STUDY OF SELECT ISSUES OF SUSTAINABLE SUPPLY CHAIN MANAGEMENT IN INDIAN ELECTRONICS INDUSTRY

A Thesis submitted

in partial fulfilment for the Degree of

Doctor of Philosophy

by

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CERTIFICATE

This is to certify that the thesis entitled "**Study of select issues of sustainable supply chain management in Indian electronics industry"** submitted by **Rakesh R. Menon** to the Indian Institute of Space Science and Technology, Thiruvananthapuram, in partial fulfilment for the award of the degree of **Doctor of Philosophy** is a *bona fide* record of research work carried out by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institution or University for the award of any degree or diploma.

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DECLARATION

I declare that this thesis entitled "**Study of select issues of sustainable supply chain management in Indian electronics industry"** submitted in partial fulfilment of the degree of **Doctor of Philosophy** is a record of original work carried out by me under the supervision of **Dr. V. Ravi**, and has not formed the basis for the award of any other degree or diploma, in this or any other Institution or University. In keeping with the ethical practice in reporting scientific information, due acknowledgements have been made wherever the findings of others have been cited.

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ABSTRACT

World over organizations are focusing on sustainable goals, where along with economic success their role in protecting the planet and people are becoming important. Sustainability has gained a lot of interest from industry and academia in recent years. An increasing number of organizations are now committing to the cause of sustainability in their supply chains. The research was conducted to address some of the critical problems in the field of sustainable supply chain management. The issues related to sustainable supply chain management were considered in context of Indian electronic industry by choosing representative case studies. *Five* problems were addressed in this research by applying suitable methodologies. The *first* problem of the research was to identify and analyze the enablers of sustainable supply chain. The enablers that assist in implementation of sustainability in supply chain are identified and categorized. A combined methodology of Grey theory and DEMATEL is employed to address this research problem. Sensitivity analysis is performed to check the robustness of the results. The findings along with managerial and academic implications are discussed.

The *second* research problem identifies barriers to implementing a sustainable supply chain. There is an apparent need to remove these barriers for effective implementation of a sustainable supply chain. The interdependence of these barriers and their prioritization at various levels are addressed. Mutual influences among the barriers are also studied. The barriers are categorized to understand the functional aspects and classified as independent, dependent and linkage. The contextual relationships and hierarchical structure of the barriers are found using Interpretive Structural Modeling and MICMAC analysis. The *third* problem is complementary to the second and investigates the causal factors, effect factors and degree of prominence of barriers to implementing SSCM using the combined methodology of Grey DEMATEL. The overall relationship among barriers is established by a diagraph. The research studies the relationship among barriers so that organizations can comprehend the hurdles while shifting to a sustainable supply chain. The results and managerial implications of the research are elaborated.

The *fourth* research problem prioritizes the customer requirements and design requirements for eco-efficiency in an electronic supply chain. It studies the improvisation of the eco-efficiency problem by identifying and analyzing the customer

and design requirements. An integrated Analytical Network Process and Quality Function Deployment methodology is applied to find out the interrelationship among the customer requirements and design requirements. The House of Quality developed translates the customer requirements to prioritize the design requirements in improving eco-efficiency levels of supply chain. The research will help decision-makers to arrive at crucial decisions on attaining eco-efficiency measures.

The *fifth* problem addressed in the thesis is to develop a model and methodology in selection of suppliers for a sustainable supply chain. Sustainability is an important factor that needs to be incorporated in selection of suppliers as well. A combined Analytic Hierarchy Process and TOPSIS approach is applied to solve this problem considering the uncertainty involved and to evaluate the quantitative and qualitative data. The model is demonstrated by its application to select a sustainable supplier in a real world electronics case company. The sustainability dimensions and criteria have been considered in the selection framework. The model elucidates the evaluation of tangible and intangible sustainability criteria in selecting suppliers. The proposed model can be used for ranking the suppliers in order of preference based on the pre-decided sustainability criterion identified by an organization. The framework gives managers insight into evaluating and selecting sustainable suppliers based on a comprehensive criterion. The robustness of the result is tested with sensitivity analysis.

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ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANP	Analytical Network Process
BIS	Bureau of Indian Standards
CDM	Clean Development Mechanism
CR	Customer Requirement
CSR	Corporate Social Responsibility
DEA	Data Envelopment Analysis
DEMATEL	Decision Making Trial and Evaluation Laboratory
DfE	Design for Environment
DoS	Department of Space
DPMO	Defects per Million Opportunities
DR	Design Requirement
EMS	Environmental Management Systems
EPR	Extended Producer Responsibility
GHG	Greenhouse Gases
GSCM	Green Supply Chain Management
GSDP	Green Skill Development Programme
HOQ	House of Quality
IIST	Indian Institute of Space Science and Technology
ISM	Interpretive Structural Modeling
ISO	International Organization for Standardization
ISRO	Indian Space Research Organisation
Kt	Kilo Ton
LCA	Life Cycle Assessment
LTIFR	Lost Time Injury Frequency Rate
MCDM	Multi Criteria Decision Making
MICMAC	Matrix of Cross-Impact Multiplications Applied to Classification
Mt	Million Metric Ton

NGO	Non-Governmental Organization
NIS	Negative Ideal Solution
NPE	National Policy On Electronics
OSHA	Occupational Safety and Health Administration
PIS	Positive Ideal Solution
PLI	Production Linked Incentive
PPM	Parts per Million
QFD	Quality Function Deployment
R&D	Research and Development
RoHS	Restriction of Hazardous Substances
SC	Supply Chain
SCM	Supply Chain Management
SDG	Sustainable Development Goals
SEM	Structural Equation Modeling
SME	Small and Medium Enterprise
SNA	Social Network Analysis
SSCM	Sustainable Supply Chain Management
SSIM	Structural Self-Interaction Matrix
SSS	Sustainable Supplier Selection
TBL	Triple Bottom Line
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UNGP	United Nations Guiding Principles on Business and Human Rights
VoC	Voice of Customer
WCED	World Commission on Environment and Development
WEEE	Waste Electrical & Electronic Equipment
ZOGP	Zero-One Goal Programming

CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent years, the area of supply chain management (SCM) has greatly evolved. The competition in business has increased due to globalization, faster transportation, higher communication access, rapid product innovations and customer awareness. This has led to organizations focusing on improving their supply chains. SCM is the process of planning, executing and controlling activities to coordinate and collaborate with suppliers, manufacturers, intermediaries, channel partners so that the goods and services can be provided in the right quantity, at the right location, and right price to the satisfaction of customer while reducing the overall cost in the supply chain. SCM has expanded its research area rather than being limited to just material flow (Burgess et al., 2007).

Sustainability has become a topic of interest worldwide due to resource depletion, climate change and public health. The concern to protect the environment and human rights has drawn more attention towards research in sustainability areas. World Commission on Environment and Development (WCED, 1987) terms sustainability as the use of resources to meet the needs of the present generation without compromising the ability of future generations to meet their own needs. With the supply chain of companies becoming global, increasing public awareness and pressure from governments and stakeholders, companies are transforming their supply chains into a sustainable supply chain (Büyüközkan and Çifçi, 2011). Sustainable supply chain management (SSCM) refers to the flow of material, information, capital, and collaboration with companies in the supply chain to attain sustainable economic, environmental, and social dimensions of concern. Sustainable supply chains ensure continuing profits, value, and viability by managing their supply chain network's economic, ecological and social consequences (UN Global Compact, 2010). This topic of sustainability that incorporates economic, social and environmental aspects into the supply chain has become a hot topic of research among industry practitioners and academicians in the last decades (Brandenburg et al., 2014).

1.2 Supply Chain Management

A complicated network of entities, facilities, and systems with varying goals forms the supply chain. Supply chains are dynamic as they evolve and develop over a period. It includes all activities, firms, information, people and resources to transform raw materials into final products satisfying customer needs. Min and Galle (2001) describe the conventional supply chain as a group of three or more organizations or individuals contributing to upstream or downstream movement of material, services, information and/or finances from a source to the end-user. A supply chain is a dynamic process that entails the continuous flow of goods, finances and information between multiple domain areas amongst the chain members (Jain et al., 2009). SCM strives for efficiently handling and linking the different organizations in meeting customer demands. A poorly managed supply chain damages reputation, deteriorates quality, causes delay and increases cost.

Supply chains have been configured and designed as lean, agile, green, resilient, closed-loop, sustainable, etc. Lean supply chains were designed to cut off the non-value adding activities considering customers and making continuous improvements using a collaborative approach (Lamming, 1996). Agile Supply Chains can respond quickly to variations in demand and modifications. They have the capability to encompass organizational structure, distribution process, information flow and mindsets (Christopher, 2000). Six Sigma Supply Chains had the goal to minimize variation with precise and timely deliveries (Garg et al., 2004). Leagile supply chains were developed by having flexibility in manufacturing and postponement strategy. The use of lean and agile strategies to stock and order were based on type of demand, volume, etc. (Naim and Gosling, 2011). Green supply chain management (GSCM) considered the environment aspects during supply chain design and operations like procurement, manufacturing, reverse logistics recycling, waste management, etc., (Srivastava, 2007). Resilient Supply Chains are capable to respond and quickly recover from disruptions and afterwards maintain a steady or better state (Ponomarov and Holcomb, 2009). Sustainable supply chains address economic as well as social and environmental aspects.

Given that a supply chain encompasses the flow of product from raw material stage to the end customer, a focus to create sustainable supply chains will lead to greater acceptance and advancement of sustainability practices (Ashby et al., 2012). SCM plays a critical role in resolving sustainability problems in businesses of all sizes and across a wide range of sectors.

1.3 Sustainable Supply Chain Management

Management of supply chains is now not restricted to producing and selling goods with affordable supplies, competitive resources, consumer demand, investment and regulations. Organizations have to address the social and environmental impact of their supply chain, which has become an influencing factor with government, stakeholders, customers, and businesses. Along with economic goals, there are calls for human welfare and planet protection when organizations offer their products and services. This has led to organizations concentrating on improving their sustainable performance (Silvestre et al., 2018).

Organizations usually focus on economic goals which include profits and return on investments. To improve the economic, social and environmental issues in their processes, companies need to introduce sustainability in their supply chains. Suppliers' unsustainable behaviour brings social and economic liability to the supply chain and the product (Kumar and Rahman, 2015; Seuring and Muller, 2008). Thus, the introduction of sustainability in supply chains becomes critical. Sustainability in SCM as depicted in Figure 1.1 is an intersection of environmental protection, social equity and economic viability in a supply chain.

Industries are being forced to introduce sustainability in their operations due to the evolving corporate and social situation (Tseng et al., 2018). Organizations become capable of achieving social commitments and environment standards by moving towards SSCM. The environmental dimension requires them to reduce the negative effects on the environment and ensure that natural resources to support life remain unimpaired. The social dimension points to their position and commitment towards social responsibility (Gaol et al., 2016). Only a few companies have fully embedded sustainability into their business model. Industrial managers need to give focused attention to scale up these dimensions and address the economic, social and environmental issues that are interconnected whilst implementing sustainability in the supply chain (Wu and Pagell, 2011, Qian, 2012). Also being an interdisciplinary area, sustainable supply chain has been of interest both to researchers and managers in industry (Sarkis et al., 2011).

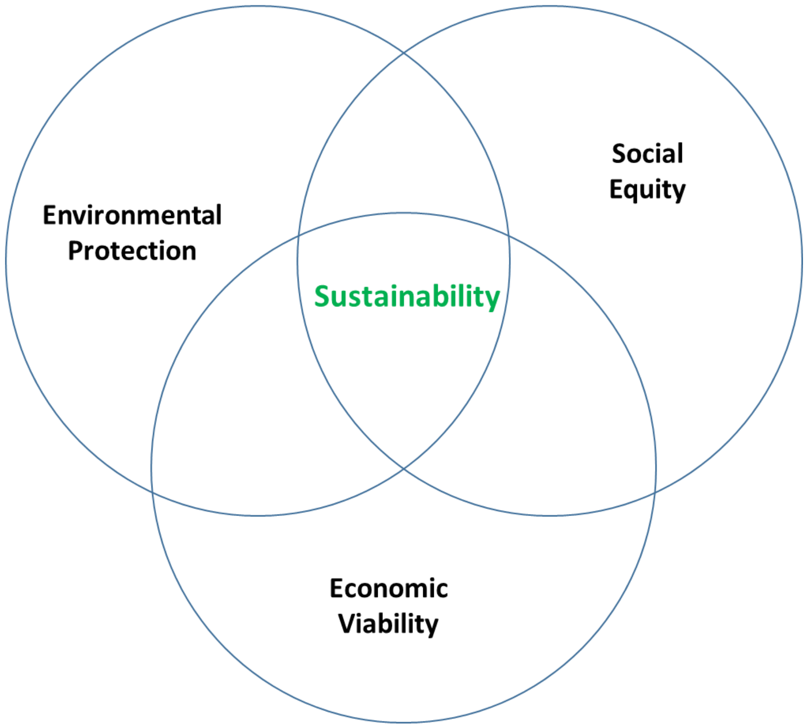

Figure 1.1: Sustainability in SCM

Companies are committing to the cause of sustainability not only due to other pressures but they are also due to the benefits supply chain sustainability can give. A sustainable supply chain can enhance an organization's reputation, provide competitive advantage, protect from regulatory issues, hazards of waste disposal and bring cost savings. Sustainability aspects in areas of product design, material substitution, packaging, disposal, resource reduction, product life cycle span, repair, recycling, refurbishing, etc., can contribute towards building a sustainable supply chain.

1.4 Conceptual Model for a Sustainable Supply Chain

There are pressures from non-governmental organizations (NGOs), governments and consumers to adapt sustainability concepts in a company's supply chain. This poses a challenge to companies in redesigning their supply chain, collaborating with a wide array of stakeholders, and applying sustainability decisions in a global scenario. Sustainability frameworks such as triple bottom line, ecological footprint, etc., are employed by businesses to overcome the sustainability issues faced by them and embrace the concept of sustainability.

In an organization the economic goals are to reduce cost, improve quality, delivery speed, innovation and efficient resource utilization (Gunasekaran et al., 2001). The sustainable supply chain along with economic goals addresses the social problems of health and occupational safety, human rights, child and bonded labour, etc., (Maignan et al., 2002) and environmental issues of natural resource depletion, pollution, water shortage, climate change, deforestation and loss of biodiversity (AlKhidir and Zailani, 2009).

SSCM considers Triple Bottom Line. A Triple bottom line model for SSCM is shown in figure 1.2. This model shows the systems necessary to support the three Ps: people, planet, and profit that needs consideration in SSCM. Sustainable supply chain management aims to maximize the ecosystem of Planet, Profit and People in the network ranging from supplier, manufacturer, transport, distributor, retailer to consumer and its disposal (Tang and Zhou, 2012). At the same time, the input of natural resources like raw material, water, energy and waste generated is minimized. Ramudhin et al. (2010) presented the design framework with triple bottom line objectives for sustainable supply chain management. A sustainable supply chain considers the entire life cycle of a product with an end-to-end supply chain approach.

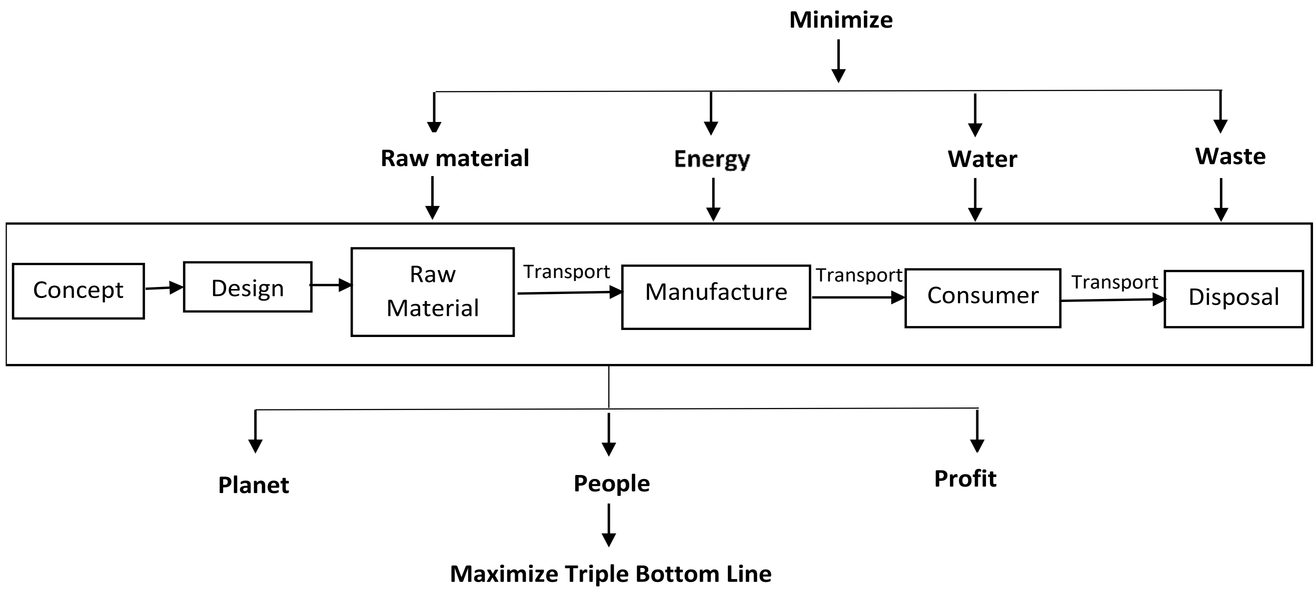

Figure 1.2: Triple Bottom Line for SSCM

1.5 SSCM issues in contemporary research

The scope of SCM has expanded in recent years with demands for transparency and accountability in business actions. Issues related to the environment and social impact of a firm's supply chain are receiving greater attention leading to increased research in SSCM. This has led to a paradigm shift in supply chains evolving from being Lean to Green and Sustainable. SSCM has captured significant attention from practitioners and academicians (Tachizawa and Wong, 2014). Numerous special issues by reputed journals on SSCM topics underlines the growing importance of this subject.

There are compulsions from local bodies demanding conduct of business in a sustainable manner and new legislations are being continuously framed in this regard. Apart from economic benefits, a sustainable supply chain is designed to perform within the environmental limits and ensure a healthy and just society. Managing their supply chain in a sustainable way plays a critical role for companies of all sizes across wide range of industries (Ghadimi et al., 2018). SSCM problems have gained contemporary interest from institutions and enterprises. Academicians, as well as practitioners, are pursuing ways to integrate sustainability in business and revisiting their supply chain models (França et al., 2017). Seuring and Muller (2008) identified four core challenges in SSCM as (i) pressures and incentives for SSCM (ii) supplier management (iii) knowing and measuring impacts (iv) supply chain issues among all the firms in the supply chain.

1.6 Future Trends in SSCM

Some of the key trends that will shape the future of SSCM are listed as follows:

- The eventual depletion of fossil energy resources is widely recognized and renewable energy sources are receiving considerable interest. Future trends indicate towards creation of novel modelling and solution approaches in sustainable supply chain for addressing the renewal energy alternatives (Ghadimi et al., 2018).
- The barriers and drivers for sustainability adoption in supply chain and the differences with regards to large firms, SMEs (small and medium enterprises), varying industry sectors, geographies, etc., could be further explored. Industries such as electronics, chemicals, etc., have large environment and societal issues. Such specific sectors and emerging markets warrants suitable SSCM solutions in future (Rajeev et al., 2017).
- The enhanced role of technology and digitization to facilitate operations of a sustainable supply chain will be a future trend of study.
- As supply chain becomes global, selection and formation of sustainable partners both upstream and downstream the supply chain as well as monitoring the different tiers of suppliers would be future trends interesting researchers in SSCM.
- There are demands to improve collaboration among supply chain firms and to incorporate a broader set of sustainability performance goals using appropriate sustainability metrics (Seuring and Müller, 2008).

1.7 An Overview of SSCM practices in India

The research in SSCM has been comparatively less established in emerging economies compared to the developed countries due to fewer resources and inadequate societal concerns (Silvestre, 2015; Gopal and Thakkar, 2016). There are hesitations on sustainability implementations due to insufficient information and facilities in developing countries like India (Dubey et al., 2017).

In India, SSCM adoption is still at a nascent stage and the regulatory framework to impose SSCM practices is evolving only. The pressure from consumers as well as the competitors for SSCM adoption is less though collaborative efforts with suppliers in product design and logistics are seen (Das, 2017). The social aspects for sustainability like wages, labour rights, health and safety have not been satisfactorily dealt with in India (Mani et al., 2016). The ramifications in terms of resource and energy savings are not fully realized by Indian industries where the idea of sustainability is associated with an expensive course of action (Luthra et al., 2018). Although SSCM implementation is visible among large and multinational companies, the sensitivity towards sustainability issues is lower among small and medium enterprises.

1.8 Motivation for this research

In addition to the economic aspects of a business, many organizations are now addressing the social and environment impact of their supply chain for which they are adopting sustainability in their supply chain. The electronics industry is one the fastest growing industry not only in India but across the world with high resource consumption. There is a much larger requirement to consider the environmental and social impact of this industry. Also, Asian manufacturers will have to face considerable social and environmental issues in the coming years (Mangla et al., 2017). Hence the study of issues of sustainable supply chain implementation in India is highly required. This has motivated us to make an attempt to study select issues in implementation of sustainability in electronics supply chain in Indian context.

Literature reveals that enablers and barriers in the sustainable supply chain have been studied but research with specific emphasis on electronics industry in Indian context has not received due attention. As the enablers and barriers may vary across industries and geography, we have concentrated in this research on the electronics industry in India. With a large population and an increased spending power, India's demand for electronics products is steadily rising. Reduction in prices and advancement in technology has fomented the growth in consumption of electronics goods. There is a lot of competition in the electronics industry, and profit-making margins are also low. Electronics products have a shorter life cycle, and adding sustainability requirements makes it a great challenge for managers. Sustainability issues in the electronic industry range from the manufacturing process, environmental policy, carbon footprints, greenhouse gas emissions, energy efficiency, e-waste management, working conditions to workers' health and safety, etc. One of the limitations of this supply chain is that it does not have proper standards for recycling, producers' responsibility and human rights. These factors have motivated us to research in analyzing the enablers and barriers of sustainability in supply chain of electronic industry with a suitable framework.

Eco-efficiency encourages companies to improve the environment while benefiting the economy. By embracing eco-efficiency measures, businesses benefit from less use of materials and energy, creating more goods and services with lesser resources, decreasing pollution and waste. However, studies to improve eco-efficiency in the rapidly growing electronics industry are not found in the literature. With the current environmental concerns, a study to enhance eco-efficiency and prioritize the decision-making requirements is needed. This has given us motivation to study the CRs and DRs to improve eco-efficiency.

Earlier supplier selection was based only on economic factors. But now, with the focus on sustainability the world over, all three pillars of Triple Bottom Line (TBL) i.e., economic, environment and social factors, are being considered across the supply chain, including supplier selection (Ghayebloo et al., 2015). A sustainable supplier helps in increasing the sustainability levels across the supply chain. This makes sustainable supplier selection a complex decision involving different objectives, legislations and organization priorities. Therefore, sustainable supplier selection (SSS) needs to be solved by the Multiple criteria decision-making (MCDM) method. The overall effectiveness of sustainability in a supplier is greatly affected by sustainable supplier selection (Amindoust et al., 2012). Sustainable supplier selection greatly influences a company's finances (Kara and Fırat, 2018). Evaluating the environmental, social, and economic characteristics is imperative and significant (Sarkis and Dhavale, 2015). It is also necessary to know the different aspects of sustainability and how they affect or interact. This has motivated us to study the supplier selection problem in a sustainable supply chain of Indian electronics industry in this research.

1.9 Objectives of present research

This research considered the important aspects that influence in implementation of a sustainable supply chain. In this study, five key problems related to SSCM are addressed.

The model evolved in the *first* research will help industries focus on the relevant enablers to assist and drive sustainability practices in their supply chain. Sensitivity analysis has been done to rule out the presence of any bias or influence. Results give an insight to managers on the enablers they have to focus upon for implementing sustainability in organizations. This study will help the Indian electronic industry in evaluating enablers in developing a sustainable supply chain. The aims of the first research problem are as follows:

- Identify the enablers in major categories to the implementation of a sustainable supply chain.
- To model and understand complex interactions among enablers of sustainable supply chains.
- To illustrate the causal and effect enablers using causal relationship diagraphs.

In the *second* research problem, barriers to sustainability in Indian electronics industry were identified. The barriers are categorized to understand the functional aspects and classified as independent, dependent and linkage variables. Companies can adopt sustainability measures specific to the nature of the electronic industry considering their shorter product life cycle, increasing consumption pattern, energy efficiency and related disposal issues. Depending on the effect of barriers, organizations can work to eliminate these barriers stage-wise. This study will help Indian electronic industry in minimization of barriers while moving towards a sustainable supply chain. The objectives of second study are as follows:

- Identify the barriers in implementation of a sustainable supply chain in electronics industries in Indian context
- Determine through a structured model the interrelationships among barriers and find their driving and driven power.

The objective of the *third* research problem is to identify the barriers in sustainable supply chain implementation and evaluate their interrelationships so that industries can be ready to deal with them. Bringing down the sustainability barriers will help companies to increase their operational efficiency (Abideen and Mohamad, 2020). Further, the model evolved will prepare industries for the amount of attention and effort required from their side to overcome the barriers of sustainability. The aims of third research are as follows:

- To model and understand complex interactions among barriers of sustainable supply chains.
- To illustrate the causal and effect barriers using causal relationship diagraphs.

The *fourth* study is done to identify and consider the Customer requirements (CRs) and Design requirements (DRs) of eco-efficiency in the electronics industry. The novelty of this research lies in studying the improvisation of the eco-efficiency problem by determining and prioritizing the customer and design requirements of an organization. The methodology considers the inter-dependency among factors during evaluation. It would be helpful for companies in deciding their needs at various stages of their implementation levels. The main objectives of fourth research are:

- Identifying important CRs and DRs for eco-efficiency in the electronics industry,
- Analyzing and prioritizing CRs and DRs and finding out the interrelationship among them, and
- Construct a House of Quality to help decision-makers arrive at crucial decisions on attaining eco-efficiency measures.

This *fifth* study explores the sustainability factors in supplier evaluation through literature review and the opinion of experts in the electronic industry. The identified criteria are applied in the electronic industry for a sustainable supplier selection. The criteria finalized in this research are in the context of supplier selection in an electronic industry's supply chain. Our proposed model selects four sets of sustainable criteria: economic, environmental, social and ethical, and sub-criteria under each group, totalling 16 sub-criteria. By pairwise comparison of criteria and sub-criteria, their weightage is determined, and then the alternatives are ranked depending on their closeness to positive ideal solution. The model is applied to select a sustainable supplier in an electronics industry in India. Suppliers of a particular component are evaluated as per the model and ranked based on preference. The proposed model can assist electronic industries in executing a sustainable supply chain by selecting a sustainable supplier instead of an economical supplier.

1.10 Research Methodology

The research methodologies used in this research are:

1. Combined Grey DEMATEL technique
    1.1. Grey Theory
    1.2. Decision-making trial and evaluation laboratory (DEMATEL)
2. Interpretive Structural Modeling (ISM)
3. Integrated ANP QFD method
    3.1. Analytical Network Process (ANP)

3.2. Quality Function Deployment (QFD)

4. Hybrid AHP TOPSIS method

   4.1. Analytic Hierarchy Process (AHP)

   4.2. Technique for order of preference by similarity to ideal solution (TOPSIS)

In the *first* problem, we have used a combination of Grey-DEMATEL methodologies to analyze key enablers of sustainability in the Indian context. Grey theory has the ability to integrate with any decision-making process to increase the accuracy of judgement. Grey theory is an effective tool to deal with the ambiguities in human judgment. It has the potential for solving uncertain and indeterminate problems. DEMATEL method can structure complicated causal relationships between the variables by creating matrices and/or graphs. One of the advantages of using these methodologies is that it gives the cause group, effect group and correlation factors of enablers. The interrelationship among the enablers is analyzed using a combination of Grey-DEMATEL methodology, and a diagraph depicting the causal relationship between enablers is established

In *second* problem, the hierarchical structure and interrelationship among these barriers are established using ISM methodology. ISM can be used to study the direct and indirect relationship between various factors of different organizations (Jolhe and Babu, 2014). The complications of factors can be structured by the ISM model (Jharkharia and Shankar, 2005). Using ISM, driving and driven powers of barriers were found. In the *third* problem, using Grey-DEMATEL methodology, the cause, effect and correlation factors among barriers are found out. Sensitivity analysis of results has been conducted to rule out the presence of any bias or influence.

It is seen in the *fourth* problem that many of the concepts of eco-efficiency are qualitative and quantitative, and they are interrelated. ANP could effectively be used under these circumstances. In recent decades, QFD has been used by companies to successfully develop their products and services. One of the advantages of using QFD is that it helps to incorporate the concept of voice of customer for the design and development of products/services. QFD helps industries in the identification of requirements of customers before the design such that it can result in exceeding the expectations of the customers. Also, the QFD method can capture the requirements at each level, right from marketing, design to sales and after-sales service, etc. To get the advantages of both the methodologies of ANP and QFD, an integrated approach combining both of them is proposed in this research.

In MCDM methods, hybrid models increase the model's strength and eliminate any drawbacks seen in the classical MCDM technique. Hybrid models enable assessing varied information evaluated on contradicting and interrelated criteria in an uncertain environment (Zavadskas et al., 2016). In the *fifth* problem, we propose a hybrid AHP-TOPSIS multi-criteria decision-making approach to solve the sustainable supplier selection issue considering the uncertainty involved and evaluate the quantitative and qualitative data. AHP is a widely used method by decision-makers to organize important criteria by breaking down constituent parts and giving a hierarchical structure to complex problems. Prof. Saaty developed this method in 1980. In this method, the prioritization is obtained by pairwise comparison of items rather than comparing all items at once. The AHP technique is done by a three-step process where first a hierarchical structure for the problems is created by identifying the criteria, alternatives and goal to be attained. By pairwise comparison, the priorities are established. The consistency of the findings can be tested by performing a consistency check. TOPSIS is an MCDM tool (Hwang and Yoon, 1981) based on the concept that the best alternative should have the shortest distance from the Positive ideal solution (PIS) and the farthest distance from the Negative Ideal Solution (NIS). The closeness of each alternative to PIS is found by dividing the distance from NIS by the sum of the distances from PIS and NIS. The alternatives are then ranked as per the closeness index.

1.11 Organization of the Thesis

The organization of this thesis is shown in Figure 1.4. Chapter 1 gives the introduction to sustainable supply chain management. It details the importance and relevance of SSCM in present era, demonstrates a conceptual model and SSCM issues in contemporary research. The motivation, objectives and research methodologies used in this research are also presented. Chapter 2 contains detailed literature review on SSCM including the gaps identified from the literature. It gives an overview of electronics industries in India and the initiatives of the government. It discusses the benefits and challenges in SSCM along with a framework for SSCM. An overview of SSCM in the Space sector and the scope for SSCM in this sector are also presented.

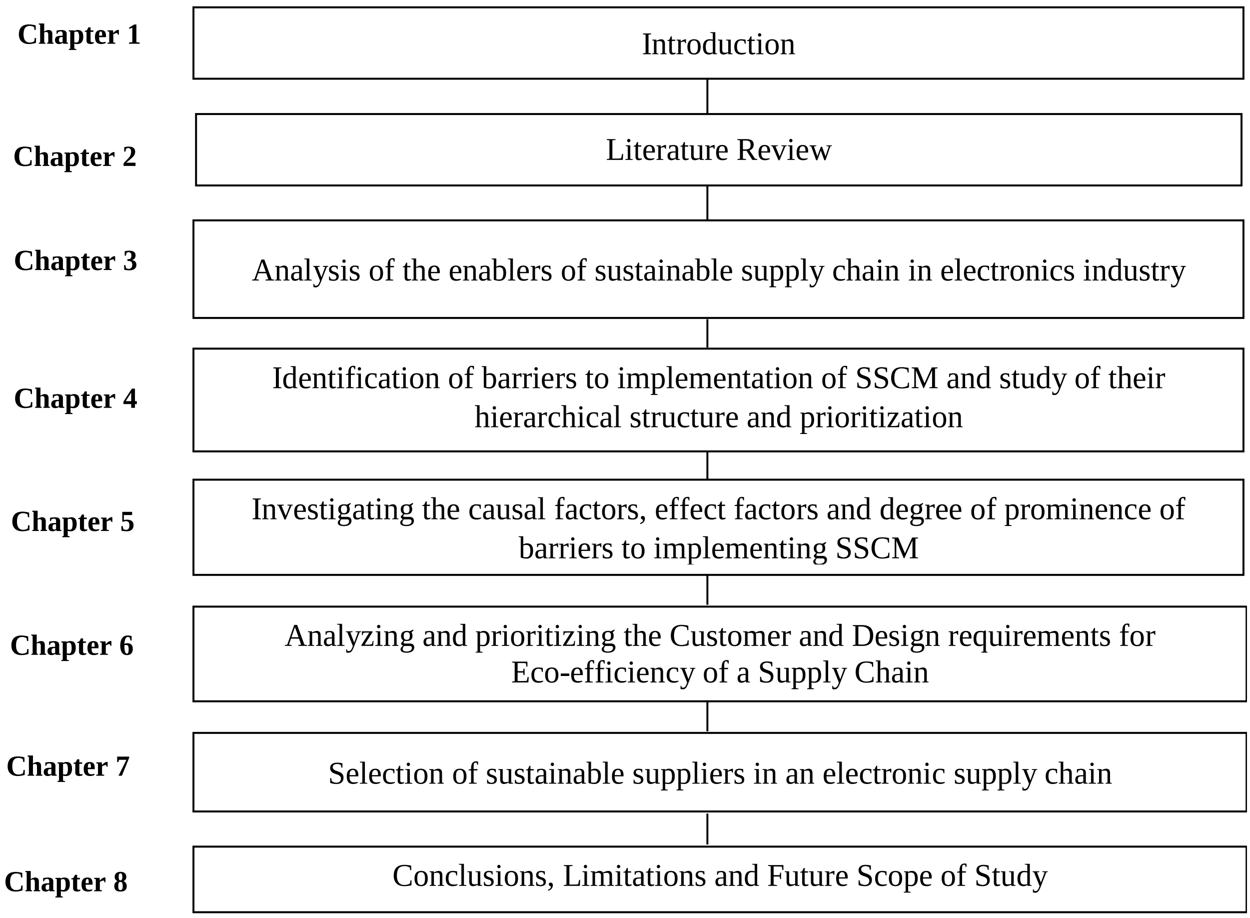

Figure 1.3: Chapter organization of the Thesis

In Chapters 3, 4, 5, 6 and 7, the details of the *five* problems addressed, related literature, methodology and the application are discussed. Chapter 3 identifies, discusses and analysis the enablers of sustainable supply chain. Chapter

4 details identification of barriers to implementation of SSCM and study of their hierarchical structure and prioritization. Chapter 5 investigates the causal factors, effect factors and degree of prominence of barriers to implementing SSCM. Chapter 6 analysis and prioritizes the Customer and Design requirements for eco-efficiency of a Supply Chain. The development of a model for selection of sustainable suppliers in an electronic supply chain is presented in Chapter 7.

Chapter 8 summarizes the research conducted in this thesis and presents the conclusions. Research findings and their implications have also been presented in this chapter. This chapter elaborates the analysis of the findings, related discussion with concluding remarks, limitations of this research work, and scope of future works for each of the five problems.

1.12 Conclusion

In this thesis, few issues related to sustainability from the gaps observed in literature are explored for implementing sustainability in the supply chain. The study analyses critical aspects that affect sustainability implementation in a supply chain. *Five* major problems associated with sustainable supply chain are addressed in this research. The conclusion chapter presents an overview of the context related to this research. It also presents information about the research's motivation and goals. The research methodologies that have been applied in this study have also been reported followed by a summary of the entire research.

The next chapter deals with detailed literature review.

CHAPTER 2

LITERATURE REVIEW

2.1 Sustainability Integration in Supply Chain

The sustainable supply chain integrates key business processes with supply chain partners by attaining environmental, social and economic objectives. The integration of sustainability aspects to a supply chain involves taking steps that are socially and environmentally responsible rather than focussing only on economic benefits (Namagembe et al., 2019). Such steps over a period of time will result in improved efficiency, company image and thus increase the economic performance (Mitra and Datta, 2014).

Integration of the supply chain is necessary to understand better firms' common goals and knowledge at all levels. The integration of the supply chain across organizational, upstream and downstream levels requires tactical and strategic collaboration. The sustainability practices must be integrated into the supply chain across all levels and the focal company for efficient sustainable supply chain management. (Vachon and Klassen, 2006). The integration of sustainability practices at inter and intra level of an organization's supply chain is positively linked to its environmental and social performance (Kang et al., 2018).

Supply chain integration is characterized by strategic collaboration with supply chain members, as well as synchronizing intra-organizational procedures linked to product flow, manufacturing, information sharing, services, cooperative decision-making, across functional areas both within and outside the organizations. A lack of sustainability integration can affect the overall sustainability performance of the supply chain.

2.2 Sustainable Supply Chain Management

Sustainability is a growing element in manufacturing and operations of companies and the significance attached can be gauged from the fact that 90 percent of companies from S&P 500 list published their sustainability reports in 2019 in comparison to 82% in 2016 and 20% in 2011 (Governance & Accountability Institute Flash Report, 2020). There is a high impact of supply chain activities on natural resources, soil, and greenhouse gas (GHG) emissions. The main functions within supply chain for sustainability transformation are sourcing, manufacturing, distribution, value proposition, consumers and product usage and reuse, recycle and disposal are shown in figure 2.1.

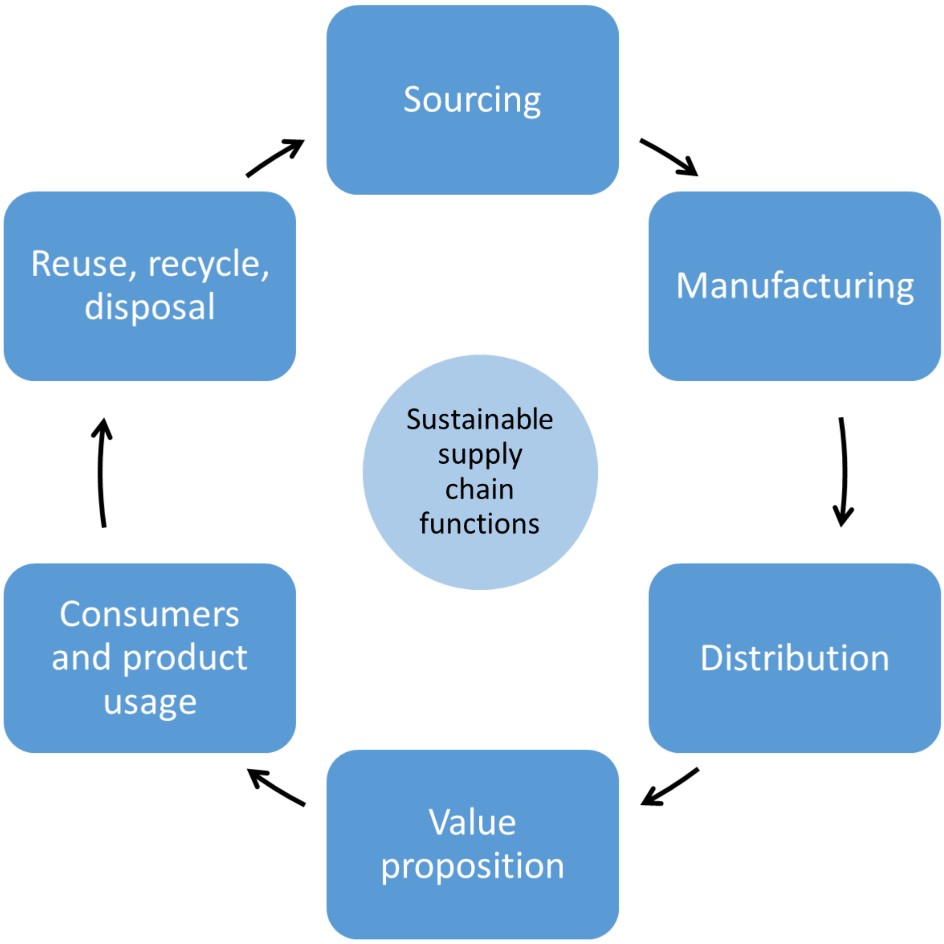

Figure 2.1: Sustainable supply chain functions

Supply chains have scaled up in size, expanded worldwide and become increasingly complex. The rapid growth of industries has caused harm to the environment and damage to human life. The sustainability concept has been introduced in industries for the benefit of organizations and the community. Sustainability involves using those resources which are renewable and cause no damage to the environment. The three Ps of sustainability are People, Planet and Profit. The allocation of resources, operations management, production process, funds, and information in a supply chain, which work to maximize profit, has to simultaneously minimize the impact on the environment and maximize social well-being (Kusi-Sarpong et al., 2019).

The issue of sustainability has become a global apprehension leading to organizations changing their supply chain arrangements to include social, environment and economic impacts of their supply chain (Carter and Rogers, 2008; Carter and Easton, 2011). There is a growing pressure on businesses to take care of the environmental and social implications of their products and process (Kleindorfer et al., 2005). The three pillars of sustainability known as Triple Bottom line (TBL) are economic, social and environment. SSCM is a larger concept and has been a topic of interest for academicians and industry practitioners (Beske et al., 2014).

Integrating sustainable practices within the supply chain has gained prominence with the hope of reducing environmental and social impact (Esfahbodi et al., 2017). SSCM is management and control of flows related to material, information, and capital as well as cooperation from all partners in the supply chain while taking into consideration the environmental, social and economic objective of sustainable development, which are generated from stakeholder and customer needs (Seuring and Mueller, 2008). Reefke and Sundaram (2018) investigated the decision process to promote sustainable development and implementation in a supply chain. Mariadoss et al. (2016) found a synergistic influence of a company's environmental and cultural orientations on its sustainable purchasing and supply practices. Due to government regulations, companies have shown a key interest in adopting SSCM practices (Marcon et al., 2017). SSCM approach involves managing economic, environmental and social impacts and clean manufacturing practices during the lifecycle of products (Mathivathanan et al., 2018). These challenges and the continuously evolving supply chain make it complex to implement sustainability in a supply chain, and organizations face challenging tasks in enabling SSCM.

The implementation of a sustainable supply chain involves many areas in the supply chain like operations, procurement, engineering and logistics. Sustainability concept is now part of various government policies and company strategies. SSCM is the strategic business integration of the supply chain by reducing the concerns of environmental, social and economic perspectives in the system and increasing the organization and shareholder values (Wang and Sarkis, 2013). A sustainable supply chain incorporates safety, good governance and mitigates supply chain risk. It comprises reducing energy and water usage, consuming renewable energy and decreasing hazardous waste generation (Jayant and Azhar, 2014; Rauer and Kaufmann, 2015).

There have been different views on whether the movement towards sustainable practices and sustainable supply chain management would effectuate a win-win or trade-off situation for business. Orlitzky et al. (2003) by a meta-analysis study, concluded that there is a positive association between social/environmental performance and financial performance of corporates. Wang and Sarkis, (2013) found that there is a direct relationship between sustainable supply chain management and corporate financial performance, but the managers need to be patient with the time lag to reap benefits. The investments made at the beginning for sustainable actions are compensated in the long term (Vachon and Klassen, 2006).

The trade-off theory contends that once organizations handle easier part like cutting down waste, energy, etc. and move to address the main concerns like supply chain framework and design changes, they will realize that deeper sustainability implementation would necessitate a major shift in operational activities, reengineering of the supply chain and substantial funding (Devinney, 2009). In industries, often social responsibility is seen just as an obligation that does not provide any financial benefits (Walley and Whitehead, 1994). However, it is apparent that sustainability and specifically SSCM, is not an option but a necessity (Carter and Rogers, 2008).

Sustainability considerations often lead to additional expenses and limitations in production process. But if effectively explored, they also offer new avenues that can bring financial rewards while simultaneously reducing the firm's sustainability concerns (Subramanian et al., 2010). By addressing sustainability issues, companies have a chance to gain competitive advantage (Rao and Holt, 2005). A sustainable supply chain delivers strategic benefits to an organization in terms of cost reduction, increased efficiency and brand building.

In view of the numerous concepts and approaches to research in the field of SSCM, several definitions of SSCM can be seen in literature which would be natural for a relatively new and progressive field. A few of the notable and frequently referred among these definitions of SSCM are presented in Table 2.1.

In general, it is seen in literature that though the environment dimension is covered in several studies, the social dimension seemed to have not been receiving due attention and lacked adequate research (Gold et al 2010). More attention has been paid to environment related issues than social aspects like diversity, equity, human well-being, quality of life, working conditions and community relations (Mani et al., 2016) in SSCM. Kitsis and Chen (2019) studied the relational, instrumental and moral motives that link SSCM practices and improve all three dimensions of SSCM applying structural equation modeling (SEM). Zimon et al. (2019) examined the implementation framework of reactive, cooperative, and dynamic SSCM which included elements such as green purchasing, consumption and emission reduction. Khan et al. (2021), in their review of the SSCM literature, pointed out that advanced modelling at macro level is required though there have been several MCDM techniques employed in this field.

Table 2.1: SSCM definitions in literature

Author	Definition
Carter & Rogers (2008)	The strategic, transparent integration and achievement of an organization's social, environmental, and economic goals in the systemic coordination of key inter-organizational business processes for improving the long-term economic performance of the individual company and its supply chains.
Seuring & Muller (2008)	The management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements.
Wittstruck & Teuteberg (2012)	An extension to the traditional concept of supply chain management by adding environmental and social/ethical aspects.
Hassini et al., (2012)	The management of supply chain operations, resources, information, and funds in order to maximize the supply chain profitability while at the same time minimizing the environmental impacts and maximizing the social well-being.
Ahi & Searcy (2013)	The creation of coordinated supply chains through the voluntary integration of economic, environmental, and social considerations with key inter-organizational business systems designed to efficiently and effectively manage the material, information, and capital flows associated with the procurement, production, and distribution of products or services in order to meet stakeholder requirements and improve the profitability, competitiveness, and resilience of the organization over the short and long term.
Turker & Altuntas (2014)	SSCM is the addition of sustainability to traditional SCM processes, taking financial, environmental, and social impacts of firm activities into consideration.
Giannakis & Papadopoulos (2016)	SSCM is considered as a sophisticated process by which firms organize their corporate social responsibility activities across dislocated manufacturing processes spanning organizational and geographical boundaries.

The sustainable supply chain is a cross-disciplinary field and it helps in improvising the traditional supply chain. For the benefit of organizations and future generations, sustainability harmonizes economic, environment and social issues (De Brito and Van der Laan, 2010). Companies have to take responsibility for their activities impacting the environment and society. The environmental effect can be optimized without any big economic loss by using effective methods (Jayakumar et al., 2020). Companies need to synchronize their resources and processes across all departments and functions to achieve supply chain sustainability. The approach of companies towards supply chain sustainability varies depending on the industry, geography and supply chain complexities.

Developing Asian countries are putting emphasis on being environmentally responsible as they have become a source for low-priced offshoring production due to economic labour and inadequate environmental regulations (Brandenburg et al., 2014). In emerging economies, the research on sustainable supply chain needs further exploration (Subramanian et al., 2020) and also the sustainability implementation in businesses is more complicated (Luthra and Mangla, 2018). The schemes practiced in developed countries for sustainable supply chain cannot be simply copied for emerging economies (Bendul et al., 2017). Research on SSCM in emerging economies has been highest in multi-industry followed by Textiles/apparel, Oil/gas/power, Automobiles and Food sector and most used method for analysis is SEM (Sánchez-Flores et al., 2020).

2.2.1 Enablers of SSCM

There are some studies on enablers of SSCM seen in literature particular to a country and/or industry. Faisal (2010) explored ten enablers for SSCM adoption to the region of Qatar. Hussain (2011) had examined 21 enablers for SSCM in the Canadian context and studied interactions among them using Interpretive Structural Modeling. Using ISM, Singh and Debnath (2012) have analyzed sustainability benefits through Clean Development Mechanism (CDM) for Indian firms. Luthra et al., (2015) identified and modelled twenty-six Critical Success Factors to implement GSCM in Indian mining sector using ISM. Based on a review of literature, Dubey et al. (2017) identified 14 enablers of SSCM. Raut et al. (2017) identified 32 critical success factors for implementing SSCM practices in Indian oil and gas industries and the mutual relationship among them was established using ISM.

2.2.2 Barriers to SSCM

Many organizations are moving towards a sustainable supply chain but face hindrances during the process of its implementation. Literature reveals that there are research papers on barriers in sustainable supply chain. Ravi and Shankar (2005) analysed 11 barriers to reverse logistics in the case of automobile industries and found lack of awareness about the reverse logistics and lack of top management commitment to have the highest influence. In apparel industries using decision-making trial evaluation laboratory (DEMATEL) method Zhu et al. (2012) investigated the barriers to eco-friendly apparel production. In context of auto components manufacturing industries in south India, Mathiyazhagan et al., (2013) analysed twenty-six barriers for implementation of GSCM using Interpretive Structural Modeling (ISM). Their study found that the issue in maintaining environmental awareness of suppliers is the leading barrier in this industry. Govindan et al., (2014) identified and ranked twenty-six common barriers through AHP impeding GSCM implementation by targeting industries from Tamilnadu, South India. Govindan and Bouzon (2018) listed 37 drivers and 36 barriers of reverse logistics using stakeholder theory. Majumdar and Sinha (2019) framed contextual relationships among twelve barriers of green textile and apparel supply chain and found complexity of green process and system design to possess the highest driving power.

2.3 Overview of Electronics Industry

The electronics industry is one of the fastest and largest growing industries globally (Wath et al., 2010). It is also an industry where physical resources are increasingly used (Yin et al., 2014). Specific processes are necessary to deal with the hazardous materials in waste electronic and electrical equipment (WEEE) and efficiently recycle the resources (Chancerel et al., 2009). This industry has high research, innovation, development, and by nature, it is fast-moving (Burgess et al., 2007).

In recent decades, there has been an exponential rise in the use of electronics products by consumers. The industry is expanding with newer technologies reaching consumers in the shortest period than ever seen before. The product life cycle for electronic items has shrunk in recent years, and companies have been launching new products at an increasing rate. The consumption rate of electronic goods has also been increasing due to this industry's characteristics, including innovations and lower product cycle. Companies are regularly coming up with innovations and new versions of existing products at regular intervals.

The ever-increasing use of electronic gadgets and the speed of their upgrades have led to increased production of electronic items. The resource consumption is happening at a rate which is beyond what earth can sustain (Sheoran and Kumar, 2020). As a consequence, issues related to the disposal of these items are growing. In the electronics industry, related efforts to minimize environmental hazards are unsatisfactory (Hankammer and Steiner 2015). The consumption trend and nature of electronics products have led to regulatory and societal pressure on industries to implement sustainability in their supply chains (Prakash and Barua, 2016).

In India, the domestic electronic industry is expanding with a growing middle class and increasing adaptation to technology usage. India's economic rise coupled with growth in the information technology sector has helped the electronics industry in the country. The industry is also growing rapidly in India with an increase in domestic consumption of electronic goods. The electronics industry is highly competitive due to rapid changes in technology, miniaturization of components and mobility demands. Major electronics industries in India consist of consumer and industrial electronics, computer hardware, communication components, strategic electronics and LED products. In India, many of the industries in this sector are into assembly rather than core manufacturing. The electronics industry contributes 1.7% to Indian GDP (NITI Aayog report “Make in India Strategy for Electronic Products”, May 2016). The country’s economic growth, rapid urbanisation and technology demands are acting as key drivers for the electronics industry. Whereas the development of electronics manufacturing industry in India is hindered by constraints at ports, good infrastructure facilities and complicated regulations and procedures (Singh et al., 2018). Due to these attributes, we study select issues of the industry in Indian context which assist in bringing sustainability in the supply chain.

2.3.1 SSCM in Indian electronic industry

Each industry has sustainability problems in their supply chain which are specific to their nature of work. The logistic industry has the issue of high energy usage and carbon emissions. The textile industry is grappled with social issues of safety norms and child labour. The chemical industry has a prevalence of hazardous emissions and environment pollution causing factories. The approach to SSCM differs in various countries and industries due to the cultural attitude towards sustainability, national policies, etc., which interest a wide scope of research.

There is a high import of electronic goods to India and the government intends to reduce it by creating a favourable environment for electronics manufacturing. By providing incentives and regulatory support, the government is promoting local production. The Indian government has launched the National Policy on Electronics (NPE 2019) which aims $400 billion turnover by 2025 from Indian manufacturing industries and establishing clusters across the value chain. Newer technologies like 5G are going to propel the growth and consumption of electronic industry in India.

India's economy is growing and it is expected that it would be the 3rd largest economy among nations of the world (United States Department for Agriculture Economic Research Service – USDA). India is promoting domestic production by introducing ‘Digital India’, ‘Atmanirbhar Bharat’ and ‘Make in India’ policies. The easing of foreign investment norms and collaborations has given a tremendous boost to the industry. The Indian government is providing facilities and encouraging local production in the electronics industry. Due to high local demand and export opportunities, the electronics device industry sees good prospects in setting up local manufacturing facilities (Patil and Suresh, 2019).

Asia generated the highest quantity of e-waste in 2019 at 24.9 Mt, while India generated 2nd highest in Asia at 3230 kt (Forti et al., 2020). The required measures to contain impact on the environment due to growth in the electronics industry remain insufficient. India has legislations such as E-Waste Management Rules, 2016 to contain e-waste. However, it is grappling with issues of sustainability awareness, lack of recycling facilities and inaccurate reporting in carrying out the implementation. It is seen that in the electronics industry, a reduction in material intensity would lead to reduced energy intensity. Similarly, improved recyclability could lead to improved service intensity. The increasing use of electronic products and issues in its disposal has put this industry in ambit of legislation and society pressure in implementing sustainability. The nature of industry makes it an apt case for implementing sustainability in its supply chain. An attempt is made in this thesis to analyse the issues affecting implementation of a sustainable supply chain in Indian electronics industry. The study will be beneficial to give a thrust to implement sustainability in Indian industries.

