STUDY OF SELECT ISSUES IN CIRCULAR SUPPLY CHAIN

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by

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CANDIDATE'S DECLARATION

I **Madhukar Chhimwal** hereby certify that the work which is being presented in the thesis entitled **"Study of Select Issues in Circular Supply Chain"** in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy, submitted in the Department of **Mechanical Engineering**, Delhi Technological University is an authentic record of my own work carried out during the period from **July 2017** to **May 2024** under the supervision of **Dr. Saurabh Agrawal** and **Prof. Girish Kumar**.

The matter presented in the thesis has not been submitted by me for the award of any other degree of this or any other Institute.

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ABSTRACT

Manufacturing sector in India is witnessing a faster growth and is set to increase its share from 16 to 25 percent in the Gross Domestic Product (GDP) of the nation by the year 2025. In the recent past, Government of India (GOI) has made various amendments in the national policy of manufacturing to provide a pathway to the multi-national companies to invest in Indian manufacturing sector. Looking at the future growth of manufacturing in India and the limited availability of natural resources, there is a need of development of such business models in the manufacturing industry which can produce product more sustainably.

Circular economy (CE) is a sustainability approach which optimizes the use of resources while empowering companies to gain profits from deliverables to market. The major advantages of the application of CE concept is resource conservation, lesser energy consumption and reduced emission of greenhouse gasses thereby abating the reliance of the economy on natural resources. Implementation of CE models may be helpful in overcoming the environmental, societal and economic issues. In the recent past many researchers have worked in this area to establish a connection of CE concept with the current sustainable supply chain business models. The concept of CE is in nascent stage and there are several challenges coming with the implementation of this concept that organizations need to face in today's business environment which need to be addressed in a systematic way. The review of literature on Circular Supply Chain Management (CSCM) showed that comprehensive integrated view of CSCM is still missing, and therefore, there is need to address various dimensions related to the incorporation of CE principle in supply chain management. Thus, this thesis offers both qualitative and quantitative approaches to address the research gaps through the utilization of survey techniques, case studies, statistical analyses, and conceptual frameworks pertaining to specific issues within the context of the Indian manufacturing sector.

A survey of the Indian manufacturing Industry was conducted to explore the current practices, challenges and risks and thereafter, hypotheses were formulated to examine the correlation between these issues and the economic, environmental, and social functioning of CSC. A questionnaire developed through Google form was employed for the purpose of data collection.

In order to gather the necessary data, questionnaire was distributed to 390 manufacturing companies via Google Forms. The survey targeted companies that have previously utilized circular concepts in their operations. Hypotheses were tested using Likelihood Ratio Test (LRT). The test results shows that there is a positive association between practices and performances and therefore, the practices identified in the study are positively effecting the adoption and implementation of CSC.

The research work explored and analyzed key challenges pertaining to the implementation of CE concept in Indian manufacturing industry. For the identification of significant challenges Pareto approach is incorporated in the study. Fuzzy logic is applied along with DEMATEL approach to prioritize the significant CE challenges for the implementation in manufacturing industry. Furthermore, the present research integrates risk management approach with Circular Economy. Risk management is inevitable for achieving a high degree of circularity in SC. Risk management involves the identification, modeling and mitigation of risk at various levels of SC. Measuring Circular Supply Chain (CSC) disruptions, and the impact on the sustainable performance of the CSC, is still lacking in the existing literature. One of the objectives of this research is to develop a circular supply chain risk framework, in order to generate risk profiles of various CSC partners and to study the disruption caused due to the occurrence of various risk on the performance of CSC. The research also explored circularity potential of non ferrous metal considering a case of the Indian Aluminium industry. This study is able to demonstrate the circularity potential of Aluminium for the non ferrous metal industry in the context of developing economy. To analyze the flow of Aluminium in a supply chain network, Markov Chain approach is used.

This study incorporates Graph Theory and Matrix approach (GTMA) for the selection of best coordination alternative across different supply chain networks. The coordination alternatives are examined on the basis of coordination attributes which are selected and analyzed through comprehensive review of literature and collecting valuable expert opinions. The study constitutes review of literature pertaining to issues of coordination addressed in the sustainability domain that may include either close loop or circular supply chain. In order to overcome sustainability based challenges the company wants to identify whether the coordination needs to be established in the forward, reverse or circular direction. Therefore the proposed study uses these three directions as three alternatives in GTMA approach applied for the above mentioned problem. The outcomes of the study indicate low value of coordination index for forward supply chain, which means the coordination among the partners as we move downstream in the supply chain does not lead to the achievement of sustainability goals. In case of reverse supply chain, the coordination among the upstream partners will be slightly more significant in achieving the objectives of sustainability. However the coordination among the members of circular supply chain (including forward as well as reverse supply chain) will significantly effect in achieving sustainability goals.

The research work has attempted to address the select issues of Circular Supply Chain (CSC), identified based on the comprehensive literature review and exploration of Circular Economy (CE), especially in the context of Indian manufacturing industry. The work reported has explored the various issues of CSC and proposed the solution methodologies by developing models, frameworks, case studies such as identifying and prioritizing key factors, decision frameworks for circularity and implementation decisions, and framework for evaluating performance of CSC. The research work will help the industrialists, academicians, and researchers in implementing, developing, and operating CE systems effectively and efficiently.

TABLE OF CONTENTS

Contents **Page No.**

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

3PRLP	Third-Party Reverse Logistics Provider
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
AMC	Absorbing Markov Chain
ANOVA	Analysis Of Variance
ANP	Analytic Network Process
BN	Bayesian Network
BS-VI	Bharat Stage Emission Standards 6
C2C	Cradle to Cradle
CAGR	Compound Annual Growth Rate
CBM	Circular Business Model
CE	Circular Economy
CEDI	Circular Economy Dynamic Index
CEI	Circular Economic Index
CESI	Circular Economy Static Index
CFCS	Converting Fuzzy data into Crisp Scores
CII	Confederation of Indian Industry
CLSC	Closed Loop Supply Chain
COP	Conference of Parties
CP	Cleaner Production
CPT	Conditional Probability Table
CRISIL	Credit Rating Information Services of India Limited

CSC	Circular Supply Chain
CSCM	Circular Supply Chain Management
CSF's	Critical Success Factors
DEMATEL	Decision Making Trial and Evaluation laboratory
DTMC	Discrete-Time Markov Chain
EGR	Emissions Gap Report
EoL	End of Life
EPR	Extended Producer Responsibility
EV	Electric Vehicle
EWMFA	Economy-Wide Material Flow Accounts
FDI	Foreign Direct Investment
FICCI	Federation of Indian Chambers of Commerce and Industry
FMEA	Failure Mode and Effects Analysis
GDP	Gross Domestic Product
GHG	Green House Gas
GOI	Government of India
GSCM	Green Supply Chain Management
GTMA	Graph Theory and Matrix Approach
IAI	International Aluminium Institute
IBEF	Indian Brand Equity Foundation
ISO	International Organization for Standardization
IT	Information Technology
LCA	Life Cycle Assessment
LRT	Likelihood Ratio Test
MC	Markov Chain

MCDM	Multi Criteria Decision Making Process
MCI	Material Circularity Indicator
MFA	Material Flow Analysis
NCR	National Capital Region
OEM	Original Equipment Manufacturer
PLM	Product Lifecycle Management
RC	Risk Category
RDI	Recycling Desirability Index
RE	Risk Event
REI	Risk Exposure Index
REPRO	Remanufacturing Product Profiles
RPI	Reuse Potential Indicator
SC	Supply Chain
SCM	Supply Chain Management
SCRM	Supply Chain Risk Management
SDG's	Sustainable Development Goals
SMEs	Small and Medium Enterprises
SWOT	Strength Weakness Opportunities Threats
TFN	Triangular Fuzzy Number
TIHC	Total Inventory Holding Cost
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TPM	Transition Probability Matrix
UNEP	United Nations Environment Programme
VIKOR	Vlse Kriterijumska OptimizacijaI Kompromisno Resenje

CHAPTER 1

INTRODUCTION

1.1 Background

According to Emissions Gap Report (EGR) by United Nations Environment Programme (UNEP, 2023), global Green House Gas (GHG) emissions in 2030 are estimated to be 58 giga tonnes of equivalent carbon dioxide based on current policies. In the Paris Agreement, countries worldwide agreed on minimizing global carbon emissions to reach the net-zero target around mid-century. The report by (UNEP, 2023) shows that updated national policies since COP26 held in 2021 in Glasgow, United Kingdom make a negligible change to the predicted 2030 emissions and they are far from achieving the Paris Agreement goal of limiting the rise in global earth temperature to well below 2^{o}C, preferably 1.5^{o}C.

In order to achieve a sustainable global environment, the world needs to advance from a traditional linear mindset towards a circular mindset (Geisendorf and Pietrulla, 2017). Circularity is an inevitable part of sustainability (Walter R. Stahel, 2015). Due to stringent environmental norms supply chains (SC) of most of the organizations are concerned about their sustainability aspect, therefore strive towards the adoption of circular practices (De Angelis, 2020; Moktadir et al., 2018). The concept of circular supply chain (CSC) is one which involves the implementation of Circular Economy (CE) principles throughout the SC of an organization (Lahane et al., 2020). CE is an approach that addresses all the three pillars of sustainability (Haas et al., 2015). CE is not only focused on the circular flow of material but it also encompasses value chain enhancement, economic returns, environmental safeguard, product longevity and waste minimization (Rizos et al., 2016). CE is a sustainable production and consumption approach which utilizes 6R (Reuse, Repair, Refurbish, Remanufacture, Redesign and Recycle) strategies to optimize the resource use (Lieder & Rashid, 2016). Optimizing the utilization of resources (man, machine and material) requires a high level of coordination among the members of SC (Kanda & Deshmukh, 2008).

CE is often used these days in the context of resource efficiency development (Figge et al., 2018). CE emphasizes the keyword “Circular”, as the business models based on CE encourage the transition from linear flow to circular flow of products in order to retain the value of resources in supply chain for as long as possible (Salvador et al., 2020). CE is rather needed to decouple natural resource use and environmental impacts from economic growth (Crane et al., 2011). Despite its (CE) huge economic, environmental and social advantage, the awareness of CE business models is limited among the industry practitioners (Lewandowski, 2016). This poses a significant challenge owing to its adoption as a sustainable business model at an industrial level (Hopkinson et al., 2018).

1.2 Circular Supply Chain (CSC)

Boulding (1966) first introduced the meaning of circularity in the supply chain. The author explained that for the maintenance of sustainability on the planet Earth, it is necessary to build a circular system, in which material can flow in a closed loop to avoid wastage of useful resources. Pearce and Turner (1989) compared the shifting of a conventional open ended system into a circular system, with the results of the second law of thermodynamics. Thierry et al. (1995) proposed the concept of product recovery management, in which various aspects of reverse logistics are integrated into the SC model.

Circular economy (CE) is a systematic approach that optimizes the utilization of resources, thereby decoupling the economic growth and environmental damage (Walter R. Stahel, 2015). Su et al. (2013) elucidated that the focus of the circular economy gradually extends beyond issues related to material management, and covers other aspects, such as energy efficiency and conservation, land management, soil protection, and water conservation. The report of Ellen MacArthur Foundation (2013) recalls circular economy as “an industrial system that is restorative or regenerative by intention and design”. European Commission (2017) also entails CE as an economy “where the value of products, materials, and resources is maintained in the economy for as long as possible, and the generation of waste is minimized”.

The CSC is also sometimes referred to as a closed-loop production and consumption model that restrains the externalities of environmental-related activities. Ghisellini et al. (2016) argued that reformation of all the processes encompassing the life cycle of a product can extract the maximum possible material and energy, thereby improving the economic, environmental and social condition. Farooque et al. (2019) performed a structured literature review in order to categorize different supply chain sustainability concepts that conceptualize a unique definition of circular supply chain management (CSCM). Bressanelli et al. (2019) identified some of the challenges in redesigning the supply chain for CE, and it took multiple case studies to examine how these challenges appear in practice and how companies tackle them. Lahane et al. (2020) highlighted research trends, gaps, and potential research directions for future studies in the field of CSCM.

The quest for circularity is acknowledged as a useful strategy in order to deal with the sustainability-related challenges that are faced by the global supply chain (Bastas and Liyanage, 2019). It enhances the competitiveness among the global companies, and also bestows them an economic advantage (Ferronato et al., 2019).

1.3 CSC practices in India

Circular supply chain practices are those activities that should be adopted within or outside the organization in order to optimize resource use, reduce harmful environmental impact and lead to the economic growth of the organization along with their supply chain partners. According to Zhu et al. (2010), CE practices can be classified into internal and external activities depending upon whether these practices are adopted within the organization or with the supply chain partners of the organization.

Circular Economy (CE) is based on the principle of Reduce, Reuse and Recycle. These practices are not just followed at micro-level, but at meso and macro level too. More and more solar operated power plants are being setup all over India to make the reliance of energy demand on renewable source of energy rather than exploiting non-renewable resources. Transportation sector is quickly shifting towards electric vehicles rather than using conventional fossil-fuel operated vehicles. E-cart companies like Flipkart and Amazon are promoting exchange of old electronic items in India by giving heavy discounts on electronic gadgets. They are also selling refurbished mobile phones at discounted rates. Private vehicle owners are using Bla-Bla cars as a car pooling application that leads to more effective utilization of resources. Manufacturing companies are incorporating green technologies in order to make their day to day operations environment friendly. These are some of the examples where Circular practices are being adopted and managed effectively at different levels in India. Adopting CE practices across various sectors such as manufacturing, agriculture, automotive, electronic, construction and mobility could generate a saving of 624 billion dollars by 2050 in India. Despite enormous opportunities in terms of monetary gains and eco-benefits, CSC practices are being adopted and implemented at a narrower prospect in India.

