant supply chain risk mitigation *enablers*. (Vidal et al., 2024) employed the Fuzzy DEMATEL approach to address sustainable practices, risk resilience, and circular economy for the paint manufacturing industry. The steps to analyze data with Grey-DEMATEL method discussed in the methodology section is implemented as follows:

Step 1: The k Initial Relation Matrices (IRM) based on the degree of influence the experts is obtained. Table 4.1 presents the IRM obtained from Expert 1

Table 4.1: Initial relation matrix of Expert 1

Enablers/ Levers	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**
E1	0	2	4	4	4	2	3	3	3	3	3	2	4
E2	2	0	3	3	3	3	4	4	4	3	4	4	4
E3	3	3	0	3	4	3	3	3	4	4	3	4	3
E4	3	4	4	0	4	1	3	3	3	2	2	3	3
E5	3	2	4	4	0	2	3	3	3	3	4	3	4
E6	2	3	2	2	1	0	3	3	3	3	4	2	2
L1	2	2	3	3	4	4	0	4	3	3	4	4	4
L2	3	2	4	3	4	4	4	0	3	4	4	4	4
L3	3	2	3	4	4	2	3	4	0	4	3	4	4
L4	3	2	3	3	4	4	4	4	3	0	4	4	4
L5	3	2	4	4	4	3	3	3	4	2	0	3	3
L6	4	4	4	4	4	4	3	4	3	3	4	0	4
L7	4	3	4	4	4	4	4	2	3	2	4	4	0

Step 2: The ‘grey relation matrices’ were computed using eq (1) by converting the integer scale rating into associated grey scales with the upper and lower values. The grey scales used to represent the integer values are defined in Table 3.5 in Chapter three. Table 4.2 presents the grey relation matrices obtained from Expert 1

Table 4.2: Grey relation matrices of Expert 1

Enablers/ Levers	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**
E1	(0, 0.1)	(0.2, 0.5)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.2, 0.5)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.2, 0.5)	(0.9, 1)
E2	(0.2, 0.5)	(0, 0.1)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0.9, 1)
E3	(0.6, 0.9)	(0.6, 0.9)	(0, 0.1)	(0.6, 0.9)	(0.9, 1)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0.6, 0.9)	(0.9, 1)	(0.6, 0.9)
E4	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0, 0.1)	(0.9, 1)	(0.1, 0.3)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.2, 0.5)	(0.2, 0.5)	(0.6, 0.9)	(0.6, 0.9)
E5	(0.6, 0.9)	(0.2, 0.5)	(0.9, 1)	(0.9, 1)	(0, 0.1)	(0.2, 0.5)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.9, 1)	(0.6, 0.9)	(0.9, 1)
E6	(0.2, 0.5)	(0.6, 0.9)	(0.2, 0.5)	(0.2, 0.5)	(0.1, 0.3)	(0, 0.1)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.9, 1)	(0.2, 0.5)	(0.2, 0.5)
L1	(0.2, 0.5)	(0.2, 0.5)	(0.6, 0.9)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0, 0.1)	(0.9, 1)	(0.6, 0.9)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0.9, 1)
L2	(0.6, 0.9)	(0.2, 0.5)	(0.9, 1)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0, 0.1)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.9, 1)
L3	(0.6, 0.9)	(0.2, 0.5)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0.2, 0.5)	(0.6, 0.9)	(0.9, 1)	(0, 0.1)	(0.9, 1)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)
L4	(0.6, 0.9)	(0.2, 0.5)	(0.6, 0.9)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.6, 0.9)	(0, 0.1)	(0.9, 1)	(0.9, 1)	(0.9, 1)
L5	(0.6, 0.9)	(0.2, 0.5)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.6, 0.9)	(0.6, 0.9)	(0.6, 0.9)	(0.9, 1)	(0.2, 0.5)	(0, 0.1)	(0.6, 0.9)	(0.6, 0.9)
L6	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.6, 0.9)	(0.9, 1)	(0.6, 0.9)	(0.6, 0.9)	(0.9, 1)	(0, 0.1)	(0.9, 1)
L7	(0.9, 1)	(0.6, 0.9)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.9, 1)	(0.2, 0.5)	(0.6, 0.9)	(0.2, 0.5)	(0.9, 1)	(0.9, 1)	(0, 0.1)

Step 3: The average grey relation matrix computed using equation (3.2) is given in Table 4.3:

Step 4: The final crisp value is computed using equations (3.3) to (3.8) and is given in Table 4.4

Step 5: The normalized crisp relation matrix, R, is found by calculating S, computed by taking product of the average relation matrix Z and S, computed using equation (3.9) and (3.10) is presented in Table 4.5

Step 6: Finally, the 'total-relation matrix T' is obtained by using equation (3.11) given in Table 4.6.

Table 4.3: Average Grey Relation Matrix

Enablers/ Levers	E1	E2	E3	E4	E5	E6	L1	L2	L3	L4	L5	L6	L7
E1	(0.00, 0.100)	(0.182, 0.441)	(0.706, 0.935)	(0.741, 0.947)	(0.771, 0.941)	(0.441, 0.706)	(0.776, 0.959)	(0.700, 0.918)	(0.812, 0.971)	(0.776, 0.959)	(0.776, 0.959)	(0.729, 0.912)	(0.729, 0.912)
E2	(0.412, 0.647)	(0.00, 0.100)	(0.582, 0.847)	(0.476, 0.771)	(0.618, 0.859)	(0.659, 0.888)	(0.706, 0.935)	(0.588, 0.865)	(0.865, 0.988)	(0.847, 0.982)	(0.829, 0.976)	(0.676, 0.894)	(0.776, 0.959)
E3	(0.571, 0.859)	(0.541, 0.818)	(0.00, 0.100)	(0.476, 0.765)	(0.547, 0.788)	(0.547, 0.794)	(0.541, 0.824)	(0.524, 0.776)	(0.512, 0.747)	(0.565, 0.800)	(0.688, 0.894)	(0.488, 0.753)	(0.547, 0.800)
E4	(0.565, 0.841)	(0.382, 0.635)	(0.547, 0.835)	(0.000, 0.100)	(0.565, 0.794)	(0.371, 0.618)	(0.306, 0.594)	(0.447, 0.729)	(0.365, 0.629)	(0.165, 0.429)	(0.365, 0.606)	(0.482, 0.782)	(0.482, 0.782)
E5	(0.541, 0.818)	(0.271, 0.571)	(0.565, 0.841)	(0.524, 0.812)	(0.000, 0.100)	(0.441, 0.718)	(0.559, 0.824)	(0.424, 0.712)	(0.465, 0.741)	(0.453, 0.747)	(0.594, 0.835)	(0.529, 0.782)	(0.600, 0.859)
E6	(0.529, 0.829)	(0.494, 0.776)	(0.412, 0.712)	(0.341, 0.641)	(0.306, 0.588)	(0.000, 0.100)	(0.500, 0.794)	(0.500, 0.788)	(0.535, 0.800)	(0.629, 0.894)	(0.571, 0.812)	(0.418, 0.694)	(0.459, 0.759)
L1	(0.565,0. 841)	(0.382, 0.676)	(0.506, 0.806)	(0.576, 0.829)	(0.471, 0.747)	(0.653, 0.871)	(0.000, 0.100)	(0.653, 0.871)	(0.459, 0.718)	(0.582, 0.853)	(0.571, 0.776)	(0.559, 0.776)	(0.559, 0.824)
L2	(0.494, 0.776)	(0.435, 0.735)	(0.488, 0.753)	(0.571, 0.812)	(0.518, 0.747)	(0.424, 0.700)	(0.547, 0.788)	(0.000, 0.100)	(0.559, 0.824)	(0.659, 0.888)	(0.618, 0.859)	(0.459, 0.724)	(0.529, 0.782)
L3	(0.600, 0.900)	(0.459, 0.759)	(0.547, 0.835)	(0.582, 0.847)	(0.459, 0.718)	(0.541, 0.782)	(0.588, 0.865)	(0.571, 0.859)	(0.000, 0.100)	(0.612, 0.888)	(0.535, 0.806)	(0.588, 0.818)	(0.565, 0.841)
L4	(0.518, 0.794)	(0.294, 0.594)	(0.524, 0.812)	(0.476, 0.765)	(0.629, 0.847)	(0.600, 0.806)	(0.571, 0.818)	(0.453, 0.712)	(0.441, 0.706)	(0.000, 0.100)	(0.535, 0.800)	(0.788, 0.947)	(0.571, 0.812)
L5	(0.500, 0.741)	(0.318, 0.618)	(0.353, 0.629)	(0.494, 0.741)	(0.471, 0.747)	(0.424, 0.706)	(0.424, 0.700)	(0.400, 0.688)	(0.335, 0.624)	(0.282, 0.565)	(0.000, 0.100)	(0.288, 0.582)	(0.547, 0.794)
L6	(0.588, 0.818)	(0.588, 0.829)	(0.529, 0.788)	(0.524, 0.771)	(0.429, 0.718)	(0.506, 0.729)	(0.488, 0.729)	(0.506, 0.771)	(0.571, 0.782)	(0.571, 0.859)	(0.576, 0.829)	(0.000, 0.100)	(0.494, 0.771)
L7	(0.529, 0.782)	(0.429, 0.718)	(0.447, 0.724)	(0.594, 0.806)	(0.582, 0.847)	(0.329, 0.612)	(0.465, 0.729)	(0.282, 0.571)	(0.341, 0.641)	(0.241, 0.512)	(0.629, 0.853)	(0.400, 0.676)	(0.000, 0.100)