2.4 Eco-efficiency

Eco-efficiency has been gaining interest as organizations try to incorporate both economic and environmental goals in their business. Eco-efficiency is a tool to bring competitively priced goods and services to satisfy human needs and bring a quality of life while reducing environmental impact during its life cycle, at least in line with Earth’s carrying capacity (WBCSD, 2006). Eco-efficiency is seen as a management philosophy in companies to promote economic as well as environmental performance. It is a concept that aims to reduce the consumption of natural resources while giving financial benefits to the firm. (Heikkurinen et al., 2019). Côté et al. (2006), in their research on small and medium enterprises in Canada, found low eco-efficiency levels. They suggested there can be greater economic and environmental gain by enhancing eco-efficiency.

Eco-efficiency needs to be applied at each regional and sector level, and the concept has to be developed specifically for particular systems (Caiado et al., 2017). Eco-efficiency can act as a tool to assess together the economic and environmental contribution of a firm (Tseng et al., 2014). The assessment promotes the idea of creating more with fewer resources (Moreira et al., 2010). To improve its eco-efficiency, a company needs to think beyond the organization and strive for better value creation across the supply chain. Increasing eco-efficiency is faced with constraints such as short-term financial outlook and lack of awareness (Clark, 2007).

Neto et al. (2009) designed a method for evaluating eco-efficiency in recycling logistic networks in Germany. Koskela and Vehmas (2012) proposed an inclusive definition of eco-efficiency and studied the relationship between Finnish companies' environmental and economic performance in the forest industry. Fujii and Managi (2013) investigated external elements affecting eco-efficiency in Chinese industries. Tseng et al. (2014) studied gain and loss functions to benchmark eco-efficiency in green supply chain practices under uncertainty for a smartphone manufacturer in the electronic industry using TODIM method. Alves and de Medeiros (2015) studied eco-efficient practices among small and micro-enterprises in Brazil. They demonstrate that eco-efficient practices give competitive advantage and cost-benefit to these enterprises. Gumus et al. (2016) applied integrated Life Cycle Assessment (LCA) and multi-criteria decision making (MCDM) for eco-efficiency analysis in US manufacturing sector. They considered greenhouse gas emission, energy usage, release of toxic substances and hazardous waste generation as having a negative impact on the environment. Vásquez-Ibarra et al. (2020) used LCA and Data Envelopment Analysis (DEA) for the assessment of eco-efficiency.

Globalization and technological advancement have increased the competition worldwide, including the electronics industry. The industry is growing tremendously with increased usage of electronic items and the resulting e-waste has led to various rules and legislations being framed. Waste Electrical & Electronic Equipment (WEEE) and Restriction of Hazardous Substances (RoHS) directives make manufacturers responsible for recycling of products after the end of their life cycle and restricts use of certain hazardous substances, respectively (Ongondo et al., 2011). Cusack and Perrett (2006) reckon that many nations do not have regulations for WEEE or are slow in formulating and implementing them. The use of physical resources in the electronic industry is high, affecting the overall eco-efficiency levels.

2.5 Sustainable Supplier Selection

This section discusses the literature on sustainable supplier selection and sustainable supplier selection criteria. In traditional SCM, profit and price were the focus, while in Sustainable SCM, organizations need to consider the environment and social impact while designing and optimizing their supply chain (Dubey et al., 2017). In the beginning, the focus was on environmental issues and much less on social issues (Singh and Trivedi, 2016). Five constructs of SSCM considered by Das (2018) include environmental management practices, operations practice, supply chain integration, socially inclusive practices for employees, and community. For an SSCM initiative, significance is given to four fundamental practices of sustainable procurement, sustainable production, sustainable distribution and reverse logistics (Esfahbodi et al., 2016).

Organizations are integrating sustainability aspects into their existing business model. Many organizations do it due to evolving legislation, whereas many feel it gives a competitive brand image and long-term benefits. Sustainability supply chain management has led companies to practice extended producer responsibility, reverse logistics and recycling. Studies reveal that apart from fostering innovation and reducing costs, sustainability introduced in the supply chain increases the economic benefits (Wang and Sarkis, 2013).

Sustainable supplier selection is an important part of attaining sustainability in the supply chain. Supplier selection also affects the competitiveness of an organization, and it impacts the final product. Supplier evaluation and selection is a complex process as various criteria are assessed in the decision making process. In an actual business situation, the problem may have to be dealt without the availability of accurate information (Simic et al., 2017). Supplier evaluation is part of the supplier selection process, which also consists of identifying the supplier and the contract with the supplier. A supplier is assessed on various criteria, including technical and commercial, with the help of MCDM methods. Evaluation is a part of the process of supplier selection. The all-around sustainability of companies can be increased using formal decision-making methods in the evaluation and selection process (Zavadskas et al., 2016).

Zimmer et al. (2016) analyzed the literature on sustainable supplier selection by reviewing 143 peer-reviewed publications. They listed the ten most common economic, environmental and social criteria in their survey. The criteria may change based on the industry, and companies must choose selection indicators pertinent to them (Amindoust et al., 2012). Fallahpour et al. (2017) identified criteria and sub-criteria for sustainable supplier selection in textile manufacturing companies. Govindan et al. (2015) reviewed the various multi-criteria decision making approaches and the most extensively used criteria for evaluating and selecting suitable suppliers in green supply chain management. Gupta and Barua (2017) ranked suppliers using fuzzy TOPSIS based on green innovation criteria among small and medium enterprises. Luthra et al. (2017) presented a framework for sustainable supplier selection by identifying 22 criteria for selection across three dimensions of sustainability. Jain et al. (2020) developed a framework for selecting a sustainable supplier in the Indian iron and steel industry. Since the work primarily included sustainability criteria applicable to the Indian iron and steel sector, a more comprehensive study of sustainability supplier selection in other industries was suggested.

To remain in a sustainable supply chain, the environmental, social and ethical criteria need to be satisfied by the members of the supply chain along with satisfying customer requirements and economic criteria (Büyüközkan and Çifçi, 2011). Due to subjectivity being an innate feature of sustainable supplier selection, especially in social areas, it becomes difficult to evaluate subjective characteristics. Individuals may interpret it differently because of the ethical differences across geographies (Memari et al., 2019). This has necessitated us to give particular attention to ethical factors in sustainable supplier selection. To succeed in the sustainability activities of an organization, effective business ethics is necessary (Gunasekaran and Spalanzani, 2012). Earlier researches have put forward that ethics play a significant role in collaboration for purchasing and sourcing (e.g., Closs et al. 2011; Mueller et al. 2009; Drake and Schlachter, 2008). Ethics contributes to conceptualizing and developing an environmentally sensitive supply chain (Beamon 2005). Companies' reputations have been tarnished due to the unethical practices of suppliers, and it affects the entire supply chain (Guarnieri and Trojan, 2019).

There is a lack of study involving economic, environmental, social, and ethical criteria for supplier selection in literature. Guarnieri and Trojan (2019) studied these aspects in supplier selection for the Brazilian Textile industry. Further, though they have taken ethical factors, it has been included as part of the socio-environmental criteria in the structure model. Social and ethical dimensions are still emerging in sustainability studies (Sarkis et al., 2010). It has been suggested to study further the impact of ethics and moral values in a supply chain (Eriksson 2015). This thesis has considered a fourth dimension, "Ethical" in sustainability for sustainable supplier selection.

2.6 Sustainability related initiatives of the Indian Government

India, the largest democracy in the world has been aspiring to expand its manufacturing base and the ease of doing business. The Indian government is supporting sustainability development by its commitment to sustainable development goals. The government has been promoting cleaner and renewable energy, sanitation and health initiatives like Swachh Bharat Mission. The government has introduced Production Linked Incentive (PLI) scheme to boost manufacturing capabilities of environmentally cleaner, electric vehicles and hydrogen-fuelled vehicles. The Indian government is trying to establish India as a manufacturing base and strengthen its value in the global supply chain through various programs and campaigns such as Make in India, etc.

Many Governments across the world have introduced legislations to enforce environmental and social responsibilities on companies doing business. In India, the Ministry of Corporate Affairs (MCA) has framed the National Guidelines on Responsible Business Conduct (NGRBC) to provide guidance on responsible conduct of business. NGRBC is national voluntary guideline which nudge firms to align with the United Nations guiding principles on business and human rights (UNGPs) and sustainable development goals (SDGs). For skilling and training youth with technical knowledge to work for environment and sustainable development, the Ministry of Environment, Forest and Climate Change has started the Green Skill Development Programme (GSDP). In India, there is a higher need to improve the social sustainability dimension and remove among supply chain channels the prevalence of child and bonded labour as well as protect human rights (Mani et al., 2016).

2.7 Benefits and Challenges for SSCM

2.7.1 Benefits of SSCM

Balancing economic, social, and environmental issues has proven beneficial for firms and mankind (Chkanikova, 2015**)**. The topic of sustainability in the supply chain has been of immense significance in the last decade, with keen interest seen from business, academia and society (Pagell and Shevchenko, 2014). The benefits of adopting SSCM to an organization are many as depicted in figure 2.2. It includes customer loyalty (Beverungen et al., 2008), resource (energy & material) efficiency, supplier satisfaction (Olugu et al., 2010), cost reduction, strengthening cooperation with partners, improved organizational reputation and corporate image, competitive advantage, reducing waste, health of workers, etc.

Literature argues that there are significant productivity and cost benefits linked to sustainable operations of a supply chain (Mefford, 2011). The benefits involved are for all stakeholders, including the shareholders, customers, employees, suppliers, distributors, environment and society. The information and knowledge about a company’s business practices are known to the consumer due to internet and faster communication. Organizational reputation and a company's corporate image adapting sustainability practices get enhanced (Davis et al., 2006). SSCM practices help businesses adopt processes that enable efficient use of material and energy resources, thus improving productivity (Luthra et al., 2016). SSCM helps the growth in market share of businesses (Hsu et al., 2016).

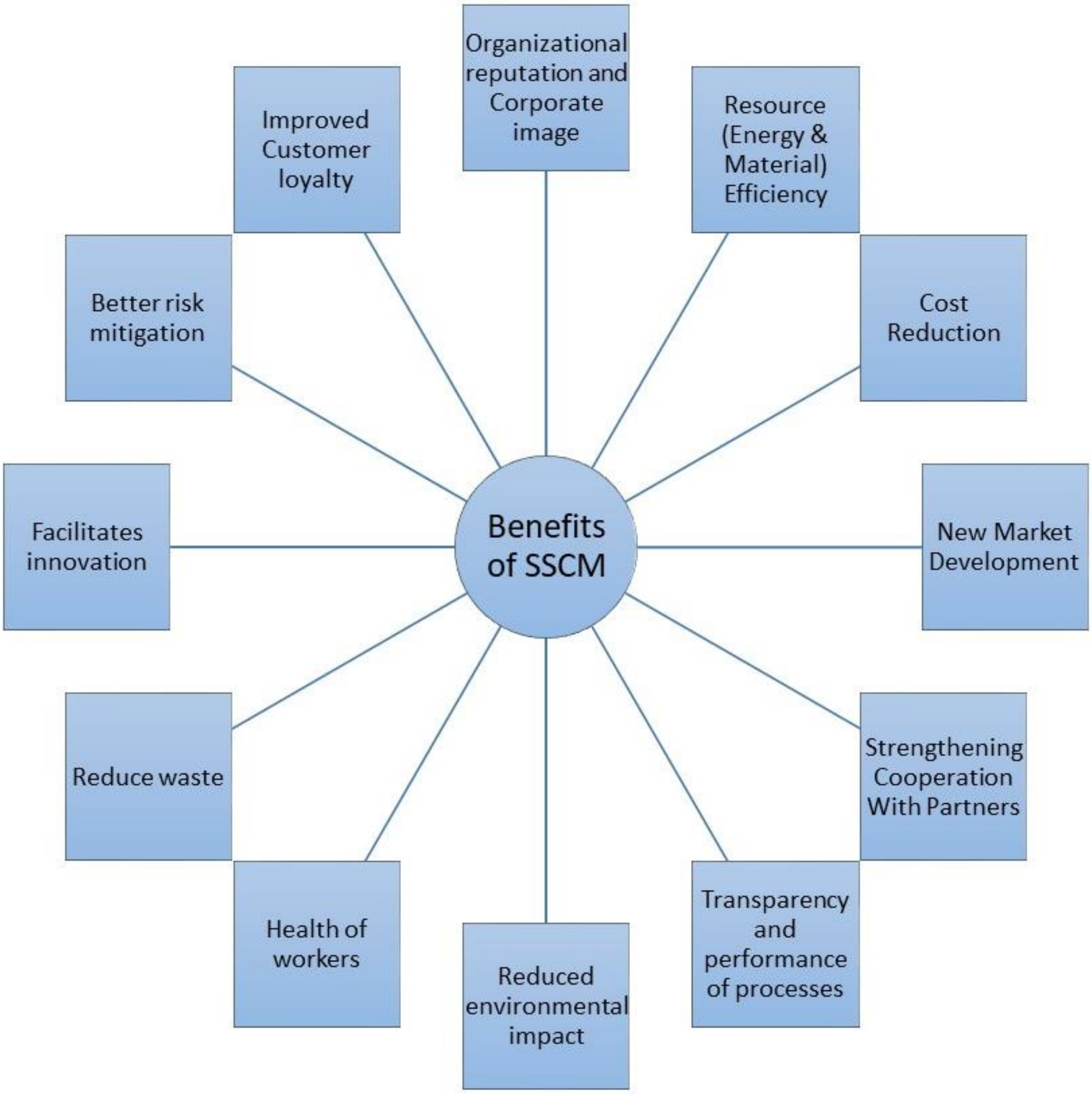

Figure 2.2: Benefits of SSCM

Literature points that though there may be initial costs in implementing SSCM, overall the activities undertaken result in cost reduction (Cruz et al., 2006). Social dimension of sustainability can prompt for certifications such as OHSAS 18001 and SA 8000 that reduce regulatory and litigation costs. SSCM strengths the cooperation among partners by building trust, long term relationships and deep partnerships (Gold et al., 2010). The social welfare and safety measures undertaken in SSCM improve workers' health and motivate them.

The amount of waste generated gets highly reduced due to the improvements in processes. Recycling, reusing and remanufacturing gives better utilization of resources, thereby reducing waste generated. Gao et al. (2017) regard SSCM as an output of innovation practices. Sustainability activities foster innovation in various areas of supply chain. Gouda and Saranga (2018) found that sustainability practices provide better risk mitigation in the supply chain particularly for emerging markets such as India. Xu and Gursoy (2015) point out that sustainability efforts influence customer loyalty positively. The environmental and social initiatives improve customer satisfaction leading to increased customer loyalty and readiness to pay extra.

2.7.2 Challenges in SSCM

The methods and strategies to implement sustainability throughout the supply chain network pose a number of challenges for businesses (Rajeev et al., 2017). Some of the challenges faced by the organization are:

- The sustainability implementation in supply chain with existing models still requires more to be attained practically and strategically (Mota et al., 2015).
- The multi-dimensional construct of SSCM has internal and external challenges in terms of its strategic and operational implementation (Chong et al., 2011).
- The metrics to measure sustainability across a supply chain is complex and developing a composite framework requires additional research (Hassini et al., 2012).
- The implications of sustainable supply chain management with regards to different industries, their scale and geographical location need to be studied comprehensively by researchers and practitioners (Reefke and Sundaram, 2016).

2.8 Framework for SSCM

Sustainability has been considered a critical requirement for conducting business by managers (Kiron et al. 2012). For a sustainable supply chain, the organization has to be mindful of its environmental and social responsibilities along with economic goals. A framework of SSCM built on three pillars of economic, environmental and social performance is shown in Figure 2.3.

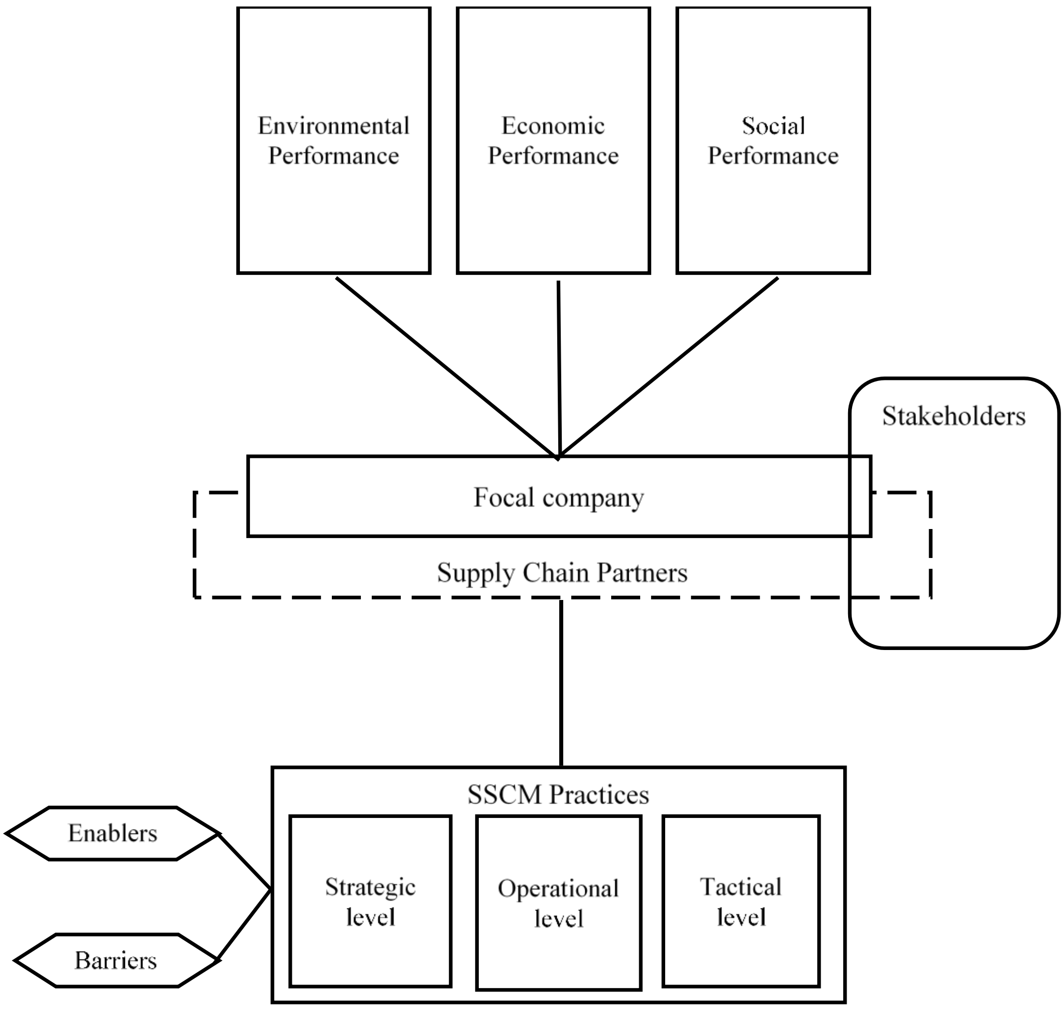

Figure 2.3: Framework for SSCM

Factors such as business ethics, human rights, gender equality, etc. aid in gauging the social performance (Drobetz et al., 2014). The social responsibilities include looking after the welfare of its employees, working conditions, and abiding by the rules and regulations (Beske et al., 2014). Fahimnia et al. (2015) studied the environmental performance with metrics like carbon emissions, waste generated and energy usage. Various other measures have been used in different studies to analyze the sustainability interactions. Standards such as SA8000, ISO26000 focus on the social accountability practices of the organization. Ageron et al. (2012) proposed a theoretical framework for sustainable supply management and analysed it using empirical evidence. Brandenburg and Rebs (2015) used modelling approaches to study relationship of supply chain actors with suppliers, risk management and stakeholder pressure and incentives in sustainable supply chain.

The framework for a sustainable supply chain should be able to manage risks, develop sustainable suppliers and improve the eco-efficiency parameters. Sustainable practices should be adopted understanding the enablers and barriers that would be encountered. SSCM practices have to be organized at a strategic, operational and tactical level in the company. An effective sustainability penetration requires efforts from the focal company to develop the concept across the supply chain and its partners while upholding the stakeholder values and expectations. The sustainable supply chain is formulated to deliver and improve performance considering the triple bottom line aspects.

2.9 SSCM in DoS/ ISRO/IIST context

In India, the space industry is largely driven by the Government's Department of Space (DoS) through its national space agency Indian Space Research Organisation (ISRO). DoS has been using space technology and applications for socio-economic development of the country (Sadeh, 2013). ISRO has been contributing to social measures as most of its activities are aimed for welfare and helping the society. The space development has been helping in societal services of connectivity in rural areas, improving literacy and helping the communities like fishermen, farmers, etc. to improve their yield. ISRO has been launching for free the nano-satellites made by students, universities and promotes the scientific temperament of the young in the country.

ISRO has been using space technology for national development and the benefit of society. It is known worldwide to work successfully on a comparatively lower budget. The launches and satellites developed are highly cost-effective. An effective and efficient supply chain plays a major role for ISRO to make this possible. India currently occupies around 2-3% of the overall space economy of the world and aspires to take it above 10% by 2030. To achieve this goal and have a global reach, sustainable development and SSCM will play a key role in DoS.

ISRO and other space agencies in the world are working towards sustainable development, addressing the environment and space debris concerns (Chakraborty, 2018). Energy generation using renewable sources, innovative materials and reusable technology has already been a subject of research. The reuse of launch vehicles is a step towards sustainability by way of reducing resource consumption, cost saving, etc. in space supply chain. ISRO is working on environment friendly fuel and green propulsion to reduce pollution causing propellants. Green fuel such as hydrogen peroxide, methane-liquid oxygen is being developed to reduce the carbon footprint and such fuels can help in cost savings too. The lithium-ion battery developed for rockets is now being used for electric vehicles through technology transfer by ISRO. The sustainable supply chain includes reuse of launch vehicles, materials, reclaim, disposal and space debris.

Indian Institute of Space Science and Technology (IIST), established by DoS, has undertaken many sustainability initiatives. It has built rainwater harvesting facility to conserve water. It has also set up water treatment plant with the capacity to meet demands of the Institute. The institute is now self-reliant for all its water needs. To use renewable energy resources, DoS is installing solar power plants across all its centres/units and in line with it, solar power plant is installed in IIST to harness solar energy. Bio-gas plant converts its canteen's organic waste into cooking gas for canteen and produces bio-manure which is an excellent bio-fertilizer for cultivation.

2.9.1 Scope of SSCM in Space Supply Chain

The Indian Government has initiated major reforms in space sector for commercialization and to boost private participation in space industry. The supply chain needs to gear up for space rated delivery and global competition scenarios. The change in role of companies from being vendors to focal companies is going to change the dynamics of space supply chain. A sustainable supply chain is essential to support and build end-to-end launch vehicles.

India's Gaganyaan program will carry humans to space and considering the safety aspects, will be using green propulsion for the orbiter module. ISRO is also focussing on electric propulsion and green fuel to reduce toxic emissions. Many other aspects of launch systems and satellite applications are being made sustainable. Like developing Isrosene, which is a rocket grade version of kerosene as substitute for hydrazine. Even the private players in the space industry are moving towards sustainability, like using green cryogenic fuel for launch vehicles' upper stage. The space transportation policy of DoS also alludes to sustainable development of space technology and industry.

Space exploration will require establishment of sustainable supply chain network both at ground and in space. It requires development of a complex SSCM network and framework. The creation of such SSCM requires contribution from academic institutions like IIST and other partners from academia, industry, etc.

2.10 Research Gaps arising out of Literature Review

In SSCM all three dimensions of economic, social and environment are to be assessed using integrated strategies. This makes it challenging for decision-makers to investigate the association between economic, environmental and social dimensions and manage organizational goals. The existing research on SSCM models and processes has not completely underpinned these challenges. The existing research in specific areas of SSCM considering aspects of triple bottom line is limited owing to the intricacies involved. The win-win and trade-off situations have to be studied and the concept requires deeper investigation with respect to the industry and geographical variations.

Literature review reveals there are still gaps in theory and its practical applications. It is observed that the existing studies are general and not industry specific. Research with respect to integration of sustainability in SCM and the decision making process is lacking in particular to Indian context. Research on the factors affecting SSCM, eco-efficiency requirements and sustainable supplier selection for the electronics industry in Indian context is not duly found in literature. Therefore, further research and insights are needed to explore and implement SSCM by companies.

Based on the gaps in literature, *five* key problems in area of SSCM have been considered in this study. Different cultures, countries and industries have varied opinions on the influence of a factor for SSCM implementation (Govindan et al., 2014). Zhu and Sarkis (2006) indicated that the sustainability issues in developing nations had not been thoroughly investigated, and their study of Chinese firms revealed that different industries have varying drivers. There are only a few empirical works on enablers and outcomes of sustainability adoption in developing countries (Köksal et al., 2017). The study of the interrelationship among enablers with categorization for a sustainable supply chain in the Indian electronics industry is not seen in literature. A framework for various enablers of SSCM and their causal effects on Indian electronic industry in particular is lacking. This *first* research problem addresses this gap by identifying enablers of SSCM in the electronics industry in the Indian context and then evaluating them using the Grey-DEMATEL approach.

The process of transformation to a sustainable supply chain will encounter some barriers which need to be eliminated or mitigated. To successfully manage these obstacles, it is crucial to know and study these barriers in specific context. The evaluation of barriers in implementing a sustainable supply chain for different industrial sectors is important for the industry to tackle them (Govindan et al., 2014). It is seen from literature that barriers specifically to implementation of sustainability in Indian context have not been fully explored till date. The interdependence of these barriers and prioritization of the barriers at various levels has not duly been addressed in literature. The *second* research problem aims to identify and analyse major barriers hampering sustainability implementation. The contextual relationships and analysis of the barriers in sustainable supply chain are found out using ISM and MICMAC analysis. Driving barriers, which can aggravate few more barriers are identified and those barriers, which are most influenced by driving barriers are determined.

The *third* problem studies the influence and relationship among barriers so that organizations can comprehend the hurdles while shifting to a sustainable supply chain. In this research, barriers affecting sustainability implementation in electronics supply chain are shortlisted from literature review and experts' opinion. Using the combined methodology of Grey DEMATEL, the causal factors, the effect factors and degree of prominence of barriers is found out. The overall relationship among barriers is established by a diagraph.

The concept of eco-efficiency has emerged as one of the primary tools for attaining sustainable development (Yu et al., 2013). Eco-efficiency determines the value of a product considering its environmental impact. Eco-efficiency has become a management technique to analyze and quantitatively assist companies seeking practical solutions for sustainable development (Willison and Côté, 2009). Studies on eco-efficiency and its benefits in the electronics industry have been reported in the literature. But research related to identifying Customer requirements (CRs) and Design requirements (DRs) while adopting eco-efficiency in the electronics industry is not duly found in the literature. To efficiently integrate various measures of eco-efficiency, this research needs attention. The *fourth* research problem has tried to address this gap. It studies the improvisation of eco-efficiency by identifying and analyzing the customer and design requirements in an electronic supply chain. The research explores and finds out the interrelationship among the CRs and DRs along with their prioritization.

Conventionally, price, quality, delivery time, and flexibility were the primary criterion used by companies for selection of suppliers. In recent times, with increasing prices of energy, industrial contamination, depletion of raw materials and environmental disasters have been reported. Sustainability is an important factor that needs to be incorporated in selection of suppliers as well. A study for selecting a sustainable supplier in a supply chain of the electronics industry in India using a hybrid selection model is not found. Thus, selection of sustainable suppliers is the *fifth* research problem addressed here. A model for sustainable supplier selection giving weightage to the ethics dimension, which is seen as an essential part of a procurement process is lacking in literature. A sustainable supplier selection using the combined MCDM technique of AHP-TOPSIS is presented in this research to address this gap.

In next Chapter, details of the *first* research problem, related literature, solution methodology and its case application are described.

CHAPTER 3

ANALYSIS OF ENABLERS OF SUSTAINABLE SUPPLY CHAIN MANAGEMENT USING GREY THEORY AND DEMATEL APPROACHES

3.1 Introduction

Sustainable development is now not only a necessity but also emerged as a potential game-changer for organizations. Still, many companies are indifferent to commit themselves to sustainability unless mandated by law. A characteristic of these companies is that they cannot evaluate sustainability benefits (Searcy et al., 2009). Companies have not shown much concern about improving sustainability in supply chain without external stimuli (Pagell and Shevchenko, 2014). For moving towards sustainability, companies need to bring socially and environmentally concerned strategies at each level of the supply chain (Rostamzadeh et al., 2015). They need to embrace concepts like extended producer responsibility, reverse logistics, environment-friendly systems, etc., to close the supply chain loop (Zhu et al., 2005) and provide cultural inclusiveness, better working conditions, compensation and equal human rights (Rajak and Vinodh, 2015).

To implement SSCM, industries will have to evaluate enablers of SSCM within their threshold, extant region and industry. Companies need to focus and utilize these enablers for moving towards sustainability in their supply chains. These enablers should be effective across the supply chain and their collaborating partners. Various enablers exist to attain SSCM but identifying the most suitable enablers is crucial for the industry to espouse all-round adoption of sustainable practices (Santos et al., 2013). Analyzing enablers for an industry's sustainable supply chain is vital.

Among these enablers, some have high causing influence while others exhibit high effecting influence. In this study, important enablers affecting the sustainability of the electronics supply chain in the Indian context have been identified from literature review and experts' opinions. The research helps in finding the causal and the effect enablers for implementing sustainable supply chain management. Further, these enablers are ranked based on their degree of prominence.

3.2 Identification of key Enablers to implement SSCM

Enablers in this study are factors that aid the adoption of SSCM for a firm (Sancha et al., 2015). The term enabler means to give power, to make, ability or competence. Grzybowska (2012) defines an enabler as one that enables another to achieve an end. Enablers can create change for small, medium and large enterprises. Owner's outlook, organization structure, resource availability, public dealings or perception, experience, data availability, etc., all impact the enforcement of enablers. Literature reveals that based on country or an industry, enablers and their influence might change. Effective implementation of SSCM demands understanding influences of enablers of sustainability that so far in literature have not been considered separately for the electronics industry in the Indian context.

For this study, we have considered enablers of SSCM in all three relevant areas, viz., economic, social and environment elicited from the context of SSCM definition laid out earlier in the thesis. Upon interviews and also in discussions with experts and managers, seventeen enablers were finalized for this study. The identified enablers are shown in Table 3.1 and classified into five categories.

This was done to categorize SSCM enablers in a broader perspective and better handling during the implementation phase. The classification is done inductively through brainstorming based on the identified enabler's functional aspects and experts' knowledge of SSCM and the electronics industry. The enablers based on their categories are classified in Policy, Financial, Technology, Environmental and Human Resource areas as shown in Fig. 3.1. Notations used for ease of reference to these enablers are shown in Table 3.2.

Table 3.1: Enablers for implementation of SSCM

	Enabler	References	Economic	Social	Environmental
E1	Top Management Commitment	Faisal (2010), Walker and Jones (2012), Luthra et al. (2015), Raut et al. (2017).	✓	✓	✓
E2	Government Policies & Legislations	Zhu et al., (2005); Tay et al. (2015), Luthra et al. (2015), Chkanikova and Mont (2015), Kausar et al. (2017).		✓	✓
E3	Availability of Funds/investment	Faisal (2010), Ageron et al. (2012), Grimm et al. (2014), Balasubramanian, (2014)	✓		
E4	Research & Development	Winkler (2010), Kim and Rhee (2012), Gupta and Barua (2018), Gupta et al. (2020).	✓	✓	✓
E5	State of the art Technologies, Materials and Process	Luthra et al. (2015), Marshall et al. (2015a), Dubey et al. (2017), Raut et al. (2017)			✓
E6	Green purchasing	Wittstruck and Teuteberg (2012), Luthra et al. (2015), Tay et al. (2015), Dubey et al. (2015).	✓		✓
E7	Environment Management systems	Diabat and Govindan (2011), Toke et al. (2012), Beske and Seuring (2014), Raut et al. (2017).			✓
E8	Environmental collaboration between supply chain partners	Büyüközkan and Çifçi (2013), Beske and Seuring (2014), Grimm et al. (2014), Dubey et al. (2017).			✓
E9	Lean Manufacturing practices	Bai et al. (2019), Mangla et al. (2020), Digalwar et al. (2020), Yadav et al. (2020).	✓		✓
E10	Reverse logistic practices	Vachon, (2007), Büyüközkan and Çifçi (2013), Raut et al. (2017), Dubey et al. (2017).	✓		✓
E11	Reducing consumption of Resources/Energy	Wittstruck and Teuteberg (2012), Al Zaabi et al. (2013), Esfahbodi et al (2017), Das (2018).	✓		✓
E12	Training & Literacy	Luthra et al. (2015), Jabbour et al. (2015), Raut et al. (2017), Mudgal et al. (2009).		✓	✓
E13	Culture related factors	Luthra et al. (2015), Oelze (2017), Mani and Gunasekaran (2018), Nayak and Dhaigude, (2019).		✓	✓
E14	Human expertise	Luthra et al. (2011), Gandhi et al. (2015), Saeed and Kersten (2019), Kumar et al. (2019).		✓	
E15	Corporate social responsibility	Faisal (2010), Beske and Seuring (2014), Tay et al. (2015), Raut et al. (2017).		✓	✓
E16	Health & Safety standards	Hutchins and Sutherland (2008), Diabat et al. (2014), Raut et al. (2017), Prasad et al. (2020).		✓	
E17	Green labeling & packaging	Verghese and Lewis (2007); Sarkar (2012), Zailani et al. (2012), Kumar et al. (2014).		✓	✓

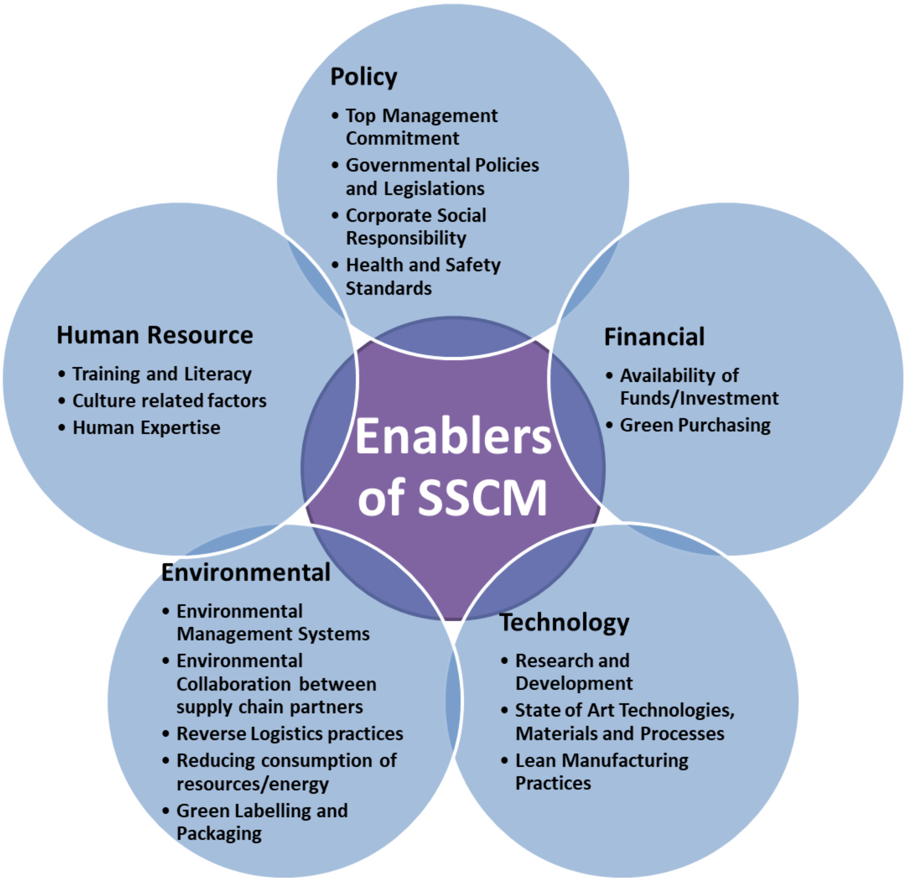

Figure 3.1: Classification of enablers of sustainable supply chain management

Table 3.2: Reference notation for enablers of SSCM

Enabler		**Notation**
E1	Top Management Commitment	TMC
E2	Government Policies & Legislations	GPL
E3	Availability of Funds/investment	AFI
E4	Research & Development	RAD
E5	State of art Technologies, Materials and Process	TMP
E6	Green purchasing	GPS
E7	Environment Management systems	EMS
E8	Environmental collaboration between supply chain partners	CSP
E9	Lean Manufacturing practices	LMP
E10	Reverse logistic practices	RLP
E11	Reducing consumption of Resources/Energy	RRE
E12	Training & Literacy	TAL
E13	Culture related factors	CLF
E14	Human expertise	HEX
E15	Corporate social responsibility	CSR
E16	Health & Safety standards	HSS
E17	Green labelling & packaging	GLP

The enablers as per their classification are discussed as follows.

3.2.1. Policy enablers

(i) ***Top Management commitment***: Top Management commitment (TMC) is an important enabler for attaining sustainability. Top management of an organization will have the powers to allot resources required to support SSCM. A strong top management commitment is needed to carry out strategic transformation and system modifications in an organization (Zhu and Geng, 2013). Commitment from top management is required to have complete environmental excellence (Rice, 2003). Leadership can give a clear vision to address environmental issues for business activities by taking proactive steps for attaining sustainability. Various studies have shown top management commitment as the most influential factor for achieving sustainability (Sharma, 2000). If there is direct participation for sustainability from the highest level, it gives better communication and positive employee motivation. Top management support is critical to driving decision making strategies on sustainability, can encourage the workforce by rewards/incentives and is highly significant for the successful implementation of SSCM (Kausar et al., 2017).

(ii) ***Governmental Policies and Legislations***: Government policies and legislations (GPL) are significant drivers for the commencement of sustainability in a business (Houda and Said, 2011). It is evident that to reduce social and environmental impact, government regulation and legislation are prime factors. There is a positive correlation between green innovation and strict government environment policies (Horbach, 2008). A strong government can support infrastructure, tax cuts, financial and technical help (Lee, 2008). Policies and government regulations induce organizations to sustainable friendly stand in their work (López-Gamero et al., 2010). Many companies go beyond compliance as regulatory scrutiny can be costlier (Rothenberg et al., 2009).

(iii) ***Corporate social responsibility***: Corporate social responsibility (CSR) is defined as the set of activities and decisions such as improving working conditions, philanthropic donations, reducing pollutants, and so on that is beneficial to the sustainable development of the supply chain (Liu et al., 2018). The concept necessitates that organizations conduct themselves not to defy social, moral standards and government restrictions voluntarily during interactions with their stakeholders. CSR can become a deciding element in business decisions to realize the sustainability goals of organizations. Corporate social responsibility shows that a company is sensitive towards societal problems and enhances its reputation (Chang, 2016). Organizations need to see that all firms in their supply chain act socially responsible for effective CSR (Enderle, 2004).

(iv) ***Health and safety standards***: Health and safety standards are required to foster an organization's workforce's physical, social and emotional well-being to promote sustainability (Raut et al., 2017). Organizations adopt standards such as ISO 45001 to reduce workplace risk, create a safer working place, and improve employees' well-being. Health and safety standards help improve occupational health and the chance of any potential disease or injuries. These standards also reduce the chances of an accident or hazard. Apart from such standards, it includes all activities and management practices that legislation or standards may not require but which firms adopt voluntarily for better health and safety. Addressing health and safety issues can positively affect the social sustainability angle in a supply chain. Health and safety standards are important enablers for workers' involvement to inspire them in SSCM implementation. Health and workplace safety is essential for adopting and implementing SSCM practices (Toke et al., 2012). Enhanced safety features and protocols may incur costs, but it boosts workers' motivation, which goes a long way for firms to realize sustainability (Muduli and Barve, 2013).

3.2.2. Financial enablers

(i) ***Availability of Funds/investment***: Availability of Funds/investment (AFI) is necessary for creating the capital infrastructure and workforce required to implement sustainable programs. SSCM implementation may require an organization to do reengineering, innovation and developing new facilities. This requires heavy financial investment in the beginning. In addition, resources are necessary to acquire new skills and to improve infrastructure. Due to limited funds, small and medium organizations find difficulty meeting environmental and social standards (Lee, 2008).

(ii) ***Green purchasing***: Green purchasing means procuring products and services that have a minimal harmful impact on the environment and protect human health at competitive prices. It makes an organization cooperate with its suppliers on sustainability by purchasing environmentally friendly products (Zhu and Sarkis 2006). Bjorklund (2010) opined purchasing to be of strategic importance in reducing adverse environmental impact and as an important corporate function in acting as a change agent for sustainability.

3.2.3. Technology enablers

(i) ***Research and Development***: Research and Development provides a positive economic impact by giving a competitive advantage, increased productivity, improved quality and product development. It brings about research facilities that help in improving the product and process within an organization. Research and development increases an organization's ability to adopt environmental and social innovations. Innovations and research related to sustainability help in the reasoned use of resources. Future progress in sustainability requires radical technological and scientific developments. Higher spending in research related to sustainability assists organizations for higher competencies in handling environmental requirements (Zailani et al., 2012). For effective sustainability, research and development should solve society's problems and not just scientific issues. Research and development extend the social effort to provide affordable and reliable alternate fuels, safety technologies, waste disposal, workplace innovation, etc. Sustainable innovations depend on an organization's research and development capability (D'Este et al., 2012). Gupta et al. (2020) presented that organizations and regulatory bodies should build strategies to facilitate the progress of research facilities and allocate more funds into research activities to improve sustainable development.

(ii) ***State of Art Technologies, Materials and Processes***: State of the art technologies, materials and processes (TMP) helps conserve natural resources. It also creates a healthy and productive environment by reducing pollution and maximizing energy efficiency. Processes like proper waste management systems, disposal methods, cleaner technologies, manufacturing processes resulting in zero emission generation, etc., reduce the harmful effect to the environment (Klassen and Whybark 1999). In addition, adopting new technology helps newer ideas in product development and brings in innovative culture (Muduli and Brave, 2011). Clean technologies have an economic impact through cost saving and improving environmental efficiency at the operational level (Mudgal et al., 2009).

(iii) ***Lean Manufacturing Practices***: Lean manufacturing is a combined approach that includes various practices, including just-in-time, quality systems, work teams, cellular manufacturing, supplier management, etc., within a system (Shah and Ward, 2003). Lean manufacturing practices aids in the development of an effective system, well organized and constantly improving to reduce all forms of waste. (Simpson and Power, 2005).

3.2.4. Environmental enablers

(i) ***Environmental Management Systems***: Environmental management systems (EMS) helps in achieving reduction on environmental impact, provide improved safety standards, and give greater management control. Environment management practices include many activities within the organization ranging from raw material inputs, production information flow, designing, packaging, technology and equipment for manufacturing and waste management (Shrivastava and Hart, 1995). Organizations can move towards ecologically sustainable business practices by Environmental management systems guidelines.

(ii) ***Environmental Collaboration between supply chain partners***: Trust, commitment and satisfaction result in collaboration among supply chain partners and promotes sustainability. Collaboration between focal firms and suppliers is a primary factor for enabling environmentally and socially responsible practices in the supply chain. A focal firm can increase social and environmental aspects of its supply chain and mitigate risk by building trustworthy relationships with its supply chain firms (Lee et al., 2016). It is now acknowledged that businesses acting alone cannot accomplish sustainability; instead, it requires the collaboration of all stakeholders in the supply chain. Environmental collaborations involve a firm's participation with its suppliers and customers to resolve sustainability issues (Chin et al., 2015). Understanding the capabilities and responsibilities downstream and upstream of supply chain partners is necessary for better collaboration. Collaboration between supply chain partners results in sustained long-term advantages and is vital in the reverse chain, just as it is in the forward chain (Olorunniwo and Li, 2010). Collaboration achieved through trust and commitment brings clarity and better assessment of supply chain partners, promoting sustainability (Prokesch, 2010).

(iii) ***Reverse Logistics practices***: Compared to forward logistics, where the material and information flows are unidirectional, reverse logistics practices include processes for returning waste material and used goods to the producer, resulting in a complete cycle. In addition, reverse logistics requires creating a network to collect end-of-life products, inspect, recycle, refurbish and dispose of these end products without harming the environment. As a result, organizations can become increasingly environmentally friendly by recycling, reusing, and reducing raw material usage through reverse logistics (Ravi and Shankar, 2005).

(iv) ***Reducing consumption of resources/energy***: SSCM is promoted by adopting policies related to reducing the use of natural resources, water and fossil fuels. Reducing the consumption of resources/energy assumes importance in curbing environmental impact. To make better decisions on continued climate change and economic development, more research among various countries is required to prioritize renewable energy resources globally (Ikram et al., 2021). This will help in reducing the consumption and usage of polluting fossil fuels. Reducing waste and consumption of energy/resources enables sustainability and reduces operational costs across the supply chain (Toke et al., 2012).

(v) ***Green Labelling and Packaging***: Eco-labelling is a performance certification of a product meeting specific environmental standards and criteria (Sarkar, 2012). They give companies a stamp of approval in their environmental quality process and help them improve overall environmental performance (D'Souza, 2004). In addition, practices such as environmentally friendly packaging are vital factors in facilitating sustainable supply chain management (Zhu et al., 2005).

3.2.5. Human Resource enablers

(i) ***Training and literacy***: Training and literacy improve employees' skills, which empowers them to perform their duties efficiently and reduces waste. Training and literacy have long been advocated for sustainable development, enhancing environment and resource management (Madsen and Ulhøi, 2001). For purchase managers, training can better understand environmental issues (Bowen et al., 2001). Training and literacy of supply chain partners help adopt technologies and processes related to sustainability in the supply chain. Training and literacy also aid in achieving social sustainability. A company's sustainability performance is affected by the mental and social health of its employees. Training and literacy also help in lowering the health and safety issues at the workplace (Varsei et al., 2014). Training has been widely recommended to change the mindset against sustainability illiteracy.

(ii) ***Culture-related factors***: Culture consists of values, beliefs, attitudes and peoples' behaviour that differs between different kinds or groups of people (Hofstede, 1993; McSweeney, 2002). Countries and even other industries have varied outlooks on the sustainable enablers based on their own culture (Zhu and Sarkis, 2006). SSCM implementation may differ as per the culture and rules prevailing in that country.

(iii) ***Human Expertise***: Specific sustainability practices are required depending on the industry, type of company, and region. To implement a comprehensive sustainability plan, human expertise with practical skills and experience is required. Companies need clean technology, carbon assessment, sustainable sourcing, hazardous waste management, etc., for successful implementation of SSCM. Experts who are highly competent and skilled guide adopting new technologies to implement sustainability in the supply chain (Sarkis et al., 2010). Small suppliers often lack the human expertise needed for sustainability implementation and would require to be facilitated by the government (Lee, 2008). Sustainability reporting and measurement also require expertise. The experts help introduce sustainability by identifying areas in the supply chain, undertaking research and analysis, and improving existing programs. Human expertise helps in strategizing and to put sustainability rolling for its successful implementation. Companies are seen to appoint practitioners in the sustainability field, such as chief sustainability officers or consultants. These experts also aid in imparting training and education to others within the organization and the supply chain partners on sustainability aspects. Human expertise is vital for successfully implementing SSCM (Luthra et al., 2011).

3.3 Solution Methodology

3.3.1 Framework for the study

At first, the enablers for SSCM were listed vide literature review and inputs from industrial and academic experts.

In the next step, a questionnaire was designed to collect the responses for the Grey-DEMATEL study. Researchers first reviewed the questionnaire, and then for validation of the questionnaire, the content validity process was assessed with opinions from experts. Using the questionnaire, the initial direct relationship matrix on the influence of enablers was obtained from five experts viz., four from supply chain managers working in the electronic industry and one from a leading academic expert engaged in research on SSCM. The responses from experts were then analyzed to evaluate causal enablers of SSCM implementation in the Indian Electronic industry using the Grey-DEMATEL method. The proposed framework for the analysis of enablers of SSCM in the electronics industry is shown in Fig. 3.2

3.3.2 Grey-DEMATEL

The DEMATEL method effectively analyzes complex models with causal relationships among its convoluted factors (Wu and Lee, 2007). DEMATEL method is useful for structuring complicated causal relationships and influence among factors through digraphs. However, human judgments are not precise, and assigning accurate quantitative values is difficult in all cases. Grey set theory can cope with incomplete information (Su et al., 2016), small samples and uncertain structures (Liu and Qiao, 2014). DEMATEL method can be used with a limited sample size (Lee et al., 2013) and has been used from inputs only from three experts (Bhatia and Srivastava, 2018).

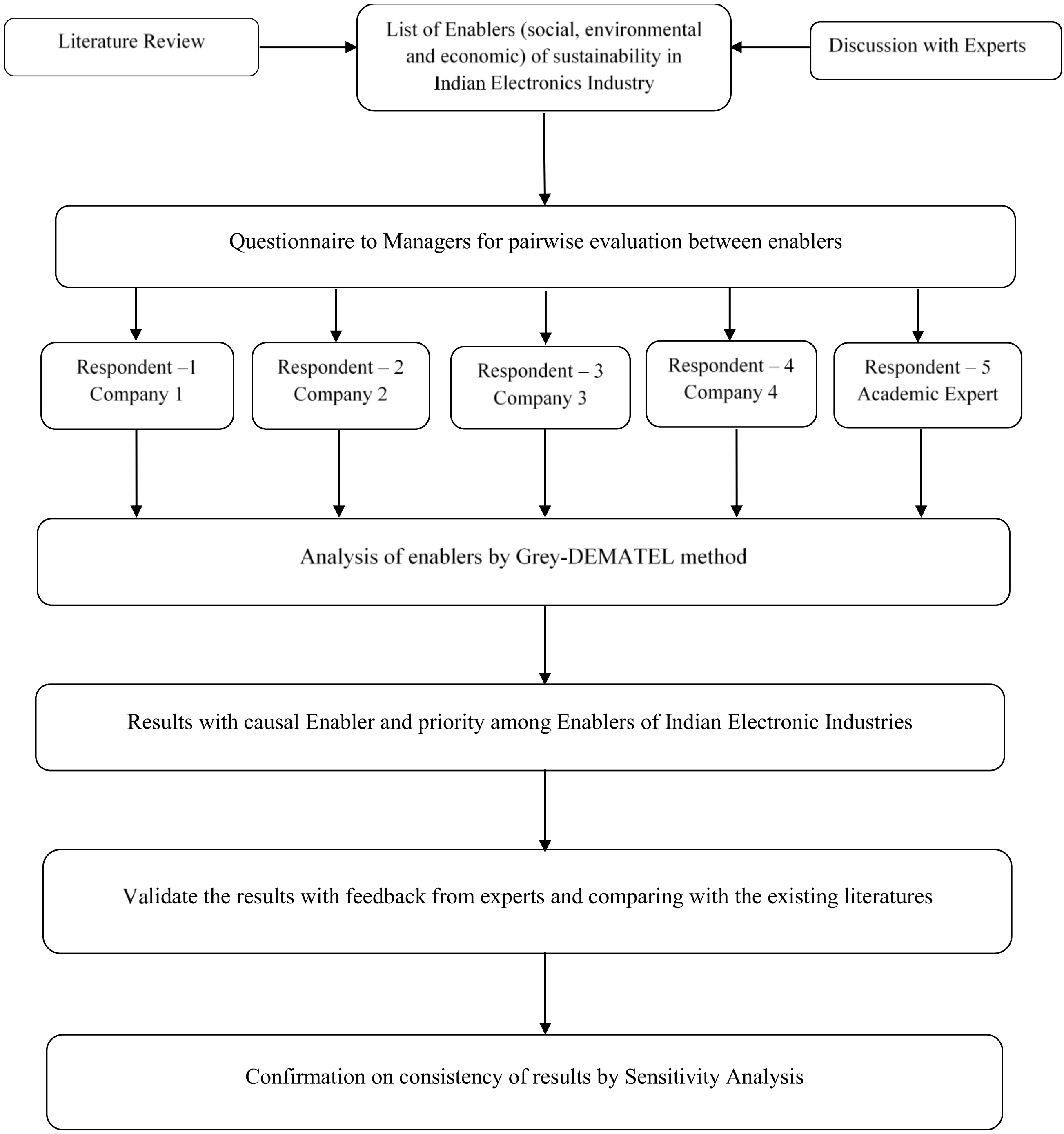

Figure 3.2: A proposed framework for identifying causal enablers for Indian electronics industry

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The steps involved in Grey-DEMATEL are as follows:

List of symbols used

k	Respondent or the evaluator
i, j	Criterion or the enabler
$\otimes x_{ij}^{k}$	The grey number where respondent *k* rates the influence of enabler *i* over enabler *j*.
$\otimes \tilde{x}_{ij}$	Average grey relation matrix
p	Number of experts or evaluators
$\underline{\otimes} \bar{x}_{ij}$	Normalized lower limit value of the grey number $\otimes \tilde{x}_{ij}$
$\overline{\otimes} \bar{x}_{ij}$	Normalized upper limit value of the grey number $\otimes \tilde{x}_{ij}$
Y_{ij}	Total normalized crisp values
Z	Crisp value matrix
X	Normalized direct crisp relation matrix
I	Identity matrix
M	Total relation matrix

Step 1: Direct relation matrices are determined by the expert's opinion using a five-level grey linguistic scale. Five levels of "No influence," "Very low influence", "Low influence", "High influence," and "Very high influence" are used in this research.

Step 2: Grey relation matrices are determined. A grey no. $\otimes x_{ij}^{k}$ is converted to an interval with known upper and lower bounds (Deng, 1989);

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

where respondent *k* rates the influence of enabler *i* over enabler *j*.