During the past few years, environmental regulations and production standards have become stern and are so-called “green challenges” for international trade (Jalilian and Mirghafoori, 2020). These challenges affect the trading revenue of developing countries, as they require a complete reformation of the technical input and also the application of green practices in the production model (Su et al., 2013). Agyemang et al. (2019) explored drivers and barriers to CE implementation in Pakistan automobile manufacturing industry. The findings revealed that profitability, cost reduction and concern for environment are the top three drivers and unawareness, financial constraint and lack of expertise are the top three barriers in implementing CE. Moktadir et al. (2018) identified and prioritized the drivers of sustainable manufacturing in the leather industry of Bangladesh. The authors used graph theory and matrix approach to examine the drivers and found that knowledge of CE is essential for its smooth implementation. Cezarino et al. (2019) explored the relationship between CE and Industry 4.0 as a contribution to management decision and identified limitations to its implementation in Brazil. Lack of communication between public and private institutions, efficacy in consolidating industrial policies and investment in remanufacturing process are some of the major limitations to its implementation. In Indian context only a few studies have been carried out in this area. Govindan and Hasanagic (2018) identified 39 challenges affecting CE application, grouped them into the interior or exterior environment and then classified into eight categories: government, economic, technological, knowledge and skill issues, management issues, CE framework issues, cultural and social issues and market issues. Mangla et al. (2017) identified thirty challenges in the application of sustainable production and consumption model in the supply chain by adopting fuzzy analytic hierarchy process (AHP) approach. Mittal and Sangwan (2014) elicited the use of nonrenewable sources of energy by the manufacturing firm causes a serious problem of locating waste disposal. The studies pertaining to Indian context failed to identify significant challenges in the implementation of CE as a novel business strategy for the manufacturing sector. Therefore, this study focuses on the identification of significant challenges and their prioritization for the implementation of a novel concept in a developing economy like India.

1.4 Indian manufacturing industry

Manufacturing sector in India is witnessing a faster growth and is set to increase its share from 16% to 25% to the gross domestic product (GDP) of the nation by the year 2022 (IBEF, 2023; Iyer, 2018). Government of India (GOI) has launched "Make in India" program to boost this sector and make India a global manufacturing hub (Mehta and Rajan, 2017). This initiative will not only offer a global recognition to the Indian economy but also create several million job opportunities (CII, 2024). India is now seen as a huge market of investment owing to rapidly increasing middle class population. Various incentives offered by the government and incubation of skilled labor at lower wages are some lucrative measures for foreign companies to invest in India (Kumar et al., 2019). In the recent past, GOI has made various amendments in the national policy of manufacturing to provide a pathway to the multi-national companies to invest in Indian manufacturing sector.

Rise in the per capita income, growth in population, rapid urbanization and changing lifestyle ensures a strong building up of manufacturing sector in India. According to a report published by IBEF, India will come out as world's fifth largest consumer market by 2025 with an average consumption expected to rise by four times during 2005–2025. The Indian Government aims to achieve 25% of its GDP share by manufacturing sectors till 2022 as against 16% current share (IBEF, 2023). This will attract manufacturers from all over the world to invest and establish their manufacturing unit in India thus creating 100 million new employment opportunities in this sector by 2022 and making India a global manufacturing hub.

Creativity has led to the adoption and implementation of latest technology in the manufacturing sector with digital transformation being a cutting edge approach in gaining advantage in the highly competitive environment. Indian manufacturing sector is gradually moving towards more automated and lean manufacturing that will help improve efficiency and increase productivity. Building on the competitive edge of skilled workforce and lower labour cost will attract foreign companies to invest in India and contribute to the total domestic production. Initiatives like Make in India, Startup India and Digital India have given the much needed thrust to the manufacturing sector in India. Make in India campaign was launched to promote Foreign Direct Investment (FDI) and attract manufacturers across the globe to invest and setup their production plant within India. Startup India encourages young entrepreneurs to come up with innovative business models that could directly or indirectly benefit domestic manufacturing. Digital India has led to the digital transformation in the manufacturing sector, not only making transactions happening more conveniently but it has also led to the real time monitoring of the entire production and supply chain processes.

The export from Indian manufacturing for the financial year 2022 reached an unprecedented 418 billion US dollars as compared to 290 billion US dollars for the previous year with a growth rate of 40 percent (World Bank, 2022). India's share in the global consumption is expected to be about 17 percent by 2030 which will be second largest in the global consumer list. Fig. 1.1 shows the total export value of goods and services year wise starting from 2000 to 2023 in US billion dollars provided by Indian manufacturing sector.

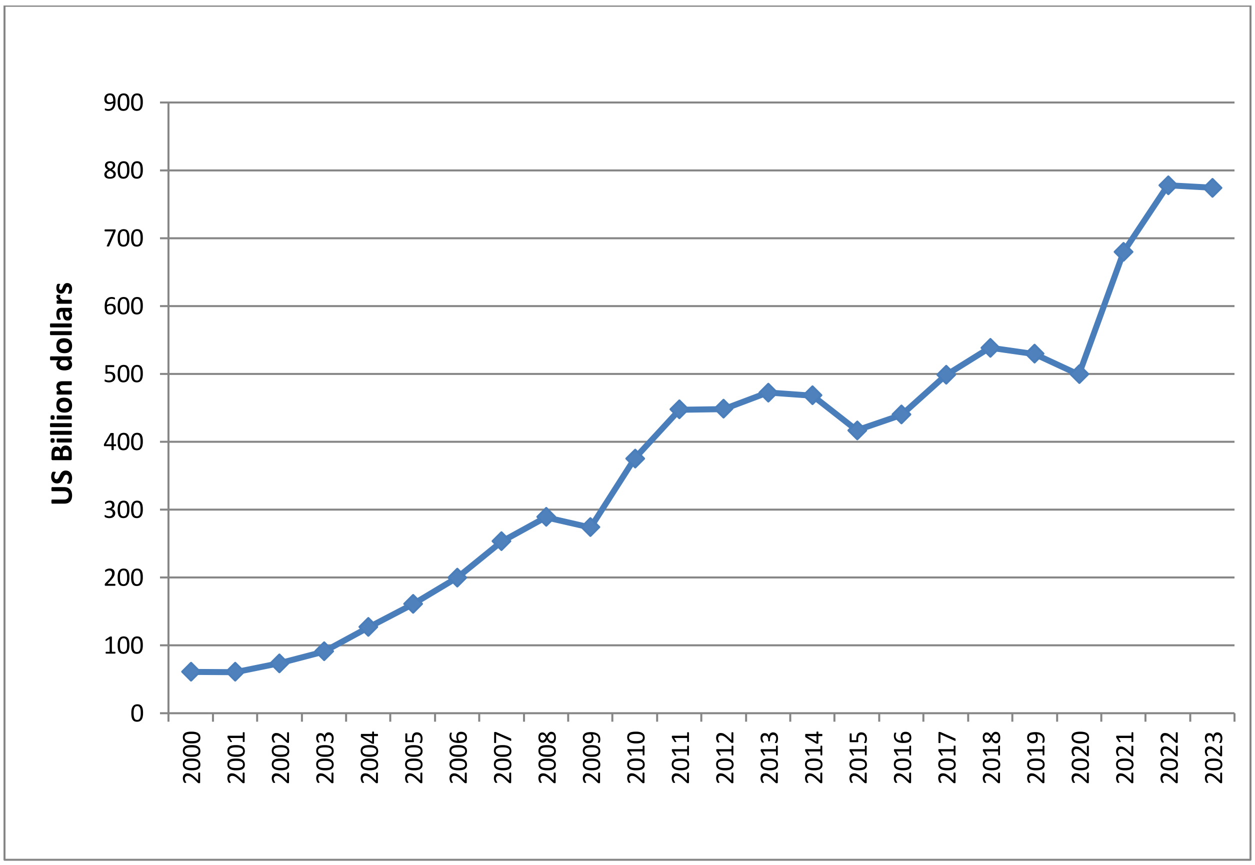

Fig. 1.1 India's total export value in US billion dollars from 2000-2023(World Bank, 2024)

Fig. 1.2 shows the contribution of the total export value of India in the GDP taken year wise from 2000 to 2023.

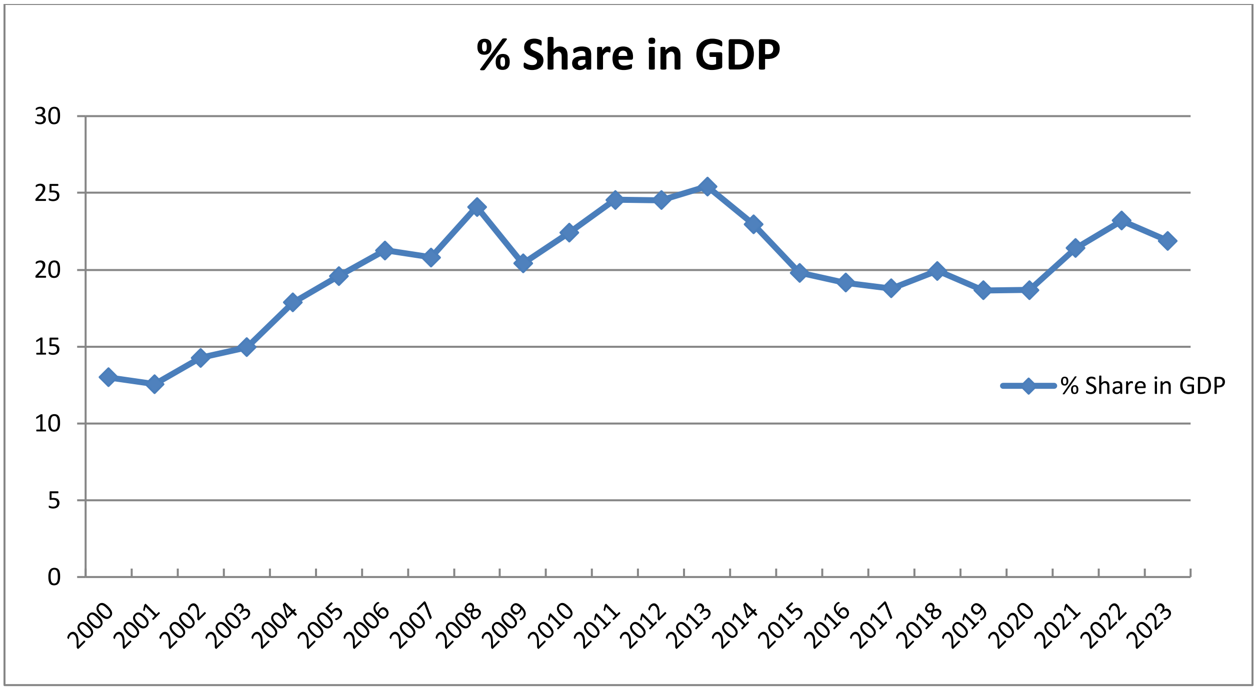

Fig. 1.2 India's export share in the GDP year wise from 2000 to 2023 (World Bank, 2024)

As per the National Industrial Classification, there are 24 allied sectors that make up the manufacturing industry in India. India's large domestic market and strong engineering base has given competitive advantage in building products indigenously and cost effective manufacturing in automobile, pharmaceuticals; and medical equipments. The growth of automobile sector is making significant contribution to Indian manufacturing industry. According to the data provided by Ministry of Heavy Industries, GoI, the automobile sector almost contributes to 7.1 percent in the National GDP for the year 2023 as against 2.77 percent in 1992-1993. This has led to the direct and indirect employment of over 19 million people. Indian government aims to double the monetary flow of its automotive market by the end of the year 2024.

Looking at the future growth of manufacturing in India and the limited availability of natural resources, there is a need of development of such business models in the manufacturing industry which can develop product more sustainably (Mathivathanan et al., 2019). India being a developing nation, hence sustainability becomes a major issue to meet the demand of majority of population. Sustainable development and technological value addition are the major reforms that have been given special attention during the amendments in the national policy of manufacturing. Therefore, it is the right time to examine the research and novel activities to help

Indian manufacturing sector in developing their approach and the essential techniques/methods to adopt circular models effectively.

The concept of CE is in nascent stage and requires utmost attention by the researchers and practitioners for its successful application in the manufacturing industry. This concept is a solution to many serious problems like waste generation, resource scarcity and sustainable economic benefits. Application of CE in the manufacturing industry entails serious challenges to the enterprise and researchers need to find ways for its successful application. Therefore, this study is focused to a developing economy having a huge customer base and manufacturing sector almost contributing one fourth in the GDP. It is necessary for a country like India to implement such business models in the manufacturing sector that could foster toward a sustainable development.

1.5 Issues in circular supply chain

Circular supply chain differs significantly in comparison to closed-looped supply chain. In closed loop supply chain, the principles of forward as well as reverse supply chain are simultaneously applied to form a closed loop cycle, whereas in case of circular supply chain the principles of circular economy are incorporated so that product goes through various cycles before being discarded. Over the past decades, there is a growing interest in investigating supply chains that are circular in nature (Agrawal et al., 2015; Ghisellini et al., 2016). Traditionally, a supply chain is defined as an integrated process that includes sourcing of raw materials and parts, manufacturing, and assembling of products, and delivering the final products to customers via distribution, retail, or both (Beamon, 2005; Hervani et al., 2005).

Sarkis (1999) argued that a traditional supply chain is based on the linear flow of materials and fails to include both environmental aspects and management of the end-of-life phase of products. The concept of green supply chain management (GSCM) integrates environmental dimensions in addition to the conventional dimensions in traditional supply chains (Ageron et al., 2012; Shibin et al., 2017). Recent developments in the area of sustainability have led organizations to incorporate economic, environmental and social factors in the supply chain (Morali & Searcy, 2013). Sustainable supply chain management intends to minimize material flows both in production and consumption process, reduce pollution and waste generation throughout the supply chain (Bai and Sarkis, 2010; Genovese et al., 2017). Both these approaches are based on the cradle-to-grave approach and have products going to the landfill though at a delayed pace (Genovese et al., 2017). Thierry et al. (1995) conceptualized the circular supply chain as an integrated supply chain model incorporating both forward and reverse aspects of the supply chain. In the recent years, organizations are seeking to methodically approach circular supply chain models to their businesses in terms of extending the product lifecycle, managing the waste, developing economic sustainability by the inclination of customer preferences towards secondary goods and products (Chhimwal et al., 2023). The concept of CE is in nascent stage and there are several challenges coming with the implementation of this concept that organizations need to face in today's business environment which need to be addressed in a systematic way.

In this new era of product development, manufacturing industries and environment need to have a healthy relationship for the improvement of their business performance since the industry environmental impact have seriously imposed pressure on the way of doing their business (Lieder and Rashid, 2016). Depletion of natural resources and the increase in human population are circumstances that confront the manufacturing industries to produce in a more sustainable way. The increased competitiveness for access to scarce resources has become an issue of major concern among the manufacturing companies belonging to the same sector. This has led to a series of challenges of resource price volatility and risk in resources supply in addition to fulfilling the obligation of adhering to environmental norms (Calisto Friant et al., 2021). Circular economic business models can be considered as a solution to these problems underlying the environmental, societal and economic benefits.