Table 4.4: Final Crisp Value

Enablers/ Levers	E1	E2	E3	E4	E5	E6	L1	L2	L3	L4	L5	L6	L7
E1	0.000	0.237	***0.807***	***0.826***	***0.829***	***0.536***	***0.844***	***0.793***	***0.861***	***0.843***	***0.843***	***0.794***	***0.794***
E2	***0.483***	0.000	***0.694***	***0.591***	***0.717***	***0.759***	***0.805***	***0.712***	***0.885***	***0.878***	***0.870***	***0.764***	***0.844***
E3	***0.702***	***0.667***	0.000	***0.587***	***0.637***	***0.646***	***0.657***	***0.620***	***0.590***	***0.649***	***0.766***	***0.585***	***0.643***
E4	***0.686***	***0.466***	***0.670***	0.000	***0.649***	***0.444***	***0.387***	***0.551***	***0.440***	0.212	***0.429***	***0.601***	***0.600***
E5	***0.659***	0.362	***0.682***	***0.642***	0.000	***0.544***	***0.665***	***0.528***	***0.562***	***0.560***	***0.687***	***0.624***	***0.708***
E6	***0.662***	***0.616***	***0.520***	***0.436***	***0.385***	0.000	***0.617***	***0.617***	***0.635***	***0.743***	***0.660***	***0.511***	***0.573***
L1	***0.686***	***0.492***	***0.630***	***0.678***	***0.573***	***0.743***	0.000	***0.741***	***0.544***	***0.694***	***0.637***	***0.634***	***0.665***
L2	***0.608***	***0.559***	***0.586***	***0.663***	***0.596***	***0.523***	***0.635***	0.000	***0.662***	***0.751***	***0.713***	***0.551***	***0.623***
L3	***0.745***	***0.587***	***0.670***	***0.693***	***0.548***	***0.635***	***0.707***	***0.700***	0.000	***0.732***	***0.640***	***0.675***	***0.680***
L4	***0.631***	***0.390***	***0.643***	***0.587***	***0.712***	***0.675***	***0.666***	***0.543***	***0.528***	0.000	***0.636***	***0.838***	***0.662***
L5	***0.587***	***0.418***	***0.437***	***0.580***	***0.573***	***0.527***	***0.517***	***0.500***	***0.419***	0.355	0.000	0.370	***0.639***
L6	***0.678***	***0.694***	***0.629***	***0.614***	***0.532***	***0.583***	***0.569***	***0.608***	***0.640***	***0.693***	***0.675***	0.000	***0.598***
L7	***0.629***	***0.544***	***0.546***	***0.669***	***0.694***	***0.417***	***0.557***	0.362	***0.432***	0.302	***0.714***	***0.491***	0.000

Table 4.5: Normalized Crisp Relation Matrix

Enablers/ Levers	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**
E1	0.000	0.026	0.090	0.092	0.092	0.059	0.094	0.088	0.096	0.094	0.094	0.088	0.088
E2	0.054	0.000	0.077	0.066	0.080	0.084	0.089	0.079	0.098	0.097	0.097	0.085	0.094
E3	0.078	0.074	0.000	0.065	0.071	0.072	0.073	0.069	0.065	0.072	0.085	0.065	0.071
E4	0.076	0.052	0.074	0.000	0.072	0.049	0.043	0.061	0.049	0.024	0.048	0.067	0.067
E5	0.073	0.040	0.076	0.071	0.000	0.060	0.074	0.059	0.062	0.062	0.076	0.069	0.079
E6	0.073	0.068	0.058	0.048	0.043	0.000	0.068	0.069	0.071	0.083	0.073	0.057	0.064
L1	0.076	0.055	0.070	0.075	0.064	0.082	0.000	0.082	0.060	0.077	0.071	0.070	0.074
L2	0.068	0.062	0.065	0.074	0.066	0.058	0.071	0.000	0.074	0.083	0.079	0.061	0.069
L3	0.083	0.065	0.074	0.077	0.061	0.070	0.078	0.078	0.000	0.081	0.071	0.075	0.075
L4	0.070	0.043	0.071	0.065	0.079	0.075	0.074	0.060	0.059	0.000	0.071	0.093	0.073
L5	0.065	0.046	0.049	0.064	0.064	0.058	0.057	0.056	0.047	0.039	0.000	0.041	0.071
L6	0.075	0.077	0.070	0.068	0.059	0.065	0.063	0.067	0.071	0.077	0.075	0.000	0.066
L7	0.070	0.060	0.061	0.074	0.077	0.046	0.062	0.040	0.048	0.034	0.079	0.054	0.000

Table 4.6: Total relation matrix *T*

Enablers/ Levers	**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**
E1	0.368	0.315	***0.437***	***0.444***	***0.437***	***0.388***	***0.444***	***0.424***	***0.424***	***0.431***	***0.473***	***0.431***	***0.458***
E2	***0.420***	0.290	***0.427***	***0.422***	***0.428***	***0.412***	***0.443***	***0.418***	***0.429***	***0.438***	***0.478***	***0.430***	***0.465***
E3	***0.394***	0.322	0.311	0.376	0.376	0.359	***0.383***	0.366	0.359	0.372	***0.419***	0.368	***0.398***
E4	0.331	0.253	0.321	0.254	0.317	0.281	0.296	0.301	0.287	0.270	0.321	0.310	0.330
E5	0.368	0.274	0.360	0.360	0.288	0.327	0.361	0.335	0.334	0.340	***0.387***	0.350	***0.381***
E6	0.362	0.294	0.338	0.333	0.324	0.266	0.352	0.339	0.337	0.355	0.379	0.334	0.362
L1	***0.391***	0.303	0.374	***0.382***	0.367	0.365	0.312	0.375	0.352	0.374	***0.404***	0.371	***0.397***
L2	0.374	0.302	0.361	0.372	0.361	0.336	0.369	0.290	0.354	0.370	***0.401***	0.354	***0.384***
L3	***0.409***	0.322	***0.391***	***0.397***	0.377	0.367	***0.398***	***0.384***	0.307	***0.390***	***0.418***	***0.388***	***0.412***
L4	0.377	0.287	0.367	0.365	0.372	0.351	0.373	0.348	0.342	0.294	***0.395***	***0.382***	***0.388***
L5	0.310	0.239	0.287	0.304	0.299	0.280	0.297	0.285	0.274	0.273	0.263	0.277	0.322
L6	***0.384***	0.318	0.369	0.371	0.358	0.345	0.367	0.357	0.356	0.369	***0.402***	0.300	***0.385***
L7	0.331	0.265	0.315	0.330	0.328	0.285	0.318	0.288	0.291	0.283	0.355	0.305	0.274

4.3 Results and Discussions

This section showcases the results obtained through applying the Grey-DEMATEL methodology and endeavors to address RQ6 and RQ7. Particularly, it recognizes the important *enablers* and *levers* that are essential in driving CE transition in the EEE sector and explore their interdependencies (Sehgal, Bali, et al., 2025).

4.3.1 Results

The results presented in this section are based on inputs obtained from 17 domain experts chosen for the study's context. This section draws the findings acquired through the application of the grey-DEMATEL technique. A critical discussion of these results is presented in Section 4.4, where the findings are analyzed in the context of CE adoption in the EEE sector and compared with findings from past literature to highlight alignments and contributions.

4.3.2 Important *Enablers* and *Levers*

The importance of drivers, that is, *enablers*/ *levers*, is determined by prioritizing them based on the highest value of $(r_i + c_j)$ (refer to Table 4.7); the drivers listed in order of their ranking are as follows:

$$E1 > L1 > E3 > L3 > E2 > L6 > L4 > L2 > E5 > L7 > L5 > E6 > E4$$

The top three key drivers in the list are industry 5.0, circular product design, and consumer & society, followed by the circular supply chain, government intervention, building a 'green image' reputation, and sustainable and cleaner production.

4.3.3 Cause and Effect Group

Based on $(r_i - c_j)$ values, the thirteen key drivers have been categorized into cause-and-effect groups. As indicated by the result, nine drivers belong in the cause group: $E2 > E1 > L3 > E3 > L2 > L4 > L6 > L1 > E6$, whereas $E5 > E4 > L7 > L5$ belong in the effect group in cause-effect relationship matrix (refer Table 4.7). Causal drivers can significantly influence the overall system. Hence, they should be given the utmost attention and control. The cause group drivers are called independent factors, whereas the effect group drivers are called dependent factors as they get influenced by the cause group drivers. The top three cause group drivers include two *enablers* and one lever; they are government intervention ($E2$), Industry 5.0 ($E1$) and circular supply chain ($L3$), whereas financial investment ($L7$) is an effect factor for various causal factors followed by innovation ($E5$), competition ($E4$) and competence & skill set building ($L5$).