Step 3: Average grey relation matrix ($\otimes \tilde{x}_{ij}$) is obtained by combining all grey direct-relation matrices:

$$\otimes \tilde{x}_{ij} = \left(\frac{\sum_k \underline{\otimes} x_{ij}^{k}}{p}, \frac{\sum_k \overline{\otimes} x_{ij}^{k}}{p}\right) \quad (3.2)$$

where *p* is the number of experts or evaluators.

Step 4: Crisp relation matrix is computed from the average grey relation matrix in this step. Grey values are converted into crisp values using the modified- CFCS method (Arikan et al., 2013) by a three-step procedure as elaborated below:

4.1 Grey values are normalized as:

$$\underline{\otimes}\,\bar{x}_{ij} = \left(\underline{\otimes}\,\tilde{x}_{ij} - {}^{min}_{j}\underline{\otimes}\,\tilde{x}_{ij}\right)/\Delta^{max}_{min} \tag{3.3}$$

where $\underline{\otimes}\,\bar{x}_{ij}$ represents the normalized lower limit value of the grey number $\otimes\,\tilde{x}_{ij}$

$$\overline{\otimes}\,\bar{x}_{ij} = \left(\overline{\otimes}\,\tilde{x}_{ij} - {}^{min}_{j}\overline{\otimes}\,\tilde{x}_{ij}\right)/\Delta^{max}_{min} \tag{3.4}$$

where $\overline{\otimes}\,\bar{x}_{ij}$ represents the normalized upper limit value of the grey number $\otimes\,\tilde{x}_{ij}$, and

$$\Delta^{max}_{min} = {}^{max}_{j}\overline{\otimes}\,\tilde{x}_{ij} - {}^{min}_{j}\underline{\otimes}\,\tilde{x}_{ij} \tag{3.5}$$

4.2 Total normalized crisp values are computed as:

$$Y_{ij} = \left(\frac{\left(\underline{\otimes}\bar{x}_{ij}\left(1-\underline{\otimes}\bar{x}_{ij}\right)\right)+\left(\overline{\otimes}\bar{x}_{ij}\times\overline{\otimes}\bar{x}_{ij}\right)}{\left(1-\underline{\otimes}\bar{x}_{ij}+\overline{\otimes}\bar{x}_{ij}\right)}\right) \tag{3.6}$$

4.3 Final crisp values are computed as:

$$z_{ij} = \left(min\,\underline{\otimes}\,\tilde{x}_{ij} + \left(Y_{ij}\times\Delta^{max}_{min}\right)\right) \tag{3.7}$$

and, $Z = \left[z_{ij}\right]$ (3.8)

Step 5: Normalized direct crisp relation matrix X is computed by obtaining K and multiplying the average relation matrix *Z* with K.

$$K = \frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n} z_{ij}} \tag{3.9}$$

and

$$X = Z \times K \tag{3.10}$$

Step 6: Total relation matrix *M* is obtained as:

$$M = X \times (I - X)^{-1} \tag{3.11}$$

where *I* is the identity matrix.

Step 7: Cause and effect parameters are computed in this step. In total relation matrix M obtained above, let represent its elements. Establish R as $n\times 1$ vector, which is the sum of row elements of M. Then, the sum of i^{th} row elements in matrix *M* shows both direct and indirect effects given by enabler *i* towards the other enablers. Establish C as $1 \times n$ vector, which is the sum of column elements of M. Then, the sum of the j^{th} column in matrix M shows both direct and indirect effects received by enabler j from other enablers.

$$R_i = \sum_{j=1}^{n} m_{ij} \; \forall \; i \tag{3.12}$$

$$C_j = \sum_{i=1}^{n} m_{ij} \; \forall \; j \tag{3.13}$$

Then dataset can be formed that gives the total effect given and received. It shows the degree of prominence an enabler has among all enablers. The larger the value of overall prominence of enabler *i* in terms of overall relationships with other enablers gives the net effect that an enabler has in the entire system. If it is positive, then enabler *i* is a net cause or foundation for other enablers, and it is negative, then enabler *i* is the net effect of other enablers (Tzeng et al., 2007).

Step 8: Digraph is plotted by setting up the threshold. The matrix *M* shows how one enabler affects another, and a diagraph is developed. Dataset is then plotted onto a two-dimensional axis for each enabler to develop an overall DEMATEL prominence-causal graph. As the number of relationships includes many possibilities, we map only those above a threshold value and leave the negligible values. This threshold value is calculated by taking the mean m_{ij} from M and adding one standard deviation to the mean. Digraph showing causal relations above the threshold value is plotted from the dataset of$\left((R_i + C_j), (R_i - C_j)\right) \forall \; i = j$.

3.4 Application of the proposed model

The described framework and methodology are used to evaluate enablers of SSCM in the electronic industry in the Indian context. Four electronic industries, each having a turnover of over USD 25 million situated in the western region of India and willing to provide data, were identified to get inputs on data. These industries have been in existence for more than 15 years since their inception. Experts from the electronic industry who had work experience of more than twenty years in supply chain management were approached to respond to data. In addition, inputs of an academic expert working in the area of the supply chain for more than

20 years were also taken to have a holistic view on sustainability. The profile of experts is shown in Table 3.3.

Table 3.3: Profile of Experts

Experts	Education	Experience	Job position
Expert 1	M.Tech	23 Yrs.	General Manager - Production
Expert 2	MBA	22 Yrs.	Head- Procurement
Expert 3	B.Tech, MBA	21 Yrs.	Senior Manager - Operations
Expert 4	M.Tech	21 Yrs.	Senior Manager – Product development
Expert 5	Ph.D.	20 Yrs.	Professor

Initially, 28 enablers of SSCM were listed from the literature review on SSCM and in discussion with experts. These enablers were further discussed with supply chain managers of four electronic companies in Western India. Based on the feedback received and further discussion with academic experts, the number of enablers was shortlisted to 17. These enablers are shown in Table 3.1, and their impact on the triple bottom line, i.e., social, economic or environment, is also marked. Four industrial respondents and the academic expert responded to the relationship among each of the two enablers. From the response obtained, enablers of SSCM were analyzed using the Grey-DEMATEL method. The steps of analysis are described below:

Step 1: In this step, a grey pairwise influence scale was defined. We use a 5-level scale with the following scale items: 0=no influence, 1=very low influence, 2=low influence, 3=high influence and 4=very high influence. This is converted to a grey number using equation (3.1). The grey linguistic scale for respondents' assessments is depicted in Table 3.4.

Table 3.4: The grey linguistic scale for respondents' assessments

Linguistic Terms	Normal Values	Grey Values
No influence	0	[0, 0.01]
Low Influence	1	[0.01, 0.25]
Medium Influence	2	[0.25, 0.5]
High Influence	3	[0.5, 0.75]
Very High Influence	4	[0.75, 1.00]

Step 2: Grey direct-relation matrix is developed by evaluators giving their grey pairwise influence relationships ($\otimes_{ij}^{k}$) between the enablers in a 17 x 17 matrix. For each of the four electronic companies and academic expert, pairwise influence matrices are shown in Tables 3.5-3.9.

Table 3.5: Direct-relation matrix for enablers of SSCM by the manager of company 1

	TMC	GPL	AFI	RAD	TMP	GPS	EMS	CSP	LMP	RLP	RRE	TAL	CLF	HEX	CSR	HSS	GLP
TMC	0	0	4	3	3	4	3	3	4	3	2	4	1	1	4	4	3
GPL	4	0	3	3	2	4	4	2	2	1	3	1	0	2	4	3	2
AFI	3	0	0	4	4	3	2	2	1	0	2	3	0	3	2	3	3
RAD	1	0	0	0	0	3	3	3	4	4	4	3	2	1	2	3	3
TMP	1	0	0	4	0	0	2	0	4	3	3	1	0	1	0	1	2
GPS	0	0	0	1	0	0	4	3	2	1	1	2	0	0	1	1	3
EMS	4	0	0	3	2	4	0	4	4	4	2	3	0	2	2	3	4
CSP	1	0	0	2	1	4	3	0	3	3	2	1	1	0	2	1	2
LMP	1	0	2	2	1	4	4	3	0	4	3	2	1	1	3	1	2
RLP	2	0	2	2	1	3	2	2	4	0	4	0	1	1	2	1	1
RRE	4	3	3	2	1	0	1	1	3	2	0	2	0	0	1	0	2
TAL	0	2	1	2	0	4	3	2	2	1	1	0	3	1	3	4	2
CLF	3	3	2	2	1	4	3	4	3	3	2	4	0	1	4	4	2
HEX	0	1	0	4	0	2	2	1	1	1	0	3	1	0	1	3	0
CSR	3	1	1	3	3	3	3	2	0	3	3	4	1	0	0	4	4
HSS	4	3	2	1	0	0	4	2	0	0	0	4	0	1	1	0	4
GLP	0	3	3	0	1	4	4	2	2	1	1	1	4	0	1	0	0

Table 3.6: Direct-relation matrix for enablers of SSCM by the manager of company 2

	TMC	GPL	AFI	RAD	TMP	GPS	EMS	CSP	LMP	RLP	RRE	TAL	CLF	HEX	CSR	HSS	GLP
TMC	0	0	4	3	3	4	3	3	3	4	2	3	1	0	4	3	4
GPL	4	0	2	2	4	4	3	2	2	3	3	2	1	2	4	4	2
AFI	3	1	0	4	4	3	3	2	1	1	0	3	0	0	2	3	0
RAD	1	1	1	0	3	1	1	0	3	2	2	0	0	2	0	0	1
TMP	1	1	0	4	0	1	4	3	2	2	1	0	0	0	1	2	2
GPS	2	1	1	0	0	0	4	3	3	2	2	1	1	0	3	1	4
EMS	1	0	1	2	3	4	0	4	3	3	1	0	0	0	2	4	4
CSP	0	0	0	2	2	4	3	0	3	3	1	2	2	0	1	0	1
LMP	1	0	1	1	1	1	3	2	0	4	2	0	0	0	2	1	2
RLP	1	0	1	2	1	2	3	2	4	0	2	1	1	1	3	2	2
RRE	3	3	3	2	1	1	2	1	1	3	0	1	0	0	1	0	0
TAL	1	1	0	2	2	3	2	3	2	2	2	0	1	0	3	4	2
CLF	3	4	3	2	1	3	3	4	2	2	3	3	0	1	4	3	3
HEX	1	0	0	4	1	1	3	1	0	3	0	4	1	0	1	2	0
CSR	3	1	0	2	1	3	3	3	1	3	4	3	1	0	0	4	3
HSS	0	0	0	1	1	2	1	3	0	0	0	1	0	0	2	0	2
GLP	3	1	1	0	3	4	3	2	2	3	1	2	0	0	1	0	0

Table 3.7: Direct-relation matrix for enablers of SSCM by the manager of company 3

	TMC	GPL	AFI	RAD	TMP	GPS	EMS	CSP	LMP	RLP	RRE	TAL	CLF	HEX	CSR	HSS	GLP
TMC	0	0	4	3	4	3	3	2	4	2	4	4	2	4	4	4	4
GPL	4	0	0	4	1	4	2	3	0	2	3	4	2	0	3	3	4
AFI	4	2	0	4	3	4	1	1	3	2	4	4	0	0	3	2	4
RAD	4	0	2	0	4	3	2	3	4	0	3	4	0	2	0	3	3
TMP	0	0	2	2	0	3	2	2	3	2	2	1	0	0	0	1	2
GPS	3	3	4	2	3	0	4	1	1	0	2	0	0	1	3	4	4
EMS	2	3	1	0	0	1	0	1	2	1	1	0	0	0	4	2	3
CSP	1	0	0	1	1	0	2	0	1	1	2	0	0	1	0	0	2
LMP	4	0	3	2	1	2	0	1	0	0	2	1	0	0	0	3	3
RLP	0	1	1	1	3	3	3	4	0	0	0	0	0	0	3	3	0
RRE	1	2	0	4	3	0	2	2	3	0	0	1	0	2	0	4	1
TAL	4	4	3	3	2	4	3	3	2	2	2	0	1	4	3	2	1
CLF	0	2	2	0	0	1	2	2	0	0	0	2	0	2	3	0	1
HEX	4	0	3	4	3	2	2	2	2	0	0	3	0	0	2	2	0
CSR	2	3	3	2	1	2	3	3	2	2	4	3	2	0	0	3	0
HSS	2	3	2	1	1	1	2	3	2	4	1	0	0	3	2	0	2
GLP	3	2	4	2	0	1	3	1	1	2	1	2	2	3	2	1	0

Table 3.8: Direct-relation matrix for enablers of SSCM by the manager of company 4

	TMC	GPL	AFI	RAD	TMP	GPS	EMS	CSP	LMP	RLP	RRE	TAL	CLF	HEX	CSR	HSS	GLP
TMC	0	0	4	3	3	4	3	3	4	3	3	4	1	2	4	4	4
GPL	4	0	2	3	2	4	3	2	1	2	3	2	1	1	4	3	3
AFI	3	1	0	4	4	3	2	2	2	1	2	3	0	1	2	3	2
RAD	2	0	1	0	2	2	2	2	4	2	3	2	1	2	1	2	2
TMP	1	0	1	3	0	1	3	2	3	2	2	1	0	0	0	1	2
GPS	2	1	2	1	1	0	4	2	2	1	2	1	0	0	2	2	4
EMS	2	1	1	2	2	3	0	3	3	3	1	1	0	1	3	3	4
CSP	1	0	0	2	1	3	3	0	2	2	2	1	1	0	1	0	2
LMP	2	0	2	2	1	2	2	2	0	3	2	1	0	0	2	2	2
RLP	1	0	1	2	2	3	3	3	3	0	2	0	1	1	3	2	1
RRE	3	3	2	3	2	0	2	1	2	2	0	1	0	1	1	1	1
TAL	2	2	1	2	1	4	3	3	2	2	2	0	2	2	3	3	2
CLF	2	3	2	1	1	3	3	3	2	2	2	3	0	1	4	2	2
HEX	2	0	1	4	1	2	2	1	1	1	0	3	1	0	1	2	0
CSR	3	2	1	2	2	3	3	3	1	3	4	3	1	0	0	4	2
HSS	2	2	1	1	1	1	2	3	1	1	0	2	0	1	2	0	3
GLP	2	2	3	1	1	3	3	2	2	2	1	2	2	1	1	0	0

Table 3.9: Direct-relation matrix for enablers of SSCM by the academic expert

	TMC	GPL	AFI	RAD	TMP	GPS	EMS	CSP	LMP	RLP	RRE	TAL	CLF	HEX	CSR	HSS	GLP
TMC	0	2	4	3	4	4	1	3	3	3	4	3	1	4	4	4	4
GPL	4	0	3	4	3	4	4	2	3	4	4	3	2	3	4	4	3
AFI	3	0	0	3	3	2	3	2	2	2	2	4	0	3	2	3	3
RAD	4	0	0	0	4	3	2	1	3	2	4	2	0	0	0	4	3
TMP	2	1	0	1	0	3	0	1	3	4	3	0	0	0	2	3	2
GPS	3	1	0	0	1	0	1	1	0	0	3	2	0	0	1	1	2
EMS	3	0	0	4	2	4	0	1	2	3	4	3	2	0	2	4	3
CSP	2	0	4	3	4	3	2	0	3	3	1	2	1	2	3	4	3
LMP	3	1	4	2	2	0	0	2	0	4	4	0	1	0	2	3	2
RLP	2	0	3	2	2	0	0	2	4	0	4	2	3	0	3	1	3
RRE	3	2	3	3	1	0	1	2	3	2	0	0	0	0	1	2	2
TAL	0	1	0	4	3	1	1	2	2	3	3	0	1	4	2	3	3
CLF	3	1	4	3	3	3	3	4	3	1	4	4	0	3	3	4	3
HEX	1	0	0	4	0	0	0	2	3	3	3	2	1	0	0	3	3
CSR	2	1	3	3	3	4	0	3	3	4	4	4	2	0	0	4	3
HSS	1	0	0	3	2	1	1	1	1	3	3	1	0	2	1	0	0
GLP	0	1	0	2	2	3	1	0	2	1	1	1	0	0	2	0	0

Step 3: Each expert's view is considered equally important, and the respondents have been given equal weightage. The weight assigned to each expert is 0.20, and an average grey relation matrix $\left[\otimes \tilde{x}_{ij}\right]$ is computed using equation (3.2).

Step 4: Grey direct-relation matrix is converted into a crisp matrix Z using the modified-CFCS process using equations (3.3) to (3.8).

Step 5: From overall crisp direct-relation matrix Z, normalized direct-relation matrix X is computed through equations (3.9) and (3.10). Since the total of each column in normalized direct-relation matrix X is less than one, the model is feasible in this case and backs the applicability of DEMATEL in analysis (Lee et al., 2013).

Step 6: Determine the total direct-relationship matrix M by equation (3.11) shown in Table 3.10.

Step 7: Using equations (3.12) and (3.13), compute R_i and C_j. Row values R_i depicts the overall direct and indirect effects of enabler i on other enablers for the electronic industry. Similarly, column values C_j depicts the overall direct and indirect effects of all enablers on enabler j. Determine overall importance or prominence $\left(R_i + C_j\right)$ of enabler *i* and the net effect $\left(R_i - C_j\right)$ of enabler *i*, which is shown in Table 3.11.

Table 3.10: Total Relation matrix (M)

	TMC	GPL	AFI	RAD	TMP	GPS	EMS	CSP	LMP	RLP	RRE	TAL	CLF	HEX	CSR	HSS	GLP
TMC	0.0688	0.0380	**0.1330**	**0.1336**	**0.1277**	**0.1650**	**0.1344**	**0.1271**	**0.1523**	**0.1368**	**0.1315**	**0.1348**	0.0357	0.0717	**0.1458**	**0.1595**	**0.1620**
GPL	**0.1465**	0.0301	0.0820	**0.1309**	0.0974	**0.1642**	**0.1428**	**0.1059**	0.0979	**0.1145**	**0.1321**	0.1000	0.0368	0.0538	**0.1387**	**0.1450**	**0.1320**
AFI	**0.1087**	0.0300	0.0350	**0.1313**	**0.1165**	**0.1184**	0.0974	0.0780	0.0849	0.0694	0.0867	**0.1111**	0.0147	0.0460	0.0802	**0.1101**	0.1048
RAD	0.0782	0.0188	0.0374	0.0414	0.0810	0.0875	0.0790	0.0700	**0.1196**	0.0798	0.1028	0.0695	0.0182	0.0368	0.0413	0.0872	0.0878
TMP	0.0339	0.0122	0.0249	0.0777	0.0211	0.0550	0.0710	0.0514	0.0906	0.0792	0.0647	0.0211	0.0073	0.0094	0.0286	0.0487	0.0622
GPS	0.0651	0.0304	0.0458	0.0400	0.0391	0.0416	**0.1078**	0.0648	0.0593	0.0434	0.0628	0.0408	0.0109	0.0130	0.0607	0.0624	**0.1078**
EMS	0.0820	0.0311	0.0354	0.0812	0.0640	0.1165	0.0545	0.0942	0.1019	0.1030	0.0719	0.0574	0.0194	0.0231	0.0864	**0.1105**	**0.1260**
CSP	0.0362	0.0126	0.0346	0.0594	0.0495	0.0896	0.0835	0.0303	0.0759	0.0754	0.0512	0.0360	0.0202	0.0164	0.0450	0.0475	0.0668
LMP	0.0681	0.0153	0.0663	0.0603	0.0396	0.0695	0.0717	0.0662	0.0383	0.0974	0.0815	0.0350	0.0117	0.0133	0.0591	0.0682	0.0755
RLP	0.0464	0.0159	0.0451	0.0601	0.0534	0.0793	0.0803	0.0832	0.0979	0.0380	0.0807	0.0334	0.0268	0.0145	0.0812	0.0640	0.0592
RRE	0.0851	0.0634	0.0640	0.0883	0.0515	0.0426	0.0594	0.0491	0.0806	0.0664	0.0360	0.0378	0.0091	0.0212	0.0356	0.0609	0.0529
TAL	0.0673	0.0556	0.0444	0.0948	0.0609	**0.1191**	0.0994	0.0968	0.0819	0.0829	0.0797	0.0401	0.0402	0.0619	0.0942	**0.1164**	0.0867
CLF	0.0946	0.0775	0.0866	0.0841	0.0609	**0.1242**	**0.1217**	**0.1286**	0.0940	0.0858	0.0981	**0.1135**	0.0171	0.0479	**0.1267**	**0.1167**	0.1038
HEX	0.0510	0.0131	0.0297	**0.1138**	0.0372	0.0545	0.0636	0.0471	0.0541	0.0566	0.0409	0.0832	0.0148	0.0136	0.0348	0.0763	0.0444
CSR	0.0974	0.0499	0.0625	0.0962	0.0753	**0.1220**	**0.1094**	**0.1094**	0.0795	**0.1166**	**0.1327**	**0.1116**	0.0366	0.0228	0.0500	**0.1385**	**0.1073**
HSS	0.0541	0.0402	0.0311	0.0444	0.0315	0.0442	0.0646	0.0704	0.0374	0.0574	0.0381	0.0475	0.0091	0.0330	0.0462	0.0308	0.0708
GLP	0.0595	0.0430	0.0630	0.0468	0.0469	0.1003	0.0944	0.0542	0.0626	0.0621	0.0399	0.0500	0.0412	0.0249	0.0490	0.0398	0.0413

Table 3.11: Degree of prominence and net cause/effect values for enablers of sustainable supply chain

	R_i	C_j	R_i+C_j	R_i-C_j
TMC	2.0577	1.2427	3.3005	0.8150
GPL	1.8505	0.5772	2.4277	1.2734
AFI	1.4231	0.9210	2.3441	0.5022
RAD	1.1365	1.3843	2.5208	-0.2478
TMP	0.7589	1.0536	1.8126	-0.2947
GPS	0.8955	1.5936	2.4890	-0.6981
EMS	1.2586	1.5349	2.7935	-0.2763
CSP	0.8300	1.3268	2.1568	-0.4968
LMP	0.9369	1.4088	2.3456	-0.4719
RLP	0.9594	1.3645	2.3239	-0.4051
RRE	0.9040	1.3311	2.2352	-0.4271
TAL	1.3223	1.1229	2.4452	0.1994
CLF	1.5819	0.3698	1.9517	1.2121
HEX	0.8287	0.5233	1.3520	0.3054
CSR	1.5177	1.2036	2.7213	0.3141
HSS	0.7509	1.4824	2.2333	-0.7316
GLP	0.9189	1.4912	2.4101	-0.5722

Step 8: Develop overall DEMATEL prominence-causal graphs with the dataset$(R_i + C_{j,}\ R_i - C_j)$. Digraphs show interrelationships among each couple of individual enablers of the electronic industry. Owing to the large number of enablers, we chose a high threshold value θ. The mean of M is 0.0690, and the standard deviation is 0.0361. This gives the value θ =0.0690 + 0.0361 = 0.1051. All values higher than the threshold value are highlighted in the overall M matrix. Then these dyadic relationships are plotted. Two-way relationships are represented by dotted lines, whereas solid lines represent one-way relationships, and the resulting graph is depicted in in Fig. 3.3.

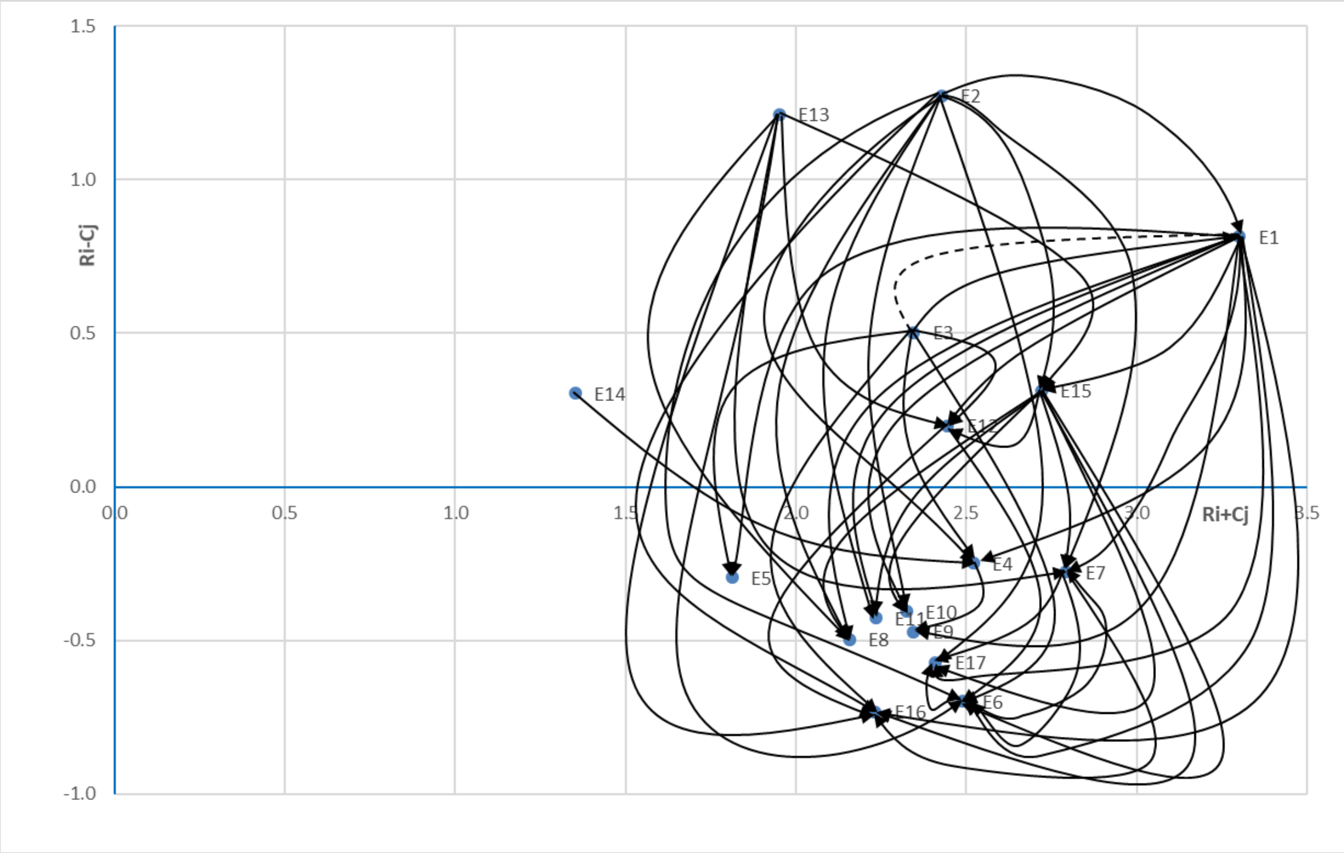


Figure 3.3: Overall DEMATEL prominence-causal relationship diagram

3.5 Results

The application of Grey-DEMATEL determines the value of $R_i + C_j$ and $R_i - C_j$ as seen in Table 3.11. Based on $R_i - C_j$ values the enablers can be classified into Cause and Effect groups. Factors with positive values are causal factors. The enablers having positive values of $R_i - C_j$ consists of seven enablers viz. GPL, CLF, TMC, AFI, CSR, HEX and TAL are in the cause group. In Fig. 3.3, factors with negative values of $R_i - C_j$ are called effect factors. Ten enablers have negative values of $R_i - C_j$ viz. HSS, GPS, GLP, CSP, LMP, RRE, RLP, TMP, EMS, and RAD form the effect group.

The values $R_i + C_j$ in Table 3.11 represents the correlation between factors. The higher value of $R_i + C_j$ depicts the greater importance order of the enabler. From Table 3.11, the co-relation strength among the enablers obtained is in the following order TMC, EMS, CSR, RAD, GPS, TAL, GPL, GLP, LMP, AFI, RLP, RRE, HSS, CSP, CLF, TMP, HEX. Fig. 3.3 depicts these results and the interrelationship among the enablers as per Table 3.10. Dotted lines show the two-way relationship between TMC and AFI. As per Table 3.11 and Fig. 3.3, the prominence of enablers along with the causal group, effect group and correlation between enablers affecting SSCM implementation in the electronic industry can be understood. The results were also discussed with the company managers and academic expert.

3.5.1 Sensitivity analysis

Sensitivity analysis is performed to know if there is any influence or personal bias in the data of respondents. For this, different weight is given to one respondent while keeping the weight of other respondents the same as per Table 3.12.

Table 3.12: Weights assigned during sensitivity analysis

	Weightage				
Respondent 1	0.28	0.18	0.18	0.18	0.18
Respondent 2	0.18	0.28	0.18	0.18	0.18
Respondent 3	0.18	0.18	0.28	0.18	0.18
Respondent 4	0.18	0.18	0.18	0.28	0.18
Respondent 5	0.18	0.18	0.18	0.18	0.28

The degree of prominence and net cause/effect values obtained during sensitivity analysis is shown in Table 3.13. On examination of ranking differences in different scenarios and as per Figs. 3.4 and 3.5, it is seen that there is only a slight deviation. There are no major changes in cause and effect group rankings obtained in these five scenarios as per Table 3.13, and the results seem to be relatively consistent.

Causal and effect factors remain the same, and GPL, CLF, TMC, AFI and CSR remain the top five causal factors in all five scenarios. The bottom two in effect factors being influenced by causal factors remain HSS and GPS. From Table 3.13, it is observed that rankings do not vary much, and there are only minor changes which is negligible. It can be concluded that the expert evaluations are robust, and no particular expert is heavily biased.

Table 3.13: Degree of prominence and net cause/effect values obtained during sensitivity analysis

	Scenario 1				Scenario 2				Scenario 3				Scenario 4				Scenario 5			
	R_i	C_j	R_i+C_j	R_i-C_j	R_i	C_j	R_i+C_j	R_i-C_j	R_i	C_j	R_i+C_j	R_i-C_j	R_i	C_j	R_i+C_j	R_i-C_j	R_i	C_j	R_i+C_j	R_i-C_j
TMC	2.0878	1.2637	3.3514	0.8241	2.0489	1.2125	3.2613	0.8364	2.0522	1.2586	3.3108	0.7936	2.0571	1.2555	3.3126	0.8016	2.0421	1.2257	3.2678	0.8163
GPL	1.8683	0.5938	2.4621	1.2744	1.8597	0.5500	2.4097	1.3098	1.8125	0.6212	2.4337	1.1913	1.8998	0.5459	2.4457	1.3538	1.8124	0.5723	2.3848	1.2401
AFI	1.4485	0.9333	2.3818	0.5152	1.4026	0.8841	2.2868	0.5185	1.4437	0.9498	2.3935	0.4939	1.4201	0.9448	2.3649	0.4753	1.4004	0.8960	2.2964	0.5044
RAD	1.1884	1.4129	2.6013	-0.2246	1.0744	1.3666	2.4409	-0.2922	1.1609	1.3617	2.5226	-0.2009	1.1453	1.4233	2.5686	-0.2780	1.1133	1.3593	2.4726	-0.2460
TMP	0.7766	1.0264	1.8029	-0.2498	0.7628	1.0603	1.8231	-0.2975	0.7413	1.0547	1.7960	-0.3134	0.7676	1.1069	1.8746	-0.3393	0.7432	1.0199	1.7631	-0.2767
GPS	0.8848	1.6745	2.5592	-0.7897	0.9137	1.6079	2.5216	-0.6943	0.9380	1.5411	2.4791	-0.6030	0.8511	1.5653	2.4165	-0.7142	0.8899	1.5855	2.4754	-0.6956
EMS	1.3316	1.6161	2.9478	-0.2845	1.2546	1.5684	2.8230	-0.3139	1.1933	1.4990	2.6923	-0.3058	1.2753	1.4391	2.7144	-0.1638	1.2391	1.5404	2.7795	-0.3013
CSP	0.8513	1.3634	2.2148	-0.5121	0.8379	1.3535	2.1914	-0.5156	0.7581	1.3110	2.0691	-0.5529	0.8987	1.2781	2.1768	-0.3793	0.8026	1.3309	2.1335	-0.5283
LMP	0.9881	1.4617	2.4498	-0.4737	0.9109	1.4119	2.3228	-0.5010	0.9130	1.3595	2.2725	-0.4465	0.9566	1.4303	2.3870	-0.4737	0.9190	1.3884	2.3073	-0.4694
RLP	0.9798	1.3902	2.3700	-0.4104	0.9603	1.4003	2.3605	-0.4400	0.9197	1.2886	2.2084	-0.3689	0.9879	1.3947	2.3826	-0.4068	0.9469	1.3375	2.2844	-0.3906
RRE	0.9330	1.3580	2.2910	-0.4249	0.8960	1.2916	2.1876	-0.3956	0.8886	1.2969	2.1855	-0.4083	0.9079	1.4105	2.3184	-0.5027	0.8929	1.2980	2.1909	-0.4051
TAL	1.3327	1.1804	2.5131	0.1524	1.3000	1.0997	2.3998	0.2003	1.3559	1.1067	2.4625	0.2492	1.3049	1.1336	2.4384	0.1713	1.3132	1.0968	2.4099	0.2164
CLF	1.6484	0.3835	2.0319	1.2649	1.6235	0.3588	1.9823	1.2647	1.4585	0.3561	1.8146	1.1025	1.6290	0.3817	2.0107	1.2473	1.5500	0.3569	1.9069	1.1930
HEX	0.8251	0.5259	1.3511	0.2992	0.8231	0.4923	1.3154	0.3308	0.8578	0.5494	1.4072	0.3084	0.8298	0.5473	1.3771	0.2825	0.8080	0.5036	1.3116	0.3045
CSR	1.5491	1.2244	2.7735	0.3247	1.5088	1.2124	2.7213	0.2964	1.4908	1.1975	2.6883	0.2933	1.5396	1.1898	2.7295	0.3498	1.4973	1.1947	2.6921	0.3026
HSS	0.8066	1.4983	2.3049	-0.6917	0.7111	1.4660	2.1771	-0.7548	0.7692	1.4686	2.2378	-0.6995	0.7277	1.5203	2.2480	-0.7926	0.7412	1.4502	2.1914	-0.7089
GLP	0.9532	1.5467	2.4999	-0.5935	0.9281	1.4801	2.4082	-0.5520	0.9276	1.4605	2.3881	-0.5329	0.8668	1.4982	2.3650	-0.6314	0.9177	1.4732	2.3909	-0.5554

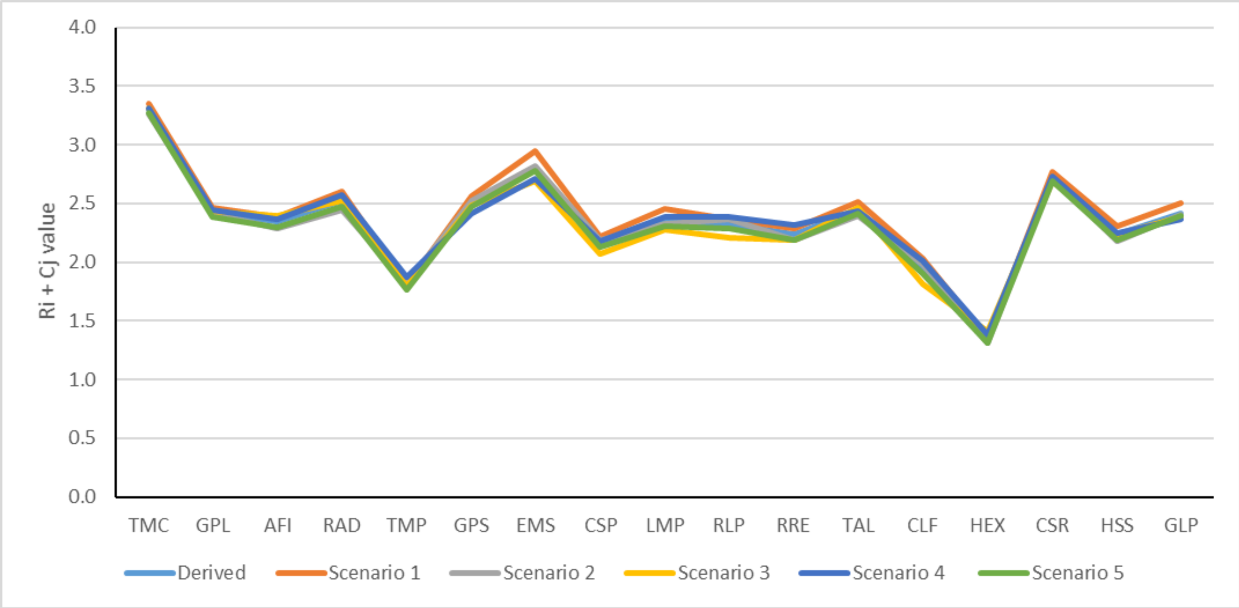


Figure 3.4: Sensitivity analysis of $R_i + C_j$ values

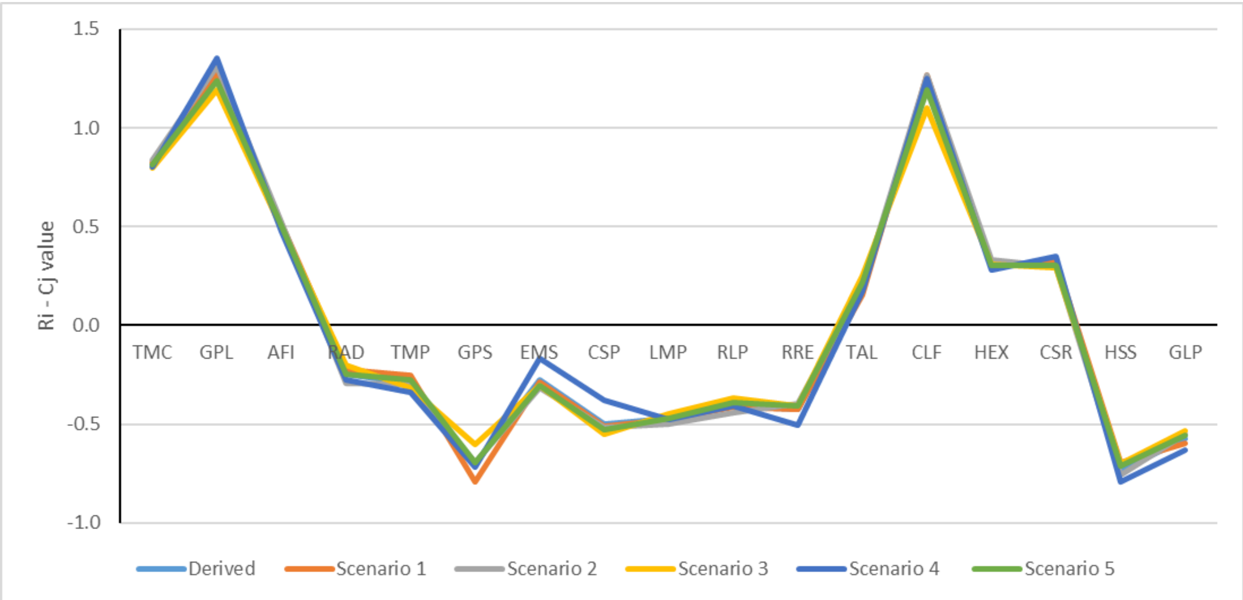


Figure 3.5: Sensitivity analysis of $R_i - C_j$ values

3.6 Discussion

The results obtained from Grey-DEMATEL analysis helps in classifying the enablers in Cause group, Effect group and gives the strength of correlation between the enablers. In decision-making, complicated criteria need to be encountered. Resolving one or two factors may not always improve the total system since influencing factors impact others due to their interrelationship (Govindan et al., 2016). Focusing and prioritizing the enablers in the cause group will improve the factors in the effect group. The importance of enablers and directions of influence assists in formulating suitable strategies for implementing a sustainable supply chain.

3.6.1. Cause group

In Fig. 3.3, higher value of $R_i - C_j$ implies the stronger influence of enabler for implementation of SSCM. They are the most affecting factors that lead to SSCM implementation directly. Causal factors are sorted by prominence for the influence of SSCM as Government Policies & Legislations > Culture related factors > Top Management Commitment > Availability of Funds/investment > Corporate social responsibility > Human expertise > Training & Literacy.

Government Policies & Legislations being on the top of the cause group shows that Government Policies & Legislations is the primary causal factor for SSCM. This was discussed with industrial experts and academic expert, and they agreed to this factor being a significant enabler. Government Policies & Legislations are the primary causal factor and, as indicated by arrows in Fig. 3.3, impact TMC, RAD, GPS, EMS, CSP, RLP, RRE, CSR, HSS and GLP. Government regulation and policies often play an important role in encouraging firms to adopt sustainability practices. Government policies should provide guidance and support to implement SSCM (Majumdar and Sinha, 2019). Governments also play a role in market-based mechanisms like emission trading programs, extended producer responsibility, etc. It provides flexibility to the focal firm or industry in choosing the compliance level. The Government policies should be clear and without any loopholes to effectively act as an enabler.

Culture-related Factors follow Government Policies & Legislations. In their study, Adebayo et al. (2020) found that culture significantly influences sustainability performance, and firms should pay increased attention to the dimensions of organizational culture. From Fig. 3.3, it can be seen that culture-related factors influence Green purchasing and Environmental collaboration between supply chain partners. This is supported by Abadiyah et al.'s (2020) findings that culture-related factors have a favourable and significant impact on employee green behaviour. To implement a socially sustainable supply chain, companies' cultural attributes go beyond behavioural change, including lower-tier suppliers and communities around the supply chain. Culture-related factors affect corporate social responsibility and environmental collaboration with suppliers (Marshall et al., 2015b). This is also evident from the results of this research and as seen in Fig. 3.5.

The next order of influencing factors is Top Management commitment and Availability of funds/investment. A firm's top management commitment towards sustainability is essential in developing and strengthening a sustainable supply chain. Senior management support provides a strategic strength to achieve social, environmental and economic goals in a supply chain (Burki et al., 2018). SSCM will become more intricate in the future, and effective sustainable development cannot occur unless there is active participation from top management. Their competency to implement SSCM in overall performance goals will be critical (Zimon et al., 2020). Results of the study indicate that availability of funds affects the enablers Top management commitment, R&D activities, state of the art technologies, materials and processes, Green purchasing, Training & literacy and Health & safety standards. Large corporations often have more funds, which allows them to engage in more sustainable practices (Lassala et al., 2017). Availability of funds gives leverage to the top management to invest in recycling infrastructure, proper disposal mechanisms, carry out technological changes and improve social welfare for enhanced sustainability. Enablers like Corporate Social Responsibility, Human expertise and Training & literacy programs have fewer influences on factors in the effect group. It is seen that most of the Policy category enablers have a causal effect, indicating that these enablers should be used more effectively for a successful implementation of SSCM.

3.6.2. Effect group

Effect factors are influenced by causal factors, which lead to SSCM implementation. The effect group based on their absolute values are sorted from high to low. In our results, they are sorted as Health & Safety standards, Green purchasing, Green labelling & packaging, Environmental Collaboration between supply chain partners, Lean Manufacturing practices, Reducing consumption of Resources/Energy, Reverse logistic practices, State of the art Technologies, Materials and Process, Environment Management systems, Research & Development. It is seen that Health & Safety standards have the highest net effect value. In addition, during interviews with experts and managers, they agreed that this factor is influenced and is a strong effect factor. It is seen from Fig. 3.3 that health and safety standards are influenced by the commitment of top management towards welfare and health of their employees, Government regulations, allotment of funds to enhance safety standards, management systems like ISO 45001:2018, which solely focus on eliminating injuries and hazards related to occupation, Training & Literacy, Culture related factors and Corporate social responsibility.

Green Purchasing follows Health & Safety standards in effect group. Factors like management policies, government rules, funds availability, etc., affect firms’ green purchasing strategies. The next factors in this group are Green labelling & packaging and Environmental Collaboration between supply chain partners. Environmental collaboration between supply chain partners gives a collective insight to all involved in the supply chain and harnesses the flow of sustainability. Collaboration extends the impact of sustainability by allowing supply chain partners to combine efforts in improving the triple bottom line. For SSCM implementation, dynamic models positively affect society and the ecosystem by active collaboration on value creation by the focal firm with downstream customers and upstream suppliers (Zimon et al., 2019).

The subsequent influenced factors are Lean Manufacturing practices, reducing resource/energy and reverse logistic practices. In recent years, reverse logistic practices have become an important part of numerous successful supply chains. Planning and controlling efficient inbound flow and storage of goods and associated information for product recovery and disposal turns into an effective way for sustainability implementation. Comparatively, state-of-the-art Technologies, Materials and Processes, Environment Management systems, and research & development are enablers at the top of the causal group graph and less influenced by causal factors. New technologies, renewable and recycled materials and process innovations aid the process of sustainability. Research & Development initiatives are affected by a company's approach towards sustainability. Results show that research & development is the least influenced enabler by causal factors among effect group to SSCM.

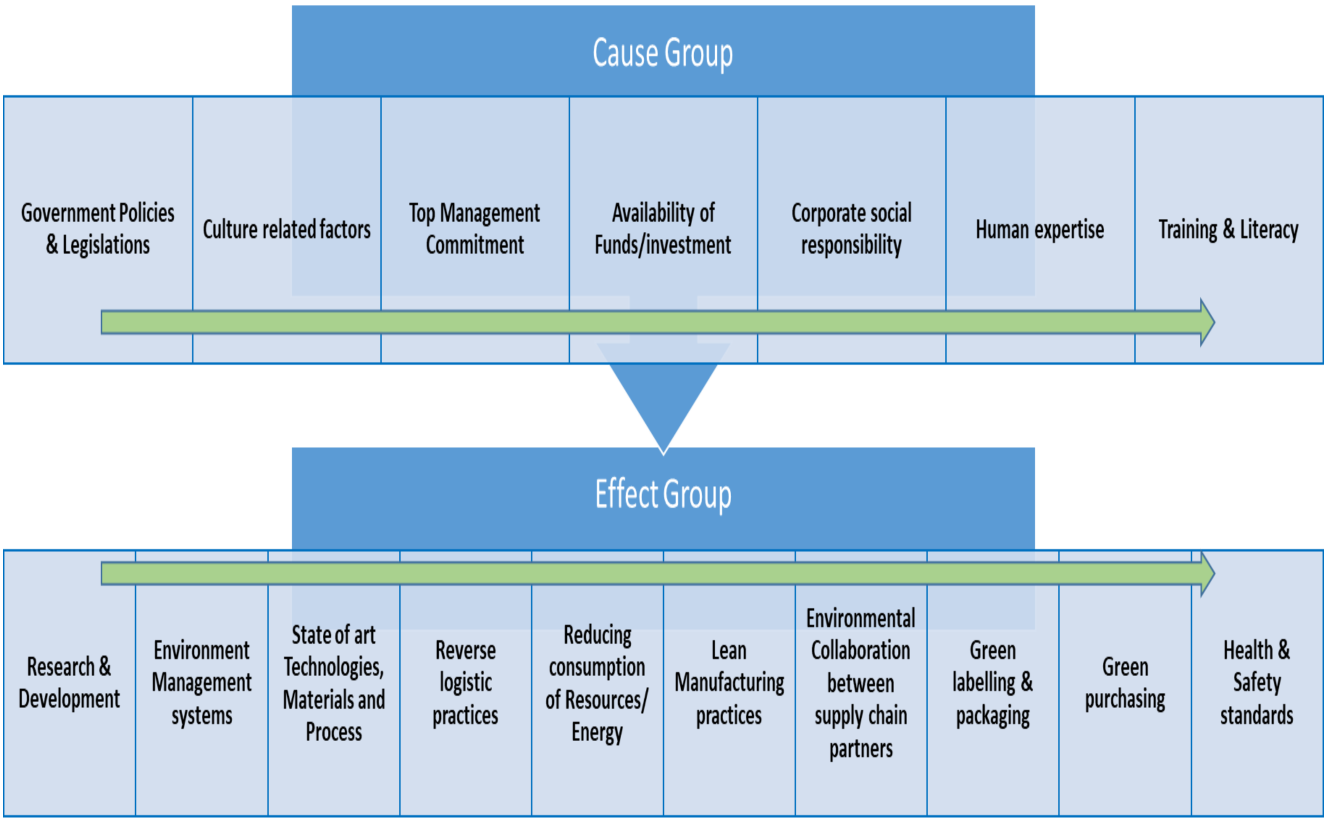


Figure 3.6: Enablers in Cause and Effect group and flow of influence

The discussions above have been depicted in Fig. 3.6. The cause and effect enablers with their flow of influence have been prepared. This model can assist firms in implementing sustainability in their supply chain to devise their line of strategy. Firms can further explore the model based on their environment and product to promote the sustainability enablers in their supply chain.

3.6.3. Correlation between the enablers

The higher value of $R_i + C_j$ of a factor or the position towards the right in Fig. 3.3, the stronger is the contribution of that enabler to SSCM implementation. Based on strength of correlation between enablers, their order is derived as follows: TMC > EMS > CSR > RAD > GPS > TAL > GPL > GLP > LMP > AFI > RLP > RRE > HSS > CSP > CLF > TMP > HEX. $R_i + C_j$ value demonstrates the degree of the role of each enabler in the context of SSCM implementation. These values can be used for prioritizing the strategies, and key measures should be developed based on them.

The factor with the strongest contribution, which leads to SSCM, is Top Management commitment. Top Management commitment demonstrates the highest correlation with other factors. The correlation strength of Top Management commitment is demonstrated by the factor influencing AFI, RAD, TMP, GPS, EMS, CSP, LMP, RLP, RRE, TAL, CSR, HSS and GLP, whereas it is affected by GPL and AFI. The commitment from top management towards sustainability implementation can work as a driver to propel other factors in achieving the same. Top management can guide, provide resources and devise strategies that correlate with many other enablers. Governmental policies & legislations and availability of funds affect top management decisions (Mangla et al., 2018) is established by the result. Top management involvement is the primary influencer for sustainable manufacturing (Harikannan et al., 2020). Top Management commitment enables a company to deliver products with improved social, environmental and economic outcomes.

The next enabler having the highest correlation strength is Environment management systems. From Fig. 3.3, it is seen that enabler Environment Management systems are influenced by Corporate social responsibility. In their study conducted in manufacturing companies, Ikram et al. (2019) analyze that organizations integrating EMS into their system have better corporate sustainability performance. The competence acquired by organizations to adopt EMS aids in implementing SSCM. Environment management systems may increase an organization's environmental performance (King et al., 2005). Still, there are doubts about its extension beyond its operational boundaries to its supply chain (Handfield et al., 2004). Human expertise is least correlated with other factors. As per Fig. 3.3, human expertise influences only Research & Development. Successful SSCM implementation depends on human insights of knowledge, abilities, skills and motivation.

3.6.4. Importance causality diagram

To make tactical decisions and plan schemes by managers to implement a sustainable supply chain, an Importance causality diagram is constructed utilizing the DEMATEL result (Chien et al., 2014). The Importance causality diagram reveals the position of enablers based on their strength of relationship and importance by classifying them into four quadrants of Critical, Driving, Independent and Impact enablers. The mean of $R_i + C_j$ along with causal, effect influences frame the enablers identified in this research into four quadrants.

From Fig. 3.7, it is seen that enablers Top Management Commitment, Government Policies & Legislations, Corporate social responsibility and Training & Literacy lie in the 1st quadrant and are Critical enablers. In their research, Kausar et al. (2017) establish that government policies, supportive systems, and adequate top management support are key enablers for SSCM implementation in Indian industries. Corporate social responsibility is critical for companies to be effective in their efforts to implement SSCM. CSR should not be dealt with by companies in a generic way but deliberated as a strategy to improve social and environmental impact. Training and literacy have been acknowledged as critical in encouraging companies, employees, and supply chain partners to pursue sustainable development (Mudgal et al., 2009).

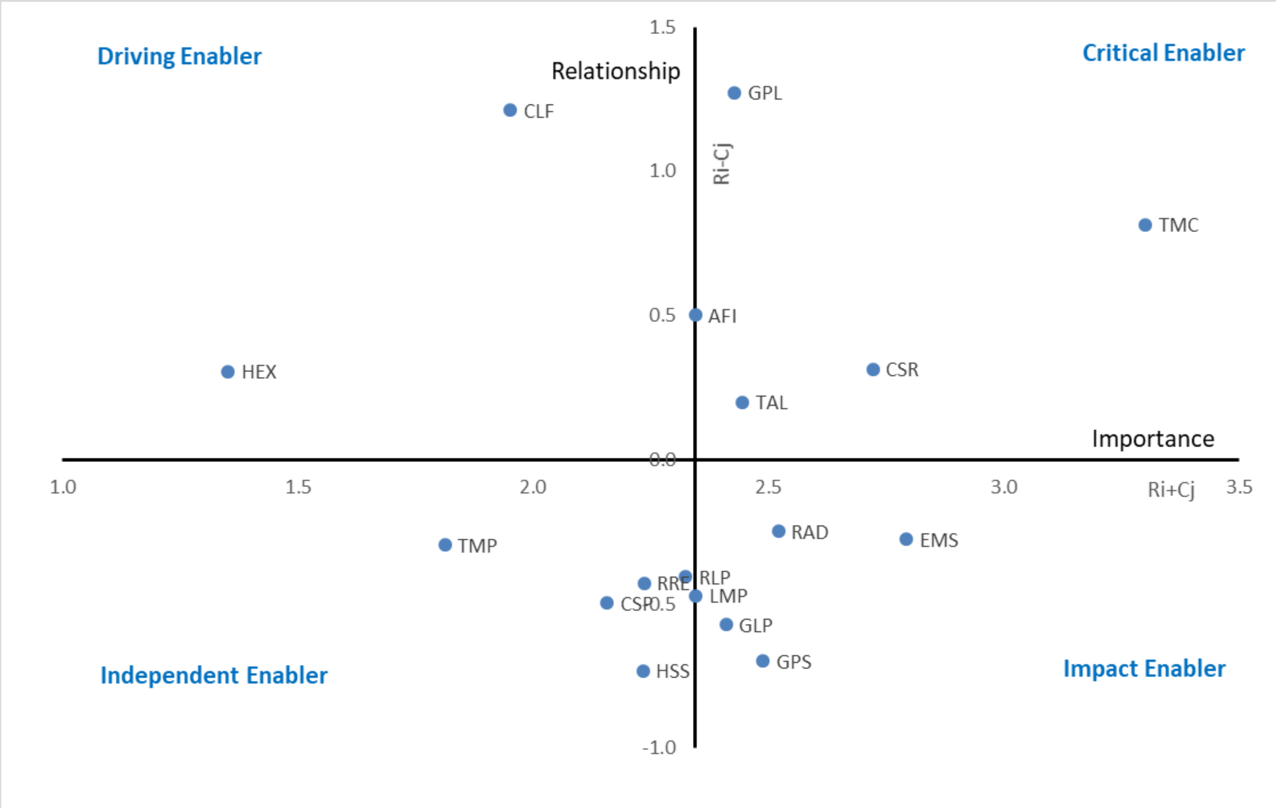


Figure 3.7: Importance-causality diagram

Apart from augmenting knowledge, training and literacy can bring changes in people's behaviour towards sustainability implementation. The Driving quadrant consists of enablers availability of funds/investment, culture related factors and human expertise. These enablers have driving effects being causal factors but are not critical and have comparatively lower importance. Governments and institutions should increase the financing options for companies pursuing SSCM, especially small and medium enterprises. Availability of funds can boost sustainability implementation by encouraging organizations to carry out transformations and build sustainable models.