The concept of CE circles around the concept of how we manage the waste. CE works on three major principles reduce, reuse and recycle. Waste management is the fundamental step in order to incorporate CE throughout the supply chain operations. The presence of waste is an indication of inefficient use of materials and poor waste disposal mechanisms (Vladimirova and Le Blanc, 2016). In a developing country with a huge customer base and poor waste management policies the adoption and implementation of CE becomes significantly challenging. A huge amount of resources are being depleted especially in India through improper waste handling leading to unsustainable waste management practices (Esfahbodi et al., 2016; Ghosh, 2016). The adoption of a circular economy program entails that a company carries out different strategies to improve the circularity of its production system and also cooperates with other companies over the supply chain for the achievement of a more effective circular pattern (Elia et al., 2020). Implementation of the CSC concept is a challenging task and therefore requires an exploratory search of the drivers, barriers, practices, and risk involved with its execution.

Organizations need to check the performance of their supply chain to acquire valuable information for the decision making at strategic, tactical and operational levels (Kumar et al., 2019). To measure the performance of circular supply chain certain premeditated indicators are required which are similar to those used for circular economic activities (Geng et al., 2013). Cullen (2017) compared theoretical circular economy with a perpetual motion machine which gives away work without any input of energy source. The author tries to indulge in the idea of future CE activities in which waste is eliminated, materials are circulated in infinite loops and there is continuous recycling of used products. The author adds the prefix 'theoretical' to 'circular economy' since circularity is an ideal state which is impossible to achieve. If the concept of Circular Economy is accepted theoretically "ideal" then it can be used as a measure of benchmarking circular activities on a scale ranging from linear at one end to entirely circular at the other end. The indicators used for measuring the performance of circular supply chain activities are entirely different from those used in a conventional supply chain. Some of the indicators used to measure the performance in a conventional supply chain were cost, quality and output (Beamon, 2005), while the performance of circular supply chain is computed considering the aspect of environmental burden and resource utilization throughout the supply chain (Genovese et al., 2017).

Circular Supply Chain requires a high synergy level among the different partners as compared to traditional linear supply chain. There are large number of uncertainties associated with circular supply chain in terms of quantity, quality and timing of product returns which make these supply chain more vulnerable to risks. Therefore it becomes a challenging task to maintain a cyclic flow so that valuable materials are not lost due to the inefficiency in applying CE principles. The transition from a linear model to a circular economic model is of disruptive nature and certainly requires radical changes and new solutions in which current ways of working need to be changed and new ideas and practices should be followed to build products more sustainably (Mashud et al., 2020a; 2020b;2020c; Mathivathanan et al., 2019).

1.6 Motivation for the research

The concept of CSC is novel and there is a huge potential for in-depth exploration of related issues in this area. The review of literature on Circular Supply Chain Management (CSCM) showed that comprehensive integrated view of CSCM is still missing in the existing literature, therefore, there is a need to address various dimensions related to the incorporation of CE principle in supply chain management. The implementation of Circular Economy principles in the Indian manufacturing sector is in nascent stage and limited studies are available in the context of emerging economies. Looking at the future growth of manufacturing in India and the limited availability of natural resources, Indian manufacturing sector was selected for the research work. The study addresses the issues related to adoption and implementation of CSC in the Indian manufacturing industry. The study also focuses on the drivers, barriers, challenges and risks associated with the implementation of CE in the manufacturing industry in context to developing economy. The study constitutes the development of circularity framework for the manufacturing industry and addresses the issues of coordination and outsourcing in CSC in context to emerging economy. The current research on CSC issues highlights the need for in-depth exploration of various aspects related to its effective implementation across various sectors. The recent steps taken for sustainable development and amendments in the policies related to Indian manufacturing has motivated to conduct research work in this area.

1.7 Thesis Organization

The thesis is being organized into nine chapters. The description of different chapters in the thesis is briefly explained in the following paragraph.

Chapter 1- “Introduction” provides an overview of research work and discusses about various Circular Economy issues in contemporary research. It presents the Circular Economy practices adopted by the various industries globally as well as in India. This chapter briefly explains the select issues and motivation for considering these issues for the research work. Importance of Circular Economy and motivation for the research are also discussed. Organization of the thesis with a brief description of chapters is also enumerated in this chapter.

Chapter 2- “Literature Review” comprises of comprehensive review of literature to construct a holistic view of the recent and state-of-the-art studies in Circular Economy. Definitions and basic processes of Circular Economy are elaborated in this chapter. It also focuses on the literature review of select issues for research work such as adoption and implementation, including drivers, barriers, enablers and challenges to Circular Economy, circular strategies, circular supply chain risks, indicators and methods used to measure circularity . Based on the comprehensive literature review, a research gaps analysis was carried out and research gaps were identified. Research objectives were established based on research gap analysis. The literature review also helped in identifying the future directions for the research work.

Chapter 3- In Chapter 3- **"Research Methodology"**, procedural framework for the research work is explained with the help of a research flow diagram. This chapter also discusses about the various methodologies used for the research work, such as descriptive analysis and hypotheses testing. Fuzzy-DEMATEL methodology is used for the identification and prioritization of key challenges for Circular Economy implementation. Bayesian Network methodology is utilized for the development of decision frameworks for Circular Supply Chain risk management. Markov Chain is used as a stochastic modeling technique to evaluate the circularity of material flow of non-ferrous metal industry. Coordination among different stakeholders in the context of Circular Supply Chain has been analyzed using Graph Theory and Matrix Approach (GTMA). The chapter also provides a brief introduction to the methodologies and the rationale for the selection of these methodologies.

Chapter 4- In Chapter 4- **"Descriptive Analysis and Hypotheses Testing"**, descriptive analysis and hypotheses testing developments and procedures are explained thoroughly. The chapter describes the hypotheses formulation based on the comprehensive literature review and research gap analysis. A questionnaire development, questionnaire administration, respondent's profile along with reliability and validity tests are explained and discussed. The Likelihood Ratio Test is used to assess whether the more complex model, which allows for more flexibility in parameter estimation, provides a significantly better fit to the data compared to the simpler model.

Chapter 5- In Chapter 5- **"Identification and prioritization of key challenges for Circular Economy Implementation"** effort has been made to explore and analyze the challenges pertaining to the implementation of CE concept in Indian manufacturing industry. For the identification of significant challenges Pareto approach is incorporated in the study. Pareto analysis is a statistical tool which is used for the ranking of the factors according to their frequency of occurrence. Empirical observation is the fundamental basis for the application of Pareto analysis and should not be considered as a mandatory rule for actions. Fuzzy logic is applied along with DEMATEL approach to prioritize the significant CE challenges for the implementation in manufacturing industry. The concept of fuzzy logic is used to remove uncertainty in the data arising from human judgment. The purpose of using DEMATEL approach is to reflect causal relationship among the challenges.

Chapter 6- In Chapter 6- "**Case Study and Problem Description**" In this chapter, three case studies pertaining to the product, process and the industry to which it pertains is discussed. Firstly the case study talks about the challenges in the implementation of Circular Economy faced by the manufacturing industry in the context of developing economy. In this regard, the study considers certain number of organizations which are directly or indirectly involved with the manufacturing sector. The second case study talks about making the process of manufacturing more sustainable. This case specifically focuses on the manufacturing process and how circular practices can be incorporated in the manufacturing environment. The third case discusses about the circularity of material flow in a particular industry and this case specifically focuses on the circularity of product. The case studies are chosen in such a way that circularity at product level as well as process level are addressed for a manufacturing industry in the context of developing economy.

Chapter 7- In Chapter 7- **"Development of decision framework in Circular Supply Chain"** conceptual framework is developed that integrates risk management approach with Circular Economy. One of the objectives of this research is to develop a circular supply chain risk framework, in order to generate risk profiles of various CSC partners and to study the disruption caused due to the occurrence of various risk on the performance of CSC.

Chapter 8- In Chapter 8- "**Development of performance framework for measuring the circularity**" explored circularity potential of non ferrous metal considering a case of the Indian Aluminium industry. Aluminium is specifically chosen in this study as it is an ideal material for the circular economy due to its high recycling potential. One of the special characteristics is that the quality of Aluminium does not deteriorate on being repeatedly recycled. This chapter is able to demonstrate the circularity potential of Aluminium for the non ferrous metal industry in the context of developing economy. To analyze the flow of Aluminium in a supply chain network, Markov Chain approach is used because the material flow across various states has a random probability distribution or pattern that could be analyzed statistically with the help of reliable data sources.

The study addresses the problem of coordination in circular supply chain and contributes to limited available literature for the selection of suitable CSC partners. In this chapter, Graph Theory and Matrix approach (GTMA) has been incorporated. This approach comprehensively evaluates all the selection criteria and the interdependencies among them. Therefore, this study considers a case of an organization facing issues on establishing coordination network among multi-stake holders in order to achieve sustainable development goals.

Chapter 9- In Chapter 9- "**Conclusions and future directions**", summary of the key research findings and major contributions of the research are discussed. Furthermore, implications of the research work for the managers, researchers, and academicians are enumerated along with the limitations, and future scope of research in the area of Circular Supply Chain.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In the recent times, the concept of circular economy (CE) has gained much attention among the policy makers, industry practitioners and researchers (Geissdoerfer et al., 2017). CE is often used these days in the context of resource efficiency development (Figge et al., 2018). CE emphasizes the keyword "Circular", as the business models based on CE encourage the transition from linear flow to circular flow of products in order to retain the value of resources in supply chain for as long as possible (Salvador et al., 2020). CE is rather needed to decouple natural resource use and environmental impacts from economic growth (Crane et al., 2011). Despite its (CE) huge economic, environmental and social advantage, the awareness of CE business models is limited among the industry practitioners (Lewandowski, 2016). This poses a significant challenge owing to its adoption as a sustainable business model at an industrial level (Hopkinson et al., 2018).

The changing customer demand and resources related issues have forced the business leaders to rethink about the sustainability of their business models (Amnesty International, 2016; Tunn et al., 2019). An interesting context arises simultaneously in terms of the opportunities and challenges in the competitive business environment (Lieder and Rashid, 2016). Amid the interesting business context, CE provides an ocean of opportunities to organizations to bring innovation in their business models so as to gain competitive advantage over their peers (Suzanne et al., 2020).

CE aims to eliminate any kind of waste which still contains embedded value (Ghisellini et al., 2016). Four different types of waste in the form of (1) resources (2) capacities (3) lifecycle and (4) embedded values can be eliminated with the application of CE models. CE has tremendous potential to extract maximum value from product by eliminating waste in each form (Zink and Geyer, 2017). CE not only eliminate waste but it also reduces the extra waste being generated due to under utilization of resources (Buchert et al., 2013; FICCI, 2018). Ellen MacArthur Foundation (2013) devised a 'butterfly' figure, which has been recognized worldwide as a standardized tool to capture the complete spectrum of circular strategies. The butterfly figure (see Fig. 2.1) depicts the hierarchy to prioritize and implement the best CE strategy in the form of reuse, repair, refurbish, remanufacture, redesign and recycle, also known as 6R. According to the recent literature on circular strategies (Blomsma et al., 2019; Elia et al., 2017), the primary concern is to retain the value of products through the application of best alternative among the 6R spectrum.

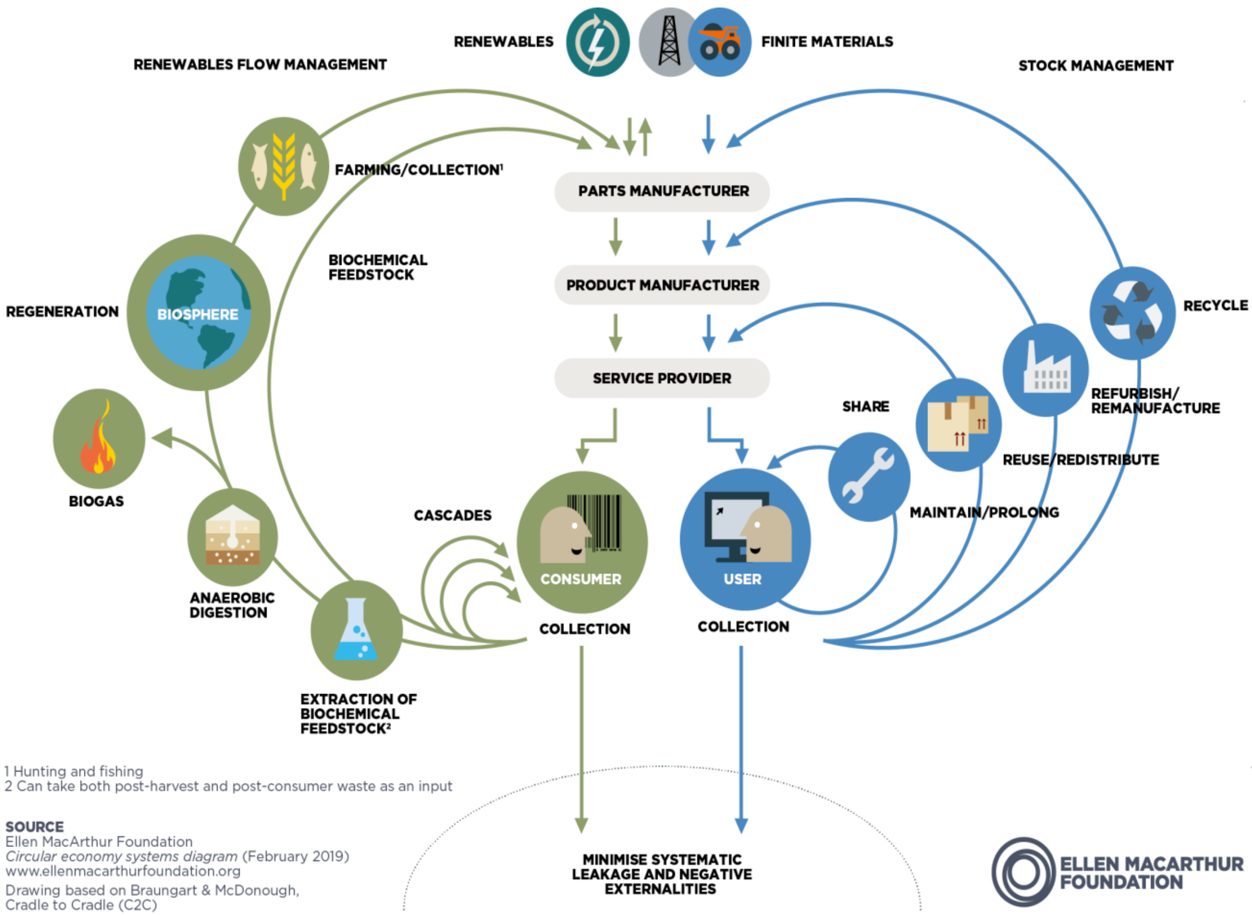

Fig. 2.1 Circular Economy Systems Diagram (Ellen MacArthur Foundation, 2019)

Many researchers have discussed several concepts and definitions related to CE but few of them have highlighted its pathway of implementation and challenges and risks faced during the process of adoption. Therefore, this chapter reviews the literature on key definitions, strategies and select issues of Circular Supply Chain (CSC) such as practices, challenges and risks faced during the implementation and identifies gap in existing literature related to CSC.