Table 4.7: Degree of Importance and Net Effect

Enablers/ Levers	**Code**	r_i	c_j	$(r_i + c_j)$	$(r_i - c_j)$	**Cause/ Effect**
Industry 5.0 Technologies	E1	5.474	4.820	10.294	0.654	Cause
Government Intervention	E2	5.500	3.784	9.283	1.716	Cause
Consumer & Society	E3	4.804	4.659	9.463	0.145	Cause
Competition	E4	3.870	4.709	8.579	-0.839	Effect
Innovation	E5	4.466	4.632	9.099	-0.166	Effect
Rising Prices of Raw Materials	E6	4.374	4.362	8.736	0.012	Cause
Circular Product Design	L1	4.768	4.713	9.481	0.055	Cause
Servitized Business Models	L2	4.629	4.510	9.139	0.119	Cause
Circular Supply Chain	L3	4.960	4.448	9.409	0.512	Cause
Sustainable and Cleaner Production	L4	4.643	4.558	9.201	0.085	Cause
Financial Investments	L5	3.710	5.094	8.804	-1.384	Effect
Building a 'Green Image' Reputation	L6	4.681	4.601	9.282	0.080	Cause
Competence & Skill-set Building	L7	3.968	4.956	8.924	-0.988	Effect

The causal diagram is drawn with $(r_i + c_j)$ and $(r_i - c_j)$ values calculated using equation (3.12) and (3.13) in step 7. Figure 4.1 presents the causal diagram.

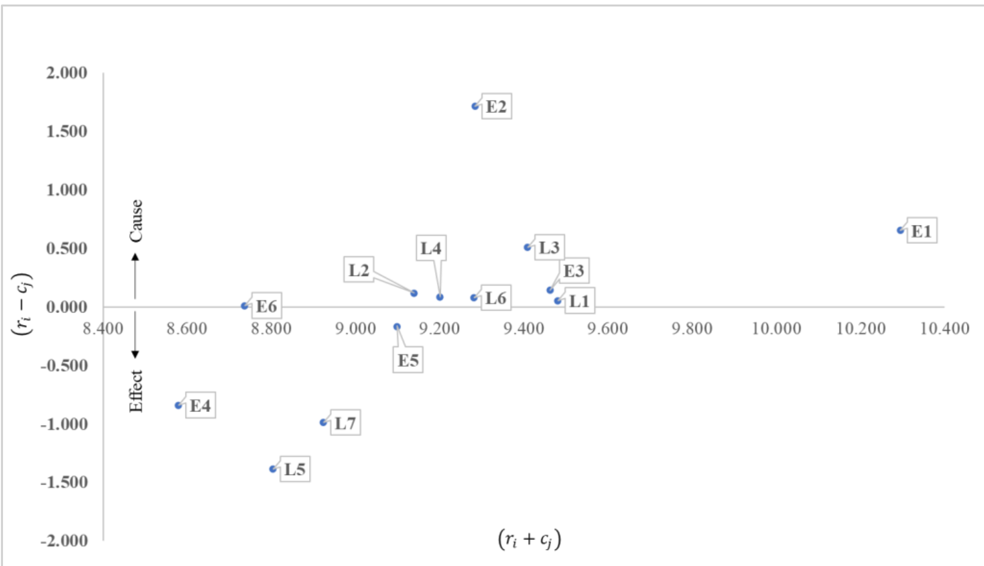

Figure 4.1: Causal Diagram

4.3.4 Inter-relationship between *Enablers* and *Levers*

The number of relations to be drawn on the diagraph were large. Therefore, a threshold value (θ) was predefined. θ was computed by adding 0.5 times the standard deviation (σ) to the mean (μ) of the elements in the total relation matrix T (refer Table 4.6). The mean and standard deviation values were 0.35 and 0.05, respectively, resulting in the threshold value of 0.38. A diagraph showing the causal relationship amongst *enablers* and *levers* is presented in Figure 4.2. The bi-directional relation is captured using a solid line, whereas the unidirectional relation is captured using a dashed line.

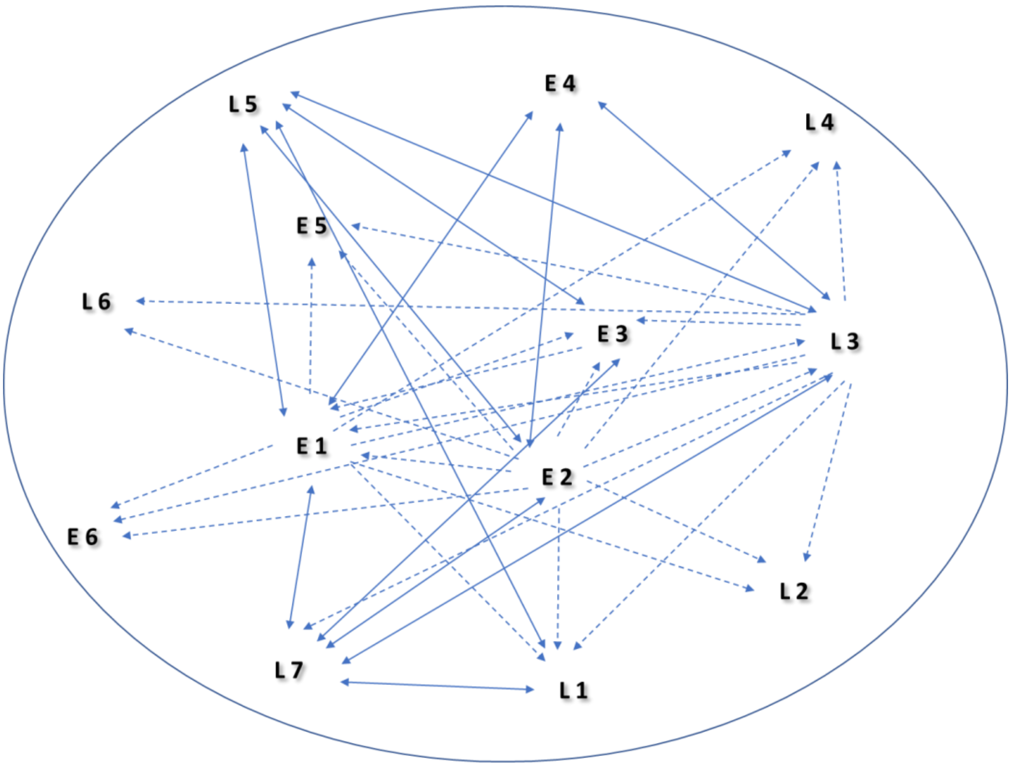

Figure 4.2: Digraph Showing Cause & Effect Relationship

4.4 Discussions

This section discusses results, focusing on achieving supply chain resilience and sustainable operations. It presents the critical *enablers* and *levers* and their interrelationships, along with the resultant economic, environmental, and social benefits (Sehgal, Bali, et al., 2025).

Industry 5.0 technologies (E1), an extension of Industry 4.0, is the topmost enabler of CE adoption in the EEE sector. I5.0 is "the first industrial revolution led by the human focus. It is based on the 6R principles of industrial upcycling – Recognize, Reconsider, Realize, Reduce, Reuse, and Recycle" (Rada Michael, 2018). The amalgamation of Industry 5.0 technologies into manufacturing operations may offer more judicious use, reuse, and recycling of resources (Bali et al., 2022; Kamble & Gunasekaran, 2023). A study by Nakandala et al., (2023) found that digitalization capabilities positively impact supply chain resilience, boosting innovation in operations and processes. Another research study by Turner et al., (2022) emphasized that the functionality of intelligent systems run by I5.0 technology, with a strong focus on the human element, helps achieve sustainability in the circular economy. Similar findings have been reported by Kazancoglu et al., (2023), emphasized that the integration of Industry 4.0 principles holds significant potential for enhancing sustainable supply chain performance by improving operational efficiency and optimizing resource utilization. India is the third largest e-waste-producing country; adopting digitalization through I5.0 technologies could be extremely beneficial as it enables the circular economy implementation to achieve economic, environmental, and social benefits. Hence, our findings on Industry 5.0 technologies echo with the findings of past researchers by reinforcing the importance of emerging technologies as a key enabler of CE transition in the electrical and electronic equipment industry.