The enablers State of art technologies, materials and processes, Health & safety standards, Environmental collaboration between supply chain partners, reverse logistic practices, reducing consumption of resources/energy are in the

Independent quadrant. These enablers are independent, being low on relationship and importance value. Engaging these enablers will have a direct effect on sustainability implementation in the supply chain. Enablers Research & development, Green purchasing, Environment management systems, Lean manufacturing practices, Green labelling & packaging are in the 4th quadrant. These are impact enablers and cannot be independently handled low in relationship value but high in importance. The success of sustainable Research & Development can be increased by cooperation between members in the supply chain network (De Stefano and Montes-Sancho, 2018). Supply chain managers can select practices in executing lean manufacturing based on their business needs to achieve sustainability targets and implement SSCM (Das, 2018).

3.7 Research implications

This work is beneficial to companies that are going to address sustainability aspects in their supply chain. Managers and practitioners involved in introducing sustainability need not put all their energies on all enablers equally. This research depicts the relationship between enablers, and managers need to focus more on the causal enablers. These enablers are essentially the strong drivers for implementation, and managers can deal with less influencing enablers at subsequent stages. Managers can devise suitable strategies knowing the cause and effect enablers to proceed with sustainability implementation effectively. The decisions and practices considering the position of enablers in this research shall facilitate SSCM implementation. The study indicates that policy enablers like Top management commitment and Government policies and legislation play a pivotal role in stimulating sustainability implementation in the supply chain. Top management should encourage sustainability implementation by having a strong vision and setting long-term and short-term goals. While formulating policies, the government should study the impact on all three dimensions of sustainability and their interactions to have a successful outcome.

The theoretical implication of this research is that it contributes to the sustainability literature by providing new dimensions on the causal and effect enablers. The classification of the enablers into Policy, Technology, Environmental, Financial and Human resources and their influence study aids to develop the framework in SSCM implementation. The interrelationship among enablers can be further utilized within the categories by probing into the specific nature of the industry. A model to strengthen causal enablers and improve the efficacy of these enablers could be a further outcome of this research.

In this chapter, the enablers to implement SSCM are identified and their causal effects are analysed. It is therefore, pertinent to investigate the corresponding research problem on barriers to SSCM and analyse the barriers in order to close the gap towards building a sustainable supply chain. The research problem of identifying barriers to implementation of SSCM and study of their hierarchical structure and prioritization is discussed next in Chapter 4.

CHAPTER 4

DEVELOPMENT OF A HIERARCHICAL MODEL AND PRIORITIZATION OF BARRIERS TO SSCM IMPLEMENTATION USING ISM APPROACH

4.1 Introduction

Whenever changes are made in the supply chain, organizations would face some challenges and obstacles in managing it. The promulgation of sustainability in supply chain brings operational challenges, product quality changes and supply chain disturbances (Lee and Klassen, 2008). As such during implementation of sustainable practices, there are barriers which need to be overcome. It is seen that the opinion on these barriers change among organizations and also with industry. Hence based on industry, the influences and impact of barriers differ (Diabat et al., 2013). To deal with these barriers it is necessary to analyse these barriers and understand interrelationships among them. Some barriers would be driving barriers and influence other barriers while some would be driven and affected by other barriers. Thus, a survey of literature was conducted and barriers of sustainable supply chain in the electronics industry were identified. Through discussion and replies to questionnaires by three experts from industry and an academic expert, eleven barriers specifically found in the electronics industry in India have been shortlisted. Experts' opinion and literature review was used to develop the relationship matrix.

In this research, barriers encountered during implementation of a sustainable supply chain are identified. The interrelationship among barriers is established and managerial implications of this study are discussed. The research flow in this study is depicted in Figure 4.1. This investigation can enable firms to have a comprehensive understanding of interrelationship among the barriers so that they can carry out sustainability programs in the organization. The prioritization of barriers can guide firms on allocation of resources related to attaining the sustainability goals.

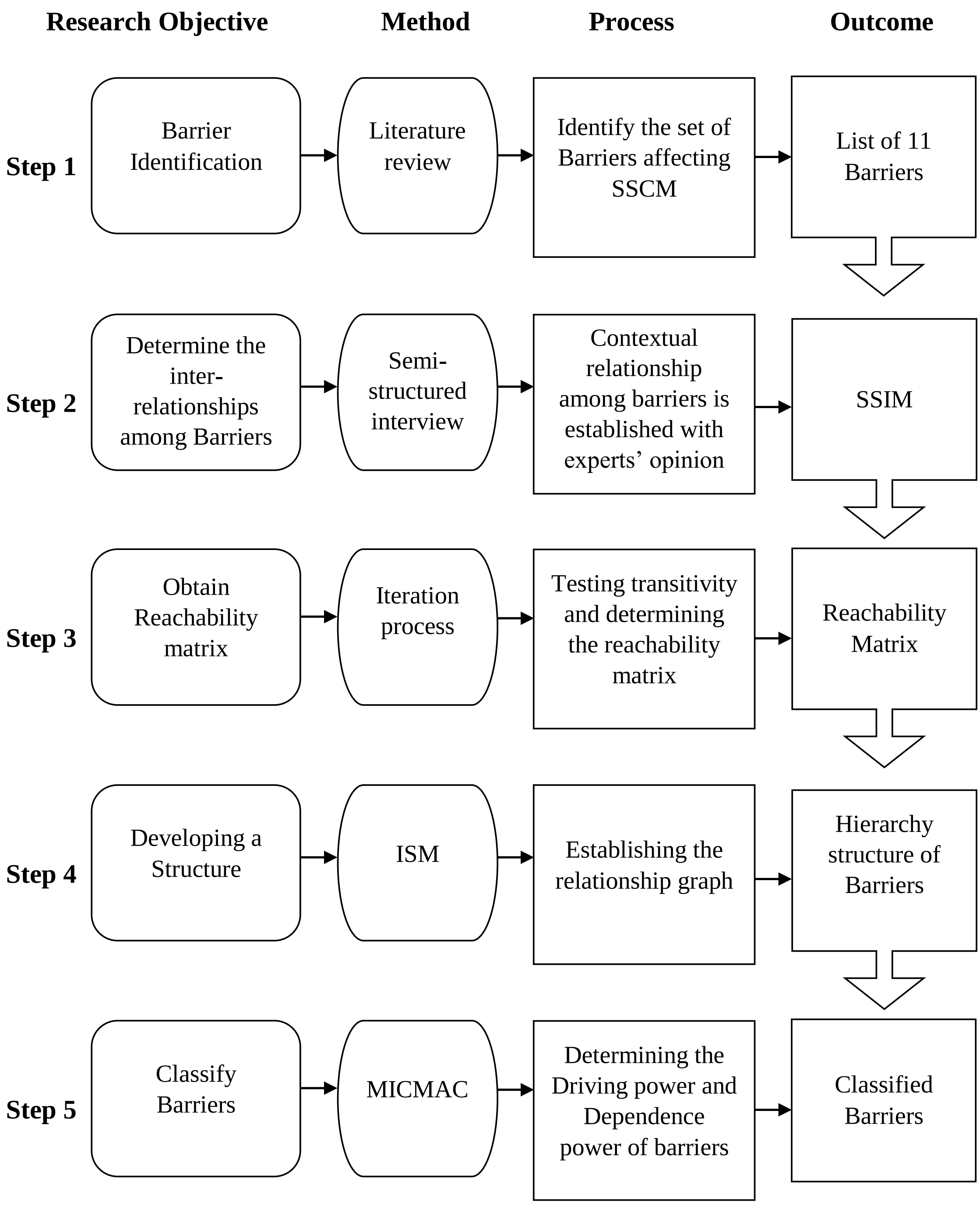


Figure 4.1: Research flow

4.2 Identification of key Barriers to implement SSCM

Literature reveals that there have been studies on barriers in SSCM. Seidel et al. (2010) studied enablers and barriers for an organizations adoption of sustainable business practises in IT companies. Faisal (2010) studied the approach to introduce SSCM by framing the enablers. Diabat and Govindan (2011) studied key drivers related to implementation of green supply chain. Luthra et al. (2016) analysed fifteen barriers in adopting sustainability in the case of plastic manufacturing firms in India.

The context of barriers has been used in research of SSCM and supplier development. For this study, a barrier is defined as a factor which is an obstacle that prevents access of sustainability in supply chain context. These factors obstruct a company's endeavour in adopting sustainable practices. For this research, the barriers that affect implementation of a sustainable supply chain in the electronics industry are shortlisted from literature review and experts' opinion. Through consultation and brainstorming sessions with the experts, the most essential barriers were shortlisted considering the industrial sector in Indian context. In our study, eleven barriers of sustainable supply chain shown in Fig. 4.2 are shortlisted. Based on experts' knowledge of SSCM and electronics industry the barriers were analysed to establish their functional traits. Brainstorming sessions were then held to categorize these barriers. While doing so previous schemes available in literature were thoroughly referred (Govindan et al., 2014; Snoek, 2017; Govindan and Hasanagic, 2018; Majumdar and Sinha, 2019; Gupta et al., 2020). The shortlisted barriers were then grouped in three categories viz. Policy, Human Resource and Technology for easier management during implementation phase. These barriers classified into categories are described in brief with their literature references as shown in Table 4.1.

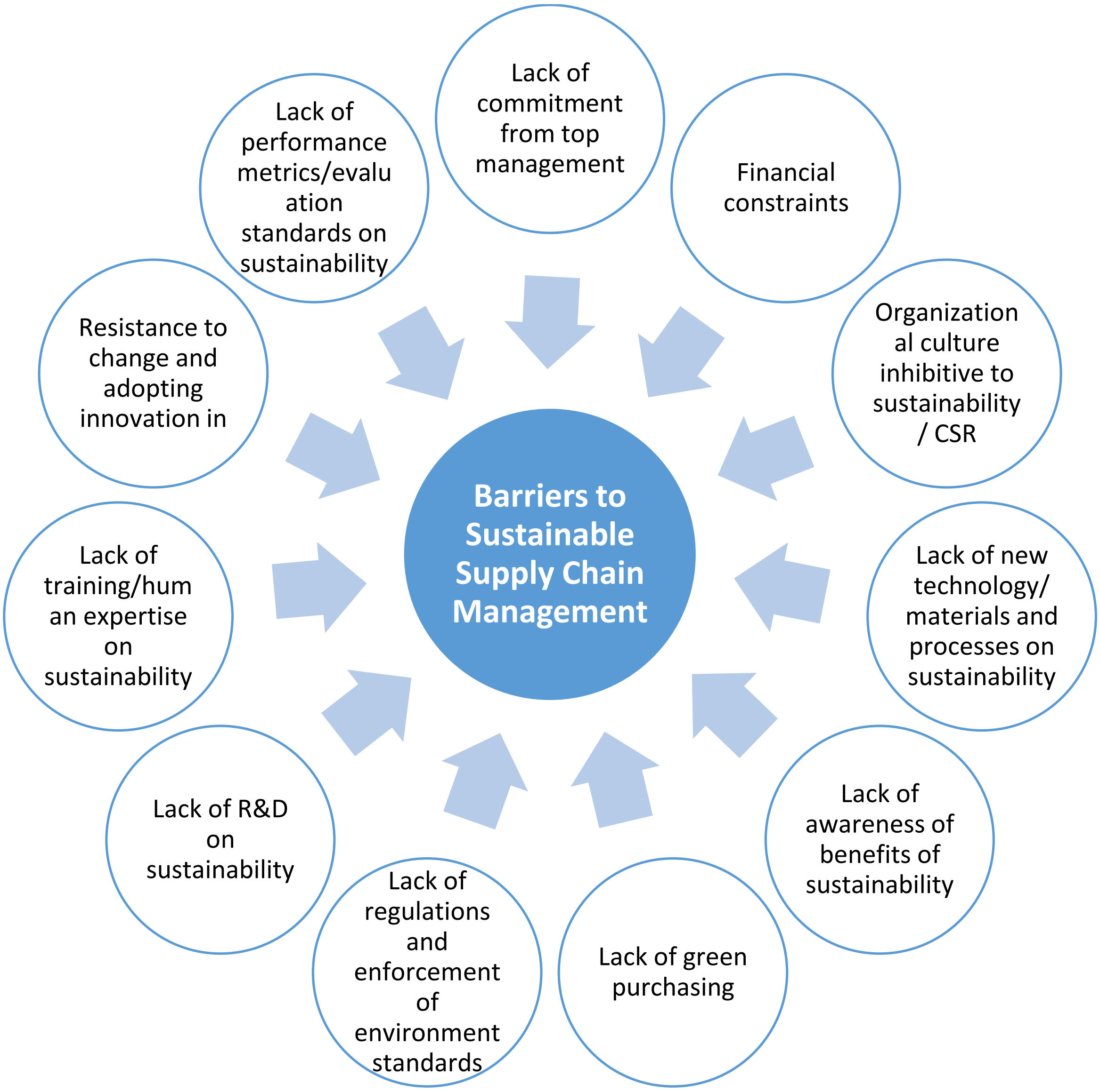


Figure 4.2: Barriers in implementation of a sustainable supply chain

Table 4.1: Barriers to SSCM implementation

Sl. No.	Barrier	Description	References	Category
1.	Lack of commitment from top management	In absence of commitment from top management, there is no priority or sufficient resource allocation for sustainability aspects. There is no direction to frame policy and achieve goals related to sustainability.	Sajjad et al. (2015); Delmonico et al., (2018); Caldera et al. (2019).	Policy
2.	Financial Constraints	Financial constraints deter initial high investments required, loan support and lower return on investment for sustainability programs.	Mangla et al. (2017); Bhanot et al., (2017); Nhemachena and Murimbika (2018).	Policy

3.	Organizational culture inhibitive to sustainability/CSR	Organisational culture and values giving importance to the social and environmental dimensions.	Paulraj et al. (2017); Delmonico et al., (2018); Soni et al., (2020); Sajjad et al. (2020).	Human resource
4.	Lack of new technology/materials and processes on sustainability	New and innovative technology, materials and processes to reduce waste, increase efficiency, improve safety systems and cut pollution levels.	Govindan et al. (2014); Movahedipour et al., (2017); Majumdar & Sinha (2018); Soni et al., (2020).	Technology
5.	Lack of awareness of benefits of sustainability	Lack of knowledge on the environmental harmful products and benefits of implementing sustainability programs	Soda et al., (2015); Mangla et al. (2017); Narayanan et al., (2019).	Human resource
6.	Lack of green purchasing	There is not due consideration and weightage given to sustainability criteria in purchase of input material.	El Tayeb et al., (2010); Guenther et al., (2013); Rostamzadeh et al. (2015); Delmonico et al., (2018).	Policy
7.	Lack of regulations and enforcement of environment standards	The enforcement of sustainable policies is not supported by strong legislation and support from the government.	AlSanad, (2018); Raut et al. (2019); Narayanan et al. (2019).	Policy
8.	Lack of R&D on sustainability	Lack of research and development on recycling methods, reusability of products and lesser polluting methods. Research and development help in reducing energy and resource consumption.	Stewart et al., (2016); Demirel and Kesidou (2019); Gupta et al. (2020).	Technology
9.	Lack of training/human expertise on sustainability	There is a lack of experts and professionals in various areas of SSCM. Training and expertise is required to guide and implement the sustainability aspects.	Mangla et al. (2017); Neri et al., (2018); Digalwar et al., (2020); Khan et al., (2020).	Human resource
10.	Resistance to change and adopting innovation in sustainability	There is in general resistance to move from traditional practices and adapt innovation by staff. There is fear of failure and opposition to changes that need to be carried out.	Christensen et al. (2015); Stewart et al., (2016); Muduli et al. (2020); Khan et al., (2020).	Human resource
11.	Lack of performance metrics/evaluation standards on sustainability	It is difficult to quantify and measure sustainability standards. The evaluation methods to verify sustainability performance are not uniform.	Al Zaabi et al., (2013); Touboulic and Walker (2015); Muniz et al. (2020).	Technology

The barriers to SSCM are further discussed as follows.

4.2.1. Lack of commitment from top management

Top management commitment in providing resources and encouraging initiatives is required for implementation of sustainability in the supply chain. Top management impacts the policy formulation, training programs and technology advancement (Luthra et al., 2013). Limited support of top management in its approach towards sustainability is a barrier for SSCM (Giunipero et al., 2012; Turker and Altuntas, 2014). The leadership should be able to provide mandate, incentives and education on company's goal of supply chain sustainability. Top management needs to fix specific targets and lay a roadmap to attain the goals of sustainability. If the short term and long term goals are not in sync it can disrupt SSCM implementation (Walker and Jones, 2012). Top management can ensure that financial goals do not completely subdue the environmental and social goals.

4.2.2. Financial constraints

Implementation of sustainability in the supply chain may require adapting to new systems which requires financial investment. Financial support is required for SSCM and lack of finance is a serious constraint (Hervani et al., 2005; AlKhidir and Zailani, 2009). Many times, sustainable infrastructure requires high capital outlay though it is argued that these costs can be recovered in the long run. Lack of funds is one of barriers for implementing sustainable projects and introducing sustainable manufacturing practices. High investments are required and processes such as eco-friendly packaging costs tend to be higher. There is also cost involvement in recycling, collecting used products and disposal of hazardous waste.

4.2.3. Organizational culture inhibitive to sustainability/CSR

An existing culture not conducive to sustainable development interrupts in SSCM implementation. Culture consists of values, beliefs, attitudes and peoples' behaviour that differs from kind or group of people (McSweeney, 2002). Different countries and even different industries have varied outlook on sustainability based on their own culture (Zhu and Sarkis, 2006). Based on country and society, the attitude and perception varies towards importance given to implementation of sustainability in the supply chain. Corporate social responsibility (CSR) undertaken by organizations combine social and environment concerns with its economic goals and also in their relationships with supply chain members. CSR being voluntary is impacted by culture and society. Cultural differences act as a major barrier in implementation of a sustainable supply chain.

4.2.4. Lack of new technology, materials and processes

Lack of advanced technology has been considered as a major reason for environmental deterioration (Mittal and Sangwan, 2014; Wang et al., 2016). Industries need to know about the new developments and use cleaner technologies to reduce pollution and wastage in the production process (Mudgal et al., 2010). Introduction or change of technology, processes or materials will require allotment of resources. But it is found that in the long term this might turn out to be advantageous. Industries need to optimise the processes and carry out technical improvements to increase its sustainability impact.

4.2.5. Lack of awareness of benefits of sustainability

Organizations tend to see the initial cost for sustainability implementation and generally oversee the benefits sustainability in the supply chain brings in long term. Low eco-literacy and unawareness about the environment management practices act as barriers (Revell and Blackburn, 2007; Herren and Hadley, 2010). Lack of awareness of reverse logistics is a major barrier in the implementation of reverse logistics operations (Ravi and Shankar, 2005). Lack of awareness in society on the benefits of sustainability does not encourage companies. Pressure from society can bring awareness to companies for making improvements in its sustainability performance.

4.2.6. Lack of green purchasing

Green purchasing is the purchase of products and services which reduce the negative effect on the environment and humans compared to competing products and services. Apart from usual purchasing criteria of cost, quality and time, green purchasing examines the issues of sustainability in purchase of inputs in a supply chain. (Kannan et al., 2008). There is limited research on low adoption and practices of green purchasing by firms (Hsu and Hu, 2008; Srivastava, 2007). Initial higher cost and no standard guidelines result in lack of green purchasing in organizations.

4.2.7. Lack of regulations and enforcement of environment standards

Government enforcement is necessary for an effective implementation of legislation in countries. Lack of regulation and adoption of environment friendly policies deters SSCM (AlKhidir and Zailani, 2009; Zhu et al., 2012; Ghazilla et al., 2015). Having strong compliance and enforcement has become an important part in designing policies to promote sustainable growth. Regulations and policies give a common compliance and performance outline in a country, but there are different across countries forcing companies to increase the effort and resources for adhering to different compliances. Apart from regulations, lack of government assistance to adopt sustainable manufacturing practises is a barrier (Prakash and Barua, 2015; Govindan et al., 2013). Regulations can be enforced by offering tax subsidies, incentives or other economic benefits to complying industries.

4.2.8. Lack of R&D on sustainability

Research and Development on sustainability in industries can improve safety aspects and environmental contribution by decreasing usage of energy as well as reducing wastages. The availability of natural resources is limited. Hence industries must research and develop processes in such a way that any type of resource is utilized optimally. The shortcoming in designing systems to reduce the consumption of energy and resources is a barrier in bringing sustainability (Russel, 2017; Perron, 2005). Organizations may not allocate necessary resources to R&D focussing on sustainability which impedes the pace of its implementation.

4.2.9. Lack of training/human expertise on sustainability

A major barrier in implementing SSCM is human related factors like no proper training, lack of qualified staff and inadequate knowledge. (Bohdanowicz et al., 2011). A certain level of expertise is required to incorporate social and environmental practices in an organisation. Training is much better than organizations trying to influence their suppliers in other ways. The success in implementation of green supply chain management can be improved by infusing literacy about sustainable practices among supply chain partners (Zabbi et al., 2013; Kumar et al., 2013). It also helps suppliers know the sustainability standards in the industry. Human resource development can be done by eco-literacy programs which become an important strategy for sustainability implementation. (Luthra et al., 2013; Govindan et al., 2014). In electronics industry for processes like recycling, proper skill acquisition through training is required (Wath et al., 2010; Yeh and Xu, 2013).

4.2.10. Resistance to change and adopting innovation in sustainability

Resistance to change and adopting innovation acts as a barrier for implementation of a sustainable supply chain (Gaziulusoy et al., 2013). A big impediment in innovation is the tendency to avoid change. The prevailing tradition, attitude and structure needs to be altered when bringing a change. There is also lack of trust and uncertainty associated during the transition phase. At consumer level also, benefits need to be communicated and change has to be accepted. Generally, there is a fear among people in moving to a new system and unwillingness to acquire new skills. It is found that innovation can solve many environmental issues but is often met with resistances (Acciaro et al., 2014).

4.2.11. Lack of performance metrics/evaluation standards on sustainability

In any industry, a measurement system is important to measure efficiency of the system. Lack of knowledge in assessing and gauging the social and environmental effect is an important barrier in sustainability implementation (Cetinkaya et al., 2011). The monitoring and measurement of sustainability is complex. Due to lack of guidance regarding environmental standards, companies are not aware of the ways and attributes to be measured (Shaw et al., 2010). Based on assessment criteria and indicators, there has to be development of common sustainability metrics. The accounting reports should also factor in the sustainability for evaluation along with economics. The environmental and social effect not being considered in traditional accounting methods is a big drawback in evaluation. (El Saadany et al., 2011).

4.2.1 Barrier studies in other industries

The barriers and their influence varies based on industry and region as seen in literature. Eleven barriers of reverse logistics in automobile industries were analysed and interactions among them was studied by Ravi and Shankar (2005). Al Zaabi et al. (2013) in a study of fastener manufacturing industry found that cost for environmentally friendly packaging, complex design to reduce consumption of resources and energy and lack of clarity regarding sustainability require utmost importance for SSCM implementation. Govindan et al. (2014) from the responses of Industrial participants in Tamilnadu, India and using AHP method found that technology category barrier is the most crucial in implementation of Green supply chain management. The specific barrier Complexity to measure and monitor environmental practices of suppliers was found to be the major obstacle in GSCM adoption. Raut et al. (2018) found that in the Indian oil and gas sector barriers management commitment and leadership and knowledge and training were having high driving power, lack of green initiatives and lack of corporate social responsibility were having highest dependence power. The modeling of barriers interrelationship in Bangladesh leather industry by Moktadir et al. (2018) revealed that lack of awareness of local customers in green products and lack of commitment from top management had high causal effect. Narayanan et al. (2019) identified and prioritized the barriers of rubber products manufacturing industry in Kerala. It was found that lack of government initiatives and lack of benchmark on sustainability measurement as the major barriers for SSCM implementation in this sector. Delmonico et al. (2018) explored the barriers to sustainable public procurement in Brazil and concluded that the category of organisational culture as the crucial one. Soni et al. (2020) studied the barriers to sustainable supply chain management in Indian marble and stone industry and found that non supporting nature of commercial banks, practice of corruption and poor environmental awareness are the influencing barriers.

4.2.2 Research gap

Due to rapid growth of industry in developing countries, the pollution levels are increasing in these countries and implementation of sustainability in supply chains has become essential (Namagembe et al., 2019). There is literature which supports that introducing sustainability in the supply chain will have a beneficial effect but due to the barriers, organizations are not inclined to implement it. Electronics companies will come across these barriers during SSCM implementation and tackling all of them simultaneously is a challenge (Ghadge et al., 2017). The sustainability issues in the supply chain of electronics industries is typical due e-waste, hazardous chemicals, recycling process, transportation etc. It is seen that the studies on sustainable supply chain management practices are limited in developing countries (Ahmed and Najmi, 2018). There is a lack of adequate research on the barriers and strategies to overcome them for implementing sustainability in the electronics industry's supply chain specific to the Indian context. This necessitates to study the issues in implementing a sustainable supply chain in electronics industries in India. The research will assist in knowing the interrelationship among barriers in a structured way and suggest ways to remove them.

4.3 Method

Interpretive Structural Modeling (ISM) is a modelling technique by which the specific relationship among related elements can be structured and presented in diagraph form. ISM has been used as a modeling method to analyse green value chains, total quality management and reverse logistics (Mangla et al., 2018). The application of method is useful when there are factors with uncertain relationship affecting a subject by converting them to a comprehensible and structured. In comparison to other MCDM methods, ISM does not need the level of dominance to investigate interrelationship among factors (Raut et al., 2019). Unlike ISM, in AHP, the interactions and indirect effects are not addressed (Zayed and Yaseen, 2020). ANP may not reflect all dependencies as removal of possible interactions within the cluster is difficult (Wu, 2008). It is different from alternate methods of Decision making trial and evaluation laboratory (DEMATEL) and social network analysis (SNA) in that it prioritises the factors apart from establishing relationships in a complex system (Abuzeinab et al., 2017). The ISM method is used as it frames the diagraph by combining the computational, theoretical and conceptual capability (Narayanan et al., 2019). The ISM method determines the mutual interactions and relationship among factors and it is a robust tool requiring a comparatively lesser amount of data (Panigrahi and Sahu, 2018). Quantitative data is not required for ISM. In this method, a model is prepared by structuring a number of different and directly related variables influencing the system. ISM is an interactive learning process and it helps in analysing inter-relationship among the variables (Bouzon et al., 2015). The sequence of steps followed in ISM methodology are presented in Fig. 4.3.

4.3.1 Interpretive structural model development

In this research to identify the contextual relationship among barriers of sustainable supply chain implementation in electronics industry, four experts were consulted. The selection of 4 experts is based on literature which states that the number of samples does not have to be too big for ISM (Shen et al., 2016) and can be few as two experts (Ravi and Shankar, 2005). For a diverse and comprehensive opinion, three experts from industry and a fourth expert from academia were approached. The three industrial experts were having an experience in the range of 15–20 years in the electronics industry and working in senior managerial level. They have been involved in implementation of sustainability practices in areas of green purchasing, quality assurance and technology development. These experts are having an experience of more than fifteen years in sustainability related areas of supply chain in the electronics industry. The academic expert is an associate professor having experience over 15 years with research interests in sustainable supply chain management.

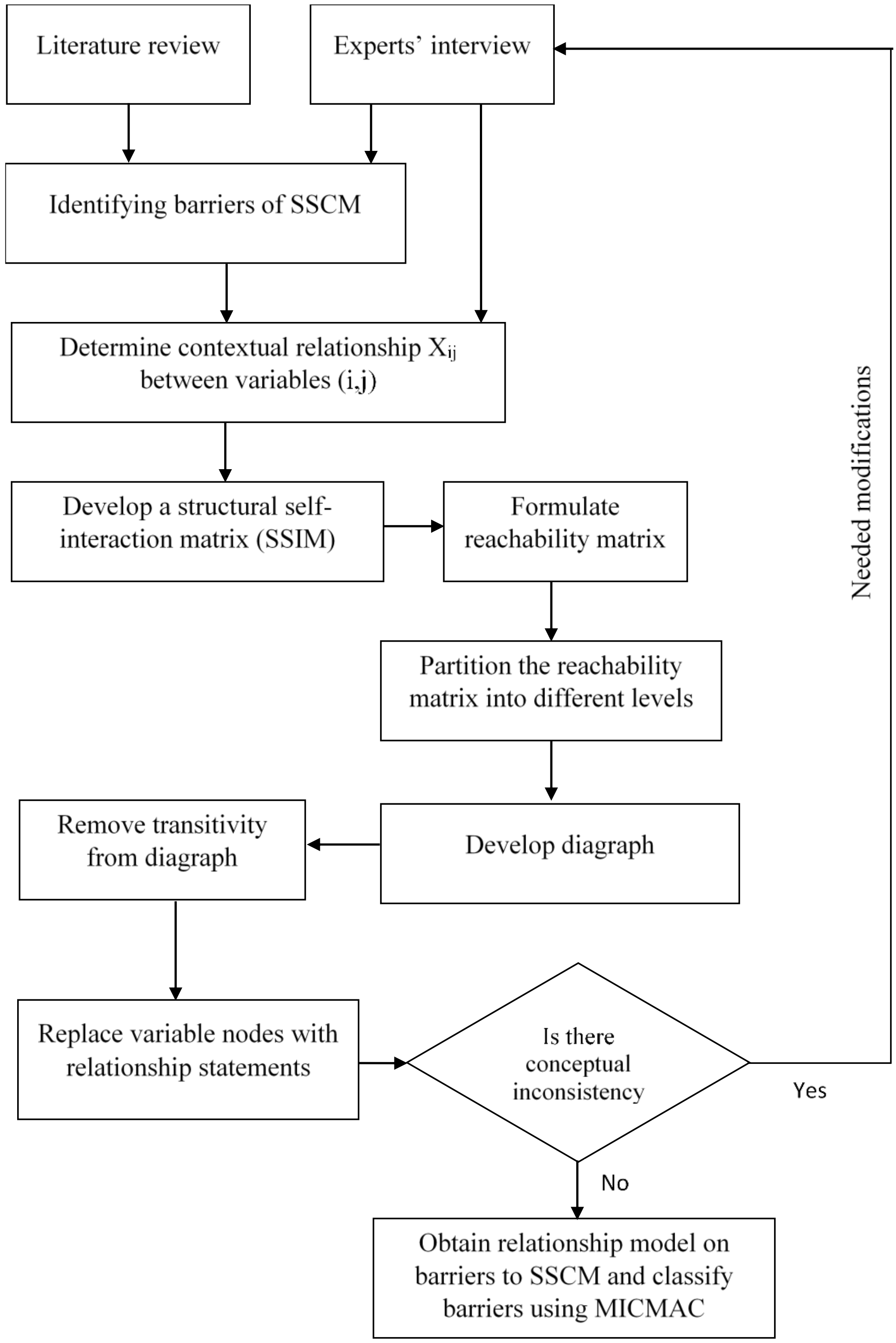


Figure 4.3: Flow diagram for ISM method

Step 1. The factors which influence the system are found and shortlisted.

For this research, the barriers to implementation of a sustainable supply chain were identified by literature review. By consultation and brainstorming sessions with experts, eleven barriers that affect the sustainability implementation in the supply chain of Indian electronics industry were identified and categorized. These barriers are shown in Table 4.1.

Step 2. From these factors, contextual relationship among them is determined. As per ISM method, contextual relationship is determined amongst variables through expert's opinion. Expert's opinion is evolved by using management methods like nominal technique, brainstorming and some others. Focussed group discussion method was used to find the contextual relationship among various barriers.

Step 3. Structural Self-Interaction Matrix - A Structural Self-Interaction Matrix (SSIM) is formulated for factors to establish a pair-wise relationship within them.

A contextual relationship of "leads to" type is used for analysing the barriers of sustainable supply chain variables. This way one variable will lead to another and using this one can establish the contextual relationship. Considering the contextual relationship of variables, the relation between two variables say i and j is worked out by probing the presence of relationship of variables i and j. In ISM, the flow of relationship among variables i and j is denoted using four symbols: These symbols are V, X, A and O. Their usage depends on the way barrier i and j help to achieve or not achieve each other, which is as follows:

- V: A forward relationship where variable *i* will lead to variable *j*,
- A: A reverse relationship where variable *j* will lead to variable *i*,
- X: A relationship where variable *i* leads to variable *j* and vice versa, and
- O: There is no relationship between variable *i* and *j* and they are independent of each other.

The SSIM for the barriers in the implementation of sustainable supply chain so obtained is given in Table 4.2.

Table 4.2: Structural Self-Interaction Matrix (SSIM)

Barriers	11	10	9	8	7	6	5	4	3	2
1. Lack of commitment from top management	V	O	V	V	A	V	A	V	V	V
2. Financial Constraints	O	V	V	V	O	V	A	V	X	
3. Organizational culture inhibitive to sustainability/CSR	V	V	V	V	O	V	A	V		
4. Lack of new technology/materials and processes on sustainability	V	X	O	A	A	A	A			
5. Lack of awareness of benefits of sustainability	V	V	V	V	V	V				
6. Lack of green purchasing	V	O	V	X	A					
7. Lack of regulations and enforcement of environment standards	V	V	V	V						
8. Lack of R&D on sustainability	V	V	X							
9. Lack of training/human expertise on sustainability	V	V								
10. Resistance to change and adopting innovation in sustainability	V									
11. Lack of performance metrics/evaluation standards on sustainability										

Barrier 9 helps in alleviating Barrier 10. This relationship in the SSIM table is shown by symbol V. This denotes that lack of training/human expertise alleviates resistance to change and adopting innovation in sustainability. In general, there is resistance to change and accepting a new system which can be solved by training and guidance. Therefore, lack of training will alleviate the resistance of employees to change and adopt innovation while implementing sustainability thus being shown by symbol V.

Barrier 4 and Barrier 10 help alleviate each other. This relationship in the SSIM table is shown by symbol X. Resistance to change and adopting innovation will lead to lack of new technology/materials and processes on sustainability. Similarly lack of new technology/materials and processes will inhibit change and innovation adoption.

Barrier 2 and Barrier 11 are not related to each other and this relation is shown by symbol O in the SSIM matrix. The barriers financial Constraints and lack of performance metrics/evaluation standards have no relationship between them and hence O is marked.

Similarly, the contextual relationships are established for all the 11 barriers identified for the sustainability implementation (Table 4.2) in SSIM.

Step 4. Reachability matrix -The Reachability matrix is prepared from SSIM by checking transitivity of the matrix. Transitivity rule states that if a factor P has a relation with Q and Q has a relation with R, then P also has a relation with R.

The information of SSIM is converted into a binary matrix i.e. 1 and 0 based on rules. This matrix is called the initial reachability matrix and here V, A, X, O are replaced by either 1 or 0. The substitution is done based on the conditions as given in Table 4.3.

Table 4.3: Rules for initial reachability matrix formulation

Value of (*i, j*) in SSIM	**Substitution in Reachability matrix**	
	(*i*, *j*) entry	(*j*, *i*) entry
V	1	0
A	0	1
X	1	1
O	0	0

For e.g. Table 4.3 can be explained as if the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0. Similarly, if the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1 and so on. Substitution as above is done resulting in initial reachability matrix as shown in Table 4.4.

Table 4.4: Initial reachability matrix

Barriers	1	2	3	4	5	6	7	8	9	10	11
1. Lack of commitment from top management	1	`1	1	1	0	1	0	1	1	0	1
2. Financial Constraints	0	1	1	1	0	1	0	1	1	1	0
3. Organizational culture inhibitive to sustainability/CSR	0	1	1	1	0	1	0	1	1	1	1
4. Lack of new technology/materials and processes on sustainability	0	0	0	1	0	0	0	0	0	1	1
5. Lack of awareness of benefits of sustainability	1	1	1	1	1	1	1	1	1	1	1
6. Lack of green purchasing	0	0	0	1	0	1	0	1	1	0	1
7. Lack of regulations and enforcement of environment standards	1	0	0	1	0	1	1	1	1	1	1
8. Lack of R&D on sustainability	0	0	0	1	0	1	0	1	1	1	1
9. Lack of training/human expertise on sustainability	0	0	0	0	0	0	0	1	1	1	1
10. Resistance to change and adopting innovation in sustainability	0	0	0	1	0	0	0	0	0	1	1
11. Lack of performance metrics/evaluation standards on sustainability	0	0	0	0	0	0	0	0	0	0	1

The initial reachability matrix so arrived has to be checked for transitive links which may be present among the variables. For e.g. in Table 4.4, barrier 9 influences barrier 8 and barrier 8 influences barrier 6. Therefore, it can be inferred that barrier 9 has an effect on barrier 6 and the relation is changed to 1 in final reachability matrix. The final reachability matrix after checking of transitivities is shown in Table 4.5. The driving power of a barrier and its dependence is also depicted in Table 4.5. The driving power of a particular barrier is found from the total barriers it helps to achieve and this includes the considered barrier itself. The dependence on the other hand is the total of barriers helping it to achieve and includes itself. The values against each barrier for driving and dependency power will be applied in MICMAC analysis which categorizes the barriers into four groups of autonomous, dependent, linkage, and independent.

Table 4.5: Final reachability matrix

Barriers	1	2	3	4	5	6	7	8	9	10	11	Driver Power
1. Lack of commitment from top management	1	1	1	1	0	1	0	1	1	1	1	**9**
2. Financial Constraints	0	1	1	1	0	1	0	1	1	1	1	**8**
3. Organizational culture inhibitive to sustainability/CSR	0	1	1	1	0	1	0	1	1	1	1	**8**
4. Lack of new technology/materials and processes on sustainability	0	0	0	1	0	0	0	0	0	1	1	**3**
5. Lack of awareness of benefits of sustainability	1	1	1	1	1	1	1	1	1	1	1	**11**
6. Lack of green purchasing	0	0	0	1	0	1	0	1	1	1	1	**6**
7. Lack of regulations and enforcement of environment standards	1	1	1	1	0	1	1	1	1	1	1	**10**
8. Lack of R&D on sustainability	0	0	0	1	0	1	0	1	1	1	1	**6**
9. Lack of training/human expertise on sustainability	0	0	0	1	0	1	0	1	1	1	1	**6**
10. Resistance to change and adopting innovation in sustainability	0	0	0	1	0	0	0	0	0	1	1	**3**
11. Lack of performance metrics/evaluation standards on sustainability	0	0	0	0	0	0	0	0	0	0	1	**1**
Dependence power	**3**	**5**	**5**	**10**	**1**	**8**	**2**	**8**	**8**	**10**	**11**	

Step 5. Level partitions - Partitioning of final reachability matrix into different levels.

From the final reachability matrix, the reachability and antecedent set (Warfield, 1974) for each barrier is found out. Reachability set consists of the variable itself and the variables it assists to achieve. An antecedent set consists of the variable itself and those variables that help to reach it. The intersection of these sets is obtained for all variables. After figuring out the top-level variable, it is removed from the other remaining variables. At level I, as seen in Table 4.6 is lack of performance metrics/evaluation standards on sustainability (Barrier 11). Since Barrier 11 is at Level I, it will come on the top of the ISM model.

Table 4.6: Iteration 1

Barrier	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 4, 6, 8, 9, 10, 11	1, 5, 7	1	
2	2, 3, 4, 6, 8, 9, 10, 11	1, 2, 3, 5, 7	2, 3	
3	2, 3, 4, 6, 8, 9, 10, 11	1, 2, 3, 5, 7	2, 3	
4	4, 10, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	4,10	
5	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	5	5	
6	4, 6, 8, 9, 10, 11	1, 2, 3, 5, 6, 7, 8, 9	6, 8, 9	
7	1, 2, 3, 4, 6, 7, 8, 9, 10, 11	5, 7	7	
8	4, 6, 8, 9, 10, 11	1, 2, 3, 5, 6, 7, 8, 9	6, 8, 9	
9	4, 6, 8, 9, 10, 11	1, 2, 3, 5, 6, 7, 8, 9	6, 8, 9	
10	4, 10, 11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	4, 10	
11	11	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11	11	I

Again in the next iteration, the intersection of reachability set and antecedent set is identified. Iteration 2 shown in Table 4.7 reveals that second level motivation is found at variable 4 and 10. Hence they will occupy the second level and be removed in ensuing iterations. This process is repeated and variables removed in each level. This is continued till the levels of each variable are obtained. The levels of barriers decide their position in the ISM model. These levels help in building the digraph and final model of ISM. The barriers, along with their reachability set, antecedent set, intersection set and the levels for barriers are enumerated in Tables 4.6–4.12.

Table 4.7: Iteration 2

Barrier	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 4, 6, 8, 9, 10	1, 5, 7	1	
2	2, 3, 4, 6, 8, 9, 10	1, 2, 3, 5, 7	2, 3	
3	2, 3, 4, 6, 8, 9, 10	1, 2, 3, 5, 7	2, 3	
4	4, 10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	4,10	II
5	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	5	5	
6	4, 6, 8, 9, 10	1, 2, 3, 5, 6, 7, 8, 9	6, 8, 9	
7	1, 2, 3, 4, 6, 7, 8, 9, 10	5, 7	7	
8	4, 6, 8, 9, 10	1, 2, 3, 5, 6, 7, 8, 9	6, 8, 9	
9	4, 6, 8, 9, 10	1, 2, 3, 5, 6, 7, 8, 9	6, 8, 9	
10	4, 10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10	4, 10	II

Table 4.8: Iteration 3

Barrier	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3, 6, 8, 9	1, 5, 7	1	
2	2, 3, 6, 8, 9	1, 2, 3, 5, 7	2, 3	
3	2, 3, 6, 8, 9	1, 2, 3, 5, 7	2, 3	
5	1, 2, 3, 5, 6, 7, 8, 9	5	5	
6	6, 8, 9	1, 2, 3, 5, 6, 7, 8, 9	6, 8, 9	III
7	1, 2, 3, 6, 7, 8, 9	5, 7	7	
8	6, 8, 9	1, 2, 3, 5, 6, 7, 8, 9	6, 8, 9	III
9	6, 8, 9	1, 2, 3, 5, 6, 7, 8, 9	6, 8, 9	III

Table 4.9: Iteration 4

Barrier	Reachability set	Antecedent set	Intersection set	Level
1	1, 2, 3	1, 5, 7	1	
2	2, 3	1, 2, 3, 5, 7	2, 3	IV
3	2, 3	1, 2, 3, 5, 7	2, 3	IV
5	1, 2, 3, 5, 7	5	5	
7	1, 2, 3, 7	5, 7	7	

Table 4.10: Iteration 5

Barrier	Reachability set	Antecedent set	Intersection set	Level
1	1	1, 5, 7	1	V
5	1, 5, 7	5	5	
7	1, 7	5, 7	7	

Table 4.11: Iteration 6

Barrier	Reachability set	Antecedent set	Intersection set	Level
5	5, 7	5	5	
7	7	5, 7	7	VI

Table 4.12: Iteration 7

Barrier	Reachability set	Antecedent set	Intersection set	Level
5	5	5	5	VII

Step 6. Formation of ISM-based model - A diagraph is prepared based on the relationship in reachability matrix and by removing the transitive links. The

diagraph is developed to an ISM model by converting factorial nodes to statements. The obtained ISM model is verified for presence of any conceptual discrepancy and if required the changes are done to remove it.

From the final reachability matrix, a structural model is developed. To depict the relationship among two barriers, i and j, an arrow is drawn from i to j and the resulting graph is called digraph. The digraph is finally converted into an ISM model as shown in Fig. 4.4.

It is observed from Fig. 4.4 that lack of awareness of benefits of sustainability (Barrier 5) is at the bottom indicating it significantly affects the system. In this model, all the eleven barriers come in 7 levels. Lack of awareness of benefits of sustainability (Barrier 5) is at level 7 and Lack of regulations and enforcement of environment standards (Barrier 7) is at level 6. This indicates that lack of awareness about sustainability (Barrier 5) influences regulation and enforcement of sustainability (Barrier 7). Lack of performance metrics/evaluation standards on sustainability (Barrier 11) is on the top of figure i.e. level I.

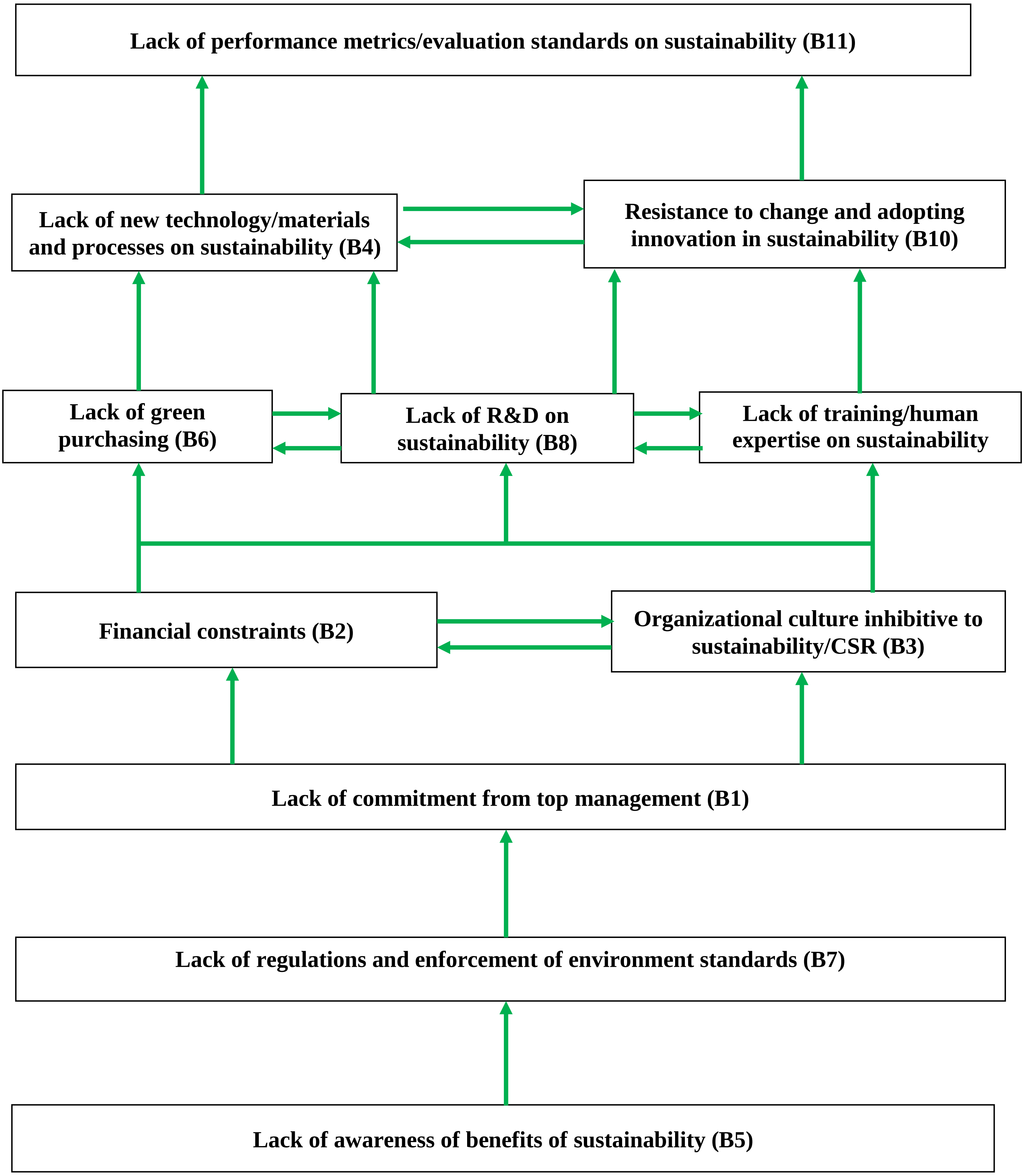


Figure 4.4: ISM-based model for the barriers in implementation of sustainable supply chain

4.4 Results

The ISM model obtained in Fig. 4.4 arranges the barriers in the supply chain of electronics industries in seven levels and shows the relationship between them. The barriers in upper levels are driven by barriers at lower levels. Lack of awareness of benefits of sustainability (Barrier5) is a key barrier as it has the highest influence being at level 7, the lowest level in the ISM model. Awareness on the benefits of sustainability should be promoted by Industry bodies, NGOs and Governments. The study by Mathiyazhagan et al. (2013) found that lack of environmental awareness of suppliers to be the most influencing barrier for GSCM implementation in automobiles industries of South India. Kumar and Dixit (2018) found that lack of awareness for recycling and lack of policies and regulation as the root cause barriers in confronting e-waste problems. Programs and activities to enhance awareness about sustainability across all levels and their benefits to the society should be extensively undertaken.

The next fundamental barrier that comes at level 6 is lack of regulations and enforcement of environment standards (Barrier7). Barrier 5 leads to lack of regulations and enforcement of environment standards as lack of awareness dilutes the enforcement. Only when people are aware of the benefits, there would be measures taken for regulation and strict enforcement. The public raises their concern on the environment to the Government and the Government should bring stringent laws as well as see that it is properly enforced by industries. It is seen that the acceptability of regulations and policies is very low by electronics industries though they are significant influencers (Ravi and Shankar, 2014). Regulations on electronic waste management, proper disposal etc. can be strengthened and support in storage, eco-friendly recycling infrastructure should be enhanced. Schemes such as extended producer's responsibility (EPR) should be widened. Mitra and Datta (2014) pointed out that there was lack of awareness on environmental sustainability and the regulatory framework was also lacking for adoption of GSCM in Indian manufacturing industries. Luthra et al. (2016) evaluated the barriers in sustainable consumption and production using Government support and policies' as the most important for plastic manufacturing organization in India.

The above barriers lead to level 5 of lack of commitment from top management. Lack of commitment from top management (Barrier1) happens when they feel that there is lack of regulation and enforcement. This is in line with Majumdar and Sinha (2019) that top management is not inclined in their commitment to sustainable supply chain management in absence of stringent regulations. Top management commitment is the main behavioural element which influences other factors in implementation of green supply chain management practices in Indian mining industries (Muduli et al., 2013). This is reflected at level 4 in the derived ISM Fig. 4.4.

At level 4, Financial constraints (Barrier2) and organizational culture inhibitive to sustainability/CSR (Barrier 3) are affected by Lack of commitment from top management (Barrier1). The top management in an organisation allocates funds which are required for implementation of sustainability. Top management attitude gives direction to the culture in an organization and its obligation towards corporate social responsibilities. Thus Lack of commitment from top management (B1) drives Financial constraints (B2) and organizational culture inhibitive to sustainability/CSR (B3).

The disposal and recycling processes requires financial investment. With rapidly changing product design and shorter life cycle of electronics products, the allocation of finance to different areas is a challenge. New technologies and optimization techniques should be developed to reduce the financial constraints. Industry and academia can collaborate on projects to find better solutions. The culture of sustainability should be moulded with organizational culture so that sustainability practices are transferred throughout the supply chain. Organizational Culture can boost participation and innovative approaches towards sustainability (Muduli et al., 2013). This leads to Lack of green purchasing (Barrier6), Lack of R&D on sustainability (Barrier8) and lack of training/human expertise on sustainability (Barrier9) being influenced by financial constraints (Barrier2) and organizational culture inhibitive to sustainability/CSR (Barrier3).

Lack of new technology/materials and processes on sustainability (Barrier4) is on level 6 above lack of green purchasing (Barrier6) and lack of R&D on sustainability (Barrier8). This relation is because new developments in technology, materials and processes related to sustainability are alleviated by R&D and green purchasing. On the same level 6, resistance to change and adopting innovation (Barrier10) in sustainability (Barrier10) is alleviated by Lack of R&D on sustainability (Barrier8) and lack of training/human expertise on sustainability (Barrier9). Lack of R&D was observed to be a critical barrier in implementation of green production practises in small and medium enterprises (Ghazilla et al., 2015). Absence of new technology/materials/processes and innovation adoption would lead to lack of performance metrics/evaluation standards on sustainability (Barrier11) which is therefore placed on the top of the Fig. 4.4. It is found that all technology category barriers Lack of R&D on sustainability (Barrier 8), Lack of new technology/materials and processes on sustainability (Barrier 4) and lack of performance metrics/evaluation standards on sustainability (Barrier 11) are in the top 5, 6 and 7 levels indicating that technology barriers are mostly influenced by other barriers.

4.4.1 MICMAC analysis

The purpose of the MICMAC (Matrix of Cross-Impact Multiplications Applied to Classification) analysis is to analyse the driver power and dependence power of variables. The variables are classified into four categories, autonomous, dependent, linkage and independent (Fig. 4.5). Variables having weak driving power and weak dependence power comes under Quadrant 1 - autonomous category. The main characteristic of these variables are that they may have a few links that might be strong and do influence the structure much. Dependent variables - Quadrant 2 possess weak driving power but strong dependence power. A linkage variable - Quadrant 3 possesses strong driving power and strong dependence power. Fourth category - Quadrant 4 includes the "independent" which have strong driving power but weak dependence.