2.2 Definitions/Interpretation of CSC

The term 'Circular' when appended with the Supply Chain makes it 100 percent efficient (Lewandowski, 2016). The concept of Circular Supply Chain (CSC) can be compared to the Carnot cycle in Thermodynamic study which is considered as an ideal cycle. A practically feasible cycle cannot have 100 percent efficiency but we want our practical cycle to be as efficient as Carnot cycle. Similar is the concept of CSC. Every feasible supply chain cannot work with 100 percent efficiency. But by minimizing wastage and through efficient use of resources its overall circularity could be improved (Chhimwal et al., 2023; Kristoffersen et al., 2021).

(Kirchherr et al., 2017) analyzed 114 definitions of the circular economy which were coded on 17 dimensions so as to create transparency regarding the current understandings of the CE concept. Geisendorf and Pietrulla (2017) proposed a revised definition of the circular economy after having analyzed and compared the most prominent related concepts. Urbinati et al. (2017) proposes a classification of CE Business Models based on the degree of adoption of circularity along two major dimensions: (i) the customer value proposition & interface, i.e. the implementation of the circularity concept in proposing value to customers; (ii) the value network, i.e. the ways through which interacting with suppliers and reorganizing own internal activities. Kalmykova et al. (2018) provided an overview of the literature on CE theoretical approaches, strategies and implementation cases. Geissdoerfer et al. (2017) discusses the sustainability performance of the circular business models (CBM) and circular supply chains necessary to implement the concept on an organizational level and proposes a framework to integrate circular business models and circular supply chain management towards sustainable development.

Ghisellini et al. (2016) performed an extensive literature review and discussed CE roots and origin along with the principles and challenges in the transition towards CSC business models. The author also discussed different CE models and its implementation at three different levels: micro (single company or consumer), meso (eco-industrial parks) and macro (city, province, region or nation). Finally, the author concluded with a statement that "the purpose of the extensive literature review was to understand to what extent CE or CSC could be a solution to reduce the environmental impact of the industrial ecosystem".

Further, due to high industrial growth and modernization, organizations across all over the world are facing issues related to the negative environmental impact of their business activities. In response, managers are seeking to develop some innovative methods and approaches to managing these concerns. The circular initiatives in the supply chain are becoming increasingly popular to address these issues (Geng et al., 2012). The CSCM can be understood as the approach that keeps resources in use as long as possible; and that reduces waste at every stage, from design to distribution and beyond (Subramanian and Gunasekaran, 2014). During the implementation of CSCM, the transformation of linear manufacturing chains to circular chains should proceed in such a way that the business network models capable to manage the streamline circular flow of both the products and of by-products/waste generated (Loomba and Nakashima, 2012)

On the one hand, the scope of implementation of CSC initiatives is extended among business organizations, because CSCM initiatives may provide a sensible linkage between their economic growth and resource depletion and community welfare issues, and hence offer opportunities for sustainability of business (Park et al., 2010). On the other hand, in today's scenario of complex environment, the adoption, and extension of CSC models for sustainability of business is challenging and needs a comprehensive understanding and theory building (Dora et al., 2016). In this sense, it is important to explore the concepts of CE/CSC and CSCM for improving the ecological, economic and social performance of industrial supply chains. Based on the previous studies, researchers and practitioners all around the world aim to address the perspectives of circular supply models in a supply chain context (Genovese et al., 2017; Sarmah et al., 2007). Literature also suggested that there are various challenges associated with the implementation of CSCM concepts, which needs to be distinguished accurately along with the scaling up of their solutions from the industrial viewpoints (Y Geng & Doberstein, 2008; Yong Geng et al., 2012; Genovese et al., 2017; Su et al., 2013). Based upon the emergent need to develop and innovate the concept of circular supply chain management some of the definitions have been reviewed and shown in Table 2.1 as stated by different authors and in reports of various organizations.

Table 2.1 Definitions/Interpretation of Circular Supply Chain/Circular Economy

Sources	Definitions/Interpretation
Boulding (1966)	A condition that must be met in order to ensure the long-term viability of human existence on our planet, which operates as a self-contained system with minimal interaction with the surrounding environment.

Pearce and Turner (1989)	The transition from the conventional unrestricted economic system to the circular economic system can be elucidated as a result of the application of the principles of thermodynamics, which govern the deterioration of matter and energy.
Frosch and Gallopoulos, (1989)	An industrial ecosystem ought to maximize the utilization of energy and resources, reduce pollution and waste, and take into account the environmental consequences of each outcome resulting from a manufacturing procedure.
Frosch (1992)	Waste ought to be utilized as a source of energy or material.
Thierry et al. (1995)	The product recovery management was conceptualized as a supply chain model that integrates various reverse aspects of the supply chain. These include repair, refurbishing, remanufacturing, cannibalization, and recycling.
Geels (2011)	Transitioning to a circular economy would necessitate tackling the task of establishing a sustainable energy supply, in addition to taking decisive action in various other domains such as agriculture, water, soil, and biodiversity.
Preston (2012)	The concept of a circular economy aims to revolutionize the way resources are utilized in the economy. Rather than being discarded, waste generated by factories would be transformed into a valuable input for another process. Additionally, products would have the potential to be repaired, reused, or upgraded instead of being disposed of.
Su et al. (2013)	The emphasis on the circular economy progressively expands beyond matters concerning material management and encompasses additional facets like energy efficiency and preservation, land administration, soil safeguarding, and water.
Jackson et al. (2014)	The transition to a circular economy is a crucial requirement for a robust industrial system that enables innovative forms of economic enterprise, enhances competitiveness, and fosters job creation.
Ellen MacArthur Foundation, (2013, 2016)	The circular economy is an industrial system that is designed to be restorative or regenerative. It aims to replace the concept of "end-of-life" with restoration and to transition towards the use of renewable energy. Furthermore, it seeks to eliminate the utilization of toxic chemicals, which hinder reuse, and strives to eradicate waste through the superior design of materials, products, systems, and, within this context, business models.
Sauvé et al. (2016)	Circular economy is characterized by the process of producing and consuming goods by means of closed-loop material flows, which effectively integrate the environmental externalities associated with the extraction of virgin resources and the generation of waste, including pollution.
Ghisellini et al. (2016)	The innovative actors who are responsible for the radical transformation of all processes throughout the life cycle of products have the ability to not only achieve the recovery of materials or energy but also enhance the entirety of the living and economic model.
Geisendorf and Pietrulla (2017)	The concept of Circular Economy is centered around the cradle-to-cradle approach. This approach ensures that after a product reaches the end of its life, it is reintegrated into the supply chain using different strategies such as reusing, repairing, refurbishing, remanufacturing, and recycling.

Genovese et al. (2017)	Circular Supply Chain Management (CSCM) is a part of the circular economy, which seeks to maximize the utilization of resources throughout the life cycle of a product by employing methods such as recycling and remanufacturing.
Mangla et al. (2018)	In recent times, companies have been increasingly interested in adopting a systematic approach to implementing circular supply chain models within their operations. This entails a focus on prolonging the lifespan of products, effectively managing waste, and promoting economic sustainability.
Farooque et al. (2019)	Circular Supply Chain Management (CSCM), which integrates the philosophy of the circular economy into supply chain management, offers a new and compelling perspective to the supply chain sustainability domain.
Morseletto (2020)	The most recognized definition of the circular economy is that it is a restorative and regenerative economy. Despite the wide use and importance attributed to the concepts of "restoration" and "regeneration," they are rarely defined or explained in the circular economy literature.
Nobre and Tavares (2021)	Circular Economy is an economic system that targets zero waste and pollution throughout materials lifecycles, from environment extraction to industrial transformation, and to final consumers, applying to all involved ecosystems.
Corvellec et al. (2022)	Circular economy is based on an ideological agenda dominated by technical and economic accounts, which brings uncertain contributions to sustainability and depoliticizes sustainable growth.
Kirchherr et al. (2023)	The circular economy (CE) is a regenerative economic system which necessitates a paradigm shift to replace the 'end of life' concept with reducing, alternatively reusing, recycling, and recovering materials throughout the supply chain, with the aim to promote value maintenance and sustainable development, creating environmental quality, economic development and social equity.

2.3 Circular Economy Implementation

CE concept application started in Germany in the year 1996, with the passing of the law that emphasized on efficient waste management and proper disposal of waste to minimize environmental degradation (Lu and Halog, 2020; Nelles et al., 2016). Thereafter, comprehensive legal framework of CE strategy was developed by the Government of Japan that directs the society on how to recycle used products (Morioka et al., 2005). In China, the CE concept is projected as a new sustainable development strategy rather than considering it as an enhanced environmental regulation policy (Geng and Doberstein, 2008; Hasan et al., 2020). Ghisellini et al. (2016) performed a comprehensive literature review and discussed CE origin along with the principles and challenges in the transition toward CE business models. Sousa-Zomer et al. (2018)

focused on the implementation of CE at the micro-industrial level where a manufacturing organization from the developing economies was considered to explore the cleaner production practices and eco-design principles adoption. Lieder and Rashid (2016) proposed a concomitant top-down and bottom-up approach in which the interest of all the stakeholders were aligned in a single direction to achieve the benefits from the implementation of CE. The government bodies and the policymakers emphasize on environmental benefits of CE, while the industries look for economic benefits neglecting the concern for environment (Jayakumar et al., 2020). Thus, a concurrent approach is necessary for the alignment of interest to obtain maximum benefits from CE implementation.

2.4 CSC practices

Circular Supply Chain practices are those practices which help in improving the overall circularity of supply chain. Circularity can be defined as minimizing the input of raw material into the supply chain and maximum utilization of the resources already present in the supply chain. Circularity can only be achieved through successful implementation of CE principles at all the three levels: micro, meso and macro (Nobre & Tavares, 2021).

Cleaner production (CP) and eco-design are some of the practices which the producers are encouraged to adopt at micro-level. Cleaner production has emerged as the foremost and extensively implemented approach in comparison to other practices, particularly subsequent to the introduction of China's "Cleaner Production Promotion Law" in January 2003 (Zhu et al., 2010). CP is a highly effective strategy that aims to tackle pollution generation and promote the efficient utilization of resources across all stages of the production process. In particular, for enterprises that are heavily involved in polluting activities, CP is mandatory and plays a pivotal role in reducing their environmental externalities and energy intensity. This underscores the critical importance of CP in fostering sustainable and eco-friendly production practices (Hicks & Dietmar, 2007). Eco-design pertains to a methodical integration of environmental considerations into the development of production methodologies and end-products. The innovative design of production lines facilitates heavily polluting companies in manufacturing and process industries to generate more integrated, efficient, and sustainable ways for production (Negny et al., 2012). Yu et al. (2008) undertook a comprehensive survey of 36 electrical and electronic manufacturers in China, and the findings indicated a notable dearth of eco-design within their product offerings.

With respect to consumer behavior, promotion of green consumption practices is crucial, as this can effectively incentivize the utilization and procurement of environmentally sustainable goods and services (Y Geng & Doberstein, 2008).

The heightened flow of product returns and the growing awareness of environmental, legal, and corporate social responsibility concerns have made reverse logistics a crucial matter for many organizations (Pokharel & Mutha, 2009). Reverse logistics activities encompass the collection, examination, and categorization of products, as well as their disposition through means such as reuse, repair, remanufacturing, or recycling, and ultimately their redistribution (Agrawal et al., 2015). One of the crucial considerations is determining if certain tasks should be partially outsourced, fully outsourced, or not outsourced at all. While there is an abundance of literature on selecting third-party reverse logistics service providers, there is a notable scarcity of literature on fully or partially outsourcing reverse logistics. Agrawal et al. (2016) developed a comprehensive framework for outsourcing strategy in reverse logistics. This framework utilizes a graph theoretic approach, which has been found to be highly effective in this context.

The principles governing extended producer responsibility have formed the foundation of numerous recent policies and legislative frameworks that address the effective management of recyclable goods at their end-of-life stage. Gupt and Sahay (2015) explored 27 instances of extended producer responsibility across both developed and developing economies, with and without informal recycling practices, in order to determine the key factors that contribute to successful implementation of extended producer responsibility initiatives. The results of the comparative analysis indicated that financial responsibility on the part of producers, as well as on the establishment of separate entities for collecting and recycling, were both critical factors in the achievement of environmental policies based on extended producer responsibility.

Recently, the manufacturing industry has been placing significant emphasis on the utilization of artificial intelligence (AI) technology (Duan et al., 2024). This technology serves as the foundation for smart manufacturing and Industry 4.0 strategy (Delke et al., 2023), and has garnered a great deal of interest. Product lifecycle management (PLM) is responsible for handling a diverse array of engineering, business, and management activities related to a product throughout its entire lifecycle (Ji & Abdoli, 2023). This lifecycle involves the product's inception as an intangible concept to the recycling of a finished product. In the context of smart manufacturing, Wang et al. (2021) have undertaken a comprehensive review of various theories, algorithms, and technologies of AI that can be applied to different stages of PLM, namely product design, manufacturing, and service. A structured roadmap has been meticulously presented to effectively guide future research and application of AI in PLM.

Shankar et al. (2017) conducted a thorough analysis of sustainable manufacturing practices, specifically in a particular domain. The authors presented a framework that aims to achieve research objectives in the context of India, where sustainability concerns are particularly pertinent. Out of the 22 prevalent sustainable manufacturing practices, it was found from the case findings that the promotion of 6R (reuse, reduce, recycle, recover, redesign, and remanufacture) principles has the biggest impact on implementation. It is apparent that focusing on 6R ideas will improve the organization's adoption of sustainable manufacturing practices.