Circular product design (L1) is the next indicator of CE adoption in the electronics sector, as this is the phase where commitment to minimizing environmental and economic impact is made (Bressanelli et al., 2021). Circular Product Design, as a lever, has added innovative design strategies such as design for disassembly, re-assembly, durability, ease of repair, and recycling (Bocken et al., 2016). According to a report published by Research and Markets, (2024), India, in the year 2023, generated around 4.1 million metric tons of e-waste, with projections indicating a rise to 7.1 million metric tons by 2030. This alarming trend highlights the urgent need for adopting the CE lever, particularly circular product design, which aims to extend product lifecycles, enable reuse, and enhance recyclability.

Due to climate change and environmental protection awareness, customers are encouraged to go for 'green purchasing' and are willing to spend more on waste recycling (Kumar et al., 2022b), (Awaysheh et al., 2023). Organizations are becoming increasingly aware of the growing public consciousness regarding the hazardous impact of WEEE and the imperative to decrease CO_2 emissions. (Rizos & Bryhn, 2022) This makes consumers and society (E3) a significant enabler of the CE transition and placed in the second position in the list. Our findings align with that of (Bressanelli et al., 2021; Kumar et al., 2022b), (Jauhari et al., 2025), indicating that consumers play an active role in enabling CE adoption during the three stages of the product lifecycle: purchase-use-EOL.

Circular supply chains (L3) are pivotal in driving the transition toward CE by reconfiguring traditional linear supply chains into closed-loop systems prioritizing resource efficiency (Bressanelli et al., 2021). Aligning with the findings of Werner-Lewandowska et al., (2025), our study also underscores that Circular supply chains are critical pillar of CE, as closing the material loop facilitates value recovery and enhances resource efficiency. By enabling the continuous circulation of materials and products, CSC reduces environmental impact, conserves critical resources, and lowers dependency on virgin materials (Ho et al., 2021). Aligned with the insights from the prior studies and experts' evaluations, this finding serves as a strategic pathway toward building resilient and sustainable future supply chains.

The next significant enabler on the priority list is government intervention (E2). Governments can push the evolution towards a circular economy by imposing robust laws & legislation (Buttke et al., 2024). Many past papers have discussed the government's role in forcing CE transition into their companies through mandatory regulations (Bhattacharjee et al., 2023; Bressanelli et al., 2021; Favot et al., 2018). In 2012, the Indian government implemented Extended Producer Responsibility (EPR) to handle EEE waste. Therefore, the standards and protocols compelled the EEE sector to undergo EPR responsibility once the product's lifecycle is complete (Aminoff & Pihlajamaa, 2020; Bhadra & Mishra, 2021).

Sustainable and cleaner production (L4) is a significant lever of CE transition. As per a similar study conducted by (Gupta, Kumar, & Wasan, 2021) to assess the sustainability effectiveness of manufacturing firms, SCP is among the top three significant practices of CE transition. SCP practices involve conserving natural resources, minimizing energy usage, properly disposing of toxic substances, and ensuring ethical and sustainable business. Past studies have also indicated that the sustainable development of businesses and the planet relies on companies embracing sustainable and cleaner practices (Govindan, 2018; Luthra et al., 2016). Next in the list is servitized business models (L2); the concept is catching the attention of the manufacturers to leverage CE transition. Manufacturers are adding services to their offerings and transforming the business model from a product-based transaction to a service-based subscription model. This powerful business model integrates digitization and servitization (Adrodegari & Saccani, 2020). Manufacturers use sensors (IoT), software, and wireless connectors to add new product features (Ingemarsdotter et al., 2020). Leading electronic manufacturing companies are rushing to connect everything from refrigerators to electronic toothbrushes. By adding service components to the products, companies have opened new avenues for generating value for customers and themselves. They have realized that SBM has allowed them to move from an open-loop system to a closed-loop system and paved the way toward achieving supply chain resilience and sustainable operations (AYYASWAMY REGU, 2023).

Competence and skill-set building (L7) are also important *levers* in the CE transition. Regular CE training programs and internal workshops must be conducted to strengthen employees' skills & capabilities to ensure continuous improvement in their performance (Bhattacharjee et al., 2023; Rizos & Bryhn, 2022). The government should support firms in organizing seminars with global experts to provide avenues for capability development. The government is also developing robust rules and procedures to tackle the challenges of electronic waste generation. (Bressanelli et al., 2021) emphasized that EEE companies implementing a CE can exploit government intervention as a critical enabler to yield economic, environmental, and social benefits. Companies also apply for certifications, such as ISO 14000, to earn a green reputation. Rising prices of virgin materials have minimized their usage in production. Product return and recovery are essential for enabling a circular supply chain to preserve the value and quality of products and materials while reducing the reliance on virgin resources (MacArthur, 2023). Therefore, companies must embrace CE practices, potentially resulting in resource conservation and economic benefits.

Finally, innovation is an emerging enabler of the CE transition in making supply chains resilient and sustainable. To a certain extent, this finding is aligned with the latest study by Coluccia et al., (2024); the authors reported that innovations in research & development are gradually improving recycling efficiency for a wide range of parts and materials.

The result of cause and effect revealed that $E1, E2, E3, E6, L1, L2, L3, L4, and\ L6$ falls under the causal. However, $E4, E5, L5\ and\ L7$ falls in the class of effect group $enablers\text{-}levers$.

The first three factors in the cause group are Government Intervention (E2), Industry 5.0 (E1), and Circular Supply Chain (L3), which should be given utmost importance when implementing the circular economy into practice. Congruent with the findings of Ikram & Sadki, (2024) and Kumar et al., (2022b), Government Intervention is a crucial enabler of CE transition as the government plays an instrumental role in enforcing laws and regulations for managing e-waste, setting up global standards, and providing financial support to e-manufacturing companies. Next in the list of cause group factors is Industry 5.0 technologies. It is essential to prioritize these cause group factors as they can have a spillover effect on the other factors. Our findings reveal that integrating I5.0 technologies may leverage factors such as Circular Product Design, Servitized Business Models, and Sustainable & Cleaner Production; when these are in place, they will positively impact the consumer and society. This research finding is aligned with H. Lu et al., (2024) and Santiago et al., (2025). Businesses may leverage Circular Supply Chain by optimizing the forward supply chain, integrating networks and close collaboration, and introducing reverse logistics into their current supply chain (H. Lu et al., 2024; Bag & Kumar Mangla, 2025; Bali et al., 2022). The Circular Supply Chain is crucial in driving other *enablers* such as consumers and society, competition, and innovation as CSC disintegrates monetary growth from ecological losses and resource extraction. Thus, Circular Supply Chain brings economic gains by minimizing the use of virgin resources in manufacturing and encouraging the use of second-hand materials in manufacturing new goods.

Factors put under the ‘effect’ group get influenced by the factors in the ‘cause’ group. Our findings reveal that financial investment (L5) is an effect factor for many causal factors. Leveraging Circular Product Design, Circular Supply Chain, and Sustainable & Cleaner Production involves high initial investment but results in resources and cost savings in the long run. Similarly, the three *enablers* influencing the financial investment lever are Industry 5.0, Government Intervention, and Consumer & Society (Khan et al., 2022; Mallick et al., 2023b). Adopting digitalization through I5.0 technologies may affect financial planning. Still, it enables a smooth transition towards a circular economy to achieve supply chain resilience and sustainable operations in the EEE sector. However, government intervention may ease the process of CE transition by providing financial support to organizations (Favot et al., 2018;

Morseletto, 2020). Our findings also conclude that consumer awareness of sustainability and climate change compels organizations to invest money in transitioning their organization from a linear to a sustainable CE model. Our findings are aligned with (Jauhari et al., 2025). The transition demands significant investment in establishing new supply chain infrastructure, both physical and digital; these initial costs are likely to be relatively high until the desired scale of operations is achieved. Our findings are allied with (Kumar et al., 2022b; Rizos & Bryhn, 2022). Next in the effect group is the lever competence and skill set building (CSB); this is also influenced by Industry 5.0, Government Intervention, Circular Product Design, Circular Supply Chain, and Sustainable & Cleaner Production. competence and skill set building is interrelated with Industry 5.0 and government intervention, which indicates that sufficient training in emerging technologies and sustainable practices will help the workforce adapt and learn the innovative *levers* of the CE transition (Bhattacharjee et al., 2023; M. Sharma et al., 2020).

4.5 Study Implications

Our findings provide valuable implications for researchers, practitioners, and policymakers to devise a strategic roadmap for the CE transition to achieving sustainable and resilient supply chain operations.

4.5.1 Implications for Theory

The study attempts to provide five notable contributions. First, the study proposed a framework to identify the significant *enablers* and *levers* of CE transition and their associations. The novelty of this design is to put the *enablers* and *levers* together in a single framework; with this, it is easy to comprehend the significant contextual factors of CE transition in the form of *enablers*, and which are the best practices the organization can adopt in the form of *levers*. The study highlighted that *enablers* and *levers* are significant drivers of CE transition and cannot be studied in isolation.