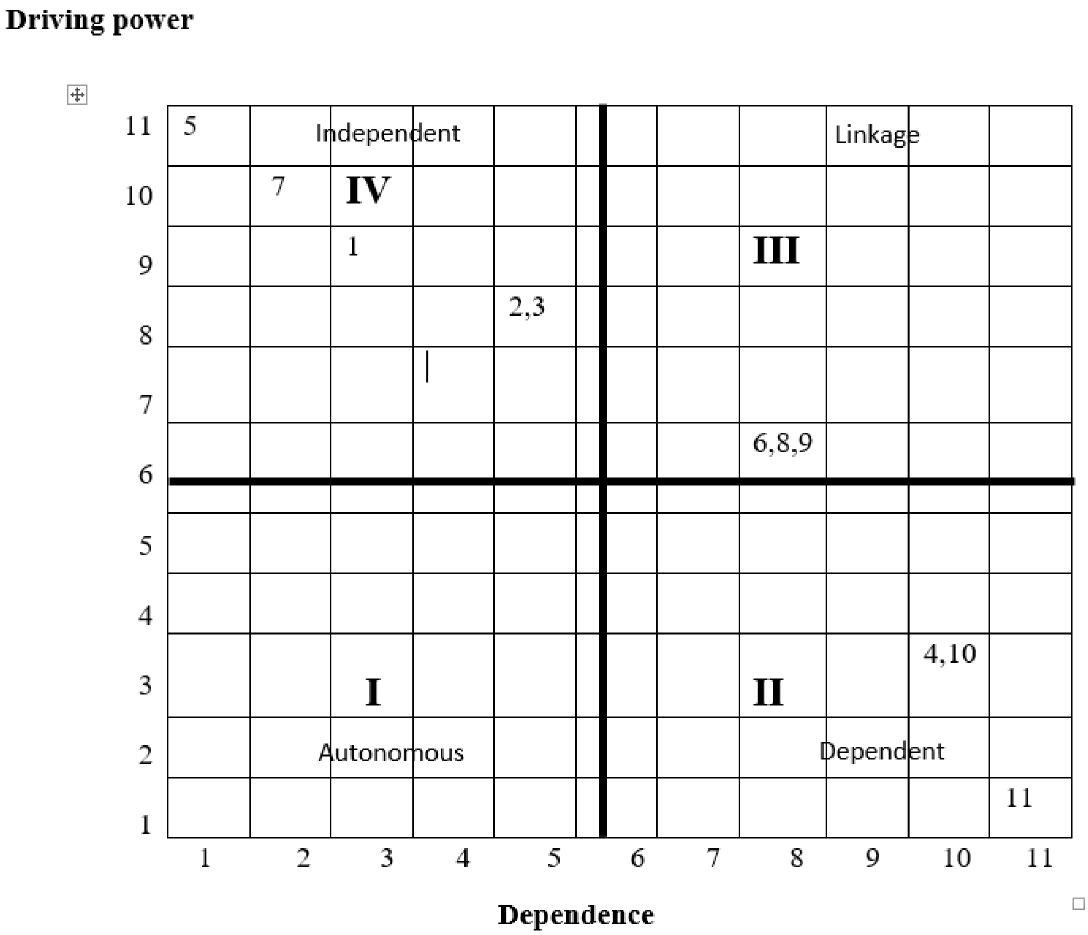


Figure 4.5: Driving power and dependence diagram

The driving power and the dependence of each of these barriers are shown in Table 4.5. The presence of 1 along the columns and rows of this table specifies the dependence and driving power, respectively. Thereafter, the diagram of driving power vs. dependence power for the barriers is made which is shown in Fig. 4.5. For example, from Table 4.5, it is seen that organizational culture inhibitive to sustainability/Corporate Social Responsibility (Barrier 3) is having a driving power of 8 and dependence power of 5. Thus, it is appropriately placed in quadrant 4 in Fig. 4.5. In the same way, all eleven barriers based on their driving and dependence power are placed in this Fig. 4.5.

From the MICMAC analysis shown in Fig. 4.5, no barriers are found in the autonomous quadrant. Thus, all barriers under consideration in this study are relevant and have an influence in the implementation of sustainability in the electronics industry. The lack of performance metrics/evaluation standards on sustainability (Barrier11), lack of new technology/materials and processes on sustainability (Barrier4) and resistance to change and adopting innovation in sustainability are in the dependent quadrant (Barrier10) which have high dependence power but low driving power. The high dependence power shows that these barriers can be influenced by other barriers but they are not guiding others. Lack of green purchasing (Barrier6), lack of R&D on sustainability (Barrier8) and lack of training/human expertise on sustainability (Barrier9) are in the linkage quadrant revealing they are unstable. The barriers in this quadrant are generally unstable and action on these barriers not only influences others but also has a feedback on them (Yadav and Barve, 2015).

Lack of awareness of benefits of sustainability (Barrier5), lack of regulations and enforcement of environment standards (Barrier7), lack of commitment from top management (Barrier1), financial constraints (Barrier 2), organizational culture inhibitive to sustainability/CSR (Barrier3) are in independent quadrant thereby suggesting that they have high driving power but low dependence. These barriers are crucial to drive the implementation of sustainability in the electronics industry. It is evident from literature that government regulations/enforcement, top management commitment and awareness play a much larger role in sustainability implementation. They are crucial and hence are required to be paid more attention.

The position of barrier category based on the results of MICMAC analysis is shown in Fig. 4.6. It is found that most of the barriers in the Policy category are in the independent quadrant indicating that policy barriers are having high driving and influencing power. Therefore, the policy related areas at both government and organizational level are to be formulated and strengthened in electronics industries to remove barriers in implementation of a sustainable supply chain management. The focus on policy areas will assist in mitigating the other barriers that are present. Managing these crucial barriers will also influence the other barriers and hence the overall system can be controlled better. The ISM model developed is in general for the electronic industry but can be applied across supply chains in similar industries.

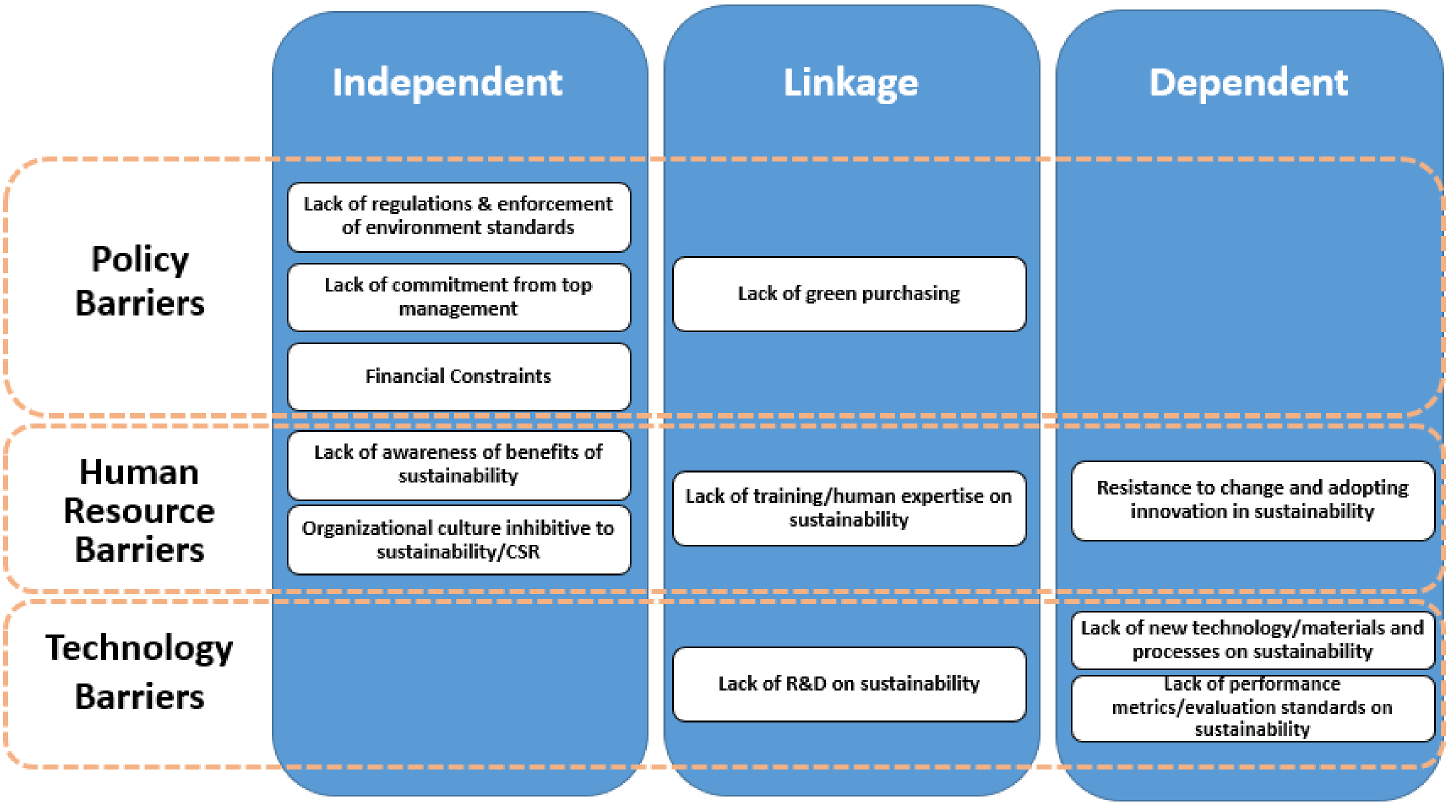


Figure 4.6: MICMAC analysis classified to barrier categories

4.5 Managerial implications

The results obtained in this research have various practical and academic implications. The research analyzes the various critical barriers in implementation of a sustainable supply chain. It models the relationship between barriers encountered while industries try to introduce SSCM. The barriers are also classified in different areas giving managers an understanding of how the barriers individually and as categories affect sustainability implementation in Indian electronics industries. Managers can know which barriers need their immediate attention and how the other barriers would be influenced. The outcome in this research reveals the driving and driven powers along with their dependence or independence on other barriers. Administrators need to develop strong policies and regulations to achieve sustainability. These policies are to be strengthened to ensure enforcement in organizations. The developed ISM model can help managers to devise strategies and develop solutions in tackling barriers to successfully implement a sustainable supply chain.

The research is extended to study a complementary research problem of identifying and analysing the causal relations among the barriers of sustainable supply chain. The research will help to understand the degree of prominence of these barriers and deal more effectively with the barriers to overcome them. This problem is discussed in Chapter 5.

CHAPTER 5

CAUSE-EFFECT RELATIONS AND DEGREE OF PROMINENCE AMONG BARRIERS OF SSCM USING GREY THEORY AND DEMATEL METHODS

5.1 Introduction

World over organizations are focusing on sustainable goals, where along with economic success their role in protecting the planet and people are becoming important. Whilst transforming the supply chain into a sustainable one, there would be some barriers that might hinder this process. Through extensive literature review, the barriers in the implementation of sustainability are identified and then classified to understand their broad hierarchy. The opinion of industrial managers on the barriers whilst implementing sustainability in the supply chain were obtained through discussion and barriers were shortlisted, which were classified among areas of policy, technology, financial and human resources. The results derived can guide policymakers of the sector and industry for mitigating barriers during the implementation of sustainable programs.

5.2 Identification of key Barriers to SSCM

A barrier is an obstacle or a circumstance that keeps people or things apart or prevents communication or progress. In our research, we define a barrier as an element which is an obstacle or prevents the implementation of sustainability in the supply chain context. The barriers were identified from the literature and shortlisted to 11 main barriers affecting the electronics industry. To see that the main areas of an organization are covered, the barriers were classified into financial, technology, human resource and policy categories. This gave a wholesome perspective of the barriers covered. In this research, an attempt is made to study the causal barriers and identify the degree of prominence of these barriers whilst initiating a sustainable supply chain model in the electronics industry. The barriers of a sustainable supply chain for the electronics industry along with references and their classification is shown in Table 5.1. Table 5.2 shows the reference notation used for barriers of the sustainable supply chain in this study. They are briefly described below based on their category:

5.2.1 Financial barriers. These are the barriers which arise due to cost considerations by an organization and their dominating tendency to focus on economic growth. Following three of the identified barriers fall in this category.

(i) *High cost for disposal of hazardous waste:* Hazardous waste management involves treatment of hazardous substances produced by considering their disposal in a safe and cost-effective way (Rabbani et al., 2019). The processing and recycling of hazardous waste requires safe storing, process modifications and use of cleaner technologies. Companies try to get newer disposal technologies to improve sustainability and proper disposal helps in reducing carbon emissions and water pollution (Harikannan et al., 2020). These implementations come at a cost which holds them back. Waste treatment costs depending on the industry can be very high. It also leads to additional collection and transportation costs. This increases the final disposal cost and research indicates that cost factors are a major impediment for not considering environmental factors during the disposal process. For an organization implementing a sustainable supply chain, it is expected that it should monitor its own by-products and waste irrespective of the government regulations and non-governmental organizations monitoring the disposal activities. Ways to reduce cost such as minimizing the hazardous waste transportation cost by multi-location routing model have been studied (Samanlioglu, 2013).

Table 5.1: Barriers of sustainable supply chain

Category	Barrier	Description	References
Financial	High cost for disposal of hazardous wastes	The by-products or wastes generated during production which are hazardous have to be disposed properly. The setting up of treatment plants and safe transportation can be costly.	Al Zaabi et al., (2013); Rabbani et al., (2019).
	High investments for sustainability and less return-on-Investments	An initial high implementation cost of investment in infrastructure and lack of funding. Cost implications in switching over to new system and increased cost for sustainable products. Expenses are also incurred for disposal of hazardous waste.	Mudgal et al., (2010); Mittal and Sangwan (2014); Nhemachena and Murimbika (2018).
	Lack of green purchase practices	Green purchase is a conscious purchasing decision by firms in ensuring that purchased products or services meet the set environmental objectives. It ensures that supply chain managers consider the issue of sustainability during procurement.	El Tayeb et al., (2010); Rostamzadeh et al. (2015).
Technology	Complexity in measuring and monitoring sustainability practices	There is a lack of effective evaluation measures and differences in sustainability standards. It is difficult to quantify sustainable achievements and accounting methods limit reporting.	Björklund et al., (2012); Muniz et al., (2020).
	Lack of new technology, materials and processes	New technology, materials and processes are required to replace pollution causing products and processes which risk the workforce. The materials and processes in a supply chain should be environment friendly.	Govindan et al., (2014); Gorane and Kant (2015); Majumdar and Sinha (2018).
	Inadequate research and development on sustainability	The lack of research and development to reuse and recycle products. Lack of new design to reduce consumption of resources and energy.	Demirel and Kesidou (2019); Gupta et al., (2020).
Human resource	Resistance to change and adopting innovation	The resistance to change and adopting a new system. The unwillingness may be due to fear of failure and hesitation in change from traditional process.	Gaziulusoy et al., (2013); Christensen et al., (2015); Muduli et al., (2020).
	Lack of cultural values and moral ethics	Lack of organizational culture and values favourable to sustainable development. There is lack of work life balance, ethics and corporate social responsibility.	Mudgal et al. (2010); Paulraj et al., (2017); Sajjad et al., (2020).
	Lack of proper training and education on sustainability	No proper training on safety and sustainable manufacturing practices. Lack of human resource and skilled personnel on sustainable programs.	Govindan et al., (2014); Digalwar et al., (2020).
Policy	Lack of commitment from top management	Lack of involvement of top management leads to non-supportive company policies for sustainability. For example, organization priorities are not there on environment and social impact but on economic side like profits.	Majumdar and Sinha (2018); Caldera et al., (2019).
	Lack of regulation and guidance from authorities	Lack of regulation and enforcement on sustainable standards in a supply chain. The low enforcement of regulatory policies along with lack of support and guidance from authorities.	Zhu et al., (2012); Majumdar and Sinha, (2019); Raut et al., (2019).

Table 5.2: Reference notation for barriers of SSCM

Barrier	Notation
High cost for disposal of hazardous wastes	HCD
High investments for sustainability and less return-on-Investments	HIC
Lack of green purchase practices	LGP
Complexity in measuring and monitoring sustainability practices	CMM
Lack of new technology/materials and processes	LNT
Inadequate research and development on sustainability	IRD
Resistance to change and adopting innovation	RCI
Lack of cultural values and moral ethics	LOC
Lack of proper training and education on sustainability	LPT
Lack of commitment from top management	LCM
Lack of regulation and guidance from authorities	LOR

(ii) *High investments for sustainability and less return-on-investments:* The path to sustainability is beset with internal and external cost constraints (Wu et al., 2012; Schrettle et al., 2014). High implementation cost makes it hard for companies to adopt sustainable supply chains. High-cost implications have been reported in the literature to be a significant barrier that companies have to encounter in the implementation of sustainable practices (Ervin et al., 2013; Mittal and Sangwan, 2014). High investments are usually needed in switching over to new systems required for sustainability compliances. Whilst companies compete to reduce price, sustainability practices such as environment friendly packaging and socially responsible procurement increases the cost of sustainable products. There are cost implications in the disposal of hazardous waste and recycling processes. The initial financial investment involved for the introduction of SSCM may not be profitable to companies in short term. Evaluation of the high costs involved versus the benefits gained by environmental programs often influence the decision of organizations towards implementing SSCM (Zhu and Geng, 2013; Nhemachena and Murimbika, 2018).

(iii) *Lack of green purchase practices:* In green purchasing apart from the usual criteria of cost, quality and delivery, the sustainability aspects such as reusability, recycling and avoiding hazardous material is being ensured (Rostamzadeh et al., 2015). Green purchase practices take into account the negative effect on the environment during the purchase of products and services whilst comparing competing products and services. In green purchasing, the issues related to sustainability are given due consideration during the purchase of inputs in a supply chain (Kannan et al., 2008). There is a lack of green purchase practices (LGP) in companies due to higher cost and the absence of standard procedures. There might also be resistance from suppliers whilst executing green purchase practices for various reasons. The reluctance towards change might be due to the traditional mind set and their interest being different from that of the supply network (Mudgal et al., 2010). Companies can overcome this by having sustainable criteria in their selection of suppliers.

5.2.2 Technology barriers. Resistance to advanced technological processes and practices plays a key role in hindering sustainability by affecting supply chain efficiency, resource monitoring and information flow. It is seen that the following factors were shaped by technological barriers.

(i) *Complexity in measuring and monitoring sustainability practices:* The monitoring and measurement of sustainability is complex where metrics misalignment can cause disruption (Mudgal et al., 2010; Björklund et al., 2012). Also, accounting methods have limitations in revealing the environment impact (Rao and Holt, 2005). The sustainability reporting, assessment and strategies depend on measuring and monitoring sustainability practices. Key performance indicators have to be identified and made uniform. Muniz et al. (2020) pointed to the problem of subjectivity in sustainability due to which it is often difficult to get a measurable output of sustainability and it becomes quite complex to convert it into quantifiable data. The complexities in combining various dimensions of sustainability makes it difficult to get an integrated composite value. Thus, the lack of this criteria is a major factor that can hinder the decision-making process and progress indication of sustainable practices.

(ii) *Lack of new technology/materials and processes:* Lack of proper technology, processes and eco-friendly materials acts as a barrier in the implementation of a sustainable supply chain (Gorane and Kant, 2015; Majumdar and Sinha, 2018).

Technology is highly useful in product redesign, information flow, process improvements, etc. Technology makes it possible to sustain the products over time such as the deterioration rate of products is decreased by using preservation technologies (Mashud et al., 2019). Govindan et al. (2014) found that technology is a leading barrier whilst executing GSCM. In the case of materials, it could be a new eco-friendly substitute or one having environment friendly properties. The designing of a sustainable supply chain gets impaired due to the deficiency of green materials in the right quantity and affordable cost (Majumdar and Sinha, 2018). Lack of processes such as waste management and lean manufacturing practices, impede sustainability implementation. Advanced technologies, materials and processes increase efficiency, reduce wastage of resources and protects the environment. Their proper usage can modernize the supply chain and aid sustainability implementation.

(iii) *Inadequate research and development on sustainability:* Gupta et al. (2020) found that inadequate research and development and innovation capabilities are among the top barriers that challenge Indian companies from implementing and adopting sustainable supply chain practices. Inability to develop products free from pollution due to insufficient knowledge impedes the creation of a sustainable supply chain. Sustainability implementation involves complex systems and process design, reuse/recycle of products, etc. Therefore, research and development is of considerable importance in offering solutions in managing complex issues related to sustainability. Demirel and Kesidou (2019) analyse that Eco-Research and Development (R&D) instead of generic R&D would assist in the move towards sustainability as it would instil focused and relevant capabilities.

5.2.3 Human resource barriers. Human resource is an important function in any organization and this extends to sustainability implementation also. Barriers that are caused due to human resource issues are described below.

(i) *Resistance to change and adopting innovation*: Modernization and innovation play a significant part in sustainability implementation across a supply chain. Organizations have to embrace innovative approaches to attain sustainability objectives. Moving to a new system requires acquiring new skills and this creates a fear of failure. Christensen et al. (2015) pointed that the adoption to sustainability-related changes require fundamental alterations in the working and policies of a firm. There is an unwillingness and fear to move to a new system which is required for SSCM (Revell and Rutherfoord, 2003). Resistance to change in the working environment is natural by staff or other stakeholders and gaining their willingness is key to sustainability implementation (Muduli et al., 2020).

(ii) *Lack of cultural values and moral ethics*: Cultural values and moral ethics influence sustainability practices such as corporate social responsibility (Waldman et al., 2006) and it also impacts corporate social and environmental performance (Ho et al., 2012). Based on the culture and people of a country, the sustainability regulations and policies in countries differ. Also, barriers in form of lack of interdepartmental cooperation makes sustainability implementation difficult. Moral principles and ethical values are necessary for a long term commitment and integration of sustainability throughout the supply chain network (Paulraj et al., 2017; Sajjad et al., 2020). At an operational level too, e.g. purchase, disposal, etc., ethics plays a major role in upholding sustainability norms.

(iii) *Lack of proper training, education and human resource*: Lack of training, education and expert human resource on sustainability delays and crumbles SSCM implementation. Training programs related to safety and waste disposal aid in realizing sustainability goals. Lack of focused training institutions and related education hamper sustainability introduction in SCM (Govindan et al., 2014). There is also a lack of training to the suppliers on the implementation of environmentally sound programs in the supply chain (Massoud et al., 2010). Lack of proper training and education to employees of the organization will make it difficult to implement SSCM (Digalwar et al., 2020).

5.2.4 Policy barriers. The basic framework that facilitates the implementation of sustainability in a supply chain is made vide the policies of a country's government and that of the organization itself. The following two barriers are identified as policy barriers.

(i) *Lack of commitment from top management*: Lack of commitment from top management (LCM) has been found to be a significant hurdle in sustainable supply chain implementation (Stremlau and Tao, 2016; Majumdar and Sinha, 2018). Commitment from top management is essential to set sustainability goals and resource allocation. Restrictive company policies towards product stewardship by failing to ensure the safe environmental impact of the products in its entire life cycle acts as a barrier for sustainability (Mudgal et al., 2010). Such company policies on sustainability implementation in the supply chain are to be spearheaded by top management. The competing priorities in the organization should not overshadow sustainability issues but this can happen if there is a LCM. It is found that managers in many cases do not give priority to sustainability practices (Caldera et al., 2019) whilst in some other cases they either lack the capacity to implement a sustainable supply chain (Majumdar and Sinha, 2018) or do not possess an intrinsic motivation to do so (Oelze, 2017).

(ii) *Lack of regulation and guidance from authorities*: Lack of guidance from regulatory authorities (LOR) and absence of robust legislation is one of the main barriers to sustainable practices (McMurray et al., 2014). Regulation and guidance in form of technical support, incentives and legislation persuade organizations to implement a sustainable supply chain. Lack of proper support and guidance from authorities make it difficult for companies to implement SSCM (Majumdar and Sinha, 2019). The differences in regulation of different countries also acts as a barrier (Giunipero et al., 2012). In developing countries there is a lack of political support (Clarke and Boersma, 2017) as more importance is given to economic development. Ineffective and unrelated government policies inhibit the implementation of a sustainable supply chain (Raut et al., 2019).

5.3 Problem Description

It is seen that various countries, cultures and even industries have different factors which can act as barriers (Mathiyazhagan et al., 2013; Govindan et al., 2014) in sustainable supply chain implementation. There have been few studies on the barriers in SSCM. Seidel et al. (2010) have studied the barriers faced by information technology companies for the adoption of sustainable business practices. Luthra et al. (2016) have analysed the barriers of a plastics manufacturing company in India in the adoption of sustainable practices. Ravi and Shankar (2005) analysed 11 barriers of reverse logistics by considering automobile industries and presented the interaction among these barriers. Al Zaabi et al. (2013) studied 13 barriers to the successful implementation of SSCM from traditional supply chain management for fastener manufacturing industries. Lack of clarity regarding sustainability, complex design to reduce consumption of resources and energy and cost for environmentally friendly packaging were found to be the dominant barriers in this study. Gardas et al. (2018) identified 14 critical challenges to sustainable development in the textile and apparel industry. The study revealed that poor infrastructure and lack of effective governmental policies as dominant barriers in the case sector.

Sustainability implementation in the electronics industry has been of prime concern due the increased usage of electronic items and the rapid growth of this industry. The lower product cycle coupled with issues of e-waste, energy efficiency and safety standards for workers has necessitated that electronics companies have a sustainable supply chain. Companies are expected to face barriers during the process of sustainability implementation in their existing supply chains. It is attempted to address this issue in the research by identifying those barriers and analysing their influences. The identification of barriers in sustainable supply chain implementation in the electronics industry in the Indian context has not been duly addressed in the literature and thus presents an opportunity to study them. This gap is addressed in this thesis by identifying the barriers and analysing them using the Grey-DEMATEL method. The framework used in this research is elucidated in Figure 5.1.

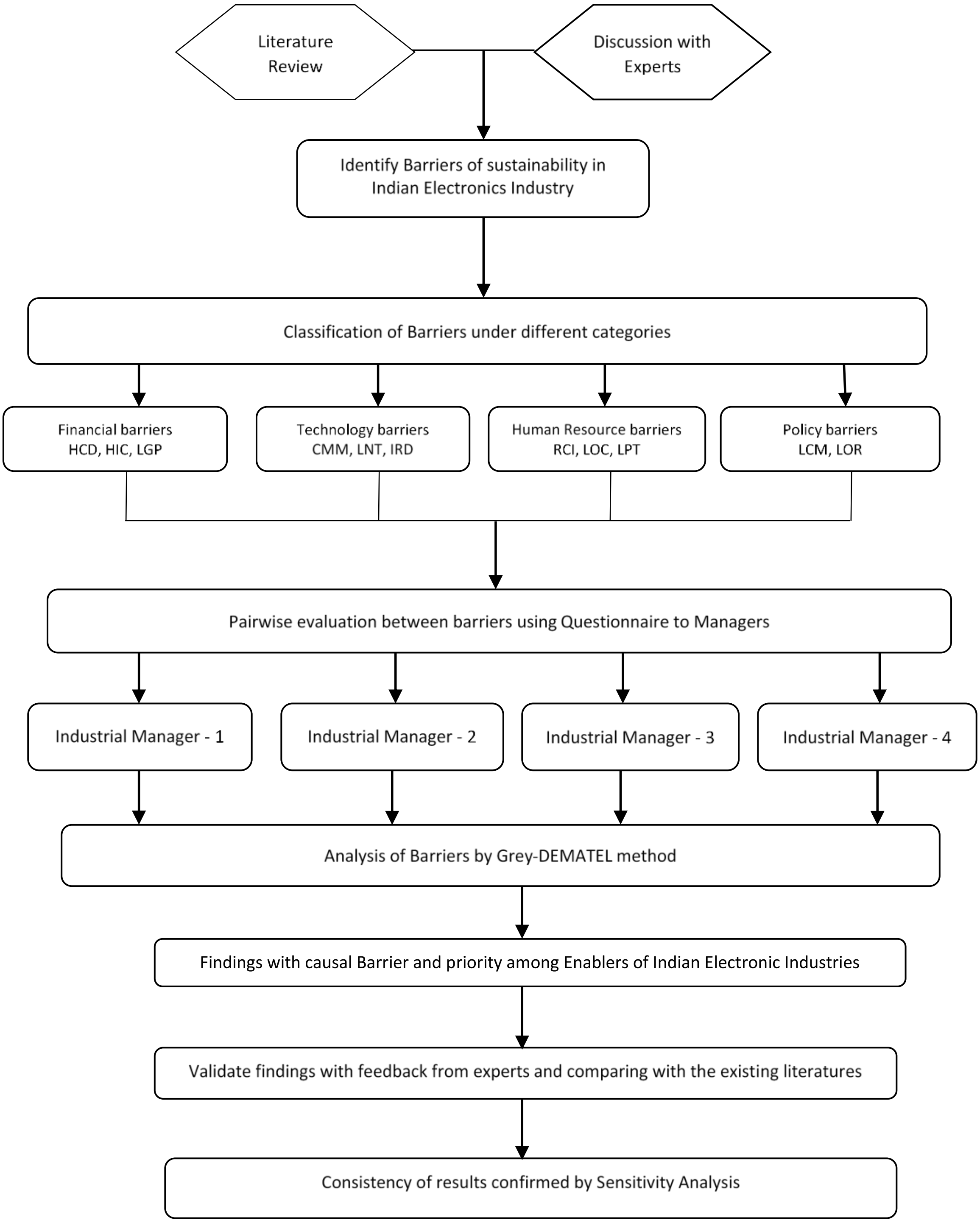


Figure 5.1: Proposed framework to identify causal barriers of Indian electronics industry

The barriers to the implementation of the sustainable supply chain in the electronics industry are identified by literature review and discussions with managers working in a large electronic industry. Through the questionnaire and the responses received, a direct relationship matrix is prepared. Using the multi-criteria decision making method of Grey DEMATEL the causal factors, effect factors and degree of prominence of barriers is found.

5.4 Solution methodology: Grey-DEMATEL

One of the important characteristics of the DEMATEL method is that it can analyse complicated models that have a causal relationship among its factors (Fontela and Gabus, 1976; Wu and Lee, 2007). Apart from depicting the interrelationship, DEMATEL provides the relationship strength among factors (Khan et al., 2020). In this method, digraphs are drawn that gives a visual representation of causal relationships among the variables. The results from the DEMATEL application helps in finding the position and level of different barriers with their strength (Susanty et al., 2020) in a sustainable supply chain. Grey set theory can accommodate uncertain structures and incomplete information with lower samples (Singh et al., 2019; Liu and Qiao, 2014; Su et al., 2016). To combine the advantages of both of these methods Grey-DEMATEL is used in this research to get a holistic view of the problem under consideration. Grey-DEMATEL has been used in many areas in the literature of supply chain management to analyse and evaluate criteria. Few studies that have applied the Grey-DEMATEL technique are shown in Table 5.3.

The steps involved in the Grey-DEMATEL method are as follows (Haleem et al., 2019):

5.4.1 Establish the initial relation matrices

Expert's opinion is taken by defining a five-level grey linguistic scale. The five levels of "No influence", "Low influence", "Medium influence", "High influence" and "Very high influence" are considered for the rating of attributes in this research.

Table 5.3: Few studies that have applied Grey-DEMATEL approach

Research study	Description
Xia et al., (2015)	Analysed internal barriers in case of an automotive parts remanufacturer in China.
Govindan et al., (2016)	Studies the interdependent relationship among third party logistics selection criteria in automotive industry in Iran.
Shao et al., (2016)	Analysis of the prioritization and interrelationships among barriers of environmentally friendly products and their consumers in European automobile industry.
Luthra et al., (2017)	Drivers related to sustainable consumption and production adoption were studied in an automotive company in northern India.
Bhatia and Srivastava (2018)	Evaluated 10 external barriers to remanufacturing in Indian electronics waste sector.
Gupta and Barua (2018)	Analysed 21 enablers of green innovation in manufacturing organizations and then established the causal relationship among them.
Wei et al., (2019)	Identified and evaluated 16 barriers that restrict large scale shale gas development in China.
Haleem et al., (2019)	Evaluation of relationship among 12 drivers in implementation of traceability in food supply chain.
Liu et al., (2020)	Identifies and analysis the critical factors in construction and demolition waste recycling in context of China.
Deepu and Ravi (2021)	The causal relationship among thirteen critical success factors for adoption of digital twin and physical internet is analysed.

5.4.2 Determine the grey relation matrices

A grey no. $\otimes x_{ij}^{k}$ is converted to an interval with known upper and lower bounds (Julong, 1989):

$$\otimes x_{ij}^{l} = \left(\underline{\otimes} x_{ij}^{l},\ \overline{\otimes} x_{ij}^{l}\right) \qquad (5.1)$$

where the respondent *l* rates the influence of barrier *i* over barrier *j*

5.4.3. Compute the average grey relation matrix

All the grey direct-relation matrices are combined in order to get average grey relation matrix $\otimes \tilde{x}_{ij}$.

$$\otimes \tilde{x}_{ij} = \left(\frac{\sum_k \underline{\otimes} x_{ij}^{l}}{q}, \frac{\sum_k \overline{\otimes} x_{ij}^{l}}{q}\right) \qquad (5.2)$$

where *q* is the number of experts or evaluators.

5.4.4 Obtain the crisp relation matrix from the average grey relation matrix

Using modified CFCS method (Arikan *et al.*, 2013; Dou *et al.*, 2014) grey values are made into crisp values by using *three* step procedure as follows:

5.4.4.1 Normalization of the grey value

$$\underline{\otimes}\,\bar{x}_{ij} = \left(\underline{\otimes}\,\tilde{x}_{ij} - {}^{min}_{j}\underline{\otimes}\,\tilde{x}_{ij}\right)/\Delta^{max}_{min} \tag{5.3}$$

where $\underline{\otimes}\,\bar{x}_{ij}$ represents the normalized lower limit value of the grey number $\otimes\,\tilde{x}_{ij}$

$$\overline{\otimes}\,\bar{x}_{ij} = \left(\overline{\otimes}\,\tilde{x}_{ij} - {}^{min}_{j}\,\overline{\otimes}\,\tilde{x}_{ij}\right)/\Delta^{max}_{min} \tag{5.4}$$

where $\overline{\otimes}\,\bar{x}_{ij}$ represents the normalized upper limit value of the grey number $\otimes\,\tilde{x}_{ij}$, and

$$\Delta^{max}_{min} = {}^{max}_{j}\,\overline{\otimes}\,\tilde{x}_{ij} - {}^{min}_{j}\underline{\otimes}\,\tilde{x}_{ij} \tag{5.5}$$

5.4.4.2 Computing total normalized crisp value

$$V_{ij} = \left(\frac{\left(\underline{\otimes}\bar{x}_{ij}\left(1-\underline{\otimes}\bar{x}_{ij}\right)\right)+\left(\overline{\otimes}\bar{x}_{ij}\times\overline{\otimes}\bar{x}_{ij}\right)}{\left(1-\underline{\otimes}\bar{x}_{ij}+\overline{\otimes}\bar{x}_{ij}\right)}\right) \tag{5.6}$$

5.4.4.3 Calculating the final crisp values

$$a^{*}_{ij} = \left(min\,\underline{\otimes}\,\tilde{x}_{ij} + \left(V_{ij}\times\Delta^{max}_{min}\right)\right) \tag{4.7}$$

and, $A = \left[a^{*}_{ij}\right]$ (5.8)

5.4.5. Obtain the normalized direct crisp relation matrix

The normalized direct crisp relation matrix X is computed by obtaining K and then multiplying the average relation matrix *A* with *K.*

$$K = \frac{1}{\max\limits_{1\le i\le n}\sum_{j=1}^{n} a_{ij}} \tag{5.9}$$

and

$$X = A \times K \tag{5.10}$$

Each element in matrix *X* falls between *zero* and *one.*

5.4.6 Determine the total relation matrix

The total relation matrix *M* is obtained as,

$$M = X \times (I - X)^{-1} \tag{5.11}$$

where *I* is the identity matrix.

5.4.7 Establish the cause and effect parameters

Let m_{ij} represent the elements in the total relation matrix M obtained above. Determine S as *n×1* vector that is sum of row elements of M. Now S_i , which is the sum of i^{th} row elements in matrix *M*, gives direct and indirect effects given by barrier *i* towards the other barriers. Determine T as *1×n* vector that is sum of column elements of M. Now T_j , which is the sum of j^{th} column in matrix *M,* gives both direct and indirect effects received by barrier *j* from other barriers.

$$S_i = \sum_{j=1}^{n} m_{ij} \; \forall \; i \quad (5.12)$$

$$T_j = \sum_{i=1}^{n} m_{ij} \; \forall \; j \quad (5.13)$$

Thereafter, dataset $(S_i + T_{j,} S_i - T_j)$ can be prepared. $(S_i + T_j)$ shows the total effect given and received. It indicates the degree of prominence a barrier has among all barriers. The higher the value of $(S_i + T_j)$, the greater the overall prominence of barrier *i* in terms of overall relationships with other barriers. $(S_i - T_j)$ shows the net effect that the barrier has in the entire system. A positive value of $(S_i - T_j)$, indicates that the barrier *i* is a net cause or foundation, for other barriers and a negative indicates that the barrier *i* is net effect of other barriers (Tzeng et al., 2007).

5.4.8 Set up threshold and plot the digraph

From the matrix *M*, how one barrier affects another can be known and then a diagraph can be prepared. A prominence-causal graph is obtained by plotting data of $(S_i + T_{j,}\, S_i - T_j)$ on a two-dimensional axis for each barrier. Relationships above a threshold value are considered for plotting. The threshold value is obtained by taking the sum of the mean and one standard deviation of the values m_{ij} from M. From the dataset of $((S_i + T_{j,} S_i - T_j)) \forall \; i = j$ a diagraph is plotted for values above threshold value showing the causal relations.

5.5 Application of the proposed model

The proposed model has been applied to study the barriers in the sustainable supply chain in the case of an electronics industry making electronic components for more than 20 years in India and having turnover above Rs. 400 cr. The experts consulted in the study were senior managers who are having industrial experience of over 20 years in the electronics industry and they were responsible for the implementation of various sustainability-related programs in areas of green purchasing, reverse logistics, technology development and product life cycle management in the firm. All these four experts in the study were familiar with the latest happenings and advancements in sustainable supply chains. The experts were in a senior managerial position with high academic qualification in their relevant field. These experts being in decision-making roles possessed practical experience in task solving and implementation of sustainability programs in their domains. The experts were involved in research projects related to sustainability across the lifecycle of the product and could give a holistic view of sustainability operations in the company. The detailed profile of experts is shown in Table 5.4. The experts' opinion was obtained by interview, discussion and brainstorming. From barriers identified in the literature review and interviews with these managers, 11 barriers were shortlisted. The identified barriers were classified via brainstorming based on functional traits of the barriers and experts' knowledge of SSCM and the electronics industry. Category schemes were extensively referred to in literature. Grouping was inspired by previous schemes in published works (Govindan et al., 2014; Snoek, 2017; Govindan and Hasanagic, 2018; Majumdar and Sinha, 2019; Gupta et al., 2020). These barriers were then grouped into four categories: financial, technology, human resource and policy. The categorization was tested for content validity by holding discussions with the experts. These barriers and the categories to which they belong are shown in Table 5.1.

Table 5.4: Profile of Experts

Experts	Experience	Division	Function	Role
Expert 1	21 Yrs.	Purchase and Stores	Senior Manager	Expert is responsible for the procurement and inventory management in the organization.
Expert 2	21 Yrs.	Dispatch and Logistics	Head	Expert is looking after the transportation, packing and dispatch.
Expert 3	22 Yrs.	Product Development	Senior Manager	The expert is involved in product development and research activities at the organisation.
Expert 4	23 Yrs.	Production	Assistant General Manager	Expert is responsible for the plant operations, production and maintenance.

The four managers gave their responses to the relationship between the barriers. With this response, the Grey-DEMATEL method was applied as explained in the following steps:

- *Step 1*: A grey pairwise influence is defined by using a five-level scale as follows: N = no influence, L = low influence, M = medium influence, H = high influence and VH = very high influence. The assessment in then transformed to the related grey values as per expression 1. The associated grey values for respondents' linguistic assessment is shown in Table 5.5.

Table 5.5: Linguistic assessment and associated grey values

Linguistic assessment	Associated grey values	Abbreviation used
No Influence	(0, 0.01)	N
Low Influence	(0.01, 0.25)	L
Medium Influence	(0.25, 0.5)	M
High influence	(0.5, 0.75)	H
Very high influence	(0.75, 1.0)	VH

- *Step 2*: The respondents give the pairwise influence relationships ($\otimes_{ij}^{k}$) between the barriers in an 11 x 11 matrix. The relationship between the same barrier in the matrix is given N (N = no influence). The pairwise influence matrices given by each of the four electronic company managers are shown in Tables 5.6 to 5.9.

Table 5.6: Linguistic scale direct-relation matrix for barriers of sustainable supply chain given by manager 1

	HCD	CMM	LNT	RCI	HIC	LGP	LOC	LPT	LCM	LOR	IRD
HCD	0	0.25	0.75	0.5	0.5	0	0.01	0.75	0.5	0	0.01
	0.01	0.5	1	0.75	0.75	0.01	0.25	1	0.75	0.01	0.25
CMM	0.01	0	0.01	0.01	0.25	0.01	0.01	0	0.01	0.01	0.25
	0.25	0.01	0.25	0.25	0.5	0.25	0.25	0.01	0.25	0.25	0.5
LNT	0	0.01	0	0.75	0.01	0.25	0	0	0	0	0
	0.01	0.25	0.01	1	0.25	0.5	0.01	0.01	0.01	0.01	0.01
RCI	0	0.25	0.75	0	0.01	0.5	0.01	0	0	0	0.25
	0.01	0.5	1	0.01	0.25	0.75	0.25	0.01	0.01	0.01	0.5
HIC	0.5	0.25	0.5	0.5	0	0.01	0.25	0.75	0.75	0.01	0
	0.75	0.5	0.75	0.75	0.01	0.25	0.5	1	1	0.25	0.01
LGP	0.75	0.25	0.01	0.5	0.01	0	0.75	0	0	0	0.01
	1	0.5	0.25	0.75	0.25	0.01	1	0.01	0.01	0.01	0.25
LOC	0.5	0.5	0.25	0.25	0.5	0.75	0	0.5	0.25	0.01	0
	0.75	0.75	0.5	0.5	0.75	1	0.01	0.75	0.5	0.25	0.01
LPT	0.5	0.25	0.01	0.01	0.5	0	0.01	0	0.75	0.01	0
	0.75	0.5	0.25	0.25	0.75	0.01	0.25	0.01	1	0.25	0.01
LCM	0.5	0.5	0.01	0	0.75	0.25	0.75	0.5	0	0.5	0
	0.75	0.75	0.25	0.01	1	0.5	1	0.75	0.01	0.75	0.01
LOR	0.25	0.5	0.01	0.25	0.01	0.25	0.75	0.25	0.25	0	0.25
	0.5	0.75	0.25	0.5	0.25	0.5	1	0.5	0.5	0.01	0.5
IRD	0	0.01	0.25	0.01	0	0	0.01	0	0	0.01	0
	0.01	0.25	0.5	0.25	0.01	0.01	0.25	0.01	0.01	0.25	0.01

Table 5.7: Linguistic scale direct-relation matrix for barriers of sustainable supply chain given by manager 2

	HCD	CMM	LNT	RCI	HIC	LGP	LOC	LPT	LCM	LOR	IRD
HCD	0	0.01	0.5	0.75	0.75	0	0.25	0.75	0.5	0.01	0.25
	0.01	0.25	0.75	1	1	0.01	0.5	1	0.75	0.25	0.5
CMM	0	0	0.01	0.01	0.25	0.25	0.25	0	0.01	0.01	0.25
	0.01	0.01	0.25	0.25	0.5	0.5	0.5	0.01	0.25	0.25	0.5
LNT	0	0.01	0	0.5	0	0	0	0.01	0	0	0.01
	0.01	0.25	0.01	0.75	0.01	0.01	0.01	0.25	0.01	0.01	0.25
RCI	0	0.25	0.25	0	0	0.01	0.01	0	0	0	0.25
	0.01	0.5	0.5	0.01	0.01	0.25	0.25	0.01	0.01	0.01	0.5
HIC	0.75	0.25	0	0.01	0	0	0.5	0.75	0.5	0.25	0.01
	1	0.5	0.01	0.25	0.01	0.01	0.75	1	0.75	0.5	0.25
LGP	0.5	0.01	0.01	0.5	0.01	0	0.75	0	0	0	0.01
	0.75	0.25	0.25	0.75	0.25	0.01	1	0.01	0.01	0.01	0.25
LOC	0.75	0.5	0.25	0.01	0.25	0.5	0	0.25	0.01	0.01	0.01
	1	0.75	0.5	0.25	0.5	0.75	0.01	0.5	0.25	0.25	0.25
LPT	0.01	0.01	0.25	0.01	0.25	0	0	0	0.5	0.25	0
	0.25	0.25	0.5	0.25	0.5	0.01	0.01	0.01	0.75	0.5	0.01
LCM	0.75	0.25	0.01	0	0.5	0	0.5	0.75	0	0.25	0
	1	0.5	0.25	0.01	0.75	0.01	0.75	1	0.01	0.5	0.01
LOR	0.5	0.5	0.01	0.25	0.25	0.25	0.75	0.5	0.25	0	0.01
	0.75	0.75	0.25	0.5	0.5	0.5	1	0.75	0.5	0.01	0.25
IRD	0	0.25	0.01	0.25	0.01	0.01	0.01	0.01	0	0.25	0
	0.01	0.5	0.25	0.5	0.25	0.25	0.25	0.25	0.01	0.5	0.01

Table 5.8: Linguistic scale direct-relation matrix for barriers of sustainable supply chain given by manager 3

	HCD	CMM	LNT	RCI	HIC	LGP	LOC	LPT	LCM	LOR	IRD
HCD	0	0.01	0.25	0.25	0.75	0	0.01	0.75	0.5	0	0.01
	0.01	0.25	0.5	0.5	1	0.01	0.25	1	0.75	0.01	0.25
CMM	0	0	0.01	0.01	0.01	0.01	0.01	0	0	0	0.01
	0.01	0.01	0.25	0.25	0.25	0.25	0.25	0.01	0.01	0.01	0.25
LNT	0	0.25	0	0.5	0	0.01	0	0	0	0	0
	0.01	0.5	0.01	0.75	0.01	0.25	0.01	0.01	0.01	0.01	0.01
RCI	0.25	0.01	0.25	0	0.01	0.5	0	0	0.01	0.01	0.25
	0.5	0.25	0.5	0.01	0.25	0.75	0.01	0.01	0.25	0.25	0.5
HIC	0.75	0.5	0.5	0.25	0	0.01	0.25	0.5	0.5	0.25	0.25
	1	0.75	0.75	0.5	0.01	0.25	0.5	0.75	0.75	0.5	0.5
LGP	0.5	0.5	0.01	0.25	0.01	0	0.25	0	0.01	0	0.01
	0.75	0.75	0.25	0.5	0.25	0.01	0.5	0.01	0.25	0.01	0.25
LOC	0.5	0.25	0.01	0.5	0.5	0.75	0	0.25	0.25	0	0.01
	0.75	0.5	0.25	0.75	0.75	1	0.01	0.5	0.5	0.01	0.25
LPT	0.25	0.01	0.25	0.01	0.25	0.01	0.25	0	0.5	0.5	0.01
	0.5	0.25	0.5	0.25	0.5	0.25	0.5	0.01	0.75	0.75	0.25
LCM	0.5	0.25	0.01	0.01	0.5	0.25	0.5	0.75	0	0.25	0.01
	0.75	0.5	0.25	0.25	0.75	0.5	0.75	1	0.01	0.5	0.25
LOR	0	0.5	0.25	0.01	0.01	0.5	0.5	0.25	0.25	0	0.01
	0.01	0.75	0.5	0.25	0.25	0.75	0.75	0.5	0.5	0.01	0.25
IRD	0	0.01	0	0.01	0.5	0.01	0.25	0.01	0.25	0.25	0
	0.01	0.25	0.01	0.25	0.75	0.25	0.5	0.25	0.5	0.5	0.01

Table 5.9: Linguistic scale direct-relation matrix for barriers of sustainable supply chain given by manager 4

	HCD	CMM	LNT	RCI	HIC	LGP	LOC	LPT	LCM	LOR	IRD
HCD	0	0.25	0.5	0.5	0.75	0	0.5	0.5	0.5	0.5	0.01
	0.01	0.5	0.75	0.75	1	0.01	0.75	0.75	0.75	0.75	0.25
CMM	0.01	0	0.01	0.25	0.01	0	0.01	0	0	0	0.01
	0.25	0.01	0.25	0.5	0.25	0.01	0.25	0.01	0.01	0.01	0.25
LNT	0	0.01	0	0.5	0	0	0	0	0	0	0.01
	0.01	0.25	0.01	0.75	0.01	0.01	0.01	0.01	0.01	0.01	0.25
RCI	0	0.25	0.01	0	0.01	0	0.01	0	0	0.01	0.01
	0.01	0.5	0.25	0.01	0.25	0.01	0.25	0.01	0.01	0.25	0.25
HIC	0.75	0.01	0.01	0.01	0	0.25	0.5	0.5	0.5	0.5	0.01
	1	0.25	0.25	0.25	0.01	0.5	0.75	0.75	0.75	0.75	0.25
LGP	0.5	0.25	0.25	0.5	0.01	0	0.5	0.01	0.01	0.01	0.01
	0.75	0.5	0.5	0.75	0.25	0.01	0.75	0.25	0.25	0.25	0.25
LOC	0.75	0.25	0.01	0.25	0.5	0.75	0	0.5	0.25	0.01	0.01
	1	0.5	0.25	0.5	0.75	1	0.01	0.75	0.5	0.25	0.25
LPT	0.5	0.01	0	0	0.25	0	0.01	0	0.75	0.01	0
	0.75	0.25	0.01	0.01	0.5	0.01	0.25	0.01	1	0.25	0.01
LCM	0.5	0.25	0	0.01	0.5	0.01	0.5	0.75	0	0.5	0
	0.75	0.5	0.01	0.25	0.75	0.25	0.75	1	0.01	0.75	0.01
LOR	0.5	0.5	0.01	0.01	0.25	0.01	0.75	0.25	0.25	0	0.25
	0.75	0.75	0.25	0.25	0.5	0.25	1	0.5	0.5	0.01	0.5
IRD	0	0.25	0.25	0.25	0.01	0	0.01	0.01	0.01	0.25	0
	0.01	0.5	0.5	0.5	0.25	0.01	0.25	0.25	0.25	0.5	0.01

- *Step 3*: In this step weightage is assigned to the response of company managers. Equal importance is given to all four managers response. Thus, a weight of 0.25 is given to each response and using equation (5.2), an average grey relation matrix $[\otimes \tilde{x}_{ij}]$ is found.

- *Step 4*: Establish the grey direct-relation matrix into a crisp matrix using the modified- CFCS process as per equations (5.3) to (5.8). The matrix obtained is shown in Table 5.10.

Table 5.10: Crisp relation matrix for barriers of sustainable supply chain

	HCD	CMM	LNT	RCI	HIC	LGP	LOC	LPT	LCM	LOR	IRD
HCD	0.0000	0.2170	0.6800	0.6680	0.8770	0.0000	0.2790	0.8770	0.6590	0.1670	0.1750
CMM	0.0180	0.0000	0.0660	0.1370	0.2040	0.1060	0.1300	0.0000	0.0190	0.0240	0.2580
LNT	0.0000	0.1420	0.0000	0.7460	0.0070	0.0850	0.0000	0.0070	0.0000	0.0000	0.0300
RCI	0.0700	0.2930	0.4480	0.0000	0.0370	0.3210	0.0370	0.0000	0.0060	0.0240	0.3410
HIC	0.8770	0.3710	0.3350	0.2890	0.0000	0.1060	0.5010	0.8010	0.7360	0.3880	0.1380
LGP	0.7260	0.3710	0.1420	0.5930	0.0570	0.0000	0.7260	0.0070	0.0190	0.0080	0.0930
LOC	0.8010	0.5240	0.2170	0.3630	0.5760	0.8770	0.0000	0.5010	0.2820	0.0470	0.0590
LPT	0.4280	0.1420	0.1870	0.0400	0.4260	0.0070	0.1060	0.0000	0.8110	0.3100	0.0100
LCM	0.7260	0.4470	0.0420	0.0200	0.7260	0.1760	0.7260	0.8770	0.0000	0.5460	0.0100
LOR	0.3930	0.6800	0.1420	0.2120	0.2040	0.3520	0.8770	0.4260	0.3550	0.0000	0.2580
IRD	0.0000	0.2170	0.1870	0.2120	0.1780	0.0180	0.1300	0.0370	0.0870	0.3080	0.0000

- *Step 5*: The normalized direct-relation matrix X is determined from the overall crisp direct-relation matrix using equations (5.9) and (5.10). The normalized direct-relation matrix X is shown in Table 5.11.

Table 5.11: Normalized direct crisp relation matrix for barriers of sustainable supply chain

	HCD	CMM	LNT	RCI	HIC	LGP	LOC	LPT	LCM	LOR	IRD
HCD	0.0000	0.0472	0.1479	0.1452	0.1907	0.0000	0.0607	0.1907	0.1433	0.0363	0.0381
CMM	0.0039	0.0000	0.0144	0.0298	0.0444	0.0230	0.0283	0.0000	0.0041	0.0052	0.0561
LNT	0.0000	0.0309	0.0000	0.1622	0.0015	0.0185	0.0000	0.0015	0.0000	0.0000	0.0065
RCI	0.0152	0.0637	0.0974	0.0000	0.0080	0.0698	0.0080	0.0000	0.0013	0.0052	0.0741
HIC	0.1907	0.0807	0.0728	0.0628	0.0000	0.0230	0.1089	0.1742	0.1600	0.0844	0.0300
LGP	0.1579	0.0807	0.0309	0.1289	0.0124	0.0000	0.1579	0.0015	0.0041	0.0017	0.0202
LOC	0.1742	0.1139	0.0472	0.0789	0.1252	0.1907	0.0000	0.1089	0.0613	0.0102	0.0128
LPT	0.0931	0.0309	0.0407	0.0087	0.0926	0.0015	0.0230	0.0000	0.1763	0.0674	0.0022
LCM	0.1579	0.0972	0.0091	0.0043	0.1579	0.0383	0.1579	0.1907	0.0000	0.1187	0.0022
LOR	0.0855	0.1479	0.0309	0.0461	0.0444	0.0765	0.1907	0.0926	0.0772	0.0000	0.0561
IRD	0.0000	0.0472	0.0407	0.0461	0.0387	0.0039	0.0283	0.0080	0.0189	0.0670	0.0000

- *Step 6*: The total direct-relationship matrix M got by equation (5.11) is shown in Table 5.12.