In recent years, sustainable manufacturing has gained commendation for its substantial benefits that are directed towards triple bottom line factors, namely social, environmental, and financial aspects (Nicoletti Junior et al., 2018). However, it is noteworthy that the majority of manufacturing strategies still focus only on one or two of these factors. Unfortunately, there are no reliable guidelines available to assure the successful adoption of sustainable manufacturing. Furthermore, the available literature fails to delve into the intricacies of this multifaceted research topic. Therefore, for the adoption and implementation of a novel concept such as Circular Supply Chain there is a need to thoroughly explore all the dimensions and consider all the aspects that can render its effectiveness in enhancing the sustainability of the organization. In this research, an attempt has been made to examine and assess the present CE practices implemented by the manufacturing sector of an emerging economy. Table 2.2 provides a structural classification of the practices adopted at different levels of supply chain targeting all the three aspects of sustainability i.e. environmental, economic and social. The next sub-section discusses about the challenges and risks encountered during the implementation of CE in the manufacturing industry.

Table 2.2 CSC practices adopted at different levels, sectors and regions

Practices	Level of SC	Industry /Sector	Country/ Region	Sources
Environmental Practices				
Cleaner production	Micro	Manufacturing	China	Zeng et al., 2017; Zhu et al., 2010)
Green consumption and purchase	Macro	General	China	(Su et al., 2013)
Eco-design	Micro	Chemical	United Kingdom	Knight and Jenkins (2009)
Following environmental norms	Macro	General	European Union	Dagiliene et al. (2020)
Sustainable logistics	Macro	Manufacturing	Global	Jayarathna et al. (2023)
Use of 6R strategy	Macro	Leather	Bangladesh	Maliha et al. (2023)
Use of AI tools and techniques for minimizing wastage	Meso	Domestic	Russia	Huang and Koroteev (2021)
Adoption of product lifecycle management	Micro	Manufacturing	Global	Singh et al. (2020)
Economic Practices				
Circular supply chain investment as a percentage of overall investment	Meso & Macro	General, SME's	United Kingdom, EU	Alkaraan et al. (2023); Demirel and Danisman (2019)
Monitoring recovered value	General	General	Brazil	Delai, and Alcantara (2022)
Revenue sharing	Meso	Dairy	Denmark	(Momeni et al., 2022)
Promoting circular practices	Macro	Manufacturing SME's	Italy	Blasi et al. (2021)

Incorporation of Extended Producer's Responsibility	Macro	General	European Union	Maitre-Ekern (2021)
Policy Implementation	Macro	General	European Union	Calisto Friant et al. (2021)
Taxation relief	Macro	General	Spain	Vence and López Pérez (2021)
Social Practices				
Working on customer mindset	Micro	Textile	Europe	Franco (2017)
Supplier evaluation	Micro	Wire and cable	Iran	Kannan et al. (2020)
Adopting public procurement policy	Macro	General	Global	Alhola and Nissinen (2018)
Social Innovation initiatives	Macro	Social Housing	United Kingdom	Marchesi and Tweed (2021)
Stakeholder involvement	Micro	General	European	Gupta et al. (2019)
Social responsibility	Macro	Energy sector	Thailand	Niyommaneerat et al. (2023)
Sustainable and Equitable business practice	Macro	General	Global	Amini and Bienstock, (2014)

2.5 Challenges and risks in the adoption of Circular Supply Chain practices

A thorough examination of the challenges impeding the adoption of CE practices and their interdependent nature can aid emerging economies manufacturing sector in transitioning smoothly to a circular business model. Hence, a comprehensive literature review is undertaken to investigate the challenges and remedies involved in implementing CE.

Shi et al. (2008) identified the challenges that arise during the adoption of cleaner production practices by the Small and Medium Enterprises (SMEs) in China. The researchers also prioritized these challenges. As per their findings, the top three challenges in this regard were the absence of regulations pertaining to economic enticement,, the reprehensible imposition of environmental taxes, and the substantial upfront expenditure required for the capital cost. Furthermore, considering a supply chain perspective, it is exceedingly challenging for a solitary manufacturing entity to restructure the complete value chain for the incorporation of Circular Economy practices, as numerous stakeholders are implicated in the manufacturing, distribution, and consumption procedures (Bressanelli et al., 2019). The recognition of such challenges is essential in the development of tactics to alleviate them, ultimately paving the way towards transitioning from conventional Supply Chain Management (SCM) to Circular Supply Chain Management (CSCM) (Govindan & Hasanagic, 2018).

The available evidence indicates that one of the primary impediments to the successful implementation of circular supply chains (CSC) is the extended payback period associated with product service systems (PSS) (Homrich et al., 2017; Werning & Spinler, 2020). PSS represents a form of circular business model (CBM) in which goods are not sold, but rather offered as services. The service provider is paid continuously during the usage of the product or solution, thus negatively affecting the firm's cash flow and presenting a financial and economic challenge to the realization of CSC. Additionally, PSS suppliers and service providers bear the financial and operational risks. For instance, customers terminating a contract prematurely, may subject suppliers to financial risks. Furthermore, service providers are responsible for maintenance and repairs, posing an operational risk in the implementation of CSC (Flachenecker & Rentschlehler, 2019; González-Sánchez et al., 2020).

The implementation of Circular Supply Chain Management (CSCM) as a Circular Economy (CE) practice is impeded by the barrier of product complexity. The increasing complexity of products, in terms of their design and constituent materials, makes it challenging and costly to undertake CE practices (Halse et al., 2020; Rosa et al., 2019). Furthermore, the challenges faced during the recovery phase are exacerbated by the mass customization of products. The processing and re-circulation of diverse materials and components require separate methods, processes, and facilities, which increase the complexity and cost of implementing CSC (Khodier et al., 2018).

Governments and research organizations have been actively encouraging the implementation of sustainable manufacturing. However, there is a lack of uniformity in the adoption of Circular Economy (CE) practices across various industries and sectors, specifically in terms of processes, activities, and materials. The absence of a holistic framework poses a challenge for manufacturing organizations to implement CSCs (Mangla et al., 2017; Ranta et al., 2018). Moreover, the absence of monetary benefits, like those linked to the utilization of sustainable energy resources and the decrease in waste, deters companies from adopting CSCM. At present, there is a scarcity of taxation systems, regulations, and policies that cover the entire scope of the manufacturing industry. These systems would be instrumental in promoting the adoption of CE practices and incentivizing firms that strive to implement CSCM (Saidani et al., 2019; Whalen & Whalen, 2018). Moreover, existing measures such as Gross Domestic Product (GDP) and industrial output concentrate on the levels of production and consumption derived from a linear economic model. A recognized and commonly used system of metrics and indicators that can gauge the level of value recovery in a circular economy is lacking, and this deficiency hinders organizations from monitoring and evaluating their CSC performance (Bressanelli et al., 2019; Kravchenko et al., 2019).

The presence of uncertainty with regards to the return flow of products, including their quality, quantity, time and location can diminish the potential for optimizing and achieving economies of scale in reverse supply chain activities. It is evident from the past research (Hartley et al., 2020; Ranta et al., 2018), that the increased costs and efforts associated with product recovery can hinder companies from adopting a circular approach within their existing supply chain. Moreover, the retrieval of previously utilized commodities requires supplementary systems and strategies for logistics, processing, manipulation, and storage, ultimately resulting in increased operational expenditures in the execution of CSCM (de Boer & Andersen, 2018; Whalen & Whalen, 2018). Additionally, it is crucial that all stakeholders involved in the supply chain adhere to the manufacturing company's strategic direction towards a circular economy and possess the requisite expertise, assets, and capacities to effectively execute diverse circular initiatives. However, identifying suitable partners can be a challenge for companies, as complete vertical integration is rarely achieved within manufacturing supply chains (E. D. de Souza et al., 2022; Tura et al., 2019). Moreover, disparate information-sharing frameworks along the supply chain may impede coordination attempts, even in the event that appropriate partners are found. A major obstacle to enterprises making the shift to circular supply chain management is the absence of standardized systems and IT integration. In addition, competition among supply chain tiers presents a major obstacle to establishing a transparent and efficient supply chain

(Bressanelli et al., 2019; Mangla et al., 2017). The adoption of Circular Supply Chain Management (CSCM) necessitates a harmonization of technologies and processes for each product manufactured. The enhancement of product design, manufacturing processes, and applied technologies would entail an upgrade of existing infrastructure, which would result in an escalation of operational costs. Conversely, durable circular products are not conducive to product innovation, thereby rendering them less appealing to firms that prioritize innovative and customized products (Bressanelli et al., 2019; Rajput & Singh, 2019). Furthermore, it has been observed that customers who do not possess product ownership exhibit negligent conduct and lack the willingness to discharge their duty of preserving and restoring the products to a reusable or recoverable state upon cessation of use. As a consequence, this results in a surge in expenses associated with repair and maintenance, and frequently entails the disposal and wastage of end-of-life (EoL) products (Agyemang et al., 2019; Maheswari et al., 2019). The preceding discourse reveals that there are various impediments to the smooth shift from conventional, linear supply chains to circular supply chain management (CSCM) in the manufacturing industry. Table 2.3 depicts the various CSC practices adopted at different strategic levels of supply chain and the challenges and risks during their adoption.

Table 2.3 Challenges and risks during the adoption of CSC practices

Strategic Level	CSC Practices	Challenges and Risks	Sources
Micro	Cleaner production	• Lack of policies related to economic incentive, • Reprehensive imposition of environmental taxes, and • Large capital investment	Berkel, 1999; Shi et al., 2008; van Berkel, 2007, 2000; Van Berkel et al., 1997; Yuan et al., 2006; Fang et al., 2007; Fresner, 1998; Frondel et al., 2007; Schnitzer and Ulgiati, 2007; Zhijun and Nailing, 2007
	Green consumption and Green public procurement	• Compliance with a scientific development philosophy • Setting of responsibility of individual stakeholders. • Fragmented regulation	Geng and Doberstein, 2008; Liao and Li, 2010; Liu et al., 2009; Su et al., 2013; Zhijun and Nailing, 2007; Zhu et al., 2013

		system • Improper resource tax imposition	
	Policies on product recycling and reuse	• Lack of financial incentives • Lack of coordination during implementation phase • Reluctance to change • Concern regarding the impact on product standard	Mukhopadhyay and Setaputra, 2011; Tsai and Chou, 2004;Thomas, 2003
Meso	Industrial symbiosis	• Formation of eco-industrial parks • Sustainable exchange of material and energy • Geographical proximity during resource sharing	Baas and Boons, 2004; Chertow, 2007; Ehrenfeld and Gertler, 1997; Gibbs and Deutz, 2005; Park and Chertow, 2014
	Waste Trade Markets	• Thorough analysis of secondary market • Empirical study of informal waste trade practices • Customer connect	Lindeman, 2012; Strohm, 1993; Su et al., 2013
	Policies for eco-industrial parks	• Monitoring carbon emissions • Optimizing exchange of material and energy. • Capacity enhancement through social integrity	Belaud et al., 2019; Fan and Fang, 2020; Geng et al., 2016
Macro	Regional level collaboration of eco-industrial	• Strengthening of regional markets for recycled materials • Risk of under utilization of local material	Guarnieri et al., 2023; Taddeo, 2016; van Bueren et al., 2023

	parks	• Risk of global trade of material • Sustainable accounting of resource sharing	
	Creating recycling oriented society	• Spreading consciousness amidst a vast multitude. • Technical know-how for circular activities • Redefining consumption through innovative zero-waste programe	Franklin-johnson et al., 2016; Geng et al., 2012; Geng and Doberstein, 2008; Geng Yong et al., 2013
	Collaborative business models	• Revenue sharing • Risk sharing • Joint decision making	He (2017); He and Zhang (2010); Cachon and Lariviere (2005); Giannoccaro and Pontrandolfo (2004); Hill and Omar (2006); Kanda and Deshmukh (2008); Thomas and Griffin (1996)

2.6 Circular strategies

The building up of the concept of circularity is devised from the key principles of CE namely cradle-to-cradle approach (Mcdonough & Braungart, 2002), reverse logistics (Agrawal et al., 2015), industrial ecology (Erkman, 1997), regenerative design (Cole, 2012), closed supply chains (Souza, 2013) and biomimicry (Reap et al., 2005). Ellen MacArthur Foundation (2016) defines CE as a strategy that is restorative and regenerative by design and intends to maximize the utilization of materials, components, and products and therefore extracting the best value at all times. European Union (EU) action plan for CE establishes another important definition which states the value of products is maintained for prolonged time; wastage is minimized and resources are kept within the economy for as long as possible to extract maximum value after the product reaches its end of life (European Commission, 2017). The latter part of the definition is bit more dubious about the condition of waste. The question arises ‘whether wastage has to be minimized or completely eliminated? Waste is generally regarded as residual which is discarded or remain unused. There has to be a deviation about the common understanding of waste when looking from CE perspective. CE considers waste as one which can be reused and may have some sort of value embedded to it. The quest on how to maximize the value extraction calls for the building up of the concept of circularity.

Several circularity indices used to measure product level circularity are currently under assessment (Gehin et al., 2008; Linder et al., 2017; Scheepens et al., 2016). In the report on CE by the Ellen MacArthur Foundation, (2016) it states that there is no such standardized way to measure product level circularity. However, the effectiveness of product label development, "Eco-labeling" to support the transition to CE is justified by the periodic revision of the included criteria's (European Commission, 2017). Recently included eco label for product provides information about the percentage composition of raw material used and their recyclability potential (Cordella et al., 2020). The results of (Boyer et al., 2021) study on the interest of the customers for circular products shows that the average number of customers prefers to purchase eco-labeled products in place of product having comparable apparent features, with no eco-label. In order to conceptualize and put into operation CE at micro level the concept of regenerative design (Cole, 2012) is introduced to craft the products such that they become recyclable and reusable. This concept was apprehended by introducing the concept of cradle-to-cradle lifecycle (Mcdonough and Braungart, 2002), where 'technical nutrients' were compared to 'biological nutrients' being circulated in an industrial symbiosis (Frosch and Gallopoulos, 2018). Keeping in view the environmental, economical and social benefits of multiple use of products and material, Stahel (2015) described the 'smallest loop' axiom as the most viable solution for the entire economic system. However, decreasing the resource intensity of eco-conceived products can make them less expensive to produce, while the availability of cheaper products can boost the demand, leading to a rebound effect, annihilating part or all of benefits obtained thanks to the implementation of CE strategies, a situation also known as the Jevon paradox.