Second, the study accessed six *enablers* and seven *levers* using the Grey DEMATEL approach. Scholars can apply other MCDM methods to confirm the model results. Third, future studies may consider adding new *enablers* and *levers* that benefit organizations by achieving sustainable goals of economic growth and environmental and social impact. Moreover, very few research papers discuss the integration of I5.0 and CE transition, leaving potential for future researchers to explore this domain. Fourth, the experts propose an enabler, namely competition, during the study's second phase, and the enabler innovation is not explored much in the extant literature; scholars can include these two *enablers* in their future research. Lastly, the study focused only on the EEE sector of developing nations; a similar framework of *enablers* and *levers* can be designed for the other industry sectors, such as textile and healthcare of both the developing and developed countries.

4.5.2 Implications for Managers

The study underscores the strategic importance of *enablers* and *levers* for supply chain and operations management practitioners in the electronic industry. These *enablers* and *levers* are crucial in achieving the strategic goal of sustainability and supply chain resilience through the CE transition. After numerous iterations, the authors identified four vital cause group *enablers*/ *levers* that should be prioritized during the CE transition process. These are GI (E2), I5.0 (E1), CSC (L3), and CS (E3). Concentrating on these factors can benefit firms, as they are essential and influence other factors to facilitate the CE transition. Therefore, practitioners must develop a comprehensive strategic plan prioritizing the four key factors necessary for transitioning from the traditional linear 'take-make-dispose' model to a more sustainable and circular paradigm.

Managers should also recognize the significant impact of the two effect group *levers*: financial investment (L5) and Competence and skill-set building (L7). Organizations that proactively invest in circular practices can position themselves as leaders in sustainability and innovation, positively impacting the three dimensions of sustainability. Equipping professionals and the workforce with essential knowledge, technical skills, and adaptability is crucial for the effective implementation of circular initiatives and for fostering a culture of innovation, sustainability, and long-term success. This transition necessitates the reevaluation of circular product design, the institution of the circular supply chain, an amalgamation of emerging technologies into the operational workflows, and proactive adjustment to evolving regulatory landscapes. Ultimately, this holistic approach reduces environmental footprints and fosters excellent resource optimization.

4.5.3 Implications for Policymakers

The findings revealed that government intervention is a critical enabler of CE transition and is at the top of the list of cause-group factors. It plays a critical role in steering the overall system by influencing other *enablers* and the *levers*. Thus, the study offers valuable insights for policymakers, administrators, and governments toward sustainable e-waste management in developing nations. Government intervention tends to leverage the circular supply chain by implementing Industry 5.0 technologies and circular product design, which is one of the key findings of our study. Policymakers, as the key players, should direct efforts towards governmental interventions such as enacting laws and legislation, offering financial support, encouraging sustainable practices, and promoting awareness campaigns to foster CE transition. This will help achieve economic, ecological, and societal benefits, underscoring policymakers' crucial role in this transition.

4.6 Summary

The growing volume of EEE waste has become a significant global concern, driven by rapid technological advancements and shorter product lifecycles. Addressing this problem requires the timely implementation of CE strategies and enhanced collaboration among stakeholders throughout the value chain. In this perspective, the study identified and analyzed key *enablers* and *levers* of CE adoption in the EEE sector, offering a structured framework to guide the sustainable transition from linear to circular supply chains.

The escalating accumulation of e-waste poses a major challenge for every country. Leveraging CE strategies into the traditional supply chain can successfully address this challenge. Electronic manufacturing firms must comprehend the *enablers* and *levers* of CE transition, as they are critical for accomplishing enduring sustainability benefits. To address the lack of understanding regarding the CE transition, this chapter utilized the grey-DEMATEL method to highlight the prominent *enablers* and *levers* and their associations. The result highlighted that the top three critical factors of CE transition are Industry 5.0, circular product design, and consumer & society, followed by circular supply chain and government intervention. The findings also reveal that government intervention and Industry 5.0 are the two top cause group *enablers*, whereas financial investment followed by competence & skill set building of the workforce are the two prominent effect group *levers* of CE adoption. The findings hold notable propositions for policymakers and practitioners, offering them the roadmap to prioritize the *enablers* and *levers* based on their rank and association. This, in turn, directs them in framing a strategic plan for successful CE transition to establish the resilient supply chains of the future.

CHAPTER – 5

CONCLUSION, LIMITATION AND DIRECTIONS FOR FUTURE RESEARCH

This thesis presents a hybrid comprehensive framework for firm-level adoption of circular economy. The study focuses on EEE sector, which is identified as a high-priority sector for CE transition due to the exponential increase in e-waste. The key objective of CE transition is to deliver economic, environmental and social benefit through the circular flow of resources. Incorporating CE practices into business has a remarkable impact on the entire value chain by minimizing waste production, enhancing resource efficiency, and encouraging sustainability-focused collaboration among stakeholders.

The study draws its foundation from a Systematic Literature Review of 94 peer-reviewed papers, which identified three major themes of CE adoption – ecosystem, design strategies, and circular business models. From these themes, two specific research gaps were selected to shape the scope of this thesis:

- The lack of a sector specific investigation of CE adoption at a firm-level
- The absence of a comprehensive framework for evaluating enablers and levers.

For the proposed frameworks the motivation behind it, data required for implementation and the experts involved in the research are discussed. Finally, the formulation of resulting model, the procedure for solving the model, and solution of decision-making framework are also presented and deliberated in the thesis. The frameworks proposed in this thesis consider many realistic factors like, the enablers & levers of CE adoption, and uncertainty involved in decision-making.

5.1 Conclusion

All said and done, there is always a scope of enhancement and expansion. Circular Economy adoption is a smoldering challenge in all industries that make a committed involvement of technological, economic, environmental and social factors. This thesis has tried to make sincere efforts in applying multi-criteria decision-making techniques to the area of circular economy adoption and circular supplier selection. Notwithstanding the research done and contributions made, the conclusion touches on some points of possibility of future research. The thesis is divided into five chapters. Chapter ***one*** sets out the context for the study by outlining the background and significance of circular economy adoption in the EEE sector. It presents the problem statement, research gaps, objectives, research questions, and scope of the study, thereby establishing the foundation for subsequent chapters. Now we briefly conclude the work presented in the rest of the chapters.

Chapter ***two*** examines the existing CE models and approaches prevailing in the EEE industry ecosystem through a systematic literature review process. From the corpus of 94 papers, the author first extracted three broad themes of CE transition at the firm level: ecosystem (n=42), design strategies (n=32), and circular economy business models (n=20). For every theme, the papers were then further classified into different sub-themes. It has been found that EEE companies can achieve firm-level CE transition through an ecosystem connected over strategic partnerships, and innovative product design strategies with the intent of waste minimization and enhancing resource recovery. The study also revealed that implementation of CEBM models results in improve business operations and increase revenue generation. Hence, CE transitions bring significant benefits; however, the process may bring several challenges.

Chapter ***three*** aims to present and justify the chosen research methodology for this research study. This study adopts a mixed-method research design that integrates qualitative insights from literature review with quantitative analysis using advanced multi-criteria decision-making (MCDM) techniques. Hence, this chapter outlined the research methodology adopted to examine circular economy adoption in the Indian EEE sector. Through this methodological foundation, the chapter presents a structured approach to comprehend the transition from theory to practical implementation.

Chapter ***four*** identifies the enablers and levers of CE adoption specific to EEE sector. The study's data was collected from expert panel within the EEE industry. The Grey-DEMATEL method was utilized to obtain the prominent enablers and levers and their associations. The top three critical factors of CE transition are Industry 5.0, circular product design, and consumer & society, followed by circular supply chain and government intervention. The findings also revealed that government intervention and Industry 5.0 are the two top cause group enablers of CE adoption, whereas, the two prominent effect group levers are financial investment followed by competence & skill set building of the workforce. The findings bring important implications for practitioners and policymakers, offering them the roadmap to prioritize the enablers and levers based on their rank and association. Hence, the proposed framework guides them in creating a strategic plan for effective CE transition to achieve the resilient supply chains of the future.

5.2 Limitations and Direction for Future Research

This research provides valuable information for academician, practitioners and policy makers. Nevertheless, like every research study has some limitations that must be recognized. These limitations are discussed in two folds – one for the systematic literature review and the other for the study of enablers and levers of CE adoption. In SLR initially, the author searched the specified keywords exclusively on the Scopus digital database. As a result, the author may have overlooked some similar research that is included in other databases. However, the possibility of overlooking appropriate research is minimal due to the wide scope of the Scopus database, which includes around 90% of the overall scientific output across all functional domains.

Second, while terminologies are frequently used within this context, it is possible that certain scholars may have employed used terminology to denote circular economy in this situation. These studies may have been overlooked. Further, future evaluations may expand the scope of keywords to identify relevant studies that offer novel academic and practical outlooks that may have been ignored, guaranteeing comprehensive coverage.

Third, although the study successfully analyzed significant enablers and levers of CE transition, several limitations remain, which open avenues for enhancement and future research. Based on the current state of sustainability and CE practices at the firm level, the author found six ‘enablers’, and seven ‘levers’ of CE adoption. These may not account for dynamic changes over time. Therefore, to capture these evolving enablers and levers and their interdependencies in future, longitudinal studies are necessary. Further study may emphasize on tracking phases of enablers and levers and how particular enablers and levers gain or lose importance.