Table 5.12: Total relation matrix for barriers of sustainable supply chain

	HCD	CMM	LNT	RCI	HIC	LGP	LOC	LPT	LCM	LOR	IRD
HCD	0.2461	0.2308	**0.2905**	**0.3106**	**0.3867**	0.1139	0.2423	**0.4133**	**0.3444**	0.1597	0.1130
CMM	0.0508	0.0378	0.0449	0.0667	0.0788	0.0471	0.0633	0.0410	0.0390	0.0271	0.0712
LNT	0.0175	0.0534	0.0256	0.1790	0.0149	0.0370	0.0153	0.0119	0.0095	0.0070	0.0254
RCI	0.0570	0.1019	0.1270	0.0559	0.0433	0.0917	0.0466	0.0324	0.0295	0.0242	0.0922
HIC	**0.4379**	0.2780	0.2353	0.2520	0.2514	0.1474	**0.3084**	**0.4279**	**0.3776**	0.2087	0.1104
LGP	0.2806	0.1867	0.1346	0.2437	0.1436	0.0829	0.2446	0.1344	0.1131	0.0563	0.0731
LOC	**0.3955**	0.2800	0.1982	0.2608	**0.3196**	0.2806	0.1842	**0.3197**	0.2499	0.1139	0.0894
LPT	0.2647	0.1628	0.1404	0.1264	0.2490	0.0788	0.1686	0.1866	**0.3114**	0.1544	0.0527
LCM	**0.4301**	**0.3008**	0.1795	0.2004	**0.3980**	0.1698	**0.3624**	**0.4526**	0.2497	0.2404	0.0865
LOR	**0.2949**	**0.3036**	0.1589	0.2027	0.2335	0.1877	**0.3392**	0.2821	0.2391	0.0924	0.1219
IRD	0.0650	0.1026	0.0801	0.0956	0.0895	0.0422	0.0831	0.0670	0.0678	0.0932	0.0260

- *Step 7*: By equations (5.12) and (5.13), S_i and T_j are found. The overall direct and indirect effects of barrier i on other barriers for an electronic industry is shown by row values of S_i. Also, the overall direct and indirect effects of all barriers on barrier *j* is shown by column values of T_j. Thereafter the overall importance or prominence $(S_i + T_j)$ of barrier *i* and the net effect $(S_i - T_j)$ of barrier *i* are computed and shown in Table 5.13.

Table 5.13: Cause/ effect parameters for barriers of sustainable supply chain

Barriers	S_i	T_j	S_i+T_j	S_i-T_j
HCD	2.85122	2.54017	5.391	0.311
CMM	0.56775	2.03837	2.606	-1.471
LNT	0.39648	1.61502	2.012	-1.219
RCI	0.70179	1.99383	2.696	-1.292
HIC	3.0352	2.2083	5.243	0.827
LGP	1.69362	1.27916	2.973	0.414
LOC	2.69181	2.05807	4.750	0.634
LPT	1.89575	2.36889	4.265	-0.473
LCM	3.07022	2.031	5.101	1.039
LOR	2.45603	1.17731	3.633	1.279
IRD	0.81208	0.86183	1.674	-0.050

- *Step 8*: Using the data set $(S_i + T_{j,} S_i - T_j)$ an overall DEMATEL prominence-causal graphs is plotted. The interrelationship among each pair of barriers can be shown in this diagraph. The plotting of the dyadic relationship among barriers is done for values equal to or higher than the threshold value. The threshold value is set by adding the mean and standard deviation of elements in the total relationship matrix. All the values greater than this threshold value θ = 0.2850 are shown in italic in Table 5.12. The two-way relationships are shown by dotted lines. One-way relationships are shown by solid lines. The diagraph plotted is shown in Figure 5.2.

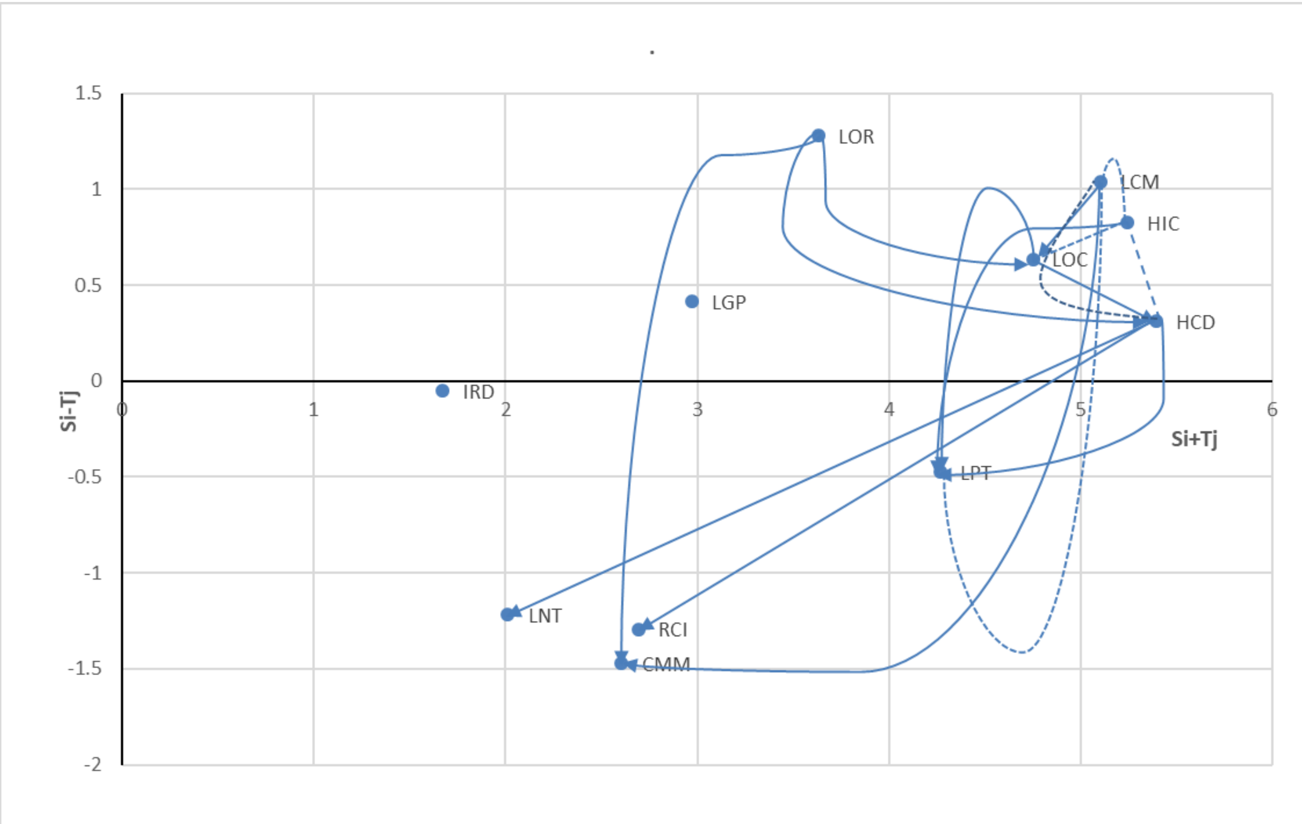


Figure 5.2: Digraph showing causal relations among barriers of sustainable supply chain

5.6 Results and Discussion

On studying Table 5.13 in conjunction with Figure 5.2, the correlation between barriers along with their grouping in causal and effect side during sustainability Implementation in the supply chain can be known.

5.6.1 Cause group

The barriers with positive values of $(S_i - T_j)$ are cause factors. The higher the $(S_i - T_j)$ value, the stronger is the influence. From the Figure 5.2, barriers can be sorted as Lack of regulation and guidance from authorities (LOR) > Lack of commitment from top management (LCM) > High investments for sustainability and less return-on-Investments (HIC) > Lack of cultural values and moral ethics (LOC) > Lack of green purchase practices (LGP) > High cost for disposal of hazardous wastes (HCD).

LOR, a policy barrier, has the highest positive value of $(S_i - T_j)$ and is on the top of the graph. This indicates that it is the primary causal factor. Experts also agreed that regulation and guidance is a major requirement to initiate the sustainability implementation process across the supply chain. The importance of this causal factor is in line with other sustainability studies too such as sustainable solid waste management where regulation and policy are having a high causal relationship (Tsai et al., 2020). Regulation and guidance from authorities have a major role in the SCM of companies complying with the environment and social aspects (Dubey et al., 2017). A host of measures being regulated by authorities has led to the implementation of SSCM in many electronics industries. Regulation and guidance in form of extended producers' responsibility help in sustainability implementation. Governments and authorities' apathy towards social and environmental protection can lead to industries abstaining from the implementation of a sustainable supply chain. Strict regulation and proper direction make sustainability a part of the supply chain rather than a choice.

The next influencing factor in order is LCM. Lack of interest from senior management results in not having any strategy or goals for SSCM implementation.

This also demotivates the movement towards introducing sustainability at lower levels and different functions. It is seen that though LCM is a high cause factor, it is affected by lack of proper training and education on sustainability (LPT) and this is consistent with the result by Mashud et al. (2020a) that education and awareness of customers encourages suppliers thereby top management to move towards greener products. Top management involvement and government regulations and support are dominant influencers for sustainable manufacturing (Harikannan et al., 2020). It is observed that both barriers LOR and LCM having the highest influence are from the policy category which means that there is a need for strong and clear policies at both government and organizational level to implement sustainability.

As seen from Figure 5.2, a LCM is followed by HIC. Moving towards a sustainable supply chain requires re-engineering and process change. This requires high investments whereas the returns may not be immediate and tangible. HIC barrier being a cause factor, it is important to understand the motives for investment in sustainability. Strict financial judgement of investments does not help the cause of sustainability whilst socially responsible investment should be given value. The returns on investment should be studied from both short term and long-term angle as mostly the financial advantages from a sustainable supply chain are long term. The barriers LOC, LGP, HCD have less influence on the barriers in the causal group. Green purchasing may lead to cost increase and acts as a cause factor as companies try to keep their cost low. Strategies to reduce cost can affect or compromise sustainability implementation as organizations may ignore issues of low wage and the environment quality of the supplier (Sajjad et al., 2020). Knowledge about environmental effects and issues has a direct bearing on green purchasing (Singh and Gupta, 2020). Therefore, organizations can address this barrier by augmenting the environmental knowledge of their procurement managers. The results also show that all financial category barriers are in the cause group indicating that cost implications are major influencers. Therefore, it can be recommended that companies going for sustainability implementation in their supply chains should earmark a sufficient budget and anticipate the financial implications before introducing the changes.

5.6.2 Effect group

In Figure 5.2, the barriers having a negative value of $(S_i - T_j)$ fall in the effect group. These barriers are influenced by the causal group. The barriers we got in our result can be sorted as complexity in measuring and monitoring sustainability practices (CMM), resistance to change and adopting innovation (RCI), lack of new technology/materials and processes (LNT), LPT, Inadequate research and development on sustainability (IRD). These five barriers are affected by the changes related to barriers in sustainable supply chain implementation in the cause group. It is seen that CMM has the largest net effect value on the implementation of a sustainable supply chain. The barriers which lie in the lower part of Figure 5.2 are LNT, RCI and these barriers may be given low importance during implementation.

The next effect barrier is the LPT. This outcome is corroborated by Soda et al. (2015) that there is a lack of awareness about sustainability with suppliers and consumers in developing countries. Without sound knowledge and professional practices, the implementation does not go smoothly. A change in the system requires understanding and capability to adopt which can be done by training and education. IRD has the least negative value of $(S_i - T_j)$. Research and development requires resources and infrastructure and hence this barrier seems to be driven by causal factors. Innovative technology and developed systems are required for taking suitable decisions when all three triple bottom line dimensions are to be factored (Brandenburg et al., 2019). Research and development helps to increase efficiency and reduces waste generation across the supply chain. The barriers arrived in effect group were discussed with the managers and they agreed with the results.

The results arrived have been elucidated in Figure 5.3. The barriers falling in cause and effect group along with their influence have been constructed. The model can be used to devise suitable strategies by companies desiring to implement sustainability in their supply chain. The model can be further developed by companies based on their position to overcome the barriers faced in SSCM implementation.

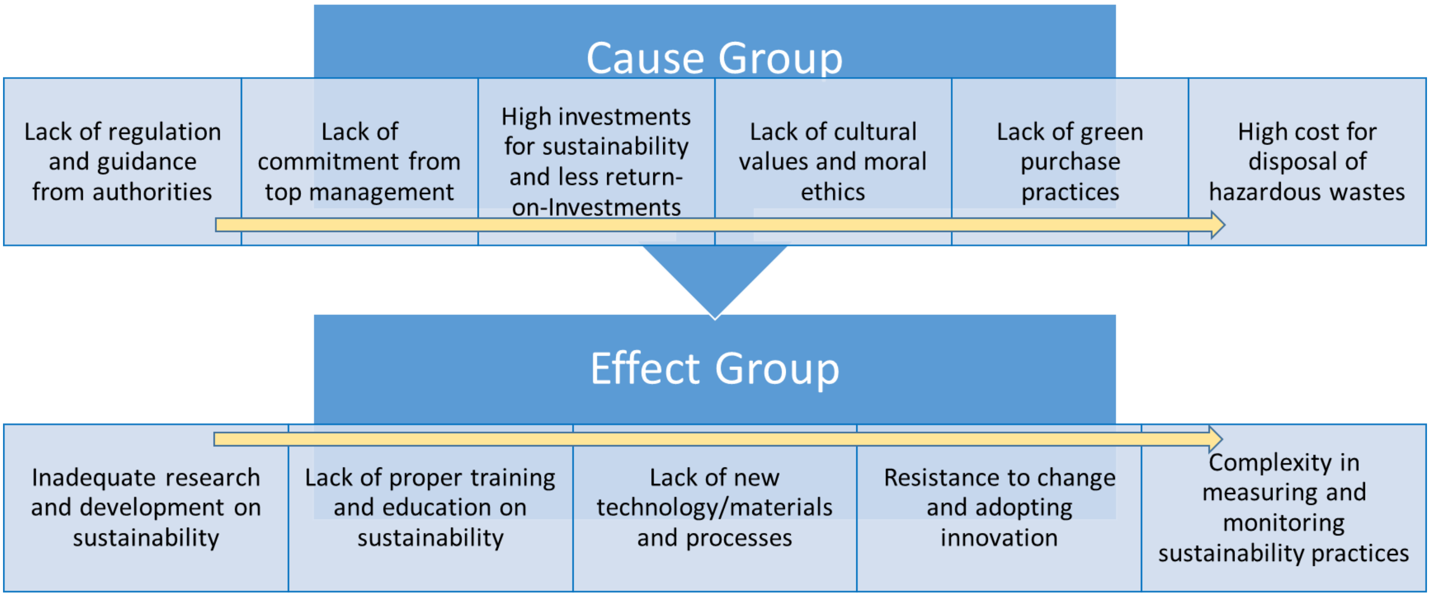


Figure 5.3: Barriers in Cause and Effect group and flow of influence

5.6.3 Correlation between the barriers

Table 5.13 shows the value of $(S_i + T_j)$ which indicates the correlation between the barriers. The barriers which are in the right side of Figure 5.2 have a high correlation with other barriers. Thus, tackling these barriers should be given high importance during the implementation of a sustainable supply chain.

From Figure 5.2, the correlation power of barriers can be known and accordingly they are arranged as follows: HCD > HIC > LCM > LOC > LPT > LOR > LGP > RCI > CMM > LNT> IRD.

The highest correlation is shown by the HCD. The absence of a disposal mechanism in an electronics industry would seriously hamper sustainability implementation. It is a basic concern whilst setting up a plant and therefore shows a high correlation. An efficient recycling program can help in reducing the cost of disposal. From the Figure 5.2, the barrier HCD is affected by HIC, LCM, LOC and LOR. LCM leads to reduced support in bringing mechanisms related to the disposal of hazardous wastes. LOR discourages companies from the adoption of proper disposal practices. Regulations are required to control the discharge of hazardous output, controlling the overall environment and fixing responsibility for violations.

The correlation strength then in order is of HIC and LCM. HIC has a high correlation considering companies have to use their funds judiciously. Sustainability implementation requires investment in modifying process and system. Financial investments for various activities are inevitable during the implementation of sustainability in SCM and thus HIC shows a high correlation with other factors. LCM is the barrier showing the next higher correlation. Top management is associated with all major decision-making in an organization and so their support and commitment is essential in dealing with other barriers arising due to sustainability implementation. The barrier having the least correlation is IRD as can be seen from its position in the left side of Figure 5.2.

5.6.4 Importance causality diagram

To further strategically analyse the barriers we use the DEMATEL result to construct the importance causality diagram (Chien et al., 2014). This will guide managers in decision-making whilst dealing with barriers during the implementation of SSCM. As shown in Figure 5.4, the DEMATEL diagraph which is divided into four quadrants based on strength of importance and relationship is drawn. The mean of $\left(S_i + T_j\right)$ and the causal, enable factors facilitate to construct the quadrants for barriers of SSCM.

It can be seen from this figure that LCM, HIC, LOC, HCD are critical barriers. LOR and LGP are driving barriers. The driving barriers are among causal factors but are not critical and comparatively low in importance. The result is in line with earlier studies (Jabbour and de Sousa Jabbour, 2016; Narimissa et al., 2019) which indicate that support from top management is an important facilitating factor in sustainability implementation in SCM. The next critical barrier is HIC. Managers need to learn about investment recovery by the sale of scraps, recycling items and savings from reverse logistics (Zhu et al., 2008). High investments may lead to high prices of products initially. Price of the product is a very important factor as it affects the decision of general public and hence managers should work to improve profit by various methods such as optimizing selling price, replenishment cycle and discount models (Hasan et al., 2020). Optimization with inventory models (Mashud, 2020) and just-in-time deliveries to reduce nonconforming items (Mashud et al., 2020b) can also be considered by managers to contain price. This along with indirect benefits such as enhanced consumer image will help organizations to recover investments at a faster rate. The next critical factor is the LOC. Culture is considered to be a highly relevant and important human factor for sustainability in organizations (Jabbour and de Sousa Jabbour, 2016).

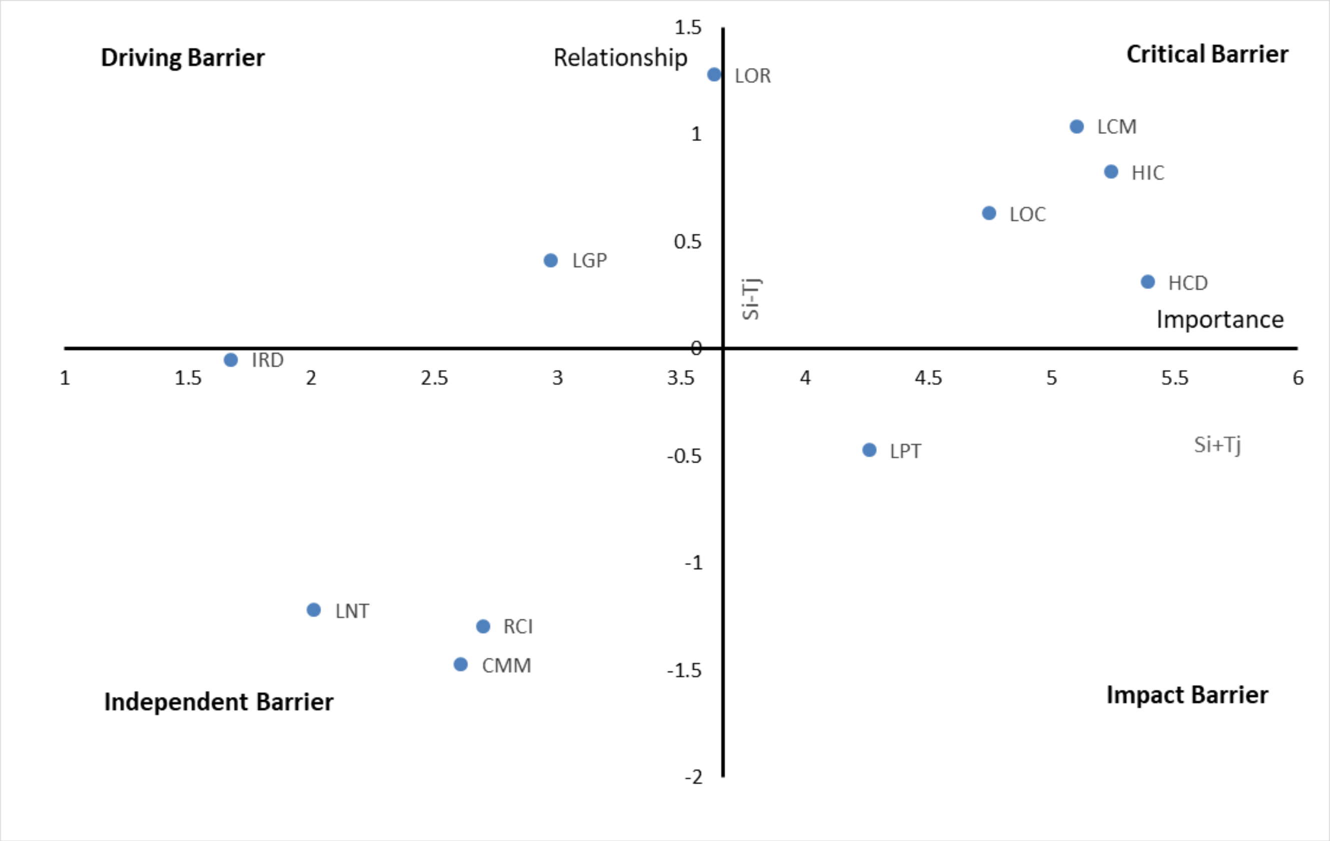


Figure 5.4: Importance–causality diagram

LNT, RCI and CMM are in the 3rd quadrant. These barriers are independent as they are low on importance and relationship. Addressing these barriers will have a direct effect in implementing sustainability in SCM. LPT is in the 4th quadrant. This barrier is an impact barrier for the implementation and cannot be independently tackled. This finding is consistent with literature that emphasizes proper training and education for making an impact on sustainability (Al Zaabi et al., 2013; Caldera et al., 2019). Training and education can impel sustainability implementation by enhancing the knowledge of employees and motivating them towards sustainability practices (Oelze, 2017).

5.7 Sensitivity analysis

During data collection, there are chances of bias or influence which may affect the result. Sensitivity analysis is performed to verify this in the result. Different weight is given for one analyst response whilst giving equal weights to other analysts. The weights assigned are as per Table 5.14.

Table 5.14: Weights assigned for analysts during sensitivity analysis

	Manager 1	Manager 2	Manager 3	Manager 4
Scenario 1	0.7	0.1	0.1	0.1
Scenario 2	0.1	0.7	0.1	0.1
Scenario 3	0.1	0.1	0.7	0.1
Scenario 4	0.1	0.1	0.1	0.7

The degree of prominence and net cause/effect values shown on performing sensitivity analysis is shown in Table 5.15. From this table, it is evident that rankings of the cause and effect group for different scenarios does not differ much.

Table 5.15: Cause/ Effect parameters obtained during sensitivity analysis

	Scenario 1				Scenario 2				Scenario 3				Scenario 4			
Barrier	**Si+Tj**	**Si-Tj**	**Rank**	**Cause/ Effect**	**Si+Tj**	**Si-Tj**	**Rank**	**Cause/ Effect**	**Si+Tj**	**Si-Tj**	**Rank**	**Cause/ Effect**	**Si+Tj**	**Si-Tj**	**Rank**	**Cause/ Effect**
HCD	5.144	0.212	6	Cause	4.472	0.316	5	Cause	3.999	0.192	6	Cause	4.623	0.308	6	Cause
CMM	2.896	-1.633	11	Effect	2.303	-0.871	9	Effect	1.927	-1.340	11	Effect	1.847	-1.207	11	Effect
LNT	2.576	-1.457	10	Effect	1.536	-0.948	10	Effect	1.673	-0.956	10	Effect	1.259	-0.754	9	Effect
RCI	3.109	-1.297	9	Effect	2.064	-1.077	11	Effect	2.249	-0.720	9	Effect	1.903	-1.171	10	Effect
HIC	5.256	0.727	4	Cause	4.158	0.678	3	Cause	4.187	0.730	1	Cause	4.141	0.679	3	Cause
LGP	3.376	0.367	5	Cause	2.235	0.462	4	Cause	2.402	-0.030	7	Effect	2.219	0.517	4	Cause
LOC	4.781	0.886	3	Cause	3.791	0.210	6	Cause	3.606	0.584	4	Cause	4.006	0.484	5	Cause
LPT	4.373	-0.232	7	Effect	3.335	-0.732	8	Effect	3.392	-0.173	8	Effect	3.240	-0.419	8	Effect
LCM	5.390	1.218	2	Cause	3.939	0.862	2	Cause	3.961	0.708	3	Cause	3.965	0.697	2	Cause
LOR	3.253	1.572	1	Cause	3.201	1.255	1	Cause	2.625	0.728	2	Cause	3.188	0.800	1	Cause
IRD	1.277	-0.362	8	Effect	1.469	-0.154	7	Effect	1.683	0.278	5	Cause	1.200	0.067	7	Cause

5.8 Managerial implications

The implications of this research for the managers in the electronic industry is in knowing the barriers that will be faced during sustainable supply chain implementation, understanding their influence and contemplating the likely effort required to overcome them. The cause and effect group of barriers along with their correlation shall help managers in devising favourable strategies whilst implementing SSCM. It also gives an indication on the sustainable practices that need to be promoted and handling of the barriers in an organization. The findings of this research indicate that LOR has a high causal effect which is also supported by literature on SSCM (Jia et al., 2018) and therefore managers must make all efforts to handle this barrier. The absence of guidance in sustainability practices have been highlighted by McMurray et al. (2014) in Malaysia which is too a developing country such as India. In this regard, addressing this barrier should be given prime focus by organizations at the time of initiating sustainability implementation. Legislations such as extended producer responsibility is a strategy by which firms become responsible for the post-consumer phase of electronic goods produced. Such strategies help in producers adopting recycling, remanufacturing and e-waste disposal. Managers need to keep in mind that ineffective and loose regulations negatively affect the implementation of a sustainable supply chain (Rueda et al., 2017) being the strongest causal factor.

The analysis of results conveys that it is necessary for top management to imbibe in their vision realization of sustainability goals. Top management should set long term and short term targets to achieve sustainability goals and monitor them. In the Indian context, investment and resources support from top management is crucial for undertaking technological initiatives and operational changes. Top management can effectively direct the implementation of lean manufacturing processes, mandate environmental compliances, provide leadership and influence the company’s culture towards sustainable practices. The results show a strong causal effect of policy barriers and a reason cited for policy turning out to be a barrier is the lack of understanding among policymakers to reach common goals and regulations (Li et al., 2015). Policy barriers need to be tackled by having a common vision, tight regulations and proper guidance.

As high investments act as a barrier in cause group, organizations should try to have dedicated funding and returns on it should not be gauged by only monetary gain but other aspects should also be taken into account such as brand image and certifications. Hall et al. (2012) conclude that organizations should see the interactions among all three sustainable dimensions and not focus on financial alone to remain significant in business. Managers should use and steer the causal factors into minimizing the effect group barriers identified in the study. The degree of prominence of barriers is identified in the research and results indicate that financial barriers have a high correlation value which is consistent with the bias towards economic benefit mentioned in the literature. Therefore, managers should give due focus to these barriers as their higher correlation value makes them lead barriers in sustainability implementation.

The research implications in academics is that it contributes to the literature in sustainability and gives a new dimension on aspects of sustainability implementation in SCM. The thesis also identifies the cause and effect nature of sustainability practices such as green purchasing, disposal of wastes and complexity in sustainability measurement which can be a topic for further research in academics.

The enablers and barriers affecting the sustainability implementation process in a supply chain have been addressed in the chapters 3, 4 and 5. The development of a framework prioritizing the design requirements for eco-efficiency, which can assist decision-makers in familiarizing themselves with the key requirements and plan effective strategies is lacking in literature. In order to address this gap in the literature, research related to identifying customer requirements (CRs) and Design requirements (DRs) is proposed and discussed in the next chapter.

CHAPTER 6

PRIORITIZATION OF CUSTOMER AND DESIGN REQUIREMENTS FOR ECO-EFFICIENCY OF A SUPPLY CHAIN USING ANP-QFD METHODS

6.1 Introduction

The concept of eco-efficiency is an important step in the move towards sustainable development. Eco-efficiency is measured as Product or Service Value/Environmental influence. In the present day business, organizations have to take care of both the economic growth and environmental impact. Embracing the concept of eco-efficiency not only adds more value throughout the product life cycle but also reduces the amount of resources and environmental impact (Lozano et al., 2018). It is vastly changing the way modern industries are doing their business. In this research, the eco-efficiency requirements of an electronics industry are analyzed. The research contributes to the environmental sustainability aspect by identifying, prioritizing and creating a framework of requirements for eco-efficiency gains by an organization.

Methods such as LCA and DEA have been used to evaluate eco-efficiency (Vásquez-Ibarra et al., 2020). Firms should include environmental considerations in their decisions and attitude change towards environmental impact caused by their business (Koskela, 2015). To achieve higher economic value with lower environmental consequences, organizations need to innovate, be creative, adopt better technologies and produce greener products. Lam and Lai (2015) presented an ANP-QFD approach for environmental sustainability in the shipping industry's operation. They emphasized that an integrated ANP-QFD method could assist in the development of a framework to attain environmental performance. The assessment for green buildings in Malaysia was done using ANP to study correlation among factors within the QFD model (Ignatius et al., 2016). The integrated approach has been utilized for supplier selection in a sustainable supply chain (Tavana et al., 2017), sustainability in the maritime supply chain (Lam, 2015) and environmental production requirements (Lin et al., 2010).

This research attempts to identify and study the customer and design requirements to improve eco-efficiency using an integrated ANP-QFD structure in the electronics industry. The integrated approach allows further apparent comparisons and distinctions between DRs in contrast to a traditional QFD method which does not consider the interrelationship among CRs and DRs (Liu et al., 2021).

6.1.1 ANP-QFD method in supply chain

Thakkar et al. (2011) propose a decision framework for managing the supply chain in small and medium enterprises using the methods of QFD, ISM, ANP and zero-one goal programming (ZOGP). Büyüközkan and Berkol (2011) QFD using customer and design requirements for a sustainable supply chain. Lam and Lai (2015) applied ANP-QFD model in the case of shipping operations to enhance eco-efficiency. Tavana et al. (2017) employ an integrated ANP–QFD framework to weigh customer requirements and decision criteria in a dairy company. Bottani et al. (2018) used a method for supplier selection in an Italian company where QFD delineates supplier characteristics, and ANP considers interdependence among the selection factors for benefits, costs, opportunities and risks analysis. Chang and Cho (2019) applied combined QFD and ANP for ranking agility factors for mitigating the bullwhip effect. Wang et al. (2020) provide a design framework for big complex projects using a combined fuzzy QFD and grey decision-making in China.

The MCDM methods in accessing eco-efficiency have not been explored related to specific issues (Meto et al., 2009). The application of QFD by considering environmental impact is not much studied in the literature (Bereketli and Genevois, 2013). It is found in the literature that ANP has been integrated with QFD for analyzing environmental impact in sustainable supply chains (Paul et al., 2021).

6.2 The proposed ANP-QFD methodology

6.2.1 Analytic Network Process (ANP)

The ANP is a MCDM method that enables in determining the optimal solution for complex situations by considering interactions of decision attributes in a hierarchical structure among different levels of decision attributes (Saaty, 2004). It establishes the comparative importance of criteria and ranks the alternatives available in the model. ANP helps to evaluate the interactions among clusters and then further among the factors in a cluster. ANP facilitates human assessment to deal with priorities and trade-offs among the objectives and criteria defined for a problem. The method can be effectively used when the criteria and alternatives are interdependent (Haron et al., 2015).

6.2.2 Quality Function Deployment (QFD)

QFD is a method that helps translate customer requirements called the voice of customer to design requirements to meet what customers want (Büyüközkan and Berkol, 2011). QFD is a customer-focused approach where customers' requirements are brought in while designing products and services (Haber et al., 2020). The adaptability and ability to capture what the customer wants have seen researchers apply QFD in various areas such as product development (Huang et al., 2019), banking services (Shahin et al., 2016) and supply chain management (Büyüközkan and Çifçi, 2013). House of Quality (HOQ), representing a house shaped diagram is a widely used matrix in QFD. QFD has the advantage of lower cost with lesser time in deployment and decision-making while modeling the interdependencies among the variables in the study.

6.2.3 An integrated ANP QFD approach

Though QFD can construe the product or service design by relating the customer requirements and design requirements, the relative importance of these requirements is not evaluated. This creates a lacuna in the design and decision-making as the crucial CRs and DRs are not judged properly. To overcome this, QFD can be integrated with other methods like AHP, ANP, fuzzy sets, etc. ANP technique has the advantage of working with tangible and intangible elements by considering the interdependencies among them (Quezada et al., 2018). In this study, we employ the integrated method of ANP-QFD to evaluate the customer requirement and design requirements in improving the eco-efficiency of an electronics supply chain. The framework for the proposed ANP-QFD approach is depicted in Fig. 6.1.

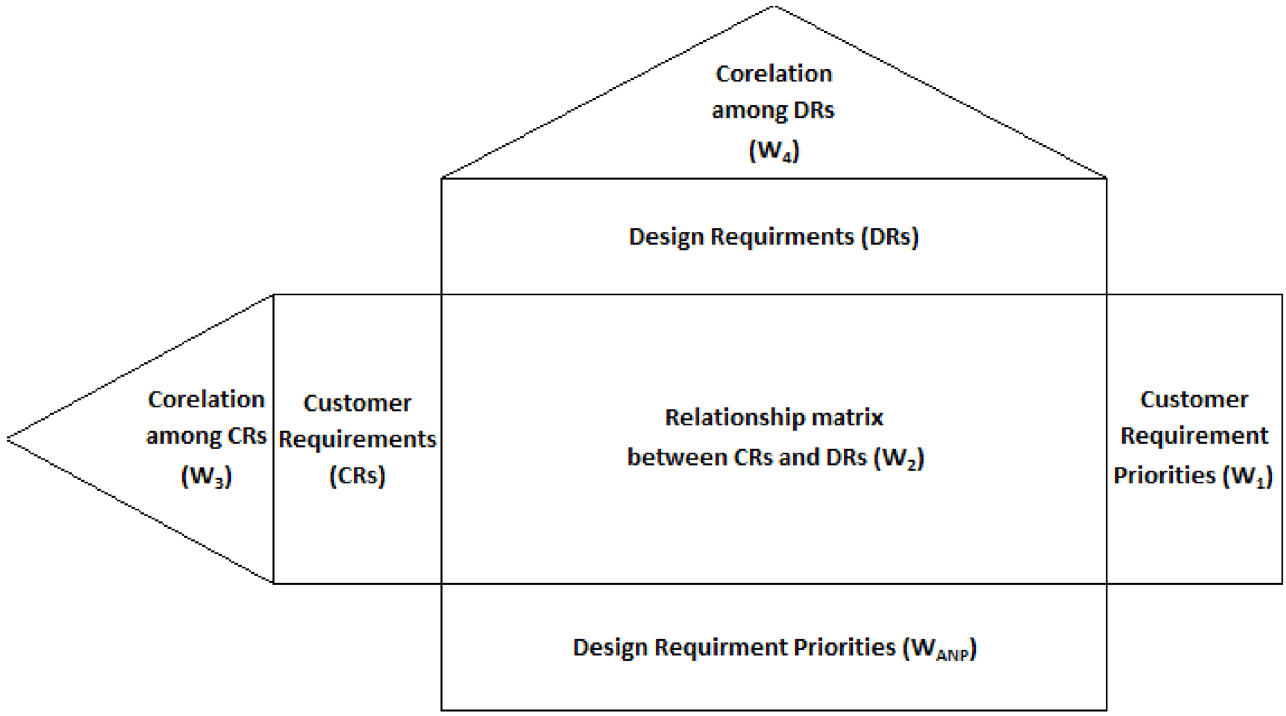


Figure 6.1: The House of Quality using integrated ANP-QFD method

6.2.4 Completing HOQ

The HOQ is the main planning instrument in QFD. It is constructed by relating customer requirements (CRs) and design requirements (DRs) from QFD. HOQ helps in knowing the voice of customer (WHATs) and identifying the design requirements (HOWs) in meeting the customer expectations. The preferences of the customer and the design requirements are found by designing the supermatrix of the HOQ model as per the following steps (Büyüközkan and Berkol, 2011):

Step 1. Identification of Customer Requirements (CRs): The customer requirements are finalized using literature review and the opinion of experts from industry and academia working in sustainable supply chains.

Step 2. Finalization of Design Requirements (DRs): The DRs are found by considering the CRs and suggesting how to do them. The DRs are identified through literature review and brainstorming sessions with experts in the electronics industry.

Step 3. Relative importance of the Customer Requirements (W_1): The CRs are rated by making a pairwise comparison to find their relative importance.

Step 4. Relationship between CRs and DRs (W_2)**:** To compare the identified CRs and DRs, an inter-dependency matrix is formed to know their relationship importance.

Step 5. Establishing inner dependence matrix among CRs (W_3): The customer requirements CRs finalized may have inner dependence among themselves, which may support or affect the achievement of other CRs. Pairwise comparisons within them establish the inner dependence matrix of CRs.

Step 6. Developing an inner dependence matrix among DRs (W_4): A correlation matrix is constructed to know the inner dependence of the DRs. It is prepared by constructing the pair-wise comparison matrix within the DRs, which appear at the roof of the HOQ. The following symbols are used to describe the strength of the interrelationship:

● A positive (+) sign represents a strong correlation,
● Blank or no sign () represents no correlation
● Negative (-) sign represents a weak correlation

Step 7. Establish interdependent priority matrix of CRs (W_C): The interdependent priority matrix of the CRs is established by construing the relation matrix, $W_C = W_3 \times W_1$.

Step 8. Establish interdependent priority matrix among DRs (W_A): The interdependent priority matrix of the DRs is established by construing the relation matrix $W_A = W_4 \times W_2$.

Step 9. Finding out the overall priority of DRs**:** The results of the above steps are used to find the overall priorities of the DRs considering the relationships within the HOQ by the following relation, $W_{ANP} = W_A \times W_C$.

The research steps in completing the House of Quality (HOQ) are shown in Fig. 6.2.

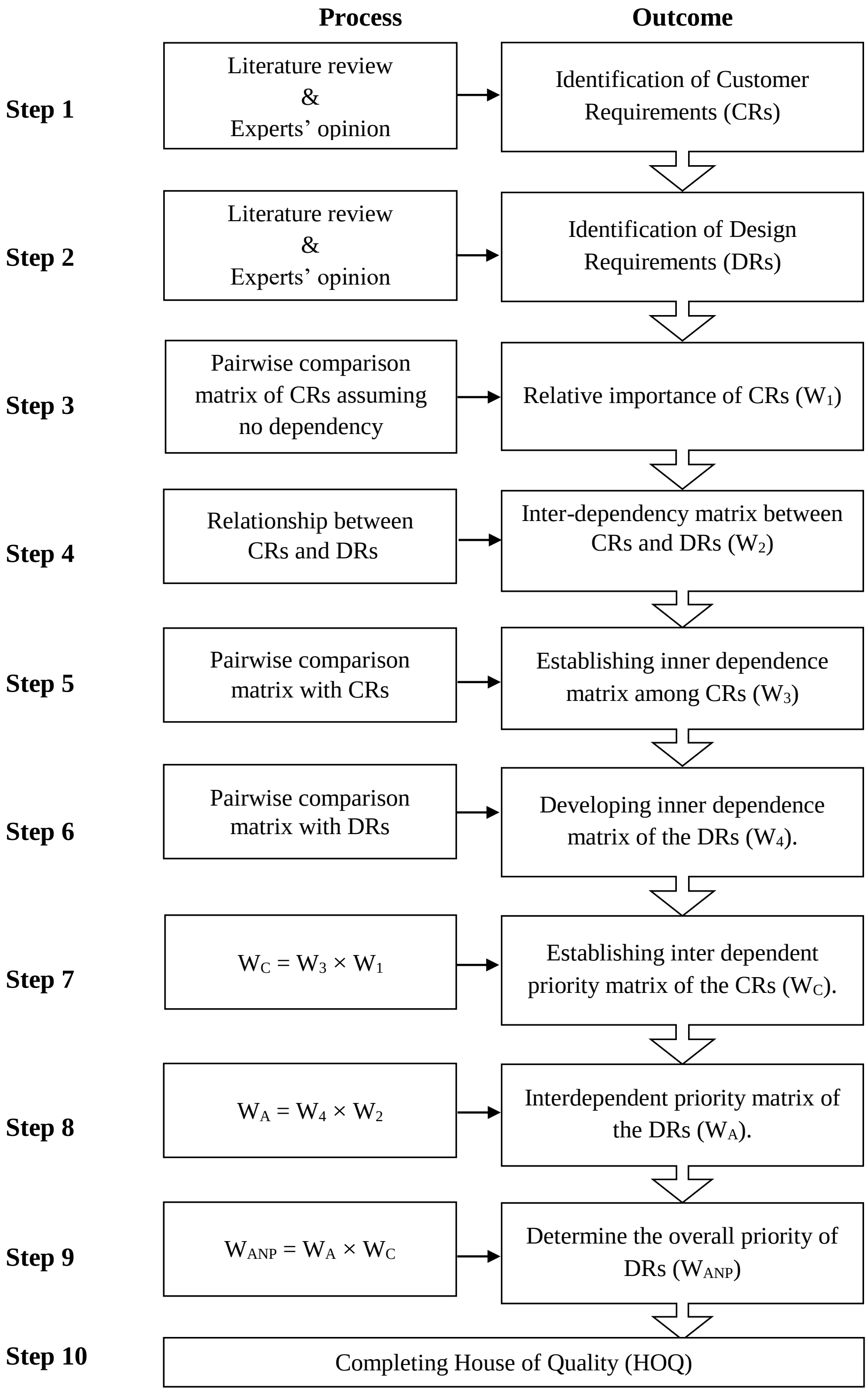


Figure 6.2: Research steps for construction of HOQ

6.3 Illustration of proposed methodology to an electronic company

The proposed methodology is applied to an electronics company in India having a turnover of more than US$ 65 M. The company has been in the manufacturing of consumer electronic components for more than 15 years. To improve its eco-efficiency, the company wants to identify and prioritize its CRs and DRs. The experts consulted in the study have experience of more than 15 years in different areas of the sustainable supply chain. The identified CRs and DRs from the literature were discussed with the experts. The CRs and DRs were shortlisted through brainstorming sessions. The proposed methodology of ANP-QFD is applied using the CRs and DRs to construct the HOQ and prioritize the DRs. The methodology involves the determination of several pairwise comparison matrices. These steps in detail are explained below, and one matrix in each step is demonstrated.

6.3.1 Step 1: Identification of Customer Requirements (CRs)

In this research, seven elements of eco-efficiency given by the World Business Council for Sustainable Development (WBCSD) have been chosen as CRs. They are (i)Reduce material intensity (ii)Reduce energy intensity (iii)Reduce dispersion of toxic substances (iv)Enhance recyclability (v) Maximize use of renewable resources (vi)Extend product durability and (vii)Increase service intensity. The CRs were discussed with the experts and it was found that they encompassed all relevant customer requirements concerning eco-efficiency. Details of CRs identified and the relevant literature is given in Table 6.1.

6.3.1.1. Reduce material intensity

This requirement improves the efficient usage of raw materials to protect natural resources. The extraction of raw materials, production process and disposal of waste causes environmental deterioration, which can be decreased by lesser material intensity. The existing efforts to reduce material intensity are restricted and largely aimed at cutting the cost rather than environmental impact (Shahbazi et al., 2017).

Table 6.1: Customer Requirement for Eco-efficiency in SCM

Ref No.	Customer Requirements	Description	Relevant Literature
CR1	Reduced material intensity	Less material is used for the same application in the lifecycle of products and services.	Popa and Popa (2013); Ravi (2015); Caiado et al. (2017); Kasulaitis et al. (2020).
CR2	Reduced energy intensity	It is to reduce the amount of energy used as well as energy allocation for a particular work.	Kerr and Ryan (2001); Li et al. (2015); Lin et al. (2019).
CR 3	Reduced dispersion of toxic substances	The requirement to reduce diffusion of toxic substances from industrial, chemical, and biological processes	Ravi (2015); Allen et al. (2017); Fernando (2017); Tian et al. (2018).
CR 4	Enhanced recyclability	Enhancing recyclability eases the process of collection, treatment, improved reusability of commodities.	Richa et al. (2017); Fernando (2017); Ding et al. (2019); Zhou et al. (2019).
CR 5	Maximized use of renewables	Maximizing renewable sources like solar, wind, etc. and reducing the dependency on fossil fuels.	Ravi (2015); Contreras-Lisperguer et al. (2017); Figge et al. (2017); Lin et al. (2019).
CR 6	Extended product durability	Product life is extended by increasing a product's utility duration. The product is kept in use for a higher and extended period. .	Pimentaa et al. (2015); Hankammer and Steiner (2015); Li et al. (2015); Slowak and Regenfelder (2017).
CR 7	Increased service intensity	To provide an increased frequency and quality of service for better product performance.	Paquin et al. (2015); Subramanian and Gunasekaran (2015); Passetti and Tenucci (2016); Rau et al. (2021).

6.3.1.2. Reduce energy intensity

Energy intensity is the amount of energy needed per unit output or activity. Utilizing less energy to make a product lowers the energy intensity. Reducing energy intensity is vital for sustainable economic development, and policies such as standards and labeling can help reduce energy intensity (Azhgaliyeva et al., 2020).

6.3.1.3. Reduce dispersion of toxic substances

Chemicals may cause harmful effects, and the proliferation of such substances in the environment has to be reduced. Chemicals are harmful, but when a small amount is harmful, it is considered highly toxic. Toxic substances cause damage to skin, eyes, lungs and other internal organs of the body.

6.3.1.4. Enhance recyclability

To reduce waste, products may be designed to be reused, recycled or remanufactured. Depending on the material and technology available, this may not be completely possible. Recyclability is the capability to be recycled. Higher recyclability will mean materials, etc., which are easily recyclable will be used.

6.3.1.5. Maximize use of renewable resources

The increasing population has been causing many environmental problems and an increase in the use of natural resources. Renewable resources consist of wind energy, solar energy, hydropower, biomass energy, etc. Renewable resources being naturally replaced does not get depleted and can be used repeatedly. Fossil fuels that are currently largely used are non-renewable resources.

6.3.1.6. Extend product durability

Extend product durability makes the product be utilized over a longer period under determined conditions of repair and maintenance. The useable life is increased in terms of time or number of usages. Since electronic waste and other durable goods have a larger quantity in landfills, the extension of product durability has received attention.

6.3.1.7. Increase service intensity

The service intensity is the number or frequency of services required and the level of coordination with multiple agencies needed. The advancement in capability to improve the product performance is what an increased service intensity tries to achieve (Baines et al., 2017).

6.3.2 Step 2: Finalization of Design Requirements (DRs)

The design requirements for the company were identified from the literature review and finalized after a brainstorming session with the experts. Fourteen DRs were identified, and they are 1)Reduced use/ consumption of resources, 2) State of the art innovative materials, 3) Technologies for reducing use/consumption of energy 4)Mandate labeling of energy performance 5)Reduce greenhouse gases, air emissions, volatile organic compounds and carbon footprint 6) Environmental Management Systems - ISO 7)Reverse Logistics practices 8)Life Cycle Assessment 9)Green suppliers and green procurement 10)Use renewable energy like Solar 11) Design for Environment 12)Increased durability of products 13)Extended Producer Responsibility 14)Health and occupational safety. Details of design requirements identified and their corresponding literature are given in Table 6.2.

Table 6.2: Design Requirements used in the study for Eco-efficiency in SCM

Ref No.	Design Requirements	Description	Relevant Literature
DR1	Reduced use/ consumption of resources	Lower the consumption of natural resources used in a product or process. Apart from using resources efficiently, leakage and losses could be plugged.	Fleury and Davies(2012); Figge et al.,(2014); Tseng et al. (2014); Ma et al. (2015); Lozano et al. (2018).
DR2	State of the art innovative materials	Innovating materials that are eco-friendly and sustainable. Replacing or substituting environmentally harmful materials with new lesser harmful materials.	Quariguasi-Frota-Neto and Bloemhof (2012); Cramer and Tukker (2013); Egilmez and Park (2014); Li et al. (2015); O'Connor et al. (2016); Lozano et al. (2018).
DR3	Technologies for reducing use/ consumption of energy	Employing technology to reduce energy utilization and a cleaner, efficient generation of energy. Technologies like LED lights and newer insulation technologies help in reducing energy	Usón et al. (2011); McKenna et al. (2013); Ma et al. (2015); Attia (2016).
DR4	Mandate labeling of energy performance	Energy performance labels enable consumers to make an informed decision while purchasing on the energy efficiency. Mandating these labels on appliances can influence consumer behavior in the buying process.	Kelly (2012); Tseng et al. (2014); Andrae et al. (2016); Spyridaki et al. (2016).
DR5	Reduce GHGs, air emissions, VOCs and carbon footprint	Reduce the generation of gases that induce climate change and cause pollution. Carbon footprint is the total quantity of greenhouse gases that come from the production, usage and end of life of a product or service.	Braungart et al. (2012); Figge et al.,(2014); Lozano et al. (2018); Tenente et al. (2020).
DR6	Environmental Management Systems (EMS) - ISO	Environmental Management System (EMS) is a tool that lays out the processes and practices which enable an organization to reduce the environmental impact due to its operations.	Lewandowska et al. (2013); Jabbour et al. (2014); Mutingi et al. (2014); Ravi (2015).

DR7	Reverse Logistics practices	Reverse logistics is a process whereby product returns in a supply chain are recaptured for their value or disposed of properly for the cause of the environment.	Ravi et al. (2008); Neto et al. (2009); Pini et al. (2019); Kaya (2016); Trochu et al. (2020).
DR8	Life Cycle Assessment (LCA)	Life Cycle Assessment helps analyze the impact on the environment during the entire life cycle of the product or services.	Lewandowska et al. (2013); Subramanian and Yung (2016); Gallego-Schmid et al.,(2018); Moreno et al. (2018); Zhang et al. (2020).
DR9	Green suppliers and green procurement	Green suppliers and green procurement ensure that the product and services sourced cause minimum environmental harm during their supply.	Jabbour et al. (2014); Mahdiloo et al. (2015); Pelton et al. (2016); Lozano et al. (2018).
DR10	Use renewable energy like Solar	Renewable energy sources like solar, wind, geothermal, hydropower, etc., provide clean energy and are carbon-neutral sources.	Tseng et al. (2014); Ravi (2015); Saling (2016); Lozano et al. (2018).
DR11	Design for Environment (DfE)	It is a design approach to eliminate or minimize the environmental impact of a product during its lifecycle.	Ravi et al. (2008); Köhler (2013); Cramer (2017); Lozano et al. (2018).
DR12	Increased durability of products	The longevity of the product due to increased durability ensures that it is used for a longer period. This reduces the usage of resources that would have otherwise gone for the replacement product.	Braungart et al. (2012); Wong (2012); Cooper (2016); Hockerts (2017).
DR13	Extended Producer Responsibility (EPR)	Extended Producer Responsibility (EPR) is a policy and practice by which a manufacturer is made responsible, financially and physically, for the disposal of used products by the consumer.	Cagno et al. (2012); Bakker et al. (2014); Lai et al. (2014); Angulo et al. (2017).
DR14	Health and occupational safety	Health and occupational safety of workers will lead to employees participating and enhancing environmental programs. Health and occupational safety is a prerequisite for economic and environmental policies.	Fleury and Davies (2012); Lee et al. (2013); Friend and Kohn (2018); Narkhede and Gardas (2018).

6.3.2.1. Reduced use/consumption of resources

Reduced consumption of resources lessens the burden on natural resources like wood, fossil fuels, water, etc. Many resources are not renewable, and higher consumption of resources affects climate change. It includes lesser use of resources like energy, water and products that use them. Physical resources are being increasingly used in the electronic industry (Yin et al., 2014).

6.3.2.2. State of art innovative materials

Innovative materials help increase the life of products to last longer. Efficient materials help to reduce usage and improve the products. High-density batteries and printed electronics are some of the innovations seen in materials in the electronics industry.

6.3.2.3. Technologies for reducing the use/consumption of energy

Technologies such as closed-loop heat pumps and cogeneration help reduce energy consumption. Better technologies help improve energy efficiency. It reduces energy generation and consumption for the same activity or unit product.

6.3.2.4. Mandate labeling of energy performance

Mandating energy performance labeling allows consumers to make an informed choice while buying. It also serves to determine the minimum performance standards for items in energy terms. Labeling of energy performance can increase the adoption of energy-efficient products, and there is a willingness to pay more for such products on familiarization with such labels (Jain et al., 2018).

6.3.2.5. Reduce GHGs, air emissions, VOCs and carbon footprint

The burning of fossil fuels, erosion of forest land, waste disposal, etc., are leading to air pollution and Greenhouse Gases (GHG) emissions which need to be reduced. GHGs include Carbon Dioxide, Nitrous oxide, methane, hydrofluorocarbons etc. Ozone precursors like non-methane Volatile Organic Compounds (VOC), oxides of nitrogen etc., also indirectly have a greenhouse effect.