The term 'circularity' is often used in connection with the product when the concept of CE comes into picture. The concept of CE has evolved to boost economic growth aiming at decoupling economic growth from its negative impacts (Crane et al., 2011.; Stahel, 2013), produce monetary gains (Giuntini & Gaudette, 2003; Heese et al., 2005) and generate new job opportunities locally (Walter R. Stahel, 2015; Webster, 2013). These claims are only possible when circularity measures are adopted at every level (micro, meso and macro). Table 2.4 shows the various metrics adopted at each of the strategic level (micro, meso and macro) and how these indicators lag while not targeting the different CE measures. In minerals and metals industry the presence of CE related indicators is insufficient to fully measure the progress towards the CE. Circularity measures currently exist for meso and macro level. However, measures used to compute circularity at micro level are still lacking in the existing literature (Geng et al., 2012). The framing of product level circularity measures is essential for the industry practitioners to gain competitive advantage over their peers.

Table 2.4 Circular Economy metrics and measures

Strategic level	Author	CE Metric	Findings	CE measures not included
Macro	Moriguchi (2007)	Material Flow Accounting (MFA)	Circular material flows are measured for the adoption of CE principles at the national level.	• Emissions • Valuable Material Losses • Functional value of products
	Haas et al. (2015)	Economy-Wide Material Flow Analysis (EW-MFA)	A model based on Quantitative analysis to evaluate the level of circularity in European Union nations.	• Emissions • Valuable Material Losses • Functional value of products
	Geng et al. (2012)	Chinese national CE indicator system	For the implementation and adoption of CE at the national level certain set of indicators were used.	• Allocation of recyclable and renewable resources • Emissions • Functional value of products
	Jiang (2011)	Fuzzy Comprehensive Evaluation Method	Measured the level of regional CE development reflecting the resource recycling characteristics.	• Functional value of products
	Yang et al. (2011)	'Tailor made' multi-criteria index method	A model incorporating Analytical Hierarchy Process (AHP) as one of the Multi-criteria decision making (MCDM) tool focusing on economic growth, environment safeguard and social upliftment.	• Functional value of products
	Zaman and Lehmann (2013)	Zero waste index	Finding out the Circular performance of waste management process across three cities worldwide	• Allocation of recyclable and renewable resources • Emissions • Functional value of products
	Ruhrberg (2006)	End-of-Life Input Rate	This indicator measures the percentage amount of metal produced from input scrap and other metals having low grade residues.	• Valuable material losses • Functional value of product • Emissions

	European Commission (2021)	Implied emission factor (IEF)	IEF approximates the amount of Green House Gas (GHG) emissions divided by the activity data of each raw materials sector.	• Valuable Material Losses • Functional value of products • Allocation of recyclable and renewable resources
	Van Schaik et al. (2004)	Recycling process efficiency rate	It tells about the efficiency of any given recycling process and is also known as 'recovery rate'.	• Allocation of recyclable and renewable resources • Emissions • Functional value of products
Meso	Li and Yu (2011)	Five categories index method	Measuring the level of circularity of Chinese chemical enterprises.	• Allocation of recyclable and renewable resources • Functional value of products
	Genovese et al. (2017)	Hybrid LCA model	Compared performances of circular production systems in two process industries	• Functional value of products
	Wen and Meng (2015)	Resource Productivity Indicator	Assessing the circularity level of printed circuit boards industry of China.	• Allocation of recyclable and renewable resources • Emissions • Functional value of products
	Scheepens et al. (2016)	LCA Eco-cost and Value Ratio (EVR) model	Eco-efficient Value Creation has a positive effect on product level and environment but has a negative effect at the societal level with low customer perseverance value required to withstand in the global market.	• Lack of input and heightened use of natural resources • Allocation of recyclable and renewable resources • Emissions • Durability of products • Valuable material losses
	Xun et al. (2020)	End-of-Life Recycling Rate	End-of-Life Recycling Rate indicates how much percentage of waste metal is recycled.	• Valuable Material Losses • Functional value of products

				• Allocation of recyclable and renewable resources
Micro	Ellen MacArthur Foundation (2016)	Material Circularity Indicator (MCI)	Succeeds in including the loss of material and durability of product when analyzing the circularity of product.	• Emissions
	Di Maio and Rem (2015)	Circular Economic Index (CEI)	This index is used as a decision making tool to assess the environment, economic and social implications of recycling.	• Lack of input and heightened use of natural resources • Emissions • Functional value of products • Valuable material losses
	Park and Chertow (2014)	Reuse Potential Indicator (RPI)	This indicator is used to assess the quality of material according to latest available technologies.	• Lack of input and heightened use of natural resources • Emissions • Functional value of products • Valuable material losses

2.7 Circularity indicators and methods

Niero and Kalbar (2019) came up with a Material Circularity Indicator (MCI) as an attempt to measure product level circularity. The MCI comprises of two factors, the utility index and the linear flow index. The utility index is calculated based on the average estimated life of product. The estimation is purely judgmental and is therefore dependent on reliable methodological principles used to measure product circularity. The linear flow index is regarded as one of the characteristic feature of Material Flow Analysis (MFA). Moriguchi (2007) carried out an in-depth analysis of the adoption of various MFA models at the regional level. The author took insights from the Japanese national policy framework on circularity of material flow. Virtanen et al. (2019) identified various indicators to effectively measure the circular flow of different materials at the regional level. The study highlights the difficulty in obtaining information about the complete cycle of material flow, the information obtained mainly relates to waste flow that lacks CE characteristics. One of the major limitations of MFA is that, it focuses on mass flow of the entire stream of different materials considered as one single component. This leads to difficulty in the extraction of various materials during material recovery (recycling) process. To resolve this issue Ellen MacArthur Foundation (2016) recommends efficiency index as a better alternative for recycling processes. However, efficiency index is not able to differentiate between the different constituents of a product. The MCI proposed by Ellen MacArthur Foundation succeeds in including the loss of material and durability of product when analyzing the circularity of product. Ellen MacArthur Foundation acknowledges the significant implications of different material use-phase extension processes (Reuse, Repair, Refurbish, Remanufacture (4R)) or recycling efficiency promoting processes (Recycle), leading to material cycling and value retention.

Di Maio et al. (2017) came up with a single index to measure product level circularity i.e. the Circular Economic Index (CEI). CEI is defined as the ratio of the value of material obtained after recycling to the one entering the recycling facility. Since CEI specifically focuses on recycling process efficiency therefore other forms of material efficiency promoting process are neglected and thus this index can have a low construct validity in terms of capturing the complete spectrum of material recovery. Another single indicator was proposed by (Park and Chertow, 2014) that characterizes each material, popularly known as Reuse Potential Indicator (RPI). It signifies how much resource value is embedded in the End of Life (EoL) product rather than considering it as 'waste-like' material. This indicator can serve as a guide to the practitioners during the decision making phase.

Circularity at the product level has been explored using various other indicators too. A cradle-to-cradle (C2C) certification framework has been developed by the Cradle to Cradle Product Innovation Institute to evaluate several types of products and companies adopting circular strategies at micro level. The framework assesses the impact of products based on five key principles. These comprise of selection of material and reutilization; use of renewable resources as input to the production system; water shepherding and social justice (C2CII, 2014). As the five key principles of C2C certification framework does not target each and every aspect of CE therefore the framework cannot be used as a standardized tool to measure circularity. Another tool to measure circularity at product level, entitled REPRO (Remanufacturing Product Profiles) analyzes the End-of-Life (EoL) product scenarios statistically. It is based on a list of 82 criteria. REPRO facilitates the improvement by designers of the product remanufacturing ability, while comparing with the remanufacturing rates of other products. The tool is however lacking practical implementation and has low construct validity due to the exclusion of reuse and recycling rates while measuring product circularity (Gehin et al., 2008). Moreover, the tool focuses on criteria used for improving the remanufacturing rates instead of measuring actual remanufacturing rates. Scheepens et al. (2016) developed a metric for measuring product circularity based on life cycle assessment (LCA). LCA is a popular method which has been applied since several years in the assessment of environmental impacts of products. LCA is a part of ISO (International Organization for Standardization) 14,040 family of standards and has been standardized under international guidelines (Finkbeiner, 2014). LCA is one of the most popular environment assessment methodologies as it encompasses several impact attributes related to eco-cost, human intervention and consequences on eco-system and resources (Hellweg & Canals, 2014). LCA assists in producing impact Fig., however one cannot completely rely on the relevancy and meaningfulness of these Fig.s (Finnveden et al., 2009). LCA requires a huge amount of data for obtaining accurate results thus limiting its scope of application. Moreover the development of LCA toolkit is time consuming as compared to other methodologies and requires a committee of expert members for improved analysis.

The degree of circularity of a given raw material can be measured when the material flow takes place in a cycle comprising of inevitable losses. Circularity can be computed by either adopting reuse, remanufacture or recycle as one of the key circular strategy. Linder et al. (2017) argues that a robust circularity metric should exclusively focus on one single attribute, given that other aspects of circularity are captured by other indicators. Hence they came up with the definition of circularity as the fraction of raw material that can be reused in a closed contour of material cycling. A well articulated raw material circularity metrics may probably combine measures for the entire economic system, though in practice it may not include all the features linked to CE. Reviewing all the available options to measure material circularity is the need of the hour and trying to improve the weaknesses inherent in each of the option will foster in the development of a robust and standardized method to measure material level circularity (Buchert et al., 2013). Therefore this study tries to capture the holistic viewpoint of various CE metrics at the material level by comparing various indexes based upon the inclusion of measures such as average quantity of material flow, average amount of material being recycled and average time spent at each lifecycle stage. Table 2.5 shows the comparison of various CE indicators identified through the literature survey.

Table 2.5 Classification of Circular Economy indicators

Author	**CE indexes**	**Material flow rate**	**Recycling rate**	**Retention rate**
Eurostat (2018)	Economy-wide material flow accounts (EW-MFA)	✓	✗	✗
Silvestri et al. (2020)	Circular Economy Static Index (CESI); Circular Economy Dynamic Index (CEDI)	✗	✓	✓
Linder et al. (2017)	Product level circularity metric	✓	✗	✗
Huang et al. (2012)	DMI (direct material input); HF (hidden flows); TMR (total material requirement).	✓	✗	✓
Huysman et	CE performance indicator	✓	✓	✗

al. (2017)				
Ellen MacArthur Foundation (2016)	Material Circularity indicator	✗	✓	✓
Niero and Kalbar (2019)	Utility index; linear flow index	✓	✗	✓
Park and Chertow (2014)	Reuse potential indicator	✓	✓	✗
Lee et al. (2014)	End-of-Life (EoL) index	✓	✓	✗
Franklin-johnson et al. (2016)	Longevity indicator	✓	✗	✓
Di Maio and Rem (2015)	Circular Economy Index (CEI)	✓	✓	✗
Scheepens et al. (2016)	Eco-cost Value ratio	✗	✗	✗
Azevedo et al. (2017)	Sustainable circular index	✓	✓	✗
Di Maio et al. (2017)	Value based resource efficiency indicator	✗	✗	✗
Gehin et al. (2008)	REPRO (Remanufacturing Product Profiles)	✓	✗	✗
Mohamed Sultan et al. (2017)	Recycling Desirability Index (RDI)	✓	✓	✗

2.8 Select issues in CSC

CSC being an emerging area of research in the context of achieving environmental, social and economic well being, different issues need to be addressed in a systematic way for the effective implementation of CSC concept. The following classification gives a brief illustration of the key issues and key factors pertaining to the effective implementation of circular supply chain business models in the organizations.

2.8.1 Adoption and Implementation

The adoption of a circular economy program entails that a company carries out different strategies to improve the circularity of its production system and also cooperates with other companies over the supply chain for the achievement of a more effective circular pattern (Winkler, 2011). Implementation of the CSC concept is a challenging task and therefore requires an exploratory search of the drivers, barriers and risk involved with its execution. Barriers or challenges related to CE implementation have been discussed in detail in the previous section. This section comprises of the drivers and risks related to the adoption and implementation of CE concept.

2.8.1.1 Drivers of CSC implementation

The reason for the implementation of Circular economy or CSC models in the industry is "global population is growing and to meet the demand for the natural resources a sustainable business model is required" (N. M.P. Bocken et al., 2014). To explore the motivational factor that guides the implementation of CSC models in the industry, there is a need to examine the drivers of Circular Economy system as proposed by various authors which are listed in Table 2.6.

Table 2.6 Drivers of CSC implementation

Authors	Drivers	Methodology/ Approach	Sector	Country
Govindan and Hasanagic (2018)	• Policy and economic, • Health, • Environmental protection, • Society, • Product development	Systematic Review	General	Denmark

Mathews and Tan 2011)	• Regulatory requirements, • Development of enhanced private property rights, • Administrative hold	Case Study	Eco-industrial parks	China
Stratan (2017)	• Desired social and environmental vision, • Value proposition, • Alignment of organizations to the strategy and acceleration of change through executive, • Leadership implication	Systematic Review	Social Enterprises	General
Moktadir et al. 2018)	• Knowledge about CE, • Customer Awareness, Environmental Collaboration with the customers) , • Leadership and commitment from top management, • Government support and legislation	Case Study	Leather Industry	Bangladesh
Geissdoerfer et al. (2017)	• System Design, • Innovation	Snowballing technique	General	General
Zhu and Geng, (2013)	• Coercive, • Normative, • Mimetic	Descriptive and hierarchal analysis	Manufacturing	China
Winans et al. (2017)	• Balancing industrial development, • Environment and human health, • Industrial growth	Extensive Literature Review	General	General
Ranta et al. (2018)	• Regulative , • Normative , • Cultural Cognitive	Case Study	Manufacturing	China, the US, and Europe

2.8.1.2 Risk associated with the implementation of Circular SC

The implementation of a novel strategy is associated with the influence of risk. Risk may generally be classified into two types: external or internal depending on whether the impact of risk occurs within the organization or outside the organization i.e. within the supply chain of that organization. For the proper assessment of risk and what impact it can have on the performance of the circular supply chain, Table 2.7 provides an organized classification of literature on risk identification by different authors.