Fouth, this research study is industry specific, focused only on EEE sector. In the upcoming research, scholars can replicate the study for automotive, e-commerce or healthcare. This would help to measure the results' generalizability. Since these industries face diverse CE adoption challenges, testing the model in this context would help gauge whether the identified enablers and levers are sector-specific or universally applicable.

5.3 Summary

This chapter furnishes chapter wise concluding remarks, along with the study limitations and the future scope of work. The study aims at providing a comprehensive framework for CE adoption in EEE organization. The author first conducted a systematic literature review to find out gaps in the current literature and to understand the need for CE adoption at the organization level. The SLR findings indicate a lack of research on CE adoption through the lens of enablers and levers, grounded in sustainability-oriented criteria. To address this gap, a hybrid decision-making framework based on Delphi and Grey-DEMATEL technique is proposed to prioritize and establish relationship amongst the enablers and levers. The findings indicate that while industry 5.0 technologies and circular product design are driving forces for CE adoption, the long-term success of CE transition depends on government intervention and strategic supplier collaboration. Despite some limitations, the study opens promising avenues for future research, including longitudinal study, cross-industry comparisons, new criteria emerging out of technology integration. Overall, the study emphasizes that the shift towards the circular economy is not just a strategic move; it also paves the way for the resilience, competitiveness, and sustainability of Indian EEE firms in the era of Industry 5.0.

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ANNEXURE A

QUESTIONNAIRE

Dear Sir/Madam,

This questionnaire is designed to gain your insights on importance of various ***enablers and levers to facilitate the adoption of circular economy (CE) practices into the business.***

Enablers are 'the conditional and contextual factors that facilitate the implementation of levers', whereas, ***Levers*** are 'tools and practices on which companies may leverage on to activate the adoption of circular economy practices'.

Table A.1: The list of **enablers** along with their description:

No.	Enabler	Description
E1	Industry 5.0 technologies	They are 'the enabling technologies centered around three interrelated essential values: human-centricity, sustainability, and resilience. These technologies are the Internet of Everything (IoE), collaborated robots, big data analytics, artificial intelligence and blockchain.'
E2	Government Intervention	Government intervention can 'enable CE implementation by enforcing regulations and laws, setting global standards, and providing financial support.'
E3	Consumer & Society	Rising societal consciousness of environmental protection and climate change concerns has changed consumer demand. Hence, consumers and society can enable firms to adopt CE.'
E4	Competition	Competition can 'enable firms to adopt CE-led practices to achieve resilience and be competitive with global competitors.'
E5	Innovation	Innovation refers to 'an ability of a firm in thinking out-of-the box and coming up with innovative ideas related to the product/ process to enhance circularity in the system.'
E6	Rising prices of raw material	Rising prices of virgin raw material can 'act as catalyst for the adoption of circular economy practices by making it more financially viable for companies to switch to sustainable alternatives and explore alternative means of cost reduction.'

Table A.2: The list of **levers** along with their description

No.	Levers	Description
L1	Circular product design	It refers to 'the designing a product in way to keep the product/ components/ parts at their highest utility and value throughout their life cycle. Various circular product designs include design for durability and lifespan extension, design for ease of maintenance and repair, and design for disassembly, re-assembly, and recycling.'
L2	Servitized business models	Servitized business models involve 'a shift away from the conventional approach of selling products towards a focus on providing services to customers to maintain ongoing relationships. These models may take different forms such as ***product-oriented*** (which includes services like after-sales support, maintenance, and repairs) and ***use-oriented*** models (such as leasing and sharing).'
L3	Circular Supply chain	Circular supply chains can be 'leveraged by companies through various means such as improving the efficiency of the ***forward supply chain***, establishing ***partnerships and collaborations*** within the supply chain, and promoting ***reverse logistics***.'
L4	Sustainable & Cleaner Production	Sustainable consumption and production (SCP) involve 'developing goods and services using processes and systems that do not harm the environment, while conserving natural resources and minimizing energy use. These practices should also be economically viable, provide safe and healthy working conditions for employees.'
L5	Financial Investments	Progress towards a CE transition requires 'high financial investment initially; however, in the long run, this will help businesses achieve substantial cost savings while improving their operational processes through greater resource efficiency.'
L6	Building 'Green image' reputation	A company with green brand image is 'viewed positively and trusted by environmentally friendly customers. To establish a reputation for sustainability, a company must incorporate environmentally friendly practices into its production processes, thereby differentiating itself from competitors.'
L7	Competence & skill set building of workforce	This pertains to 'the training of workers and managers with the necessary skill sets to enable a seamless transition from a linear to a circular economy. The skillset and competency include training in industry 5.0 technologies, sustainable design, waste minimization, recycle etc.'

The Enablers and levers are listed below (Table A.4-onwards). All the listed enablers/ levers have either no or some degree of influence over the other. Each table includes the degree of influence between the pair of enablers/ levers (*i* & *j*). The degree of influence ranges from ***'no influence'*** to ***'very high influence'***.

Note- In each table respondents have to fill the degree of influence of one enabler/ lever (*i*) over the other enabler/ lever (*j*). Left side of the table shows enabler/ lever (*i*), and enabler/ lever (*j*) is given in extreme right. In between the two sides are the different degree of influence, you can tick **<u>any one of them</u>** based on your experience with the circular economy adoption practices. (Refer Illustration)

<u>Illustration</u>

You are requested to mark the degree of influence of "Industry 5.0" technologies denoted by (*i*) on the enabler/ lever (*j*) (such as government intervention, consumer and society and others). Just click the box for your preferred degree of influence. See the table below, Table **A.3**

Table A.3: Illustration

Indicate the degree of influence of <u>Industry 5.0 technologies</u> *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler/lever (*j*)**
Industry 5.0 technologies	☒	☐	☐	☐	☐	Government Intervention
Industry 5.0 technologies	☐	☐	☐	☒	☐	Consumer & society
Industry 5.0 technologies	☐	☐	☐	☐	☒	Competition
Industry 5.0 technologies	☐	☐	☐	☒	☐	Innovation

*box with a cross is the selected degree of influence for a particular enabler/ lever (*i)* on (*j)* (i.e. the degree of influence is from left to right).

*If you want to remove the selection, click the selected box, the selection will disappear.

Table A.4: Degree of influence of 'Industry 5.0_technologies' *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of <u>Industry 5.0 technologies</u> *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influen ce**	**Very low influen ce**	**low influen ce**	**High influen ce**	**Very high influen ce**	**Enabler/ lever (*j*)**
Industry 5.0 technologies	☐	☐	☐	☐	☐	Government Intervention
Industry 5.0 technologies	☐	☐	☐	☐	☐	Consumer & society

Industry 5.0 technologies	☐	☐	☐	☐	☐	Competition
Industry 5.0 technologies	☐	☐	☐	☐	☐	Innovation
Industry 5.0 technologies	☐	☐	☐	☐	☐	Rising prices of raw material
Industry 5.0 technologies	☐	☐	☐	☐	☐	Circular product design
Industry 5.0 technologies	☐	☐	☐	☐	☐	Servitized business models
Industry 5.0 technologies	☐	☐	☐	☐	☐	Circular Supply chain
Industry 5.0 technologies	☐	☐	☐	☐	☐	Sustainable & Cleaner Production
Industry 5.0 technologies	☐	☐	☐	☐	☐	Financial Investments
Industry 5.0 technologies	☐	☐	☐	☐	☐	Building 'Green image' reputation
Industry 5.0 technologies	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.5: Degree of influence of 'Government Intervention' (i) on different enabler/lever (j)

Indicate the degree of influence of Government Intervention *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler/lever (*j*)**
Government Intervention	☐	☐	☐	☐	☐	Industry 5.0 technologies
Government Intervention	☐	☐	☐	☐	☐	Consumer & society
Government Intervention	☐	☐	☐	☐	☐	Competition
Government Intervention	☐	☐	☐	☐	☐	Innovation
Government Intervention	☐	☐	☐	☐	☐	Rising prices of raw material
Government Intervention	☐	☐	☐	☐	☐	Circular product design

Government Intervention	☐	☐	☐	☐	☐	Servitized business models
Government Intervention	☐	☐	☐	☐	☐	Circular Supply chain
Government Intervention	☐	☐	☐	☐	☐	Sustainable & Cleaner Production
Government Intervention	☐	☐	☐	☐	☐	Financial Investments
Government Intervention	☐	☐	☐	☐	☐	Building ‘Green image’ reputation
Government Intervention	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.6: Degree of influence of ‘Consumer & Society’ *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of Consumer & Society *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influenc e**	**Very low influenc e**	**low influenc e**	**High influenc e**	**Very high influenc e**	**Enabler/lever (*j*)**
Consumer & society	☐	☐	☐	☐	☐	Government Intervention
Consumer & society	☐	☐	☐	☐	☐	Industry 5.0 technologies
Consumer & society	☐	☐	☐	☐	☐	Competition
Consumer & society	☐	☐	☐	☐	☐	Innovation
Consumer & society	☐	☐	☐	☐	☐	Rising prices of raw material
Consumer & society	☐	☐	☐	☐	☐	Circular product design
Consumer & society	☐	☐	☐	☐	☐	Servitized business models
Consumer & society	☐	☐	☐	☐	☐	Circular Supply chain