6.3.2.6. EMS – ISO

Environmental management systems (EMS) like ISO (International Organization for Standardization) aids in reducing the impact on the environment with standards like ISO 14001. EMS helps in environmentally sustainable practices in sourcing material, design, production, packaging and waste management. (Shrivastava and Hart, 1995).

6.3.2.7. Reverse logistics practices

By having reverse logistics practices in their supply chain, organizations reduce resource usage and environmental impact by reusing and recycling their products (Ravi and Shankar, 2005). Reverse logistics enables the return of the used goods to the producer by creating a complete cycle in the supply chain. It requires creating a network to collect and return the goods, inspect, refurbish, and dispose of the waste without harming the environment.

6.3.2.8. Life Cycle Assessment (LCA)

LCA is a systematic assessment of the environmental impact a product or service will make during its life cycle. LCA identifies the environmental effect during the design and implementation stage to identify the environment-sensitive points, benchmarking the process, reducing the environmental harm in production and better design for sustainable consumption and production (Ibn-Mohammed et al., 2017).

6.3.2.9. Green suppliers and green procurement

Green procurement is sourcing products and services with minimal harmful effects on the environment at competitive prices. Green suppliers put efforts to have a green supply chain causing minimum impact to the environment while offering their products and services. Green suppliers and green procurement play a key corporate role and are of strategic importance in protecting the environment (Björklund, 2010).

6.3.2.10. Use renewable energy like solar

Renewable energy is the generation of energy from naturally replenishing sources. Solar, Wind, Geothermal, Hydropower and Biomass like ethanol are the major types of renewable energy. It has the benefits of reducing dependence on fossil fuels leading to lesser greenhouse gas emissions.

6.3.2.11. Design for Environment (DfE)

DfE is a concept in which guidelines are given at the design phase to examine the product over its entire life cycle to reduce the environmental impact (DeMendonça and Baxter, 2001). The design evaluates the alternatives available to reduce the energy consumption, waste generation and recycling options during the product life cycle.

6.3.2.12. Increased durability of products

Durable products are made long-lasting and of high-quality materials. The product's life is also lengthened by making it easily repairable, reusable and recyclable. It is seen that especially in electronic products, the life cycle of products is reducing as newer products are increasingly introduced, resulting in the durability of products being designed for a shorter period.

6.3.2.13. Extended Producer Responsibility (EPR)

EPR refers to producers taking back products from customers after their end of life. This concept has become popular in the electronics industry as concern for e-waste, and its proper treatment is growing. EPR makes companies responsible financially and physically for collecting the products after their end of life and their recycling, recovery or reuse.

6.3.2.14. Health and occupational safety

Health and occupational safety of workers is important for embracing and implementing environmental policies (Toke et al., 2012). Paying attention to occupational safety and health has a positive effect and it motivates employees from a social angle, which could benefit the environment.

6.3.3. Step 3: Relative importance of CRs (W_1)

The relative importance of CRs is identified by finding which CR is to be given more attention and to what degree. The eigenvector determined by making the pairwise comparison assuming that there is no dependency among CRs is shown in Table 6.3.

Table 6.3: Relative importance of each CR

Item Description	Reduced material intensity	Reduced energy intensity	Reduced dispersion of toxic substances	Enhanced recyclability	Maximized use of renewables	Extended product life	Increased service intensity	Weight (W_1)
Reduced material intensity (CR1)	1	2	0.5	3	3	4	5	0.2260
Reduced energy intensity (CR2)	0.5	1	0.33	2	3	4	5	0.1675
Reduced dispersion of toxic substances (CR3)	2	3	1	2	3	5	6	0.2960
Enhanced recyclability (CR4)	0.33	0.5	0.5	1	2	3	3	0.1167
Maximized use of renewables (CR5)	0.33	0.33	0.33	0.5	1	5	6	0.1142
Extended product life (CR6)	0.25	0.25	0.2	0.33	0.2	1	2	0.0461
Increased service intensity (CR7)	0.2	0.2	0.17	0.33	0.17	0.5	1	0.0333

6.3.4. Step 4: Relationship between CRs and DRs (W_2)

In this step, assuming no dependence among DRs the interdependence of DRs to each CR is found. The calculation of interdependence of DRs to the CR reduced material intensity is given in Table 6.4. For example, answering the question on "What is the relative importance of Reverse Logistics practices (DR3) compared to Life Cycle Assessment (DR4) in achieving reduced material intensity?" gives the result as 2, which is shown in Table 6.4. Similarly, the degree of importance of DRs for other CRs is found and shown in Table 6.5. The transpose of this table is put in the body of the House of Quality.

Table 6.4: Relative importance of the DRs for reduced material intensity

	Reduced use/consumption of resources	State of art innovative materials	Reverse Logistics practices	Life Cycle Assessment	Green suppliers and green procurement	Design for Environment	Increased durability of products	Weight
Reduced use/consumption of resources	1.00	2.00	3.00	4.00	5.00	4.00	3.00	0.31
State of art innovative materials	0.50	1.00	3.00	3.00	4.00	4.00	2.00	0.22
Reverse Logistics practices	0.33	0.33	1.00	2.00	4.00	3.00	0.50	0.12
Life Cycle Assessment	0.25	0.33	0.50	1.00	3.00	2.00	0.33	0.08
Green suppliers and green procurement	0.20	0.25	0.25	0.33	1.00	0.50	0.20	0.04
Design for Environment	0.25	0.25	0.33	0.50	2.00	1.00	0.25	0.05
Increased durability of products	0.33	0.50	2.00	3.00	5.00	4.00	1.00	0.17

Table 6.5: The column Eigen vectors of DRs with respect to each CR

W_2	Reduced material intensity	Reduced energy intensity	Reduced dispersion of toxic substances	Enhanced recyclability	Maximized use of renewables	Extended product life	Increased service intensity
Reduced use/consumption of resources	0.314	0.105	0.092	0.000	0.000	0.079	0.400
State of art innovative materials	0.223	0.000	0.024	0.041	0.035	0.036	0.000
Technologies for reducing use/consumption of energy	0.000	0.332	0.136	0.000	0.000	0.000	0.261
Mandate labeling of energy performance	0.000	0.218	0.000	0.000	0.000	0.000	0.000
Reduce GHGs, air emissions, VOCs and carbon footprint	0.000	0.000	0.261	0.052	0.097	0.051	0.000
EMS - ISO	0.000	0.088	0.179	0.030	0.000	0.000	0.000
Reverse Logistics practices	0.118	0.063	0.071	0.286	0.000	0.144	0.000
Life Cycle Assessment	0.080	0.042	0.000	0.213	0.000	0.106	0.000
Green suppliers and green procurement	0.038	0.000	0.110	0.136	0.247	0.000	0.000
Use renewable energy like Solar	0.000	0.152	0.000	0.000	0.303	0.000	0.000
Design for Environment	0.055	0.000	0.038	0.121	0.195	0.223	0.000
Increased durability of products	0.171	0.000	0.000	0.000	0.000	0.360	0.094
Extended Producer Responsibility	0.000	0.000	0.040	0.122	0.051	0.000	0.178
Health and occupational safety	0.000	0.000	0.050	0.000	0.073	0.000	0.067

6.3.5. Step 5: Establishing inner dependence matrix among CRs (W_3)

The interdependence between CRs is derived by using pairwise comparisons on the impact of each CR on other CRs. Customer requirements that have no impact are not considered in the comparison matrix. For example, the relative importance of Enhanced recyclability compared to Extended product life in achieving reduced material intensity is depicted as 2 in Table 6.6. Accordingly, eigenvectors obtained from pairwise comparisons for other CRs are mentioned in Table 6.7. Zero is assigned to the eigenvector weights for the CRs that are independent.

Table 6.6: The inner-dependence of customer requirements against the reduced material intensity

	Enhanced recyclability	Extended product life	Increased service intensity	Reduced material intensity	Weight
Enhanced recyclability	1.00	2.00	0.33	0.33	0.139
Extended product life	0.50	1.00	0.20	0.25	0.082
Increased service intensity	3.00	5.00	1.00	0.50	0.335
Reduced material intensity	3.00	4.00	2.00	1.00	0.445

Table 6.7: The inner dependence matrix of Customer Requirements

W_3	Reduced material intensity	Reduced energy intensity	Reduced dispersion of toxic substances	Enhanced recyclability	Maximized use of renewables	Extended product life	Increased service intensity
Reduced material intensity	0.4448	0.0000	0.0706	0.1226	0.0000	0.2875	0.2303
Reduced energy intensity	0.0000	0.4992	0.1920	0.0000	0.0000	0.0981	0.1508
Reduced dispersion of toxic substances	0.0000	0.0000	0.3812	0.0000	0.2000	0.0000	0.1342
Enhanced recyclability	0.1386	0.0000	0.0964	0.5571	0.0000	0.0000	0.0000
Maximized use of renewables	0.0000	0.2600	0.2085	0.0000	0.8000	0.0000	0.0000
Extended product life	0.0817	0.1613	0.0000	0.3202	0.0000	0.4063	0.0659
Increased service intensity	0.3349	0.0796	0.0513	0.0000	0.0000	0.2081	0.4188

6.3.6. Step 6: developing inner dependence matrix of the DRs (W_4)

Next, the dependence among the DRs is found by pairwise comparisons among the DRs as earlier done for CRs, and the inner dependencies are determined. For example, the relative importance of using renewable energy like solar compared to increased durability of products in achieving reduced material intensity results in 4 and is shown in Table 6.8. Accordingly, the relative importance of the weights obtained from pairwise comparisons is presented in Table 6.9.

Table 6.8: The inner dependence matrix of DRs with respect to reduced material intensity

	State of art innovative materials	Reverse Logistics practices	Life Cycle Assessment	Use renewable energy like Solar	Design for Environment	Increased durability of products	Reduced use/ consumption of resources	Weight
State of art innovative materials	1.00	4.00	5.00	2.00	3.00	6.00	0.50	0.2424
Reverse Logistics practices	0.25	1.00	2.00	0.33	0.50	2.00	0.20	0.0665
Life Cycle Assessment	0.20	0.50	1.00	0.25	0.50	2.00	0.17	0.0500
Use renewable energy like Solar	0.50	3.00	4.00	1.00	2.00	4.00	0.33	0.1574
Design for Environment	0.33	2.00	2.00	0.50	1.00	3.00	0.25	0.0963
Increased durability of products	0.17	0.50	0.50	0.25	0.33	1.00	0.17	0.0374
Reduced use/consumption of resources	2.00	5.00	6.00	3.00	4.00	6.00	1.00	0.3498

Table 6.9: The inner dependence matrix of the DRs

W_4	DR1	DR2	DR3	DR4	DR5	DR6	DR7	DR8	DR9	DR10	DR11	DR12	DR13	DR14
DR1	0.3498	0.1574	0.0000	0.0000	0.1932	0.0000	0.1900	0.2771	0.0000	0.0000	0.0308	0.0716	0.0000	0.0000
DR2	0.2424	0.3663	0.0000	0.0000	0.0382	0.0000	0.0294	0.0000	0.0000	0.0000	0.0000	0.1633	0.3293	0.0000
DR3	0.0000	0.0000	0.3611	0.2039	0.0000	0.0984	0.0000	0.0000	0.0484	0.1110	0.1610	0.0000	0.0000	0.0000
DR4	0.0000	0.0000	0.2558	0.2976	0.0337	0.0000	0.0000	0.0000	0.1110	0.0725	0.0000	0.0000	0.0000	0.0000
DR5	0.0000	0.2449	0.2220	0.2208	0.2533	0.2062	0.0780	0.0000	0.1661	0.2358	0.0820	0.0000	0.1493	0.1653
DR6	0.0000	0.0000	0.0000	0.1158	0.1411	0.3066	0.0574	0.0000	0.1955	0.0000	0.1032	0.0000	0.0000	0.2550
DR7	0.0665	0.0684	0.0000	0.0000	0.0473	0.0309	0.3320	0.1611	0.0000	0.0000	0.0566	0.0000	0.0787	0.0000
DR8	0.0500	0.0000	0.0000	0.0000	0.0000	0.0000	0.1119	0.4658	0.0000	0.0000	0.0000	0.2661	0.0000	0.0000
DR9	0.0000	0.1195	0.0000	0.0753	0.1086	0.1051	0.0000	0.0000	0.4006	0.1692	0.0466	0.0000	0.0000	0.0000
DR10	0.1574	0.0000	0.0548	0.0370	0.0223	0.1489	0.0000	0.0000	0.0785	0.4116	0.2099	0.0000	0.0000	0.1083
DR11	0.0963	0.0000	0.1063	0.0495	0.0912	0.0443	0.0414	0.0000	0.0000	0.0000	0.3099	0.0000	0.0987	0.0000
DR12	0.0374	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0960	0.0000	0.0000	0.0000	0.4026	0.0000	0.0000
DR13	0.0000	0.0435	0.0000	0.0000	0.0000	0.0000	0.1600	0.0000	0.0000	0.0000	0.0000	0.0965	0.3440	0.0000
DR14	0.0000	0.0000	0.0000	0.0000	0.0711	0.0595	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4715

6.3.7. Step 7: establishing inter dependent priority matrix of the CRs (W_C)

The interdependent priorities of the CRs are determined by using the relation $W_C = W_3 \times W_1$.

$$W_c = \begin{pmatrix} 0.1567 \\ 0.1500 \\ 0.1402 \\ 0.1249 \\ 0.1967 \\ 0.1038 \\ 0.1278 \end{pmatrix}$$

6.3.8. Step 8: interdependent priority matrix of the DRs (W_A)

The interdependent priorities of the DRs, W_A is obtained as follows: $W_A = W_4 \times W_2$.

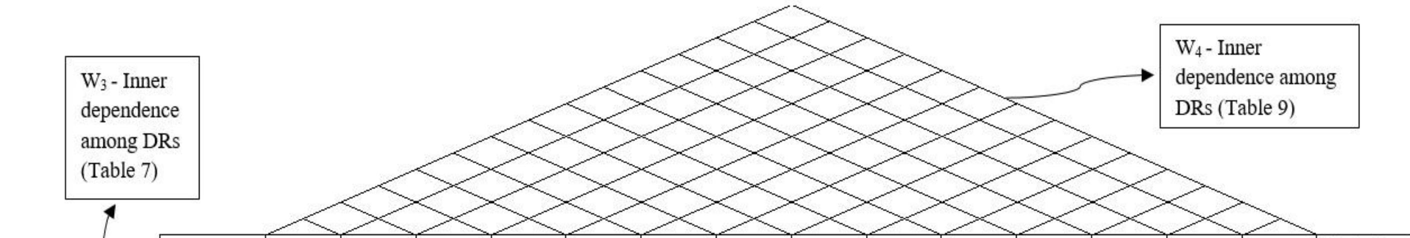
$$W_A = \begin{pmatrix} 0.2037 & 0.0603 & 0.1011 & 0.1334 & 0.0301 & 0.1327 & 0.1468 \\ 0.1893 & 0.0273 & 0.0562 & 0.0657 & 0.0332 & 0.0974 & 0.1710 \\ 0.0106 & 0.1900 & 0.0780 & 0.0289 & 0.0770 & 0.0360 & 0.0943 \\ 0.0043 & 0.1610 & 0.0557 & 0.0168 & 0.0527 & 0.0017 & 0.0668 \\ 0.0747 & 0.1808 & 0.1800 & 0.1024 & 0.1811 & 0.0513 & 0.0956 \\ 0.0199 & 0.0558 & 0.1339 & 0.0720 & 0.1005 & 0.0386 & 0.0170 \\ 0.0914 & 0.0374 & 0.0546 & 0.1517 & 0.0220 & 0.0876 & 0.0406 \\ 0.1118 & 0.0317 & 0.0126 & 0.1309 & 0.0000 & 0.1653 & 0.0450 \\ 0.0445 & 0.0514 & 0.0957 & 0.0738 & 0.1740 & 0.0203 & 0.0000 \\ 0.0639 & 0.1185 & 0.0764 & 0.0416 & 0.1951 & 0.0605 & 0.0845 \\ 0.0521 & 0.0627 & 0.0737 & 0.0673 & 0.0742 & 0.0875 & 0.0839 \\ 0.0885 & 0.0079 & 0.0034 & 0.0204 & 0.0000 & 0.1582 & 0.0527 \\ 0.0452 & 0.0101 & 0.0261 & 0.0895 & 0.0191 & 0.0593 & 0.0703 \\ 0.0000 & 0.0052 & 0.0526 & 0.0055 & 0.0411 & 0.0037 & 0.0314 \end{pmatrix}$$

6.3.9. Step 9: Finding out the overall priority of DRs

The total priorities of the DRs (W_{ANP}), reflecting interrelationships within HOQ, are obtained by multiplying W_A and W_C.

$$W_{ANP} = \begin{pmatrix} 0.1300 \\ 0.1102 \\ 0.0992 \\ 0.0883 \\ 0.0756 \\ 0.0737 \\ 0.0707 \\ 0.0652 \\ 0.0651 \\ 0.0633 \\ 0.0538 \\ 0.0423 \\ 0.0412 \\ 0.0213 \end{pmatrix} \begin{pmatrix} \text{DR5} \\ \text{DR1} \\ \text{DR10} \\ \text{DR2} \\ \text{DR3} \\ \text{DR9} \\ \text{DR11} \\ \text{DR6} \\ \text{DR7} \\ \text{DR8} \\ \text{DR4} \\ \text{DR13} \\ \text{DR12} \\ \text{DR14} \end{pmatrix}$$

The results obtained from ANP show that reducing GHGs, air emissions, VOCs, and carbon footprint (DR5) has the highest important design requirement with a relative importance value of 0.1300. It is followed by Reduced use/consumption of resources (DR1) and Use renewable energy like Solar (DR10) with a relative importance rate of 0.1102 and 0.0992. With the result of the above steps, HOQ is framed and illustrated in Fig. 6.3.



	DR1	DR2	DR3	DR4	DR5	DR6	DR7	DR8	DR9	DR10	DR11	DR12	DR13	DR14	Relative weight of CRs
CR1	0.314	0.223	0.000	0.000	0.000	0.000	0.118	0.080	0.038	0.000	0.055	0.171	0.000	0.000	0.226
CR2	0.105	0.000	0.332	0.218	0.000	0.088	0.063	0.042	0.000	0.152	0.000	0.000	0.000	0.000	0.168
CR3	0.092	0.024	0.136	0.000	0.261	0.179	0.071	0.000	0.110	0.000	0.038	0.000	0.040	0.050	0.296
CR4	0.000	0.041	0.000	0.000	0.052	0.030	0.286	0.213	0.136	0.000	0.121	0.000	0.122	0.000	0.117
CR5	0.000	0.035	0.000	0.000	0.097	0.000	0.000	0.000	0.247	0.303	0.195	0.000	0.051	0.073	0.114
CR6	0.079	0.036	0.000	0.000	0.051	0.000	0.144	0.106	0.000	0.000	0.223	0.360	0.000	0.000	0.046
CR7	0.400	0.000	0.261	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.094	0.178	0.067	0.033
Overall priorities of DR	0.110	0.088	0.076	0.054	0.130	0.065	0.065	0.063	0.074	0.099	0.071	0.041	0.042	0.021	

Figure 6.3: House of Quality for the case electronics company

6.4 Results and Discussion

In this research, we have tried to determine customer requirements, design requirements and their priority for improving the eco-efficiency in the electronics industry's supply chain. The eco-efficiency approach encourages organizations to achieve sustainability goals by reducing environmental impact and economic savings. This approach helps decision-makers of companies by aiding them in strategic and operational decisions to advance their sustainable practices. The customer requirements and design requirements for improving eco-efficiency in the electronics industry are identified and prioritized using the ANP-QFD method.

The study finds that the most important customer requirements for eco-efficiency in the electronics supply chain are Reduced dispersion of toxic substances (CR3), Reduced material intensity (CR1), Reduced energy intensity (CR2) and then Enhanced recyclability (CR4). Tseng et al. (2014) point out that benchmarking of eco-efficiency parameters in the electronic production process has not been addressed in the green supply chain. The CRs and their significance identified will assist in the objective of improving eco-efficiency in a supply chain.

In the case electronics company, Reducing GHGs, air emissions, VOCs, and carbon footprint (DR5) is the most significant design requirement to achieve eco-efficiency. The greenhouse gases, air pollutants, volatile organic compounds and carbon footprint are increasing and a source of concern globally. They are generated from the burning of fossil fuels and chemical processes in the industry. Companies need to analyze and control the emissions in all stages of their supply chain. Eco-efficiency can be increased by shifting from polluting sources and improving efficiency in all areas. A study on the use of battery-operated electric vehicles in China showed a 35% reduction in GHG emissions compared to gasoline cars (Zheng et al., 2020). Electronics industries should have a vision and target time to achieve carbon neutrality and produce goods with zero carbon impact. A set of indicators showing the environmental profile over its lifecycle and action towards standardization in the microelectronic industry can help control environmental damage (Villard et al., 2015).

The next important design requirement for achieving eco-efficiency is Reduced use/consumption of resources (DR1). Consumption can be reduced by reducing the waste generated and improving production efficiency. Strategies to meet the resource for the growth and reduce resource consumption need to be evolved (Tseng et al., 2014). Collaboration and communication within the supply chain are key to reducing the consumption of resources. Using renewable energy like Solar (DR10) can help to improve environmental performance. The widespread usage of traditional energy sources contributes to growing pollution and economic deficits. (Kousksou et al., 2015). Renewable energy sources like solar, hydropower, wind etc., can replace fossil fuels and be more reliable. Renewable energy is a cleaner and sustainable resource. Companies using renewable energy are in a much better position to tackle their business's legislative, social, and environmental performance. State of art innovative materials (DR2) can help reduce consumption and pollution due to their usage in industries. Corrugated materials can replace materials like plastic, which is environmentally harmful. In the electronics industry, printed memory and sensors that can be stretched or bent can help reduce products' weight, cost, and energy consumption. Research and development of materials can provide materials with better properties and characteristics. Innovative materials have enabled the development of flexible and printed electronics. The development of higher-density batteries has improved battery life in electronics products. Carbon-based nanomaterials can efficiently store and convert energy for mobile electronic devices (Paul, 2019).

Technologies for reducing the use/consumption of energy (DR3) is the next DR in importance. Technology can help in reducing the losses in energy transmission and distribution. Better technologies in lighting, heating and cooling equipment, transportation, etc., can help reduce energy consumption and improve the economic benefits. (Wan et al., 2015). Green suppliers and green procurement (DR9) can promote the use of non-hazardous items during procurement (Rostamzadeh et al., 2015). In Green purchasing, the issues related to sustainability are given due consideration during the purchase of inputs in a supply chain. Green suppliers and purchase practices evaluate various products' impact on the environment during the purchase of products.

Design for Environment (DR 11) is planning the engineering aspect of design to reduce the effect on the environment during the design stage itself. This process can lead to a competitive advantage as the time to comply with legal regulations decrease, and the hazardous wastes are reduced (Klassen, 2000). The cost of compliance can be evaluated at the design stage itself. Design for environment assesses the health, safety and environment aspects for the full life cycle of products. Environmental management systems (DR6) like ISO 14000 provide an effective management system for organizing best practices and information for the environmental impacts of products and services of an organization. EMS cover the supply chain environmental impact from raw material to packaging. It is found that institution pressures in developing countries can encourage the implementation of EMS, such as ISO 140001 environmental certifications (Zhu et al., 2013).

Reverse Logistics (DR7) requires creating a network to facilitate reuse and recycling. The design requirements later coming in order of importance are Life Cycle Assessment (DR8), Mandate labeling of energy performance (DR4), Extended Producer Responsibility (DR13), Increased durability of products (DR12) and health and occupational safety (DR14).

6.5 Research implications

Eco-efficiency aids in reducing wastage and pollution while creating an increased output with the same amount of resources. Managers should devise a strategic plan with indicators and incentives to improve the eco-efficiency of their processes. Eco-efficiency gives a competitive advantage to an organization by utilizing the resources efficiently and creating a positive image among consumers. This study has identified the CRs and DRs for improving the eco-efficiency in the electronics industry, and a House of Quality is constructed. Organizations can prioritize their attention to the CRs of Reduced dispersion of toxic substances, Reduced material intensity and Reduced energy intensity initially as they are found to have high weightage in the study. Accordingly, the 14 DRs are prioritized in order of importance, which managers could focus on to improve eco-efficiency.

Reducing GHGs, air emissions, VOCs, and carbon footprint (DR5) can be adopted by considering life-cycle emissions for greenhouse gas mitigation targets (Babaee et al., 2020). Managers can achieve Reduced use/consumption of resources (DR1) by promoting a circular economy in the electronics sector (Rossi et al., 2020). Bhuiyan et al. (2021) advocate using low-power electronic appliances using renewable energy for developing countries. Such applications can be supported by using renewable energy like Solar (DR10) with advances in power electronics devices and distributed generation systems. There is extensive use of raw materials due to the increased use of electronics products. Managers should introduce innovative state-of-the-art materials (DR2) like nanocellulose, which are natural renewable sources and biodegradable material for printed electronics (Agate et al., 2018). Managers may widely adopt technologies to reduce the use/consumption of energy (DR3) to improve the eco-efficiency of their process and organization.

Managers can use the framework of CRs and DRs in this research to develop and devise policies to improve eco-efficiency. Based on the inter relationships and influence of CRs and DRs in this study, managers can assign due importance to DRs in their planning process. This model can be implemented in other industries as well with suitable modifications in CRs and DRs to reduce the environmental impact while adding economic value.

The research implications in academics are its contribution to the eco-efficiency literature. It brings a new element to the concept of eco-efficiency in terms of customer requirements and design requirements. The research identifies and prioritizes the CRs and DRs for eco-efficiency and the topics discussed offers scope for further research. Given the larger academic focus on environmental performance, the research could be a base for developing complex frameworks to increase eco-efficiency.

For a sustainable supply chain, it is fundamentally essential to manage the upstream supply chain. The process of sustainability management in supply chain should commence from the selection of suppliers itself. From the literature it is found that study for selecting a sustainable supplier in a supply chain giving due weightage to the ethics dimension, which is seen as an essential part of a procurement process and applying a hybrid MCDM method in the Indian electronics industry is lacking. To address this gap, a model for sustainable supplier selection is proposed and discussed in the next chapter.

CHAPTER 7

A MODEL FOR SELECTION OF SUSTAINABLE SUPPLIERS IN SUPPLY CHAIN USING AHP-TOPSIS APPROACH

7.1 Introduction

SSCM manages collectively and effectively the supply chain's economic, environmental, and social performances (Seuring and Müller, 2008). The sustainable supply chain is implemented by inducing sustainability in design, logistics, supplier selection, manufacturing practices, workers' welfare, etc. Supplier selection is crucial as it is done upstream of a supply chain and thus has economic, environmental and social bearing downstream (Sarkis and Dhavale, 2015; Hofstetter, 2018).

Strategic sourcing is a vital part of supply chain management. Supplier selection is critical for an organization as it affects the end product's price, competitiveness, and profit. The decision becomes complex due to globalization, government regulations, changing customer requirements and outsourcing, which fluctuate a purchaser's selection set (De Boer, 1998).

There has been research in literature for supplier selection in GSCM (Islam et al., 2018, Tseng et al., 2016, Kannan et al., 2014) and SSCM. The research has mainly concentrated on the Triple Bottom Line, focussing on economic, social and environmental criteria. A very important criterion during supplier selection is ethics. The ethics dimension is often put as part of social criteria in literature and thus lacks due weightage and attention. Ethics is the root of fundamental principles like integrity, fairness and transparency in procurement (United Nations, 2017). The ethical elements of the supply chain are used to assess the corporate reputation.

Leading electronic companies are making their supply chains closed-loop wherein used products are recycled, refurbished or disposed of in an environment-friendly manner. Large electronic companies are reducing their greenhouse emissions and electricity consumption per unit of production. Companies pursue practices such as DfE for the eco-design of their products. For e.g., Epson gives an ecology profile of their printers. Technology modernization like micro-joining and high energy density material help increase the longevity of products while increasing sustainability. Thus, the selection of sustainable suppliers is a responsibility that the industry needs to adapt.

In this research, we attempt to select a supplier satisfying the requirements of being a member of a sustainable supply chain and can be called a "sustainable supplier". These requirements are defined by the focal company considering its TBL approach towards people, planet and profit. We define a sustainable supplier as a "supplier who can meet the standards of an organization's set attributes for environmental impact, social compliances and ethical practices while delivering on the economic factors of quality, price, delivery along with managing the varying demands". The organization's set attributes are the targets or benchmarks set by the focal company in the social, environmental and economic areas. They can be related to performance, capabilities or other measures.

The multiple-criteria decision making (MCDM) methods have been widely used to prioritize and select the most suitable strategies. Using this approach, the criteria and sub-criteria are evaluated to get their weightage, and the alternatives are prioritized utilizing MCDM techniques (Shaifee, 2015).

7.2 Supplier Selection Methods

The supplier selection involves multiple criteria to be evaluated in an uncertain environment. Different modeling approaches have been used in selecting suppliers for a sustainable supply chain. They can be broadly classified into mathematical, analytical, qualitative, artificial intelligence and hybrid models

(Zimmer et al., 2016). The MCDM method has largely been used in supplier selection, considering multiple goals of different dimensions and uncertainty.

Table 7.1: Methodologies and SSCM dimensions in literature for supplier selection in SSCM

Reference	Methodology	Dimensions			
		Economic	Environmental	Social	Ethical
Lee et al., 2009	Fuzzy AHP Delphi	✓	✓		
Bai and Sarkis 2010	Rough Set Theory	✓	✓		
Çifçi and Büyüközkan, 2011	Fuzzy AHP	✓	✓		
Kuo and Lin, 2012	ANP DEA	✓	✓		
Shaw et al., 2012	Fuzzy AHP and MOLP	✓	✓		
Hsu et al., 2013	DEMATEL	✓	✓		
Govindan et al., 2013	Fuzzy TOPSIS	✓	✓	✓	
Yu and Wong, 2014	Fuzzy TOPSIS	✓	✓		
Mahdiloo et al., 2015	Fuzzy DEA	✓	✓		
Azadi et al., 2015	Fuzzy DEA	✓	✓	✓	
Hashemi et al., 2015	GRA ANP	✓	✓		
Akman, 2015	Fuzzy c-means and VIKOR	✓	✓		
Fallahpour et al., 2016	DEA ANN	✓	✓		
Jain et al., 2016	DEA	✓	✓		
Luthra et al., 2017	AHP VIKOR	✓	✓	✓	
Tavana et al., 2017	ANP QFD	✓	✓	✓	
Babbar and Amin, 2018	Fuzzy QFD	✓	✓		
Azimifard et al., 2018	AHP TOPSIS	✓	✓	✓	
Hatefi and Tamosaitiene, 2018	AHP GRA	✓	✓	✓	
Guarnieri and Trojan, 2019	AHP ELECTRE-TRI	✓	✓	✓	✓
Mohammed et al., 2019	Hybrid MCDM-FMOO	✓	✓	✓	

Literature review indicates that the MCDM technique is widely used for sustainable supplier selection problems (Govindan et al., 2015). Researchers have used many methodologies to develop models in supplier selection for practicing green and sustainable SCM. The focus in earlier research has been mainly on green suppliers. There has been a noticeable shift towards selecting sustainable suppliers and integrating methods for decision making. Each combination has its uniqueness and advantages to evaluate a set of supplier criteria. TOPSIS method has been used in supplier selection problems as it is easier to implement and less complex (Zimmer et al., 2016). It is also a proven and effective method to handle supplier selection problems involving multiple objectives. Hybrid methods have evolved considering the multiple goals involved in the selection process. The summary of approaches used in literature for sustainable supplier selection is depicted in Table 7.1.

7.3 Sustainable Supplier Selection Criteria & Framework

From the literature on sustainable supplier selection, the selection criteria and sub-criteria have been extracted based on their relevance and application to the electronics industry in India. This was discussed with the managers of the case industry and an academician, thus giving a wholesome approach from both industry and academia perspectives. In this study, the criteria have been finalized considering their applicability to 1st tier suppliers in the industry. The dimensions of sustainability finalized criteria with codes, and their references are given in Table 7.2 and elaborated in the next section.

7.2.1 Economic factors

In any business, the main purpose is to generate profits and therefore, traditionally, economic factors remained the primary consideration (Sarkis and Talluri, 2002, Chen et al., 2006). It is necessary that to stay in business, a firm has to be economically viable. Firms need to manage the trade-off in making profits while dealing with environmental impacts and social responsibilities. The four economic factors considered in supplier selection are Quality, Cost, Delivery and flexibility described further.

(i) ***Quality***: It is the degree to which the product meets the acceptable level of functioning and service. The performance, repairs required, availability of spares, and after-sales service are also considered. Firms look for the best quality as it looks towards consumer satisfaction, repeat purchase and market reputation. Adherence to specifications, quality test techniques and defect rate are the parameters on which the quality is benchmarked.

Table 7.2: Sustainability dimensions and criteria considered for sustainable supplier selection

Dimension	Criteria	Code	Explanation	References
Economic	Quality	QLY	Quality is the degree to which a product performance and characteristics meet or exceed the requirements expected.	Junior et al. (2013); Dou et al. (2014); Hashemi et al. (2015).
	Cost	CST	It is the cost to buy raw materials and the ability to supply the products at reasonable rates.	Sarkis and Dhavale (2015); Tahriri et al. (2014); Kilic (2013).
	Delivery	DLY	It is the ability to deliver on time and level of delivery reliability.	Sawik (2016); Akman (2015); Sarkis and Dhavale (2015).
	Flexibility	FXY	To manage the variations in demand, production capacity and responsiveness.	Wang et al. (2012); Bai and Sarkis (2014); Hashemi et al. (2015).
Environment	Eco-design	ECD	The designing of products to minimize harmful effects to the environment during its lifecycle.	Handfield et al. (2002); Humphreys et al. (2003); Akman (2015).
	Resource reduction and consumption	RRC	Reduce or use a substitute for renewable resources, water, etc., and thereby its consumption..	Govindan et al. (2013); Humphreys et al., 2003
	Pollution control	PUC	It is controlling the pollution caused to air, water, soil, etc.	Çifçi and Büyüközkan (2011); Baskaran et al. (2012); Büyüközkan (2012); Kannan et al. (2014); Sarkis and Dhavale (2015).
	Environment Management Systems	EMS	Conformance to environmental policies and regulation.	Shen et al. (2013); Kannan et al. (2014); Hashemi et al. (2015).
	Green Image	GRI	It is the image created when consumers are actively aware of the business's sustainable practices and eco-friendly actions.	Awasthi et al., (2010); Mafakheri et al., (2011); Bali et al., (2013); Kannan et al., (2015).
Social	Human rights	HUR	The rights giving certain standards of protection in labour issues and associated legal rights.	Azadnia et al. (2012); Govindan et al. (2013); Sarkis and Dhavale (2015).
	Safety Systems & Occupational Health	SSH	The deployment of systems to protect humans, plants and equipment. It is the prevention of work-related injury or illness, both physical and mental.	Wang et al., (2012); Baskaran et al., (2012); Amindoust et al., (2012).
	Corporate Social Responsibility (CSR)	CSR	Grant, Donations and welfare services to local communities.	Govindan et al.,(2013); Hutchins and Sutherland, (2008); Sarkis and Dhavale (2015); Amindoust et al. (2012); Xu et al. (2013).
	Education & Training	EAT	Education & training upgrades the knowledge and motivates action towards a sustainable world.	Awasthi et al., (2010); Govindan et al., (2013); Kannan (2018).

Ethical	Code of Conduct	COC	A code of conduct shows the ethical practices and provides direction to its employees on ethical behaviour under various circumstances. A supplier's code of conduct demonstrates the ethical, social and environmental standard a firm sets for itself.	Kuo et al. (2010); Amindoust et al., (2012); Wang et al., (2012); Sarkis and Dhavale (2015).
	Conflict of Interest	COI	Conflict of interest is the position of an employee or company to exploit a functionary in his official capacity for personal benefit.	Paine (1994); Reuter et al., (2012).
	Transparency in Accounting and Business	TAB	Furnishing information on emissions, legal issues along with fair accounting practices in business.	Tseng (2011); Dou et al. (2014); Grimm et al., (2014).

(ii) ***Cost***: The cost of the product includes not only the cost for purchase of raw materials but also inventory cost, after-sales cost, order cost, fixed and variable cost. Cost is a primary factor in supplier selection, and products or services have to be competitively priced in the market. It is an important criterion as procurement cost dictates profit maximization. Cost minimization helps increase the profits for a company. To achieve this, they strive to have a low-cost supplier base. Sourcing is now global to seek competitive suppliers wherein the focus is to reduce the procurement price, logistics cost, levies & duties, and documentation cost. The cost incurred to assess a supplier's parameters like performance, financial stability, service, etc., is also aspired to be kept low.

(iii) ***Delivery***: Timely delivery of demanded products is important to serve the purchaser's purpose. The lead time required for delivery, safe and reliable delivery are parameters to be considered. Organizations are much dependent on the reliability of a timely delivery schedule of suppliers (Genovese et al., 2013; Azadnia et al., 2015). The delay in the delivery of essential parts can critically affect the production schedule of a firm. The inventory strategy of an organization is also based on the lead time and delivery schedules of items it purchases.

(iv) ***Flexibility***: Flexibility is required to manage demand volatility, add products to existing operations and market variations. This has to be handled by increasing responsiveness, maintaining inventory and supplier base. Flexible suppliers enhance a firm's capability in responding rapidly to changing customer demands and unexpected emergencies. Suppliers are also exploring ways to increase their flexibility (Zhang et al., 2002) to increase their competitiveness in the market.

7.2.2 Environment factors

The environment dimension has been an important part of research in sustainable supply chain management. The industrialization has caused much pollution, making it necessary for firms to have supply chains that do not harm the environment and conserve the ecology. This is possible for firms by directing their supplier to adopt sustainable practices. The green procurement strategies contribute significantly in addressing this aspect in a supply chain (Varnäs et al., 2009). The five environmental factors considered in supplier selection are Eco-design, Resource reduction and consumption, Pollution control, Environment Management Systems and Green Image, which are described further.

(i) ***Eco-design***: This refers to the designing of products so as to minimize the harmful effects to the environment while making, using and disposing of it. It supports achieving sustainability aims by reducing waste, usage of non-renewable resources and aiding recycling. It is an approach of integrating the environmental protection criteria over a product or service's lifecycle. It leads to designing or redesigning systems, processes, products or services to restore or prevent damage to the environment and society. It has to be ensured that the principle of eco-design should be applied to projects having an environmental impact from conception to development. New eco-design approaches of smaller and efficient circuity, maximum material recovery, flexible electronic systems, wire bonding and toxic reduction, are being taken up by industry to improve sustainability (Li et al., 2015)

(ii) ***Resource reduction and consumption***: Non-renewable resources and energy consumption is to be reduced. Natural resources are used judiciously and to be replaced by renewable resources. Suppliers with lean supply chains, waste minimization and reverse logistics systems can reduce consumption. Organizations can become increasingly environmentally friendly by recycling, reusing, and reducing raw material usage through reverse logistics (Carter and Ellram, 1998). Electronic products use a large amount of metals and minerals, which include precious and rare metals. Therefore, reducing resource consumption by resource recovery and using new materials such as carbon nanomaterial should be pursued.

(iii) ***Pollution control***: Control and prevention of pollution to air, water, soil, etc., is essential and monitored by various regulations. This includes green gas emissions, water pollution, air emissions, use of hazardous material etc. Production and manufacturing processes consume high energy, and a by-product of this increased use is pollution. As a mandate, the polluting wastes should be monitored and controlled through specific programs and directives (Marshall and Farahbakhsh, 2013). Pollution can also be reduced by reducing the use of harmful materials. Firms can keep a tab on this by demanding or knowing the input materials of their suppliers. The production process of high-end electronic appliances causes pollution by releasing chemical compounds, water pollution, etc. Companies should take adequate measures to control and reduce pollution while manufacturing electronic products.

(iv) ***Environment Management Systems (EMS)***: Environment Management Systems is the framework and implementation for adhering to environmental protection policies. It includes certifications such as ISO 14000, regulator compliances and green processes. ISO 14001 sets the aspects for the environmental management system in the firm. The waste electrical electronic equipment (WEEE) directive is to reduce the quantity of waste electrical and electronic equipment by promoting reuse, recycling and other forms of recovery (Lee et al., 2009). With rapidly changing technology and their higher use, electronic & electrical equipment disposal has become a serious problem for the industry. The Restriction of Hazardous Substance (RoHS) guidelines limit hazardous chemicals in electrical and electronic equipment. RoHS bars manufacturers and sellers from the generation of more than agreed levels of toxic and harmful material.

(v) ***Green Image***: The green image is the image of a supplier to be seen as an environment conscious supplier and manufacturing green products. This portrayal of a company is affected by its green product, relationship with stakeholders, reputation in promoting sustainability and share among customers opting for green products. The green image is enforced by following directives such as RoHS (Hsu & Hu, 2009). The perception of stakeholders on the green image of the company encourages the business prospectus. The green practices adopted by companies impact customer perceptions of their green image (Namkung and Jang, 2013). Companies aspire for a green image to build their industry position and have a competitive advantage.

7.2.3 Social factors

The social perspective involves managing the social resources, including the social values and human resources (Sarkis et al., 2010). It is to be seen that at the individual and organizational level the fundamental human rights are protected. Many authors have argued that the social aspect is the crucial dimension in sustainability involving various stakeholders with differing goals, and managing this difference is a challenge (Hall and Matos, 2010). The four Social factors considered in supplier selection are Human rights, Safety Systems & occupational Health, Corporate Social Responsibility and Education & Training, which are described further.

(i) ***Human rights***: It includes working hours, child labour, gender equality & diversity, employee rights, wages, etc. Human rights and labour issues are highly important to organizations extending across the supply chain (Emmelhainz and Adams, 1999). The inclusion of human rights criteria in supplier selection creates a socially sustainable value chain. It shows that suppliers treat their employees equally, with respect and dignity. The employees are not subjected to physical, psychological or sexual harassment. They are neither discriminated against nor intimated based on their ethnicity, gender or religion. It warrants that the workers are paid fair wages and legally compliant benefits and establish grievance redressal mechanisms in the workplace.

(ii) ***Safety Systems & Occupational Health***: Safety systems include deployment of systems for the safety of humans, plants and equipment when the process goes out of set control margins. These include fire safety, accident prevention, safety engineering techniques, etc. It prevents accidents or injuries to workers during their job. It also encompasses ergonomic measures and protection tools for worker's safety and well-being. Occupational Health is taking care of the health of employees and avoiding their exposure to hazardous environments. Healthcare of workers is primary social care that has to be provided by the employer, and it includes both physical and mental health. This practice is also important while delivering, installation and commissioning equipment by the supplier's staff. Organizations follow specific health and safety protection practices based on their electrical works, working at heights, chemicals handling, and civil works. e.g., scaffolds, safety nets, safety harnesses, precautions against fire, radiation hazards, non-conductive gloves, insulated tools and handling equipment. Companies can adopt standards such as BIS (Bureau of Indian standards), electrical safe work practices specified in OSHA (Occupational Safety and Health Administration), implementation of NDMA (National Disaster Management Authority) guidelines on CDM (chemical disaster management), etc. In electronics industries such as chip manufacturing plants, the workers may face occupational health risks from inhalation of harmful chemicals and need to be adequately protected (Cai et al., 2018).

(iii) ***Corporate Social Responsibility (CSR)***: Selecting a socially responsible supplier is a key criterion. This criterion ensures that companies deal with self-regulating suppliers who are socially accountable while doing business. Companies can also be evaluated based on the amount which they set aside for CSR activities. To be effective in corporate social responsibility, the focal company apart from itself also needs to see that all firms in its supply chain act socially responsible way (Enderle, 2004).

(iv) ***Education & Training***: Education & Training are necessary to upgrade the knowledge and skills of employees. It gives an insight to them to look for sustainable development as a whole. It creates value and motivates employees and the community towards biodiversity and climate change in creating a sustainable process. The level of service from a supplier is highly influenced by the emphasis they put on training and education in their firm.

7.2.4 Ethical factors

In this research, the standard sustainability dimensions are extended by adding the Ethical dimension. The ethical dimension involves ethical value collaboration among supply chain members and ethical purchasing (Roberts, 2003). Organizations that leverage ethics and introduce systems that uphold ethical values can achieve true sustainability. Suppliers to qualify as sustainable suppliers need to maintain high ethical standards apart from meeting societal and environmental criteria. The three Social factors considered in supplier selection are Human rights, Conflict of Interest and Transparency in Accounting and Business, which are described further

(i) ***Code of Conduct***: A sustainable supplier selection is highly influenced by an organization's code of conduct (Goebel et al., 2012). Workplace compliances and regulations vary in different countries. To address this, leading firms develop their codes of conduct to monitor their supply chain and ensure a higher level of compliance. A code of conduct is compiled by considering well-established principles of sustainability. Suppliers and professionals should act with integrity and ethically do their business as part of their social responsibilities. A supplier's code of conduct demonstrates the ethical, social and environmental standard a firm sets for itself. A code of conduct shows the ethical practices and provides direction to its employees on ethical behaviour under various circumstances (Preuss, 2010). The code of conduct can guide the course of action to be followed specifically by procurement professionals when facing dilemmas during trade-offs with environmental or social issues.

(ii) ***Conflict of Interest***: It is a provision or guidelines on decision-making when there is a situation of conflict of interest (Paine, 1994). It is a situation where there are competing interests or loyalties. Sometimes the position of an employee or organization makes it capable of exploiting an official for their benefit, and it is an unethical way of doing business. Purchasers are now coming up with solutions like signing the integrity pacts with vendors to address such issues. This ethical factor helps in maintaining professional integrity in procurement dealings with the supplier. It assures decisions on the employee or supplier do not unduly influence the procurement transactions. Any member of the organization or their family should not have any financial interest or benefit by awarding the contract to a certain company. The members should refrain and not seek favour or gratitude in monetary or other forms from their subcontract.

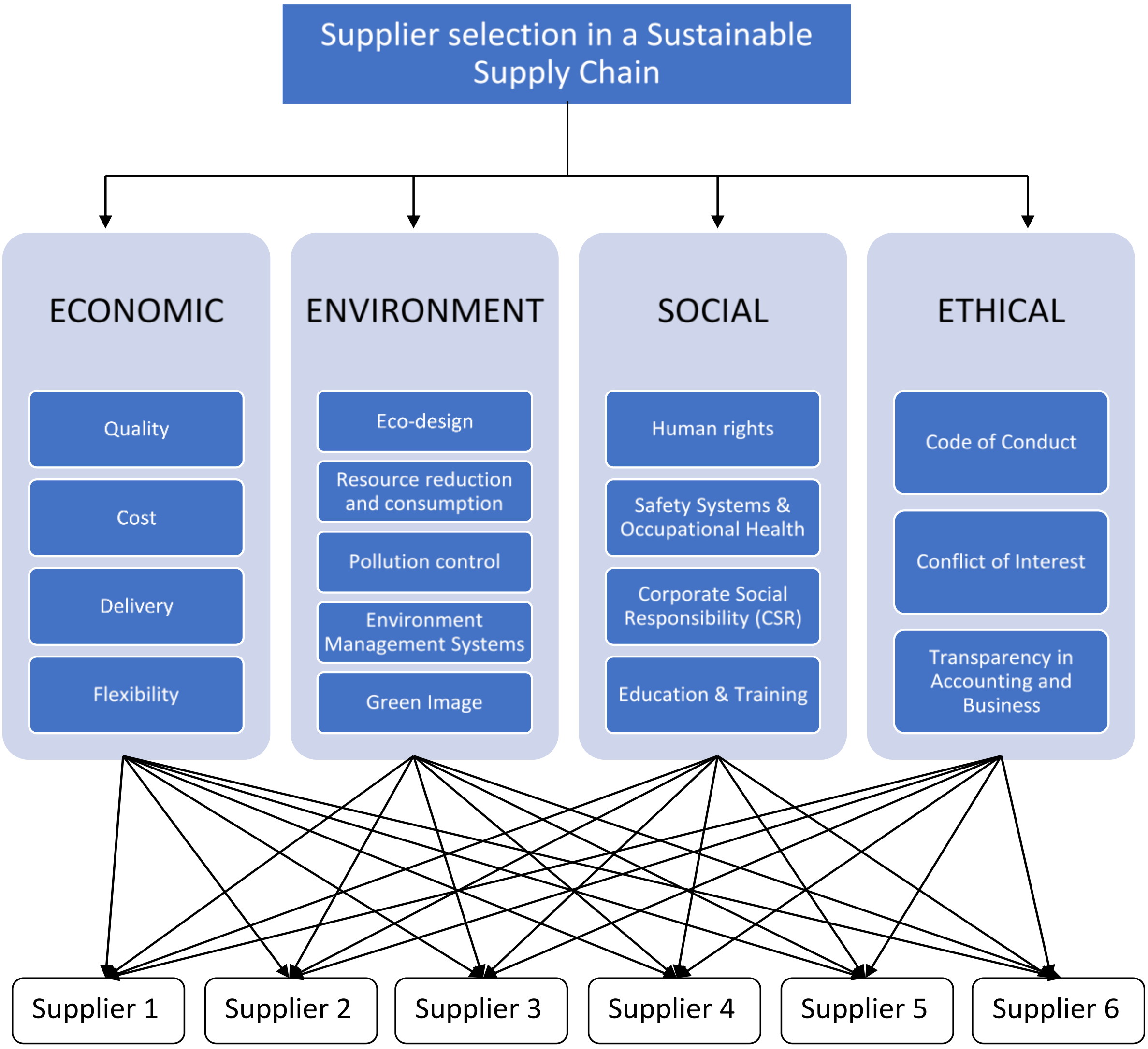


Figure 7.1: Criteria hierarchy model for selection of supplier in sustainable supply chain

(iii) ***Transparency in Accounting and Business***: A transparency in accounting records and business practices instils confidence and trust in the supplier. The traditional accounting process does not reveal clear information on the environment and social dimensions. The accounting principles are reviewed in countries to increase business transparency. In accounting, it offers a clear and understandable financial situation for the company. Reports of cash flows, income, and balance sheets are made available to the stakeholders. This helps in reducing uncertainty about a firm during procurement evaluation. Business transparency is demonstrated in a company's culture of information sharing and openness in decisions. Transparency in business increases trust in the supply chain, improves relationships and leads to powerful partnerships.

The criteria hierarchy model in this thesis for selecting suppliers in the sustainable supply chain is shown in Figure 7.1.

7.4 Research Design

7.4.1 Methodology Framework

The proposed methodology framework for sustainable supplier selection is shown in Figure 7.2. The framework can be divided into four phases.

Phase 1 – The product or service in the industry is determined, leading towards the relevant sustainability criteria and sub-criteria. This study considers the electronics industry and determines the sub-criteria through literature review and discussion with experts. A potential list of suppliers can be identified considering the objectives and product.

Phase 2 – Our approach considers four main criteria for sustainability implementation, which are further assessed to identify the sub-criteria. Through literature review and experts' opinions, the sub-criteria are identified. Delphi method is employed to substantiate the result. Questionnaires were given for obtaining responses to identify the sub-criteria in sustainability dimensions. Based on the responses, three rounds of discussions were held with the experts to reach a consensus on the sub-criteria finalized in the study.

Phase 3 – In selecting a sustainable supplier, all criteria may not have the same significance. So the weights of criteria and sub-criteria are determined by AHP. After deciding the local weights, global weightage of sub-criteria is found.

Phase 4 – The potential suppliers are evaluated on their parameters against the criteria. Technique for order of preference by similarity to ideal solution (TOPSIS) is adopted to rank and find the optimal supplier for a sustainable supply chain. Sensitivity analysis is performed to check the robustness of the result.