Table 2.7 Risk associated with the implementation of CSC

Risk	Types	Internal/ External	Sources
Economic risk	• Supply risk, • Problematic ownership structures, • Deregulated markets, • Flawed incentive structures, • High investment	External Internal External Internal Internal	Jackson (2009); Sachs (2015); Wang et al. (2008)
Environmental Risk	• Limited store of resources, • Uneven geographical distribution of resources and appropriation, • The implications of the assimilative capacities of ecosystems over economic growth	External External External	Georgescu-Roegen (1977);(Swaney, 1994)
Technological Risk	• Threat of implementing newer/complex technology, • Fear of problems, • Compatibility issues with existing systems	Internal Internal Internal	Mittal and Sangwan (2014)
Enterprise Risk	• The risk associated with enterprise operations, • The risk associated with enterprise resource management	Internal Internal	Christopher and Lee (2004);(Sodhi et al., 2012); Zhao and Guan (2018)
Waste management Risk	• Health-associated risk to the society • Improper disposal of waste can impose serious penalty on the organization	External External	Giunipero and Eltantawy (2003)
Fashion Vulnerabil	Being unable to respond to fashion changes is another potential issue with introducing a	Internal	Jüttner et al. (2003)

ity	Circular Business Model.		
Risk of Cannibalization	The introduction of a Circular Business Model may lead to decreased sales if the new, longer lasting products reduce sales of the previous products	External	Guiltinan, (2009);Michaud and Llerena (2011)

Supply chain-related risk and risk management approaches have been extensively explored in the past (Chopra and Sodhi, 2004). Typical supply chain risk involves disruption from the supplier side, which includes supply delay, quality-related problems, limited capacity of raw material, dependency on selected suppliers, frequent changes in the design of products, and liquidity of material from the supplier side (Sharma and Pandey, 2020). Apart from supplier risk, there is procurement risk, which involves volatility in currency exchange rates, piling up of inventories due to the bullwhip effect (Mishra et al., 2016) and stock-out due to logistics failure (Kocabasoglu et al., 2007). Also, there are demand related risks that arises due to an inaccuracy in forecasting, and frequent variations in the demand and distortion of information during communication (Kazancoglu et al., 2020). Most of the literature related to supply chain risk management (SCRM) is focused on the forward aspect, rather than considering the reverse side of the supply chain (Giunipero and Eltantawy, 2003). In order to understand how the implementation of circularity in the supply chain can expose it to a variety of risks, the existing literature on SCRM does not address this question. However in the recent time, the identification of risk during the implementation of circular economy in SC is gaining attention among the researchers, because of its huge economic advantage and less environmental damage (Kazancoglu et al., 2020). This study explored the literature related to risk management for the maintenance of sustainability throughout the SC.

In circular supply chain, the 6R (reuse, repair, refurbish, remanufacture, recycle, redesign) operations can be performed in house or outsourced to a specialized outsourcing partner. Outsourcing of these operations involves a variety of risks, which include disruptions of other internal activities, loss of the competitive base, opportunistic behaviors, rising transaction and coordination costs, and higher procurement costs. Since in a CSC there are numerous SC partners that are involved in achieving circularity of the flow of material (Singhal et al., 2019), a high level of coordination has to be maintained in order to achieve improved circularity. The

CSCs are exposed to a variety of coordination risks that may include distortion during the sharing of valuable information, issues of trust among the partners, commitment failure, and a lack of risk sharing among the partners. He and Zhang (2010) stated that a particular degree of relationship should exist among the SC members, as a means to share risk that results in a higher business performance than would be achieved by the firms individually. With the introduction of a circular business model, the demand of new and long lasting products increases and it may lead to reduced sales of the previous products, which is commonly referred to as the risk of cannibalization (Guiltinan, 2009). Being unable to respond to agile changes is another potential issue while introducing a circular business model. This is also sometimes termed as agile vulnerability (Kull and Talluri, 2008). The major categories of supply chain risk that have been identified in the past are summarized and enlisted in Table 2.8.

Table 2.8 Risk Topology

Author	Area of Risk	Methodology	Type of risk
Chan and Kumar (2007)	Global Supplier Selection	Fuzzy extended AHP	Supply Risk
Kull and Talluri (2008)	Supplier selection problem	AHP and Goal Programming	Supply Risk
Chen and Wu (2013)	Supplier selection problem	Modified FMEA	• Customer Demand • Amount of supply and cost fluctuation.
Giannakis and Papadopoulos (2016)	Supply chain sustainability	FMEA	• Environment • Social • Economic
Tuncel (2010)	Supply chain network	FMECA and Petri nets framework	• Supplier risk • Inbound/Outbound logistics risk • Manufacturer risk • Customer risk
Sinha et al. (2004)	Aerospace supply chain	IDEFO method	Supplier risk
Faisal et al. (2006)	Supply Chain network	Interpretive Structural Modeling	Supply chain related risk
Radivojevi and Gajovi (2013)	Complete Supply Chain	AHP and fuzzy AHP	• Operational risk • Technological risk • Economy/Competition • Natural Hazard • Social Risk • Legal/Political

Tummala and Schoenherr (2011)	Complete Supply Chain	SCRMP	• Demand Risk • Delay risk, • Disruption risk • Inventory risk • Manufacturing • Breakdown risk • Physical Plant Risk • System Risk • Sovereign risk
Teng et al. (2006)	Collaborative supply chain of Automobile industry	Integrated FMEA	• Product quality • On-time delivery • Competitive cost
Hu et al. (2009)	OEM/ODM of electronic manufacturer in Taiwan	FMEA and FAHP	Green component risk
Chaudhuri et al. (2013)	Aircraft manufacturing industry	Group decision making and FMEA	Supplier related risk
Paksoy et al. (2019)	Green Supply Chain	Fuzzy linguistic approach	Supplier Risk

Only those categories of risk that are critical, from the aspect of achieving circularity in the supply chain, are further utilized in developing a CSC risk framework. Risk identification is the first step where all the possible CSC risks are identified with taxonomies, checklists, and mapping of conventional risk. These identified risks are then assessed, in terms of their likelihood of occurrence and their impact on CSC performance. The next subsection discusses various strategies identified in the past for the achievement of circularity in supply chain. Thereafter, key insights about circularity indicators and methods used in the past by various researchers are also discussed.

2.8.2 Coordination in Circular Supply Chain

The issue of coordination within circular supply chains is one that has received limited attention (Agrawal et al., 2022). Coordination plays a pivotal role in enhancing the efficacy of supply chain operations (Ryu et al., 2009). In a Circular Supply Chain (CSC), coordination becomes a matter of great concern for achieving a high degree of circularity owing to the involvement of a larger number of partners as compared to the traditional linear supply chain (Roy et al., 2022). The integration of various actors within a circular supply chain is of utmost importance as it pertains to the coordination necessary to continuously enhance the overall circularity of supply chain (Alonso-Muñoz et al., 2021; Chhimwal et al., 2023). For achieving high level of circularity, there is a need to establish coordination among the different stakeholders without which it is hard to achieve desired objectives (Ahmed et al., 2020; Cao et al., 2021). Management of any organization plays an important role in establishing coordination among the different stakeholders involved in the business (R. K. Singh, 2011). The main responsibility of management is the selection of suitable actors of SC that could lead to improved business performance and fulfillment of the targets (C. P. Garg & Sharma, 2020). There must exist a collaborative and synergistic relationship among the various partners of the CSC during the product's design and development phase, as well as among the end-users who will ultimately consume it (Sanguino et al., 2020). Unlike the traditional linear supply chains, in CSC consumers are the major actors which significantly contribute to the business of the organization (Testa et al., 2020). Selection of suitable consumer base is again an important field of research.

Supply chain coordination improves if all the actors of the chain take actions that are aligned to achieve the desired objective (Simatupang and Sridharan, 2005). It requires each partner of the SC to share information and take in account the impact its action have on other partners (Sahin and Robinson, 2005). Lack of coordination may arise as a result of conflicting objectives among various partners of SC or due to the delayed or distorted flow of information between these partners (Titah et al., 2016). In the context of supply chain management, it is possible that discrepant objectives arise at varying stages due to the involvement of distinct owners. This often results in actions that decrease the total profit of the supply chain. (Sarmah et al., 2007). The lack of coordination in the supply chain arises when individual stages strive to optimize their local objectives. A significant consequence of this approach is the reduction in total profit, which has a major impact on the performance of the supply chain.

Given the critical significance of coordination in SC, few researchers have addressed the concept of coordination in SC. (Ravinder Kumar & Kumar Singh, 2017) illustrated various issues pertaining to coordination and responsiveness within the context of the supply chain of small and medium-sized enterprises (SME's). Risk management, strategy development and performance analysis are some of the major issues of improving coordination among the SC partners. Improving supply chain coordination in SME's can be achieved through several methods, including the sharing of information, collaboration, and supplier and customer involvement in the decision-making process. Ciasullo and Troisi (2013) concluded that ethics and value systems of individual stakeholders play a significant role in achieving coordination and developing suitable strategy for the SC members. For this purpose engagement of each of the stakeholder and awareness among the SC members results in better coordination. Peter (1990) emphasized on system thinking that can be used to understand the reality behind SC operations. The knowledge gained through ‘system thinking approach’ helps in achieving coordination among the chain members. Konijnendijk (1994) examined the issues of coordination at operational and tactical level. The author stressed on the awareness about product specification and volume of production to each of the SC members to coordinate the activities related to product flow. One of the operational perspectives of SC coordination is the logistics alliances. Coordination in logistics operations offers opportunities to improve customer service at the same time reduce storage and distribution costs (Huiskonen and Pirttilä, 2002). Dependency among the members of the chain is again another important coordination issue. Managing dependency among SC members leads to improved coordination. Coordination not only involves the management of interdependencies but also requires sharing of risks and rewards among the SC members (He, 2017). Coordination with joint operations and planning results in higher business performance than would be achieved individually (Hill and Omar, 2006). Coordination can be visualized as collaboration and sharing of information (real time data pertaining to point of sales, demand, inventory, production schedule, production capacity and consumption) that helps build trust among the SC partners and integrates to achieve the common goals (Liu et al., 2015). Table 2.9 presents some of the aspects of improving coordination among the supply chain partners that can be regarded as pillars of coordination.

Table 2.9 Pillars of Coordination in SC

Types	Description	Sources
Exchange of information	The concept of information exchange encompasses the capacity of a company to efficiently and effectively disseminate knowledge to its partners within the supply chain. Effective dissemination of information has been recognized as one of the fundamental pillars of coordination.	Troy et al. (2008); Shore and Venkatachalam (2003); Patnayakuni et al. (2006); Makitie et al. (2023)
Revenue Sharing	The right distribution of profit earned among the Supply Chain partners by selling a product leads	Cachon and Lariviere (2005); Giannoccaro and

	to better coordination capabilities and performance enhancements.	Pontrandolfo (2004); Chauhan and Proth (2005)
Risk Sharing	A specific level of interconnectivity between members of a supply chain, utilized as a strategy to distribute risks, can lead to a superior level of business performance compared to what each individual firm could achieve on their own.	He (2017); He and Zhang (2010); Lambert et al. (1996)
Resource Sharing	Cooperation amongst autonomous yet interdependent enterprises in order to pool resources and competencies to fulfill the exceptional requirements of their customer's.	Sezen (2008)
Joint decision making	Supply chain coordination may be pursued through the adoption of either a centralized or decentralized decision-making approach. The former option is implemented when there exists a singular entity that makes decisions within the supply chain, while the latter option involves multiple independent actors making decisions at various stages within the supply chain.	Hill and Omar (2006); Kanda and Deshmukh (2008); Thomas and Griffin (1996)
Joint product development and promotional activities	The involvement of suppliers into the new product development process has the potential to yield significant advantages in the pursuit of enhanced quality, decreased new product costs, and the seamless introduction of new products.	Petersen et al. (2005); Larsen et al. (2003); Barratt (2004); Mentzer and DeWitt (2001)
Environmental Collaboration	A failure to collaborate on green practices will ultimately undermine an organization's environmental performance. The environmental concerns of each stakeholder are crucial in achieving sustainability across the entire supply chain.	Ahmed et al. (2020); Zhu et al. (2008); Zhu et al. (2012)
Stakeholder pressure	Customer inclination towards sustainable manufacturers forces the organization to adopt environmental oriented strategies thereby increasing their sustainable performance.	Chavez et al. (2016) ; Zhu et al. (2016); Zhu et al. (2012); Singh et al. (2022); Adebanjo et al. (2016)

2.8.3 Outsourcing in Circular Supply Chain

Outsourcing stands for "outside resource using" (*Quinn, 1994*). First of all the company must decide the borders of outsourcing which implies what all activities or resources lies 'outside' the capabilities or control of an organization and what activities can be performed 'in-house' or in collaboration with supply chain partners (Picot et al., 2020). Secondly, the company must identify its strength and the core activities that can be performed in-house following the resource-based view (Penrose, 1959). CSCM involves the management of the flow of material and service in both the forward as well as in the reverse directions. Since CSCM involves a wide range of activities that can be performed within or using outside resources, therefore, organizations must strategically look into their strengths and weakness and accordingly assign third-party service providers for outsourcing of the activities. There are various strategic issues based upon which outsourcing can be performed in a circular supply chain.

Coase (1937) came up with the issue of transaction cost perspective. 'Transaction cost' in outsourcing can be defined as the cost of making each contract. These costs arise due to the expenditure on the evaluation of suppliers, negotiation during the contract making and controlling the functions during the phase of establishment of contract (Picot et al., 2020). Organizational structure can significantly affect outsourcing decisions and the hierarchy cost spend on the governance of the organization are inevitable (Arnold, 2000). So the company must have a deeper insight into the transactions related to running the system of controlling the productivity of workers. According to (Williamson, 2008) specificity is a vital part of the transaction. Goods and services with high specificity cannot be used in another transaction. Specificity refers to resource asset and human capital asset. Specificity is closed related to core competency approach. According to Prahalad and Hamel (1990) only those goods and services which are having high specificity will be produced internally under core competency approach.

Core competency approach mainly relies on the strength of the company to carry out circular activities internally and thus giving a competitive advantage in the global market. For example, the original equipment manufacturer (OEM) of a product has the capability to carry out remanufacturing operations in-house. From the perspective of the association of the company's strength and capabilities with its co-existence in the global market, the circular activities may be classified into four types: core activities, core-close activities, core-distinct activities, and disposable activities (Arnold, 2000). The contribution of core circular activities is the highest in the global competitiveness and disposal activities are the least contributing to providing a competitive edge. Therefore, the strategy of outsourcing changes with the scale of the contribution of activities in achieving competitiveness at the global level. Stål and Corvellec (2018) in their article stated that a company should outsource only those circular economy activities which are not the part of its core functions. Agrawal et al. (2016) developed a conceptual framework for outsourcing decisions in reverse logistics. Based upon graph theory and balanced scorecard approach the authors found that outsourcing of all the reverse logistics functions is the best choice among the considered alternative scenarios.