Consumer & society	☐	☐	☐	☐	☐	Sustainable & Cleaner Production
Consumer & society	☐	☐	☐	☐	☐	Financial Investments
Consumer & society	☐	☐	☐	☐	☐	Building 'Green image' reputation
Consumer & society	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.7: Degree of influence of 'Competition' *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of <u>Competition</u> *(i)* on different enabler/lever *(j)*						
Enabler/ lever (*i*)	**No influenc e**	**Very low influenc e**	**low influenc e**	**High influenc e**	**Very high influenc e**	**Enabler/lever (*j*)**
Competition	☐	☐	☐	☐	☐	Government Intervention
Competition	☐	☐	☐	☐	☐	Consumer & society
Competition	☐	☐	☐	☐	☐	Industry 5.0 technologies
Competition	☐	☐	☐	☐	☐	Innovation
Competition	☐	☐	☐	☐	☐	Rising prices of raw material
Competition	☐	☐	☐	☐	☐	Circular product design
Competition	☐	☐	☐	☐	☐	Servitized business models
Competition	☐	☐	☐	☐	☐	Circular Supply chain
Competition	☐	☐	☐	☐	☐	Sustainable & Cleaner Production
Competition	☐	☐	☐	☐	☐	Financial Investments
Competition	☐	☐	☐	☐	☐	Building 'Green image' reputation
Competition	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.8: Degree of influence of 'Innovation' *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of <u>Innovation</u> *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler/lever (*j*)**
Innovation	☐	☐	☐	☐	☐	Government Intervention
Innovation	☐	☐	☐	☐	☐	Consumer & society
Innovation	☐	☐	☐	☐	☐	Competition
Innovation	☐	☐	☐	☐	☐	Industry 5.0 technologies
Innovation	☐	☐	☐	☐	☐	Rising prices of raw material
Innovation	☐	☐	☐	☐	☐	Circular product design
Innovation	☐	☐	☐	☐	☐	Servitized business models
Innovation	☐	☐	☐	☐	☐	Sustainable & Cleaner Production
Innovation	☐	☐	☐	☐	☐	Cleaner Production
Innovation	☐	☐	☐	☐	☐	Financial Investments
Innovation	☐	☐	☐	☐	☐	Building 'Green image' reputation
Innovation	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.9: Degree of influence of 'Rising prices of raw material' *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of <u>Rising prices of raw material</u> *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler/lever (*j*)**
Rising prices of raw material	☐	☐	☐	☐	☐	Government Intervention
Rising prices of raw material	☐	☐	☐	☐	☐	Consumer & society
Rising prices of raw material	☐	☐	☐	☐	☐	Competition
Rising prices of raw material	☐	☐	☐	☐	☐	Innovation
Rising prices of raw material	☐	☐	☐	☐	☐	Industry 5.0 technologies
Rising prices of raw material	☐	☐	☐	☐	☐	Circular product design
Rising prices of raw material	☐	☐	☐	☐	☐	Servitized business models
Rising prices of raw material	☐	☐	☐	☐	☐	Circular Supply chain
Rising prices of raw material	☐	☐	☐	☐	☐	Sustainable & Cleaner Production
Rising prices of raw material	☐	☐	☐	☐	☐	Financial Investments
Rising prices of raw material	☐	☐	☐	☐	☐	Building 'Green image' reputation
Rising prices of raw material	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.10: Degree of influence of 'Circular product design' *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of Circular product design *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler/lever (*j*)**
Circular product design	☐	☐	☐	☐	☐	Government Intervention
Circular product design	☐	☐	☐	☐	☐	Consumer & society
Circular product design	☐	☐	☐	☐	☐	Competition
Circular product design	☐	☐	☐	☐	☐	Innovation
Circular product design	☐	☐	☐	☐	☐	Rising prices of raw material
Circular product design	☐	☐	☐	☐	☐	Industry 5.0 technologies
Circular product design	☐	☐	☐	☐	☐	Servitized business models
Circular product design	☐	☐	☐	☐	☐	Circular Supply chain
Circular product design	☐	☐	☐	☐	☐	Sustainable & Cleaner Production
Circular product design	☐	☐	☐	☐	☐	Financial Investments
Circular product design	☐	☐	☐	☐	☐	Building 'Green image' reputation
Circular product design	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.11: Degree of influence of 'Servitized business models' *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of Servitized business models *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler/lever (*j*)**
Servitized business models	☐	☐	☐	☐	☐	Government Intervention
Servitized business models	☐	☐	☐	☐	☐	Consumer & society
Servitized business models	☐	☐	☐	☐	☐	Competition

Servitized business models	☐	☐	☐	☐	☐	Innovation
Servitized business models	☐	☐	☐	☐	☐	Rising prices of raw material
Servitized business models	☐	☐	☐	☐	☐	Circular product design
Servitized business models	☐	☐	☐	☐	☐	Industry 5.0 technologies
Servitized business models	☐	☐	☐	☐	☐	Circular Supply chain
Servitized business models	☐	☐	☐	☐	☐	Sustainable & Cleaner Production
Servitized business models	☐	☐	☐	☐	☐	Financial Investments
Servitized business models	☐	☐	☐	☐	☐	Building 'Green image' reputation
Servitized business models	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.12: Degree of influence of 'Circular Supply Chain' *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of <u>Circular Supply Chain</u> *(i)* on different enabler/lever *(j)*						
Enabler/ lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler/lever (*j*)**
Circular Supply chain	☐	☐	☐	☐	☐	Government Intervention
Circular Supply chain	☐	☐	☐	☐	☐	Consumer & society
Circular Supply chain	☐	☐	☐	☐	☐	Competition
Circular Supply chain	☐	☐	☐	☐	☐	Innovation
Circular Supply chain	☐	☐	☐	☐	☐	Rising prices of raw material
Circular Supply chain	☐	☐	☐	☐	☐	Circular product design
Circular Supply chain	☐	☐	☐	☐	☐	Servitized business models
Circular Supply chain	☐	☐	☐	☐	☐	Industry 5.0 technologies
Circular Supply chain	☐	☐	☐	☐	☐	Sustainable & Cleaner

						Production
Circular Supply chain	☐	☐	☐	☐	☐	Financial Investments
Circular Supply chain	☐	☐	☐	☐	☐	Building 'Green image' reputation
Circular Supply chain	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.13: Degree of influence of 'Sustainable & Cleaner Production' *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of Cleaner Production *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler/ lever (*j*)**
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Government Intervention
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Consumer & society
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Competition
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Innovation
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Rising prices of raw material
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Circular product design
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Servitized business models
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Circular Supply chain
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Industry 5.0 technologies
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Financial Investments
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Building 'Green image' reputation
Sustainable & Cleaner Production	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.14: Degree of influence of 'Financial Investments' *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of Financial Investments *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler/ lever (*j*)**
Financial Investments	☐	☐	☐	☐	☐	Government Intervention
Financial Investments	☐	☐	☐	☐	☐	Consumer & society
Financial Investments	☐	☐	☐	☐	☐	Competition
Financial Investments	☐	☐	☐	☐	☐	Innovation
Financial Investments	☐	☐	☐	☐	☐	Rising prices of raw material
Financial Investments	☐	☐	☐	☐	☐	Circular product design
Financial Investments	☐	☐	☐	☐	☐	Servitized business models
Financial Investments	☐	☐	☐	☐	☐	Circular Supply chain
Financial Investments	☐	☐	☐	☐	☐	Sustainable & Cleaner Production
Financial Investments	☐	☐	☐	☐	☐	Industry 5.0 technologies
Financial Investments	☐	☐	☐	☐	☐	Building 'Green image' reputation
Financial Investments	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.15: Degree of influence of 'Building Green image' reputation' *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of Building 'Green image' reputation *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler/ lever (*j*)**
Building 'Green image' reputation	☐	☐	☐	☐	☐	Government Intervention
Building 'Green image' reputation	☐	☐	☐	☐	☐	Consumer & society
Building 'Green image' reputation	☐	☐	☐	☐	☐	Competition
Building 'Green image' reputation	☐	☐	☐	☐	☐	Innovation
Building 'Green image' reputation	☐	☐	☐	☐	☐	Rising prices of raw material
Building 'Green image' reputation	☐	☐	☐	☐	☐	Circular product design
Building 'Green image' reputation	☐	☐	☐	☐	☐	Servitized business

						models
Building ‘Green image’ reputation	☐	☐	☐	☐	☐	Circular Supply chain
Building ‘Green image’ reputation	☐	☐	☐	☐	☐	Cleaner Production
Building ‘Green image’ reputation	☐	☐	☐	☐	☐	Financial Investments
Building ‘Green image’ reputation	☐	☐	☒	☐	☐	Industry 5.0 technologies
Building ‘Green image’ reputation	☐	☐	☐	☐	☐	Competence & skill set building of workforce