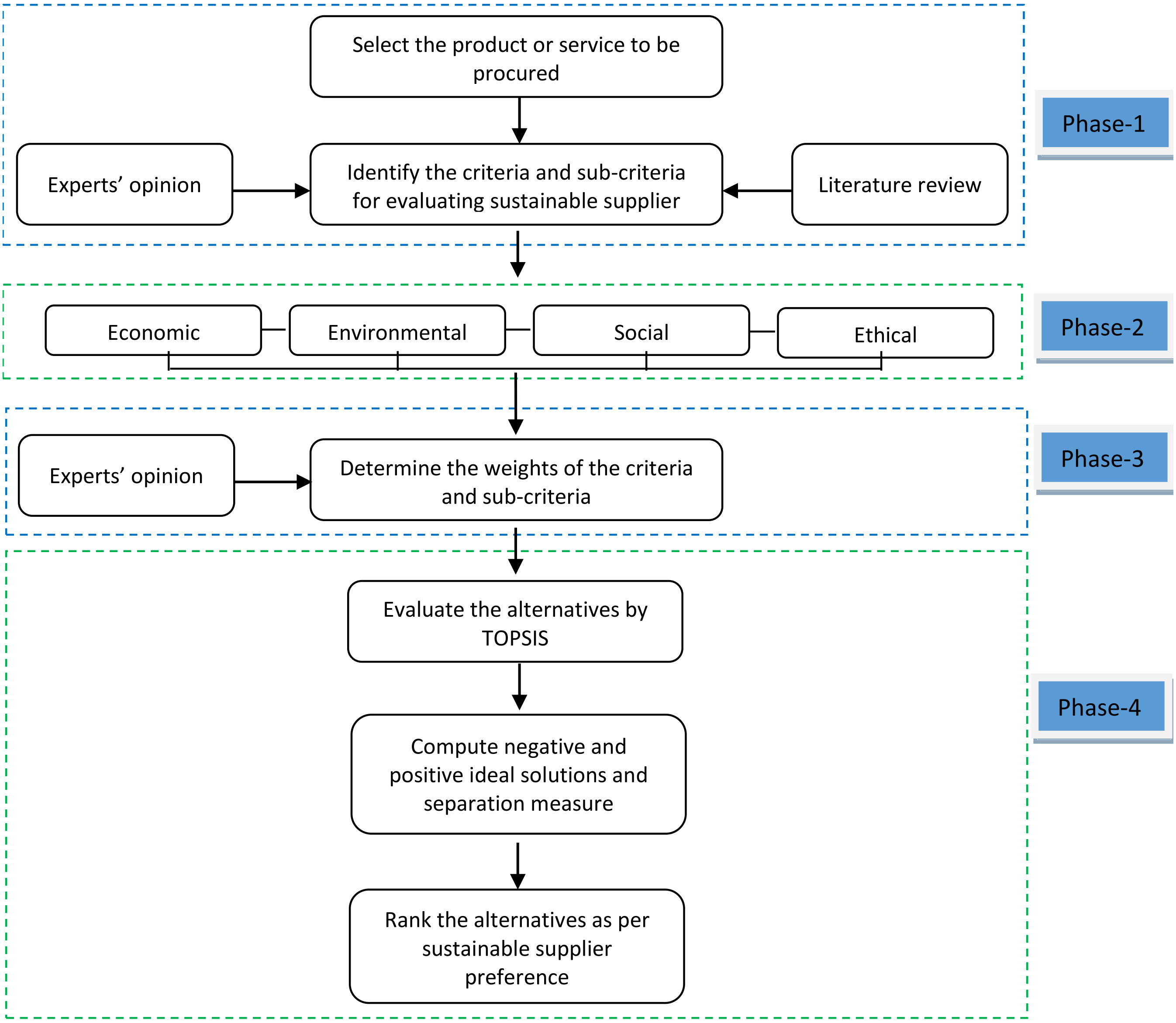


Figure 7.2: Sustainable supplier selection framework

7.4.2 AHP-TOPSIS Method

Supplier selection in a sustainable supply chain has multiple criteria, and for solving it, multi-criteria decision making methods are utilized. The criteria used in this selection have sub-criteria of both quantitative and qualitative nature. AHP can be effectively used in such situations. AHP helps structure the problem and is used in this research to determine the weights of criteria in a sustainable supplier selection. The TOPSIS method is used in this research to rank the suppliers considering the sustainability perspective. In TOPSIS, the priority is given to the alternative nearest to the positive ideal solution and farthest from the negative ideal solution. The TOPSIS method consists of the following steps. (i) preparation of the normalized decision matrix. (ii) determining the PIS and NIS. (iii) by utilizing the n-dimensional Euclidean distance, the separation measures are calculated (iv) calculation of the relative closeness to the PIS (v) ranking the preference order. The combination of AHP and TOPSIS is used in this research to select sustainable suppliers.

In AHP, a pairwise comparison of objectives and alternatives is carried out to find the relative importance of alternatives. In determining the importance of each objective with others in a pairwise comparison, Saaty's nine-point scale as given in Table 7.3 is used.

Table 7.3: Scale of pairwise comparison for AHP

Weight	**Definition**	**Description**
1	Equal importance	Elements *i* and *j* are equally important
3	Moderate importance	Element *i* is weakly more important than element *j*
5	Strong importance	Element *i* is strongly more important than element *j*
7	Very strong importance	Parameter *i* is very strongly more important than parameter *j*
9	Absolute importance	Element *i* is absolutely more important than element *j*
2, 4, 6, 8	Intermediate values	Represents compromise between the priorities

The eigenvector method is used to calculate the weights and see the possibility that the weights obtained by pairwise comparison are consistent. The consistency of the result is checked by the Consistency Ratio (CR). For the result to be consistent, the CR should not be more than 0.10 or 10%. AHP and TOPSIS are clubbed for decision making in multi-criteria problem, and the procedure is elaborated as follows:

Step 1. A decision matrix having criteria/attributes is constructed by pairwise comparison. The matrix is represented as:

$$C = \begin{bmatrix} c_{11} & c_{21} & c_{13} & \cdots & c_{1n} \\ c_{21} & c_{22} & c_{23} & \cdots & c_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & c_{n3} & \cdots & c_{nn} \end{bmatrix}$$

where c_{ij} denotes the comparative importance of i^{th} attribute with respect to j^{th} attribute vis-a-vis overall objective.

Step 2. The decision matrix is then normalized with this formula.

$$m_{ij} = \frac{c_{ij}}{\sum_{j=1}^{n} c_{ij}} \tag{7.1}$$

Step 3 Calculate the local weights of criteria/sub-criteria and test the consistency.

Prepare the weighted normalized decision matrix

$$W = [w_i]_{n\times 1} \tag{7.2}$$

where $w_i = \sum_{j=1} \frac{m_{ij}}{n}$ (7.3)

i=1,2,3…n, j=1,2,3…n

Calculate the consistency vector. The consistency vector CV = $[cv_i]_{1\ldots n}$ is used to denote the consistency values for different criteria where $cv_i = \frac{C\,w_i}{w_i}$ for i=1,2,…n.

Determine the maximum Eigen value λ_{max}.

$$\lambda_{max} = \frac{\sum_{i=1}^{n} cv_i}{n} \tag{7.4}$$

Calculate the consistency index & consistency ratio. The consistency index is found using the formula, where n is the number of criteria:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{7.5}$$

Pairwise comparison is said to be consistently evaluated if the consistency index is 0. The consistency ratio (CR) is calculated to check the consistency.

$$CR = \frac{CI}{RI} \tag{7.6}$$

RI is the average random index where value is determined by different orders of pairwise comparison matrix. If the CR value obtained is smaller or equal to 10% or 0.10, then the evaluation of attribute importance is accepted, and inconsistency is ignored. Else, the evaluators are asked to revisit their judgments to increase the consistency level.

Step 4 Construct normalized decision matrix. The matrix has attributes with different units; it is transformed into a dimensionless unit that enables comparisons across criteria. The data is normalized as follows:

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum a_{ij}^2}}$$

for i = 1, …, m; j = 1, …, n

Step 5. The weighted normalized matrix v_{ij} is determined by multiplying each column of the matrix r_{ij} by the weight w_j, obtained by AHP.

$$v_{ij} = w_j r_{ij} \tag{7.7}$$

Step 6. The ideal, i.e., best and negative-ideal worst solutions are found using the formula shown below, where J = (j = 1, 2... n)/j is associated with the beneficial attributes and J' = (j = 1, 2, ..., n)/j is associated with the non-beneficial attributes. The maximum value of benefit attributes and minimum value of cost attributes is taken for the positive ideal solution (A*), whereas the minimum value of benefit attributes and maximum value of cost attributes is taken for the negative ideal solution (A^-). A* and A^- are defined as follows:

$$A^* = \{\left(\sum_i^{max} v_{ij} \mid j \ \varepsilon J\right), (\sum_i^{min} v_{ij} \mid j \ \varepsilon J') \mid = 1, 2, \ldots m\} = \{v_1^+, v_2^+, v_3^+, \ldots v_n^+\} \tag{7.8}$$

$$A^{-} = \{\left(\sum_{i}^{min} v_{ij} | \ j \ \varepsilon J \right), (\sum_{i}^{max} v_{ij} | \ j \ \varepsilon J') | = 1, 2, \ldots m\} = \{v_1^-, v_2^-, v_3^-, \ldots v_n^-\} \quad (7.9)$$

Step 7. The distance of each alternative from the ideal solution is measured using the formula as shown below (for i = 1,2,...m):

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2} \quad (7.10)$$

The distance from the negative ideal solution is measured as

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2} \quad (7.11)$$

Step 8. The relative closeness to the ideal solution is determined by using the equation as elaborated here.

$$C_i^* = \frac{S_i^-}{S_i^+ + S_i^-} \quad (7.12)$$

Step 9. A set of alternatives are then ranked according to relative closeness values C_i^* in descending order. In other words, a higher relative closeness value is the better alternative.

7.5 Application of the proposed model

The proposed model has been applied to select suppliers in the supply chain of an electronics company making electronic components for over 15 years in India and having turnover above Rs. 400 cr. The company is into the manufacturing of electronic components for industrial customers. The manufacturing plants of the company are located in western India. The company has two manufacturing plants and has a product portfolio of three major items. The company has a supplier base of more than 100 suppliers, and 75% of the sourcing is indigenous. The experts consulted in the study were senior managers with industrial experience of over 20 years in the electronics industry. They were responsible for implementing various sustainability-related programs in green purchasing, reverse logistics, technology development, and product life cycle management. All these four experts in the study were familiar with the latest happenings and advancements in sustainable supply chains. The profile of experts is shown in Table 7.4. Sixteen sub-criteria under the four criteria were shortlisted through literature review and interviews with the experts. These sub-criteria are shown in Table 7.1 and the criteria to which they belong. The four managers gave their responses to the importance of the criteria. The first response was obtained by individual interviews with the managers. This was followed by combined discussions to reach a consensus on the response. With this response, the AHP TOPSIS method was applied, as illustrated in the following steps.

Table 7.4: Profile of Experts

Experts	Experience	Division	Role	Designation
Expert 1	23 Yrs.	Plant Operations	Product life cycle management	Assistant General Manager
Expert 2	22 Yrs.	Purchase	Green purchasing	Senior Manager
Expert 3	22 Yrs.	Product Development	Technology development	Head
Expert 4	21 Yrs.	Logistics and Disposal	Reverse logistics	Senior Manager

Step 1: Firstly, the four criteria are taken for creating a pairwise comparison matrix. The pairwise comparison matrix is prepared by comparing the relative importance between the two criteria. The comparison matrix of the main criteria is shown in Table 7.5.

Table 7.5: Criteria Comparison Matrix

Dimension	Economic	Environment	Social	Ethical
Economic	1.00	3.00	2.00	3.00
Environment	0.33	1.00	0.50	2.00
Social	0.50	2.00	1.00	2.00
Ethical	0.33	0.50	0.50	1.00

Step 2: Normalize the matrix obtained as per equation (7.1) and calculate the criteria weights. The weightage indicates the importance given to each criterion. The normalized matrix and criteria weights are shown in Table 7.6.

Table 7.6: Normalized matrix and Criteria weights

Dimension	Economic	Environment	Social	Ethical	Weight
Economic	0.46	0.46	0.50	0.38	0.450
Environment	0.15	0.15	0.13	0.25	0.171
Social	0.23	0.31	0.25	0.25	0.260
Ethical	0.15	0.08	0.13	0.13	0.120

Step 3: The consistency check is performed to see that the values obtained are permissible. The consistency ratio is calculated CR=0.0265 Since the Consistency ratio obtained is less than 0.1, the evaluation of criteria weights is reasonable.

It is seen from the evaluation that the highest weightage is given to economic criterion followed by Social, Environment and Ethics.

After forming the comparison matrix with four main criteria, the pairwise comparison matrix of sub-criteria with respect to its corresponding main criterion is prepared. The pairwise comparison matrix of four Economic sub-criteria is shown in Table 7.7. The economic sub-criteria normalized matrix and priority weights are shown in Table 7.8. The consistency ratio is found to be within acceptable limits.

Table 7.7: Economic sub-criteria comparison matrix

Criteria	QLY	CST	DLY	FXY
QLY	1	2	3	4
CST	0.50	1	4	5
DLY	0.33	0.25	1	3
FXY	0.25	0.20	0.33	1

Table 7.8: Economic sub-criteria normalized matrix and weights

Criteria	QLY	CST	DLY	FXY	Weight
QLY	0.48	0.58	0.36	0.31	0.432
CST	0.24	0.29	0.48	0.38	0.349
DLY	0.16	0.07	0.12	0.23	0.146
FXY	0.12	0.06	0.04	0.08	0.074

CR=0.077

Similarly, using steps 1, 2 & 3, the pairwise comparison matrix of five Environment sub-criteria and their priority weights is shown in Table 7.9. It is seen that the consistency ratio is found to be within the acceptable limit.

Table 7.9: Environment sub-criteria normalized matrix and weights

Criteria	ECD	RRC	PUC	EMS	GRI	Weight
ECD	0.06	0.05	0.10	0.03	0.03	0.053
RRC	0.28	0.26	0.19	0.35	0.46	0.310
PUC	0.22	0.53	0.39	0.26	0.31	0.342
EMS	0.17	0.07	0.13	0.09	0.05	0.100
GRI	0.28	0.09	0.19	0.26	0.15	0.195

CR = 0.073

The pairwise comparison matrix of four Social sub-criteria and their priority weights is shown in Table 7.10. The consistency ratio is found to be within the acceptable limit.

Table 7.10: Social sub-criteria normalized matrix and weights

Criteria	HUR	SSH	CSR	EAT	Weight
HUR	0.46	0.55	0.40	0.33	0.435
SSH	0.23	0.27	0.40	0.33	0.309
CSR	0.15	0.09	0.13	0.22	0.150
EAT	0.15	0.09	0.07	0.11	0.106

CR = 0.045

The pairwise comparison matrix of three Ethics sub-criteria and their priority weights is shown in Table 7.11. The consistency ratio is found to be within the acceptable limit.

Table 7.11: Ethics sub-criteria normalized matrix and weights

Criteria	COC	COI	TAB	Weights
COC	0.55	0.43	0.60	0.525
COI	0.18	0.14	0.10	0.142
TAB	0.27	0.43	0.30	0.334

CR = 0.046

The weight W_j for each sub-criteria thus obtained is illustrated in Table 7.12.

Table 7.12: The normalized sub-criteria weightings

Criteria	Sub-criteria	Weight
Economic	QLY	0.1941
	CST	0.1567
	DLY	0.0655
	FXY	0.0331
Environment	ECD	0.0091
	RRC	0.0528
	PUC	0.0583
	EMS	0.0171
	GRI	0.0334
Social	HUR	0.1130
	SSH	0.0803
	CSR	0.0390
	EAT	0.0274
Ethical	COC	0.0631
	COI	0.0170
	TAB	0.0401

Figure 7.3 illustrates that the factor Quality has the highest weightage. The managers agreed that this criterion is given the highest importance and is crucial for selecting the electronics component. This is followed by the cost and social criteria of human rights.

Step 4: The decision matrix giving each supplier's criteria value is constructed and shown in Table 7.14 based on applying the model in supplier selection of a major component sourced by the company. The sub-criteria Quality, Cost, Delivery, Flexibility, Pollution control, Human rights, Safety systems & occupational health and conflict of interest were identified as cost attributes. In contrast, Eco-design, Resource reduction and consumption, Environment management systems, Green image, Corporate social responsibility, education & training, Code of conduct and Transparency in accounting and business were identified as benefit attributes. In this application, the following metrics were used to measure each sub-criterion in evaluating the six suppliers. Quality is measured by Defects Per Million Opportunities (DPMO) based on previous supply or commitment given by the supplier. The cost is in Indian Rupees. Delivery is in number of days for delivery after placement of order. Flexibility is the electronics manufacturing services (EMS) provider's time taken for supplying in case of change in volume or providing the alternative part measured by changeover time taken and is graded based on scale. Eco-design, Environment management systems, Green image and Corporate social responsibility were graded high to low as per the scale. Resource reduction and consumption is measure in kilogram reduction, pollution control in parts per million (PPM), Human rights in the number of violation incidents, Safety systems & occupational health in Lost Time Injury Frequency Rate (LTIFR), Education & training on the number of training sessions held, conflict of interest in the number of cases and transparency in accounting and business on the disclosure level rated by the experts. The subjective factors are converted using a common scale as per Table 7.13. The decision matrix obtained is normalized and shown in Table 7.15.

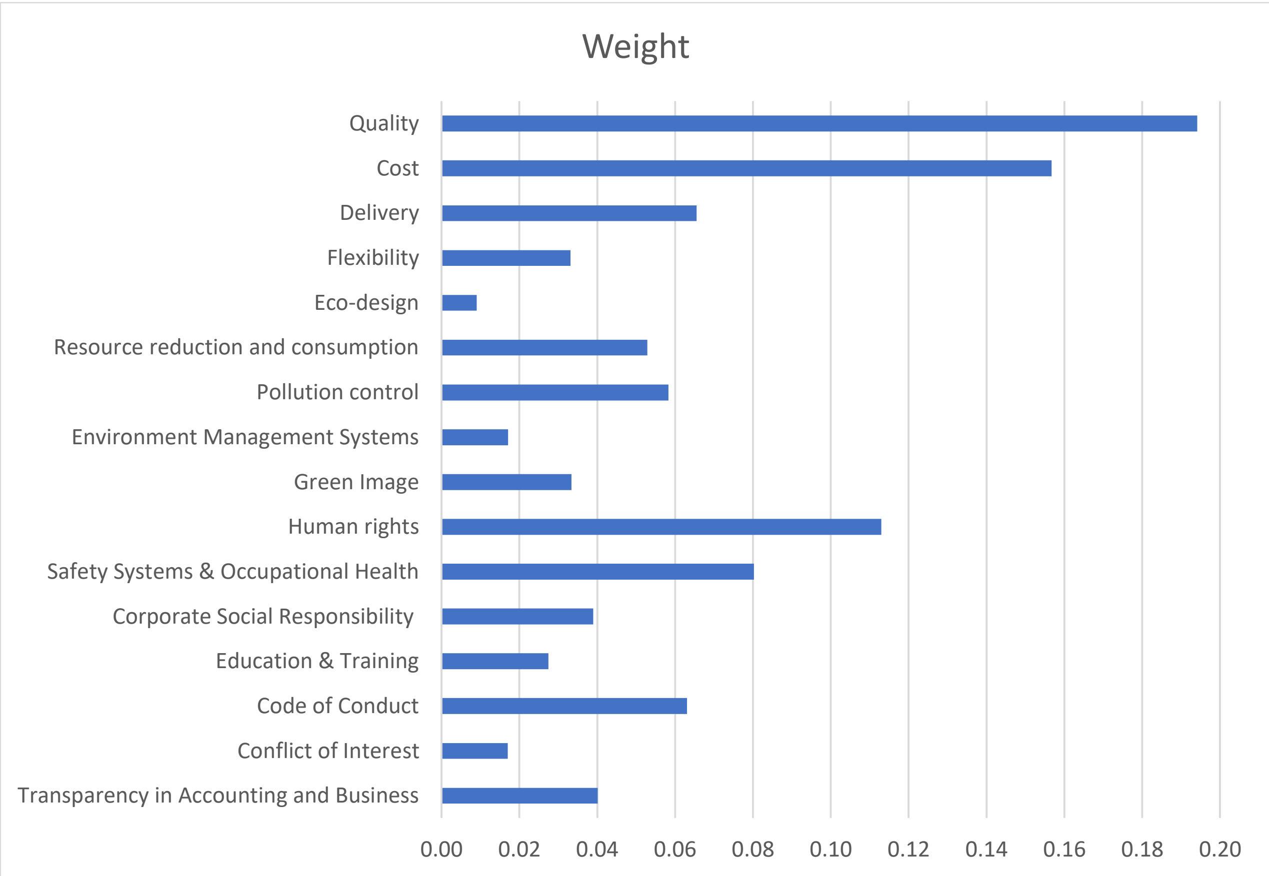


Figure 7.3: Weights of sub-criteria

Table 7.13: Scale for Intangibles

Cost Attributes	Scale	Benefit Attributes
Very High	1.0	Very Low
High	3.0	Low
Average	5.0	Average
Low	7.0	High
Very Low	9.0	Very High

Table 7.14: Decision matrix constructed for the AHP TOPSIS method

	QLY	CST	DLY	FXY	ECD	RRC	PUC	EMS	GRI	HUR	SSH	CSR	EAT	COC	COI	TAB
Alternatives/ Suppliers	*DPMO*	*Rs.*	*Days*	*Changeover time*	*High - Low*	*Kg*	*ppm*	*High - Low*	*High - Low*	*No. of violation incidents*	*Lost Time Injury Freq. Rate*	*High - Low*	*No. of Training sessions*	*High - Low*	*No. of Cases*	*Disclosure level*
S1	0.50%	10000	90	5	7	10	390	3	7	1	7	5	14	7	1	5
S2	1%	9000	80	6	5	15	380	5	5	5	7	3	21	7	1	3
S3	0.50%	10500	100	5	3	13	370	5	6	5	5	5	16	7	5	5
S4	0.75%	9500	110	4	5	18	380	4	6	7	3	9	11	9	3	3
S5	0.40%	9750	100	5	5	12	330	4	5	1	3	7	15	9	1	3
S6	0.80%	10500	85	6	7	16	370	4	5	3	5	7	14	7	2	3

Step 5: The normalized matrix is multiplied by the global weights of sub-criteria obtained from the AHP method, and a weighted normalized decision matrix is developed. The weighted normalized decision matrix is shown in Table 7.16.

Table 7.15: Normalized Decision Matrix

Supplier	QLY	CST	DLY	FXY	ECD	RRC	PUC	EMS	GRI	HUR	SSH	CSR	EAT	COC	COI	TAB
S1	0.2955	0.4128	0.3879	0.3916	0.5189	0.2865	0.4297	0.2900	0.5000	0.0953	0.5433	0.3241	0.3696	0.3700	0.1562	0.5392
S2	0.5911	0.3715	0.3448	0.4700	0.3706	0.4298	0.4187	0.4834	0.3571	0.4767	0.5433	0.1945	0.5544	0.3700	0.1562	0.3235
S3	0.2955	0.4335	0.4310	0.3916	0.2224	0.3725	0.4077	0.4834	0.4286	0.4767	0.3881	0.3241	0.4224	0.3700	0.7809	0.5392
S4	0.4433	0.3922	0.4741	0.3133	0.3706	0.5158	0.4187	0.3867	0.4286	0.6674	0.2328	0.5834	0.2904	0.4757	0.4685	0.3235
S5	0.2364	0.4025	0.4310	0.3916	0.3706	0.3438	0.3636	0.3867	0.3571	0.0953	0.2328	0.4537	0.3960	0.4757	0.1562	0.3235
S6	0.4728	0.4335	0.3664	0.4700	0.5189	0.4585	0.4077	0.3867	0.3571	0.2860	0.3881	0.4537	0.3696	0.3700	0.3123	0.3235

Table 7.16: Weighted normalized decision matrix

Supplier	QLY	CST	DLY	FXY	ECD	RRC	PUC	EMS	GRI	HUR	SSH	CSR	EAT	COC	COI	TAB
S1	0.0574	0.0647	0.0254	0.0130	0.0047	0.0151	0.0251	0.0050	0.0167	0.0108	0.0436	0.0126	0.0101	0.0233	0.0027	0.0216
S2	0.1147	0.0582	0.0226	0.0156	0.0034	0.0227	0.0244	0.0083	0.0119	0.0538	0.0436	0.0076	0.0152	0.0233	0.0027	0.0130
S3	0.0574	0.0679	0.0283	0.0130	0.0020	0.0197	0.0238	0.0083	0.0143	0.0538	0.0312	0.0126	0.0116	0.0233	0.0133	0.0216
S4	0.0861	0.0615	0.0311	0.0104	0.0034	0.0272	0.0244	0.0066	0.0143	0.0754	0.0187	0.0227	0.0080	0.0300	0.0080	0.0130
S5	0.0459	0.0631	0.0283	0.0130	0.0034	0.0182	0.0212	0.0066	0.0119	0.0108	0.0187	0.0177	0.0109	0.0300	0.0027	0.0130
S6	0.0918	0.0679	0.0240	0.0156	0.0047	0.0242	0.0238	0.0066	0.0119	0.0323	0.0312	0.0177	0.0101	0.0233	0.0053	0.0130

Step 6: The ideal (best) and negative-ideal (worst) solutions for each sub-criterion are calculated. As seen in Table 7.14, the benefit criteria are ECD, RRC, EMS, GRI, CSR, EAT, COC and TAB, while the cost criteria are QLY, CST, DLY, FXY, PUC, HUR, SSH and COI. The values depending on the benefit/cost criterion are shown in Table 7.17.

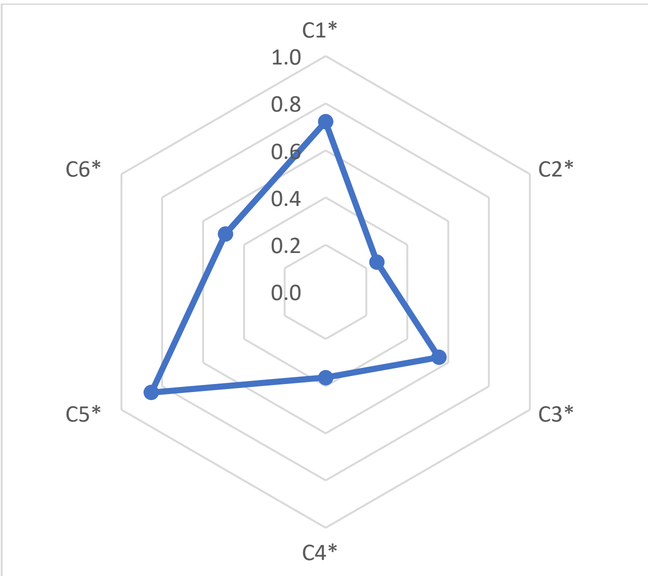
Table 7.17: Positive and negative ideal solutions

A^* (Best)	0.0459	0.0582	0.0226	0.0104	0.0047	0.0272	0.0212	0.0083	0.0167	0.0108	0.0187	0.0227	0.0152	0.0300	0.0027	0.0216
A^- (Worst)	0.1147	0.0679	0.0311	0.0156	0.0020	0.0151	0.0251	0.0050	0.0119	0.0754	0.0436	0.0076	0.0080	0.0233	0.0133	0.0130

Step 7: Using equation 7.10 and 7.11, the distance of each supplier from ideal solution is determined. The separation measures from positive and negative solutions are given below:

S_1^* = 0.0340 S_1^- = 0.0881
S_2^* = 0.0875 S_2^- = 0.0294
S_3^* = 0.0512 S_3^- = 0.0639
S_4^* = 0.0778 S_4^- = 0.0444
S_5^* = 0.0171 S_5^- = 0.0994
S_6^* = 0.0554 S_6^- = 0.0534

Step 8: Using equation 7.12, the relative closeness to the ideal solution is calculated and is shown in Figure 7.4.



C_1^* = 0.7217
C_2^* = 0.2518
C_3^* = 0.5548
C_4^* = 0.3635
C_5^* = 0.8534
C_6^* = 0.4909

Figure 7.4: Relative closeness to the ideal solution [C_i^*]

Step 9: The suppliers are now ranked in descending order based C_i* value. Hence the preference for sustainable suppliers for the company should be S5, S1, S3, S6, S4, and S2.

7.5.1 Sensitivity Analysis

Sensitivity analysis is done to check the variation in supplier ranking in different scenarios. The different scenarios are investigated by keeping the weight of one criterion as derived, whereas the rest criteria are given equal weightage. The scenarios with the changes in weights are checked for deviation from the original results. In the first scenario, the economic criteria's weight is kept, whereas the other three criteria are given equal weightage.

Table 7.18: Weights allotted to different Scenarios

	Derived	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Criteria Weight for Sensitivity analysis	**Weights as obtained**	**Environment, Social & Ethical equal weight**	**Economic, Social & Ethical equal weight**	**Economic, Environment & Ethical equal weight**	**Economic, Environment & Social equal weight**
Economic	0.450	0.450	0.276	0.247	0.293
Environment	0.171	0.184	0.171	0.247	0.293
Social	0.260	0.184	0.276	0.260	0.293
Ethical	0.120	0.184	0.276	0.247	0.120

Table 7.19: Relative closeness values obtained under different Scenarios

Relative Closeness Values	**Derived**	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
C_1*	0.7217	0.7233	0.6974	0.6792	0.6783
C_2*	0.2518	0.2565	0.3274	0.3333	0.2992
C_3*	0.5548	0.5952	0.4574	0.4514	0.4656
C_4*	0.3635	0.3903	0.3566	0.3671	0.3609
C_5*	0.8534	0.8164	0.7903	0.7732	0.8080
C_6*	0.4909	0.4465	0.5345	0.5424	0.5587

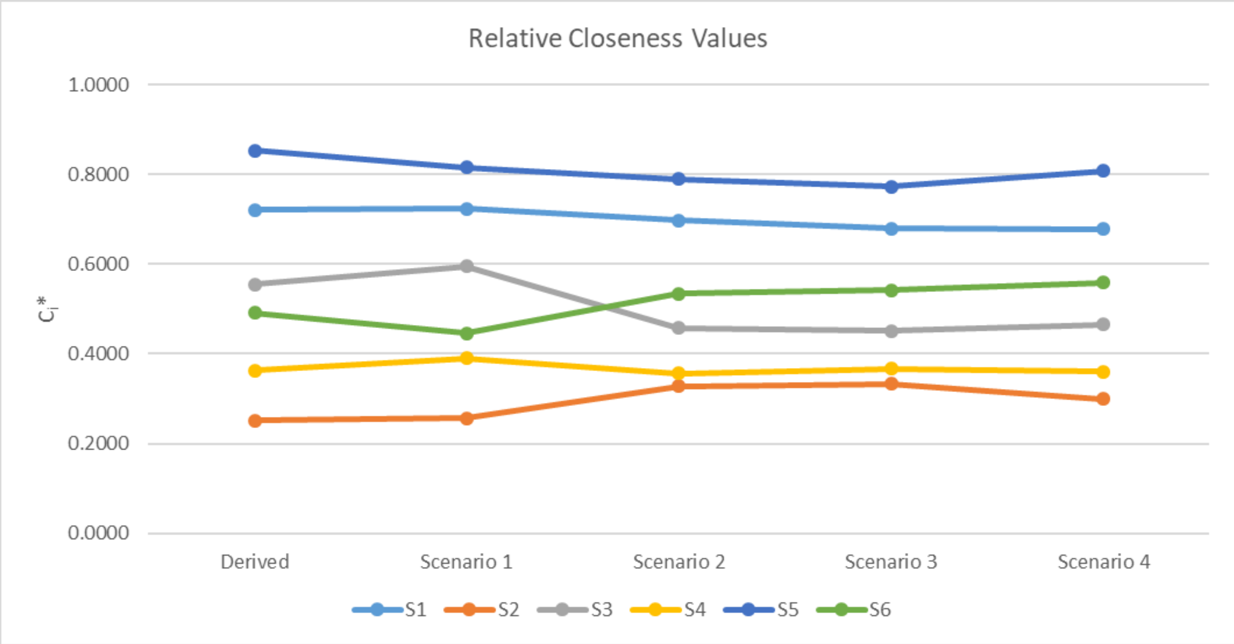


Figure 7.5: Result of sensitivity analysis

The supplier ranking is found to be in the order of S5, S1, S3, S6, S4 and S2. Similarly, the scenarios are changed by considering the actual weight of one criterion and giving other criteria equal weightage. The weightage given is shown in Table 7.18. The relative closeness values obtained under different scenarios are shown in Table 7.19. The result of sensitivity analysis is shown in Figure 7.5.

The variations in supplier rankings under different scenarios in sensitivity analysis are shown in Table 7.20. It is seen that there are no major variations in the ranking order under different scenarios, and S5 is the preferred supplier in all scenarios. The relative change in criteria weights do not make the proposed model sensitive, and thus the model is robust.

Table 7.20: Suppliers ranking under different Scenarios of Sensitivity analysis

Suppliers Rank	Derived	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	S5	S5	S5	S5	S5
2	S1	S1	S1	S1	S1
3	S3	S3	S6	S6	S6
4	S6	S6	S3	S3	S3
5	S4	S4	S4	S4	S4
6	S2	S2	S2	S2	S2

7.6 Discussion and Managerial implications

The above study encompasses an overall representation of sustainability criteria in the selection of a supplier. It contributes to the literature by giving due importance to ethics as part of sustainability and determining the sub-criteria of the four pillars of sustainability. In this study, we have taken economics, environment, social and ethics as the main criteria. They are further probed and discussed to obtain the sixteen sub-criteria to analyze in the sustainable supplier selection process. A common issue for selecting a sustainable supplier has been the uncertainty involved and evaluating quantitative and qualitative data. The pairwise comparison in AHP data helps an organization to understand the weightage given to main sustainability criteria, which can be improved based on the product and industry.

In the applied case, it is seen that the economics criteria got the maximum weight of 0.45. This is due to the primary importance given by companies to the economic factor. This is followed by social, environmental and ethics. Social had a weight of 0.26, which is more than the weight for the environment of 0.17. This indicates that the social dimension is given priority in managers' choice among sustainability dimensions. This confirms worker-related issues and safety are shown more concern than environmental impact. The global weights for sub-criteria indicate that Quality and Cost remain dominant factors in the selection process with 0.19 and 0.16. The sub-criteria of human rights, safety systems & occupational health and code of conduct are given a weightage of 0.11, 0.08 and 0.06 in the sustainable selection process, demonstrating the inclination towards workers' welfare. The environmental criteria of pollution control and resource reduction & consumption follow the importance with 0.05 weights. The results corroborate that more importance and preference are given to social and economic dimensions. Hence, organizations should try strategies that focus more on the environment and ethical dimensions to improve the overall sustainability performance. The case being studied involves the evaluation of tangible and intangible measures of supplier data to be evaluated. Using the TOPSIS method, these measures are evaluated and suppliers ranked in order of preference. The supplier S5 came as the preferred supplier for the product and continued to remain so in the different scenarios analyzed during sensitivity analysis. The combination of AHP TOPSIS gives the advantage to know the importance of criteria and sub-criteria associated with a selection process while finally giving the suppliers ranking, enabling comparison of their relative performance.

Kannan (2018) provided a decision support system for the sustainable supplier selection (SSS) problem in the Indian textile industry. The social components were determined to be the most influential critical success factors, and supplier rankings were significantly impacted by critical success factors of the social dimension. Hsu and Hu (2008), in their study on the electronic industry, indicate that firms that prioritize supplier management make it easier to execute sustainable practices in the supply chain. Mathiyazhagan et al. (2019) found that supplier category is a foremost challenging factor towards sustainability initiatives in the Indian electronic industry. In this study, it is found that economic factors such as cost and quality dominate. They are followed by social factors such as human rights, safety systems & occupational health. Liu et al. (2019) demonstrate a method for supplier selection in the agri-food value chain and point that a long-term view has to be taken to make the right selection. Economic factors tend to dominate if a short-term view is taken.

Big electronic contract manufacturers such as Foxconn Technology Group are setting up plants in India, and suppliers need to ante up their sustainability aspects to be globally competitive. In India, the Ministry of Electronics and Information Technology (MeitY) has introduced policies to incentivize electronic industries that develop sustainable products through schemes such as PLI and other benefits. A truly sustainable electronic manufacturing base can be developed in India only when the firms can evaluate and select a sustainable supplier for their supply chain.

The study provides a definition of a sustainable supplier and provides an insight to sourcing managers to evaluate and select a sustainable supplier based on comprehensive criteria. The framework developed in this research can assist the managers in the sustainability assessment procedure and its subsequent impact on supplier selection. Sustainable supplier selection is an important link for achieving sustainability in the supply chain. The model can assist procurement managers in contributing to sustainability implementation. Adopting this framework by focal firms will propel its suppliers to accommodate sustainability principles in their businesses.

It can be argued that the criteria importance order may vary with the industry, country and other factors. The management priorities attached to various criteria play a pivotal role in the decision making process. The designed framework gives an application perspective to implement the selection of a sustainable supplier in the supply chain operations of the Indian electronics industry. The model can be extended to other products and industries, which otherwise mainly confine to economics and profits as the sole criteria for partnering with a supplier. The selection of criteria, sub-criteria and the study outcome may motivate changes in selection procedure advertised in tenders and other modes by procuring companies.

The details of *five* research problems are elaborated in Chapters 3, 4, 5, 6 and 7. The present study does have certain limitations and practical constraints. The following chapter discusses the conclusions derived from the study, limitations of this research and future scope of the study.

CHAPTER 8

CONCLUSIONS, LIMITATIONS AND FUTURE SCOPE OF THE STUDY

Sustainability has become a global issue, and industries worldwide are now moving towards a sustainable supply chain. Sustainable supply chains are essential to achieve the sustainability goals of organizations. Due to the specific nature of the industry and the consumption pattern, it is imperative for Indian electronic industry to come up with sustainability practices in their supply chain. This research has tried to address some of the particularly significant research problems in sustainable supply chain management in context of Indian electronics industry. The research has studied *five* problems to aid implementation of sustainable supply chain by companies. The conclusions from this research, limitations and future research directions are discussed in the subsequent sections.

8.1 Problem 1

The *first* problem was to analyze the enablers that help implement SSCM. The implementation of sustainability in supply chains is required to be assisted by effective enablers. The present situation in India points out that SSCM enablers and their understanding are much needed to enhance environmental and societal causes in industries. In this context, this research has attempted to identify and study the enablers.

In this study, based on literature review plus inputs of industry managers and academic expert, 17 criteria enabling a sustainable supply chain in the Indian electronic industry were identified. DEMATEL method, together with Grey theory, is deployed to analyze the response of five experts about SSCM enablers. Grey theory takes into consideration the uncertainty. The Grey-DEMATEL converts qualitative inputs to quantitative value and helps determine the most important criteria that enable SSCM implementation. The feasibility of solutions prevailing or not is examined as per the criteria given by Lee et al. (2013), which validates the DEMATEL analysis's applicability.

From the framework developed, it is found that Government policies & legislations are the highest influencing enabler in implementing SSCM in Indian electronic industries. It is seen that the result is consistent with the literature and endorsed by the experts. In the beginning, corporations move towards sustainability due to pressure from legislation (De Brito et al., 2008). Government support plays an important role in giving subsidies and encouraging employees to realize SSCM as it sets regulatory laws for organizations (Mudgal et al., 2009). Timely and well-defined policies affecting the electronic industry like e-waste management and workers' health needs to be brought out by the government. Legislations and regulations must be effective to increase the influence of this enabler. The causal enabler culture-related factors influence sustainability at various levels. It influences consumption patterns, customer behaviour and contributes to sustainable practices at macro and micro levels. It is found in this study that most Policy enablers have a causal effect signifying they should be focussed more during the implementation of SSCM.

It is seen that besides being a causal enabler, top management commitment has the strongest co-relation with other factors and can lead to the implementation of SSCM. The inclination and willingness of top management and leadership are significant if sustainability is to be realized. The amount of investment and approach to environmental issues depends greatly on management's attitude (Lee and Rhee, 2007). Ageron et al. (2012) validate the vital role played by top management in practicing social and ethical practices in the supply chain. Environment management systems like ISO 14001 are influenced by causal factors but at the same time have a high correlation with other factors driving sustainability implementation. The next high correlation strength is displayed by enablers Corporate social responsibility and research & development related to sustainability. The Importance causality diagram determined the Critical, Driving, Independent and Impact enablers in SSCM implementation. Top management commitment, Government policies & legislations, Corporate social responsibility and training & literacy, were the critical enablers. In contrast, the availability of funds/investment, culture-related factors, and human expertise were driving enablers.

The research has managerial implications in guiding supply chain managers desirous of initiating sustainability practices in their organization's supply chain. The framework developed in this study can equip managers to understand enablers affecting SSCM to improve sustainability performance. Sensitivity analysis of results shows that is no major influence or bias in the findings.

The study has some limitations. Supply chain managers of electronic companies who have given the opinion for this research are all from the western region of India. The data collected from a different region or a different country need to be examined to see variations. The study analyzed 17 enablers identified from the literature review and experts' opinions. It is possible that due to limitations in cognition, some important enablers may not have been considered. Future studies can explore more enablers by collecting additional responses from stakeholders. In addition, replies by managers to questionnaire may be subject to personal opinions. More experts could be consulted in the future to augment the reliability and robustness of the results obtained. Also, results for a different sector of industry and the findings using other multi-criteria decision-making methods such as AHP, ANP, TOPSIS and VIKOR can be examined. The present model obtained by Grey DEMATEL can also be validated statistically by using structural equation modeling.

8.2 Problem 2

The *second* problem, studies the hierarchical structure and prioritization of barriers to SSCM. The industries are going to face many barriers while implementing sustainability. The thesis addresses the problem first by identifying the barriers in implementation of a sustainable supply chain. Then a structured model showing the interrelationships among these barriers is constructed using ISM method. The driving and driven powers of the barriers as well as their interdependence is also established. Further, applying MICMAC analysis the dependent, linkage and independent barriers are determined.

With the help of literature review and four experts, eleven barriers encountered during SSCM implementation were identified. Based on their functional traits the barriers were categorized in group of Policy, Human resource and Technology for easier management during implementation phase. Results from ISM reveal that Lack of awareness of benefits of sustainability is a key barrier as it has the highest influence being at the lowest level in the ISM model. The order of influence is followed by lack of regulations and enforcement of environment standards and lack of commitment from top management. Thus, the most important barriers that need to be addressed during SSCM implementation are Lack of awareness of benefits of sustainability, lack of regulations and enforcement of environment standards, lack of commitment from top management. These barriers drive financial constraints and organizational culture inhibitive to sustainability/CSR. Lack of green purchasing, lack of R&D on sustainability and lack of training/human expertise on sustainability are linkage barriers indicating they are driven by the independent barriers as well as they themselves influence barriers at a higher level of the ISM model. The linkage barriers characterize all three categories of Policy, Human resource and Technology barriers. Technology category barriers, viz., lack of performance metrics/evaluation standards on sustainability and lack of new technology/materials and processes on sustainability along with resistance to change and adopting innovation in sustainability are influenced by other barriers.

As an outcome of this work, activities and programs promoting awareness on the socio-environment impact of electronic goods at all levels and the benefits of sustainability adoption to the society is strongly recommended. The analysis reveals that mainly policy category barriers are independent and they have high driving power. It is suggested that targeted policies at both government and organizational level be formulated as well as strengthened for the electronics industries to remove barriers in implementation of a sustainable supply chain management. Programs like extended producer's responsibility and recycling should be encouraged in the electronics industry. Managerial implications and mitigating strategies are discussed to overcome the barriers. The finding can motivate further academic research in strategies to overcome the barriers and formulation of policies at various levels for electronics industries in India.

The ISM model and MICMAC analysis will help electronic companies to know which barriers need to be tackled on priority and given more attention while introducing sustainability in the supply chain. This framework gives an understanding on the link between barriers, their position and their dependence/independence in the system. The complexities involved in sustainability implementation are high and the framed model can guide on the criticality of barriers that will be faced.

In this research, the barriers in implementation of sustainable supply chain in the Indian electronics industry are identified and analysed using ISM model. In taking the opinion of experts, there is a possibility of bias and hence in future study, the number of experts can be increased and results compared. The study finds the relationship between factors but the strength of this relationship is not known because of ISM method limitations. This model needs to be statistically validated and this can be done through SEM or other approaches. For future research, the relationship between more barriers and their categories can be studied. Further, barriers in other industries can be identified and other MCDM methods can be considered for analysis.

8.3 Problem 3

The *third* problem, investigated the causal factors and correlation between barriers. The industry has been facing barriers in the implementation of sustainability and an attempt is made in this research to analyse these barriers so as to minimize the efforts that go in eliminating them. Eleven barriers were identified through literature review and discussion with managers in the industry. On the basis of response from the managers through questionnaire and discussion, the Grey DEMATEL method is applied.

From the results, it is found that LOR has the highest causal effect. It is interesting to note that this is followed by a LCM which is also a policy barrier. It can be inferred from this result that policy category barriers seem to have a high causal effect in sustainability implementation. Thus, it is important that policymakers frame regulation at all levels to push towards the common objectivity of removing barriers of SSCM. The diagraph plotted shows that barriers IRD, LPT, LNT, RCI, CMM are affected by the causal factors. The highest correlation among the factors from the model is seen in HCD, HIC and LCM in that order. Sensitivity analysis of the model does not show any bias and verifies the robustness of the results.

In this research, we analyse and categorize the barriers to understand their effect on sustainability implementation in the Indian electronics industry. By using Grey DEMATEL methodology, the cause and effect group of barriers is known with the degree of their influence. The study analyses the barriers of an electronics supply chain and determines the cause/effect group and degree of correlation among barriers. The results can be used by policymakers of the electronic sector in creating a framework to mitigate these barriers and promote sustainable development.

There are some limitations in this study as the respondents are from a single electronic industry. Future research can consider responses from multiple electronics industries and compare the results. The analysis has been done on 11 shortlisted barriers in the implementation of sustainability in supply chain management which could be further subcategorized and barriers increased in future studies. The study was done with responses from four respondents which is consistent with existing literature but for future studies, a greater number of respondents can be included to enhance the result robustness. Future research can also evaluate the result using different methods and variables.

8.4 Problem 4

Eco-efficiency is a concept that has gained popularity among organizations demonstrating their efforts in safeguarding the environment and economic growth. Eco-efficiency is attained by delivering fair-priced goods or services fulfilling human requirements and better life quality while lessening the environmental harm and resource intensity during its life cycle to at least be in line with the Earth's estimated carrying capacity. The electronic industry has grown tremendously worldwide, and electronics components are used in all high-tech areas in various sectors. With its growth, the industry is reeling with problems of e-waste, hazardous chemicals, rare earth metals mining, energy consumption, resource crunch and disposal of products. In this study, the important CRs and DRs for improving eco-efficiency in the electronics industry are identified. A House of Quality is constructed by the QFD method to help managers take decisions and relevant measures on attaining eco-efficiency.

The application of an integrated ANP QFD method is made in the case of an electronics firm to improve eco-efficiency. Seven CRs and Fourteen DRs are identified based on literature review and experts' opinions. The interdependencies among CRs and DRs for eco-efficiency are examined, and the relative importance is found using ANP. The QFD method can be used to construct the House of Quality for an informed decision-making process to achieve eco-efficiency. The results show that reducing GHGs, air emissions, VOCs and carbon footprint (DR5) is the most important factor for eco-efficiency. The then important factors to achieve eco-efficiency in order are Reduced use/consumption of resources (DR1), Use renewable energy like Solar (DR10), state of the art innovative materials (DR2), Technologies for reducing use/consumption of energy (DR3) and Green suppliers and green procurement (DR9). Companies may take due care in studying the emissions involved in their process, use efficient methods to reduce raw materials intake, adopt cleaner technologies, procure green products and promote green suppliers in their supply chain. This study suggests that adhering to these requirements will assist in enhancing the eco-efficiency for companies.

The study explores the CRs and DRs and assists in knowing their interdependence and significance. This will enable managers to make effective decisions in increasing the eco-efficiency targeted goals of their organizations. The extent of influence of CRs and DRs can help firms in prioritization of policies for eco-efficiency. The framework being specific in the context of identified requirements can assist in expediting the implementation of eco-efficient processes and curtailing the environmental impact.

The study conducted has few limitations. The pairwise comparisons are based on the judgement of experts of one electronics company. There is a possibility of bias due to this though it has been addressed by checking the consistency ratio. The scope of this study has been limited to the electronic company in India, and geographical location might have influenced the priorities. The pairwise calculations are extensive and time-consuming.

In the future, the study can be extended to other industries as well to identify and prioritize their design requirements for eco-efficiency. MCDM techniques such as TOPSIS can also be applied to the prioritization of CRs and DRs. The results so obtained could be compared and analyzed for any variations.

8.5 Problem 5

The *fifth* problem is in consideration that suppliers are important in ensuring that an organization gets clean and green products to ensure that their end-products are eco-friendly. Usually, in supplier selection, economic factors were only considered. But sustainability has become an instrumental characteristic of a supply chain, and the environmental, social and ethics factors are given weightage. The decision to select a supplier based on pre-decided sustainability criteria is a multifaceted approach. It is imperative that the decision makers in procurement are aided by suitable tools in achieving sustainability goals. In the practical world, organizations, while selecting suppliers, are now giving due importance to ethics, which can be seen in the introduction of additional practices like the Integrity pact while awarding contracts. In this study, ethics is introduced as the fourth pillar in selecting a sustainable supplier in a supply chain.

An implementable approach to select a sustainable supplier in the electronics industry in India has been presented in this thesis. The four criteria for sustainable supplier selection economics, environment, social and ethical, have been further divided into 16 sub-criteria based on experts' opinions and literature review. These sixteen sub-criteria - Quality, Cost, Delivery, Flexibility, Eco-design, Resource reduction and consumption, Pollution control, Environment Management Systems, Green Image, Human rights, Safety Systems & Occupational Health, Corporate Social Responsibility, Education & Training, Code of conduct, Conflict of Interest, Transparency in Accounting and Business have been given weightage by using AHP method.

The data obtained from an electronics company was evaluated for the six available suppliers for a particular component being procured. A decision model combining AHP and TOPSIS is used to rank the suppliers for a sustainable supply chain. The AHP method is used to find the weights of the criteria and sub-criteria. The TOPSIS technique calculates the relative distance of alternatives from positive and negative ideal solutions to prioritize the six supplier alternatives. The ranking obtained was S5, S1, S3, S6, S4, and S2. The result derived was discussed with company managers, and they corroborated with the supplier preference obtained considering all aspects for a sustainable supply chain.

The study considers both quantitative and qualitative data by converting them to comparable data among suppliers and selects the supplier by considering all dimensions of sustainability. It also ranks the suppliers in order of preference showing their distance from an ideal solution. It helps the company managers understand the importance of sustainability in a procurement process and assess the suppliers accordingly.

The model developed in this research contributes by considering the most relevant criteria, including ethics, in selecting a sustainable supplier. Four criteria and sixteen sub-criteria were applied, thus giving due importance to social, environmental, and ethical criteria apart from economics criteria, usually given importance during normal procurement. The framework is validated by applying it in a case study of an electronics company. The framework can help organizations identify the importance of main sustainability dimensions and develop their suppliers accordingly in a supply chain.

The criteria used in this study are general and can be applied to other industries with minimum modifications. Still, the weightage and relative importance to criteria need to be finalized by the management. The grading of the sub-criteria during evaluation has to be fixed by decision makers. These steps are to be executed by companies by gauging their requirements and supplier options. A selection model for sustainable suppliers will motivate them to invest in sustainable practices, increasing their chances of getting preference. The managers in the company agreed that going forward and in line with the sustainability vision that many companies aspire, such a selection process would add to the overall value.

The scope for future research is to test the model using other MCDM or hybrid models. The framework can be applied in other industries and results compared. Future research can also evaluate the long-term cost-benefit analysis based on selecting a sustainable supplier using the applied method vis-a-vis the conventional supplier selection method. The number of criteria sub-criteria can be increased or changed in future studies. The proposed model can also be extended by incorporating criteria based on industry-specific situations and issues.

8.6 Conclusion

Globalization has led organizations to think beyond economic benefit goals and move towards sustainable supply chains to address their business's societal and environmental concerns. Global warming, emission of pollutants, depleting ozone layer, and other such issues affecting the value of human life make it imperative for industries to balance their business's social, environmental, and economic impact. Companies have to consider people and the planet along with profit to remain in business. As societies become aware, sustainability issues are becoming critical in all activities. The concept of sustainability has now been added to the supply chains of organizations. An increasing number of companies are now committing to the cause of sustainability in their supply chain due to pressures from government, non-governmental organizations, stakeholders and foreseeing the rewards sustainable supply chains can deliver. Sustainable supply chain goes beyond financial benefits to include environment protection, resource utilization and social responsibility. The process of changing to a sustainable supply chain is complex, and understanding the enablers and barriers to SSCM, concepts of eco-efficiency and sustainable supplier selection assist in achieving this effectively. This research is aimed to study the issues that affect sustainable supply chain management in Indian electronics industry.

The findings of this thesis present theoretical perspectives, frameworks, and integrated models that aid the process of sustainable supply chain implementation in organizations. To summarize in conclusion:

- The study considers the enablers to sustainable supply chain and its analysis will aid organizations in moving towards a sustainable supply chain.
- The identification of barriers and findings on their hierarchical structure and prioritization can help organizations mitigate the barriers while implementing SSCM.
- Similarly, the causal factors, effect factors and degree of prominence of barriers to SSCM are investigated to comprehend the hurdles while shifting to a sustainable supply chain.
- The customer and design requirements for eco-efficiency in a supply chain are analyzed and prioritized to improve eco-efficiency of organizations.
- The thesis also contributes to providing insights into the selection of a sustainable supplier for a sustainable supply chain.

Overall this research has focussed on select issues in sustainable supply chain management in context of electronic industries in India. The study can help firms make decisions for the value creation in their businesses by improving social, environmental and economic performance. It is crucial for today’s industry to protect society and the environment along with their business by building a sustainable supply chain. The thesis recommends that organizations transform their supply chain to a sustainable supply chain using enablers that aid their implementation, overcome the barriers faced, improve their eco-efficiency levels, and choose sustainable partners. Creating and managing a sustainable supply chain will enhance an organization's reputation and further legitimize its business.

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LIST OF PUBLICATIONS BASED ON THE THESIS

PUBLISHED IN INTERNATIONAL JOURNALS

1. Menon, R.R. and Ravi, V. (2021), Analysis of enablers of sustainable supply chain management in electronics industries: The Indian context. *Cleaner Engineering and Technology*, p.100302. https://doi.org/10.1016/j.clet.2021.100302 **(*Elsevier*).**

2. Menon, R.R. and Ravi, V. (2021), "An analysis of barriers affecting implementation of sustainable supply chain management in electronics industry: A Grey-DEMATEL approach", *Journal of Modelling in Management*, Vol. ahead-of-print No. ahead-of-print. https://doi.org/10.1108/JM2-02-2021-0042 **(*Emerald*).**

3. Menon, R.R. and Ravi, V. (2021), Analysis of barriers of sustainable supply chain management in electronics industry: An interpretive structural modelling approach. *Cleaner and Responsible Consumption*, p.100026. https://doi.org/10.1016/j.clrc.2021.100026 **(*Elsevier*).**

4. Menon, R.R. and Ravi, V., 2021. Using ANP and QFD methodologies to analyze eco-efficiency requirements in an electronic supply chain. *Cleaner Engineering and Technology*, p.100350. https://doi.org/10.1016/j.clet.2021.100350 **(*Elsevier*).**

UNDER REVIEW IN INTERNATIONAL JOURNAL

- Selection of sustainable suppliers in an electronic supply chain: An AHP-TOPSIS Approach (*First revision*).

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- Deepu T S., Ravi, V & Rakesh R Menon., (2016). An investigation on the Role of Information Technology Tools in Supply Chain Integration. *International Conference organized by Indian Institution of Industrial Engineering (IIIE), jointly organized by CET and GEC-W.*