Table A.16: Degree of influence of ‘Competence & skill set building of workforce’ *(i)* on different enabler/lever *(j)*

Indicate the degree of influence of <u>Competence & skill set building of workforce</u> *(i)* on different enabler/lever *(j)*						
Enabler/lever (*i*)	**No influence**	**Very low influence**	**low influence**	**High influence**	**Very high influence**	**Enabler /lever (*j*)**
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Government Intervention
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Consumer & society
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Competition
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Innovation
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Rising prices of raw material
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Circular product design
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Servitized business models
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Circular Supply chain
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Cleaner Production
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Financial Investments
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Building ‘Green image’ reputation
Competence & skill set building of workforce	☐	☐	☐	☐	☐	Industry 5. 0 technologies

Please fill the following details:

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Thanks so much for your time :)

ANNEXURE B

LIST OF PUBLICATIONS

Journal publications

1. Sehgal, S., Bali, S., Gunasekaran, A., Roy, M. H., & Gugnani, R. (2025). Leveraging Circular Economy Transition to Achieve Resilient and Sustainable Supply Chains of the Future: A study of EEE Industry. *Sustainable Futures*, *10*, 101053. https://doi.org/10.1016/j.sftr.2025.101053

2. Sehgal, S., Gugnani, R., & Bali, S. (2025). Navigating circular economy transition at a firm level: a systematic literature review of the electronic industry. *International Journal of System Assurance Engineering and Management*. https://doi.org/10.1007/s13198-025-02948-5

Conference Participation

1. Sehgal, S. (2025). Navigating circular economy transition at a firm level: A review of EEE industry. Paper presented at 4th International Conference on Recent Trends in Engineering, Technology and Business Management (ICRTETBM-2025) (Theme: Digital Transformation & Business Sustainability), organized by the Amity International Business School & Amity Centre for Interdisciplinary Research, Amity University, Noida; February 19-21, 2025.

Sustainable Futures 10 (2025) 101053

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Leveraging Circular Economy Transition to Achieve Resilient and Sustainable Supply Chains of the Future: A study of EEE Industry

Sandeep Sehgal [a], Shivani Bali [a,*], Angappa Gunasekaran [b], Matthew H. Roy [c], Ritika Gugnani [a]

[a] Jaipuria Institute of Management, Noida 201309, Uttar Pradesh, India
[b] School of Business Administration, Pennsylvania State University Harrisburg, Middletown, PA 17057, USA
[c] University of Massachusetts Dartmouth, North Dartmouth, MA 02747, USA

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ABSTRACT

The substantial rise in the scale of electronic waste is a considerable concern for electrical and electronic equipment (EEE) manufacturers. Transition to Circular Economy (CE) is a strategic move to combat the challenge of e-waste generation. Traditional supply chains (SC) and operations were designed to support linear 'take-make-waste' models. To successfully transition to CE and achieve a resilient supply chain in the future with sustainable operations, organizations will have to reconsider their current business models, product designs, and supply chains. While previous studies have identified enabling factors for CE transition, limited research has examined it through the combined lens of enablers and levers. This study addresses this gap through a structured three-phase methodology. In phase 1, a structured literature review was conducted using Scopus, Web of Science, and relevant industry reports to extract potential enablers and levers. In phase 2, expert validation was performed through the Delphi technique. Further, in phase 3, the Grey-DEMATEL (Decision-making Trial and Evaluation Laboratory) technique was used to understand the importance and association among enablers and levers. The findings indicate that government intervention and Industry 5.0 are the top two cause group enablers, followed by a circular supply chain, which emerged as an essential lever of the CE transition. At the same time, financial investments, followed by competence & skill set building of the workforce, are the two effect group levers. By combining theoretical depth with practical validation, this study contributes a novel, practice-oriented framework for accelerating the CE transition within the EEE sector and advancing the development of resilient and sustainable supply chains of the future.

1. Introduction

Circular Economy (CE) has gained traction over the past decade due to the rapidly changing climate, the diminution of natural resources, and growing social and environmental pressures [1–3]. CE has replaced the End-of-life (EOL) concept with the closed-loop system as a regenerative system [4]. While circular economy principles are gaining traction, many industries still rely on linear economy models, prioritizing value creation through virgin materials [5]. The CE approach emphasizes the retention of the economic value of the products. It aims to enhance resource efficiency by prolonging the useful life of the products or parts in the closed-loop system. As we transition from a linear "take, make, waste" model, CE provides businesses with the chance to rethink and redesign their supply chains [6], enabling them to meet sustainability goals [7], lower costs, and reduce greenhouse gas emissions.

Fast-paced evolution in digitization and innovation in the production of new products coupled with convincing marketing strategies have increased customers' inclination towards buying electronic products more frequently. Consequently, this has given rise to exponential growth in the waste of the EEE, making it a global issue for the last decade [8]. Therefore, integrating circular economy practices in the EEE industry has substantial potential in achieving resilient supply chains and operations. Global e-waste generation in 2019 was estimated to be 3.6 million metric tons; it will likely accomplish a staggering growth of 73 million metric tons by 2030 [9]. It is also projected that just 17 percent of global e-waste undergo proper recycling every year. India ranks third in generating e-waste behind China and the US. Apart from producing e-waste, the developing nations of Africa and Asia also carry the load of electronic waste generated by developed countries. These developing nations get approximately 80% of the e-waste produced by developed

* Corresponding author.
E-mail address: lbsshivani@gmail.com (S. Bali).

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REVIEW PAPER

Navigating circular economy transition at a firm level: a systematic literature review of the electronic industry

Sandeep Sehgal[1] · Ritika Gugnani[1] · Shivani Bali[1]

Received: 16 April 2025 / Accepted: 22 August 2025

Abstract
The circular economy (CE) is a sustainable method of reusing products by employing recovery processes of reuse, repair, remanufacturing, and recycling. It focuses on creating better products, materials, processes, and business models to eliminate waste. The circular economy offers an excellent opportunity to address pressing global concerns, including biodiversity loss, climate change, and land degradation while providing social, economic, and environmental benefits to individuals, businesses, and communities. The research aims to identify strategies that enable the electronics sector to progress towards CE transition and to examine the current CE models and strategies prevailing in the electronics industry ecosystem. To achieve this, a comprehensive literature study is carried out. The key finding of this study is the extraction of three broad themes of CE transition at the firm level: ecosystem (n = 42), design strategies (n = 32), and circular economy business models (n = 20) along with the identification of research gaps and corresponding research questions under each theme. Based on these insights, the study proposes a novel, sector-specific CE adoption framework with implications for researchers, practitioners, and policymakers. This review also serves as practical reference for industry stakeholders seeking to enhance their understanding of firm-level CE adoption in the electronic sector.

Keywords Circular economy · Transition · Ecosystem · Design strategies · Business models

1 Introduction

Businesses and nations worldwide are favouring strategic long-term growth over a linear growth model (Mallick et al. 2023a). Using the recovery processes of reuse, repair, remanufacture, and recycling, the circular economy (CE) is a sustainable strategy for recirculating items (Gupta et al. 2021). To eradicate waste, it focuses on creating better goods, materials, processes, and business models. In addition to benefiting people, companies, and communities economically, a circular economy presents a significant chance to address urgent global issues, including biodiversity loss, climate catastrophe, and land degradation (Awan et al. 2021; Bhatia et al. 2020).

Research on circular economies focusses on three main areas: helping businesses implement circular processes at the micro, macro, and intermediate levels; influencing societal and economic dynamics and discussing experiences of industrial symbiosis respectively (Merli et al. 2018). One aspect of circular economy that generates much discussion is the concept of closed loops. Biological loops are closely aligned with the environment and ecology, while technological closed loops are more connected to manufacturing operations (Homrich et al. 2018). Circular economy business models must maximize value while using minimal resources (Foroozanfar et al. 2022). The CE system incorporates various concepts, including spaceman economy (Boulding 1966), industrial ecology (Graedel and Allenby 1995), C2C (cradle-to-cradle) (Braungart et al. 2007), and waste prevention (Yano and Sakai 2016). Separating circularity from circular strategies can quickly solve the problem of different conceptualizations by scholars (Zotti & Bigano 2019). Circular economy adopters must rethink their value

✉ Sandeep Sehgal
sandeep.shehgal.fpm20n@jaipuria.ac.in

Ritika Gugnani
ritika.gugnani@jaipuria.ac.in

Shivani Bali
lbsshivani@gmail.com

[1] Jaipuria Institute of Management, Noida, Uttar Pradesh 201309, India

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PLAGIARISM REPORT

Sandeep Sehgal

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