Another important aspect is the risk involved in the outsourcing decision (Duncan, 1998). The risk associated with outsourcing decision generally involves disruptions of internal activities, loss of the competitive base, opportunistic behaviors, rising transaction and coordination costs, limited learning and innovation and higher procurement costs in relation to the fluctuating currency exchange rates (Gewald and Hinz, 2004). Therefore, companies should carefully examine the risk associated with the outsourcing of circular activities. (Li et al., 2018) analyzed the selection of optimum third-party reverse logistics provider (3PRLP) for outsourcing RL practices on the basis of certain criteria. The selection was done by using integrated cumulative prospect theory (CPT) based on hybrid information MCDM and model was validated using fuzzy TOPSIS approach. The results indicated that considering a psychological factor in decision making contributes to avoiding potential loss risks.

Flexibility in outsourcing of circular activities is strategically imperative keeping in view the way in which the current business environment is changing. According to Tan et al. (2006), flexibility is defined as the ability to change the extent, nature, or scope of the outsourced business service. While establishing the outsourcing contract with the third party service providers, companies must raise the issue of flexibility in the contract because of changing customer demands and uncertainty in the business environment (Suarez-villa, 1998). Serrato et al. (2007) on the basis of Markov decision model explored the hypothesis that outsourcing Reverse Logistics functions are more suitable when returns are more variable. Guo et al. (2017) emphasized on some of the outsourcing contracts which are unexplored and are highly relevant for the value creation to the end users. Weraikat et al. (2016) quoted an example of a remanufacturer or retailer exploring an outsourcing contract with the third party service providers for managing the product return. Such types of strategic issues need to be explored for a better decision making process during the outsourcing of circular activities to enhance the value provided to the end users. Table 2.10 briefly describes some of the strategic issues of outsourcing of the circular activities.

Table 2.10 Issues of Outsourcing in Circular Supply Chain

Issues	Description	Authors
Transaction Cost perspective	These "costs of making each contract" appear because of information asymmetry, bounded rationality and opportunism. Such costs arise from activities which include: evaluating suppliers, negotiation, control function, etc.	Arnold (2000); Coase (1937); Picot (1991); Williamson (2008)
Core Competency Perspective	Its main idea is that only goods and services which are considered to be core competencies should be produced internally (insourcing).	Prahalad and Hamel (1990)
Risk Management perspective	Outsourcing risks involve disruptions of internal activities, loss of the competitive base, opportunistic behaviors, rising transaction and coordination costs, limited learning and innovation and higher procurement costs in relation to the fluctuating currency exchange rates	Kotabe et al. (2008); Duncan (1998); Kang et al. (2009) Harland et al. (2005)
Resource-based perspective	In case of the resource-based view, the company can be understood as a unique complex of resources and knowledge	Penrose (1959); Duncan (1998)
Flexibility	Flexibility is the ability to change the extent, nature, or scope of the outsourced business service, and such flexibility is strategically imperative in today's dynamic business environment.	Tan and Sia (2006); Harris et al. (1998); Suarez et al. (1998)
Coordination with suppliers	Every organized human activity gives rise to two fundamental and opposing requirements: the *division of labor* into various tasks to be performed and the *coordination* of this task to accomplish the activity.	Handley and Benton (2013); Pentina and Hasty (2009)
Role of IT in outsourcing	IT outsourcing is defined as the transfer of an organization's staff, IT infrastructure, processes, applications, and other IT-related activities to an external entity that possesses the capability to provide such service.	Lacity (1993); Levina and Ross, 2003; Pati and Desai (2005)

Environmental Perspective	Environmental Perspective of outsourcing keeps in mind the sustainability aspect of outsourcing the activities that lead to less consumption of resources, lesser emissions and high-cost savings.	Facanha and Horvath (2005); Viitanen and Kingston (2014); Wang and Song (2017)
Social Perspective	Social Perspective of outsourcing leads to a building up of healthier buyer-supplier relationship depending upon various social dimensions.	Schoenherr and Narayanan (2015); Goles et al. (2005)
Cultural Perspective	Cultural Perspective takes into account the cross-cultural issues related to offshore outsourcing across the globe.	Ang and Inkpen (2008); Gurung and Prater (2017); Tiwana and Bush (2007)

2.8.4 Benchmarking

Organizations need to check the performance of their supply chain to acquire valuable information for the decision making at strategic, tactical and operational levels (Jain et al., 2018). To measure the performance of circular supply chain certain premeditated indicators are required which are similar to those used for circular economic activities (Geng et al., 2013). Cullen (2017) compared theoretical circular economy with a perpetual motion machine which gives away work without any input of energy source. The author tries to indulge in the idea of future CE activities in which waste is eliminated, materials are circulated in infinite loops and there is continuous recycling of used products. The author adds the prefix 'theoretical' to 'circular economy' since circularity is an ideal state which is impossible to achieve. If the concept of Circular Economy is accepted theoretically "ideal" then it can be used as a measure of benchmarking circular activities on a scale ranging from linear at one end to entirely circular at the other end.

The indicators used for measuring the performance of circular supply chain activities are entirely different from those used in a conventional supply chain. Some of the indicators used to measure the performance in a conventional supply chain were cost, quality and output (Beamon, 2005), while the performance of circular supply chain is computed considering the aspect of environmental burden and resource utilization throughout the supply chain (Genovese et al., 2017). Geng et al. (2012) in their study on the implementation of the circular economy as the national development strategy in China, found some of the indicators such as material consumption, energy consumption, emission reduction, environmental compliance, supplier environmental assessment that are strategically important to measure the performance of the CE activities.

Franklin-Johnson et al. (2016) in their study argued that almost all the existing studies consider resource use as a burden rather than considering it as creating value through material retention in the product lifecycle. Based upon the previous study on product lifecycle assessment the author found some of the sub-factors of longevity indicators depending upon the amount of time resources are kept in use. The subfactors were classified as: initial lifetime, earned refurbished lifetime and earned recycled lifetime. Table 2.11 shows some of the indicators used to measure the performance of circular supply chain activities.

Table 2.11 Performance indicator of Circular Supply Chain

Performance Indicators	Type	Industry/ Sector	Country	Source
Longevity Indicator	Measures contribution to material retention based on the amount of time a resource is kept in use. The measure is composed of three generic components: • Initial lifetime, • Earned refurbished lifetime and • earned recycled lifetime.	Electronic /Mobile phones	General	Franklin-Johnson et al. (2016)
Sustainability indicator	• Resource output, • Resource consumption, • Integrated resource utilization • Waste disposal/pollutant emission	Manufacturing/ General	China	Geng et al. (2012)
Environmental indicators	• Material Consumption • Energy Consumption • Emission reduction • Environmental Compliance • Supplier environmental assessment	Manufacturing/ General	China	Geng et al. (2012); Zhijun and Nailing (2007); Genovese et al. (2017)
Economic indicators	Economic strength indices, • per-capita GDP	General/ General	China	Zhijun and Nailing (2007);

	• growth rate of GDP, and Economic efficiency indices • Consumer Price Index (CPI), • the industrial mix Index, and • the ratio of investment in fixed assets to GDP • Return on investment • Market presence • Green GDP '**Green GDP**' it represents the value of GDP after deducting capital depreciation of products, loss of natural resources, and losses caused by pollution.			Geng et al. (2013); Pan et al. (2015)
Social Indicators	Human development index comprising of • No. of jobs created • Social security • Occupational health and safety • Effective utilization of local resources. • Supplier Assessment • Socio-economic compliance	General/ General	General	Van Dieren (1995)
Operational Indicators	• Amount of safety stock • Production Variability • Equipment utilization	Manufacturing	General	Beamon (2005)

The literature specifically focuses on the strategic aspects of implementation to improve the overall performance of circular supply chain management. Supply chain contract is one of the important strategic issues which enhance the overall functional performance of circular supply chain (Li et al., 2021). Building up of the relationship of the parent organization with the upstream and downstream partners depends upon various factors. These are classified as: simple revenue sharing (Mafakheri and Nasiri, 2013; Ran et al., 2016), risk sharing (He, 2017; He and Zhang, 2010), quantity discount contract (Kun and Jian, 2011), consignment contract (Hu et al., 2014). Information management is also an important strategic issue that facilitates the smooth functioning of the supply chain as a whole. For the proper management of the flow of information, there are certain issues that should be considered for benchmarking purpose which may be classified as: IT infrastructure, system reliability, cost performance levels, interconnectivity, flexibility (Duncan, 1998).

The economic aspect in the design, production, consumption and waste management stages mostly reflects the net profit earned during the implementation of sustainable supply chain activities. Effective and optimum utilization of resources throughout the supply chain leads to less capital investment and high returns (Gunasekaran and Ngai, 2004). To address the issue of circularity in the supply chain certain strategic aspects should be taken into consideration. These are classified as eco-design (Bocken et al., 2016); green purchasing (Green et al., 1998); cleaner production (Shi et al., 2008); product recycling (Dahmus and Gutowski, 2007). Table 2.12 consists of the identified issues of benchmarking in circular supply chain.

Table 2.12 Strategic issues of benchmarking in circular supply chain

Issues	Description	Sub-parameters/ Components	Authors
Supply Chain Contracts	Relationship of the parent organization with the 3PRLP plays a major role in improving the performance of the circular supply chain.	Wholesale price	Atasu et al. (2013); Hong et al., (2008); Li et al., (2012)
		Simple revenue sharing	Mafakheri and Nasiri (2013); Weraikat et al. (2016); Ran et al. (2016)
		Simple buyback	Arcelus et al. (2011); Bose and Anand (2007);Chen (2011); J. Chen and Bell, 2011)
		Risk Sharing Quantity discount contract	He, 2015; He and Zhang (2010); Huang et al. (2011); Jena and Sarmah, (2016)
		Consignment contract	Hu et al. (2014)
Information Management	Management of the flow of information among the supply chain partners in	IT infrastructure	Duncan (1995); Wang et al. (2015)
		System	Chang (2006); Hsu (2005); Ngai et

	the forward as well as reverse supply chain helps in the smooth functioning of the supply chain as a whole.	Reliability Cost performance levels Interconnectivity Flexibility	al. (2004) Fawcett et al. (2007); Hendricks et al. (2007); Sanders (2007) Bhatt (2000); Malhotra and Grover (1998) Lambert et al. (1996); Christopher (2000); Gunasekaran and Ngai (2004)
Economic Optimization of resources	Effective and optimum utilization of resources throughout the supply chain leads to less capital investment and high returns.	Eco-design Green purchasing Cleaner production Product Recycling	Donnelly et al., (2006); Knight and Jenkins (2009); Luttropp and Lagerstedt (2006) Green et al. (1998); Min and Galle (1997); Schlegelmilch et al. (1996) Fresner (1998); Kjaerheim (2005); Moors et al. (2005); Shi et al. (2008) Dahmus and Gutowski (2007); Li et al. (2021); Thomas, (2003)
Strategic Outsourcing	Outsourcing which means 'outside-resource-using' describes which supply chain activities should be outsourced depending upon the core competency approach, cost of making contract, resources in hand and risk related outsourcing of the activity.	Transaction Cost Core Competency Risk Management Resources in hand	Zsidisin et al. (2004); Arnold (2000); Williamson (2008); Prahalad and Hamel (1990); Arnold (2000); Gilley and Rasheed (2000) Kotabe et al. (2008); Duncan (1998); Kang et al. (2009); Harland et al. (2005) Penrose (1959); Duncan (1998); Barney and Arikan (2005); Mowery et al. (1998)
Value creation	How much value has been created by following the principles of circular economy in	Product Service System	Despeisse et al. (2015); Tukker (2015);Williams (2007); Stahel (2016)

	the supply chain always remains an important parameter of benchmarking.	Promotion	Baxendale et al. (2015); Park et al. (2010)

2.9 Research gaps

Based upon comprehensive review of literature, research gaps are identified and enumerated briefly in the following section:

- The implementation of Circular Economy principles in the Indian manufacturing sector is in nascent stage and limited studies are available in the context of emerging economies.
- It is inferred after reviewing the literature that there are few studies addressing the issues of adoption and implementation of Circular Economy in the manufacturing sector of developing countries.
- The review of literature on Circular Supply Chain Management (CSCM) showed that comprehensive integrated view of CSCM is still missing in the existing literature, therefore, there is a need to address various dimensions related to the incorporation of CE principle in supply chain management.
- As the concept of CE is in nascent stage, therefore there are several challenges coming with the implementation of this concept that organizations need to face in today’s business environment which need to be addressed in a systematic way.
- The concept of implementing circularity in the supply chain is novel and dynamic in nature, and it involves certain risk. Risk management is inevitable for achieving a high degree of circularity in SC. Past research reveals that risk management approaches have only been applied in the forward direction of the supply chain. Risk identification and propagation in the reverse direction is still missing in the current literature of SCRM.
- The present academic research on CE covers a wide range of issues namely: drivers, barriers and practices, however the exploration of circularity potential both at the product and system (micro, meso and macro) level is still lacking in the existing literature related to CE.

- Optimizing the utilization of resources (man, machine and material) requires a high level of coordination among the members of SC. The importance of coordination in context to the implementation of CE principle is an issue which is scarcely addressed in the existing literature.

2.10 Concluding remarks

The contemporary research in CSC is currently in the developmental phase, with extensive efforts being dedicated to addressing various issues of CSC across different sectors. It is evident that research endeavors are distributed among different sectors, with no single sector being thoroughly investigated, particularly in emerging economies like India. A thorough examination of existing literature reveals that certain aspects of CSC, such as adoption and implementation, circularity decisions, and performance evaluation, have not been extensively explored. The present research aims to delve into and analyze these factors within the context of the Indian manufacturing industry, employing survey methods, case studies, and the development of models in subsequent chapters. The forthcoming chapter will elaborate on the research methodology and framework to be employed for this study.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

This chapter pertains to the methodology employed in conducting research, which is to be adhered to during the course of the research endeavor. Research methodology is defined as "a functional structure wherein the various facts are positioned in such a manner that their significance may be comprehended with greater clarity". It is a "procedural structure under which the research is executed." Within this chapter, research objectives are established on the basis of the analysis of gaps in existing research, and these objectives are enumerated in section 3.2. The research is grounded on the philosophy of pragmatism, which highlights the research objectives as the paramount element of examination. A deductive research methodology with a mixed-method approach has been embraced for the study. Each research methodology possesses its own merits but also presents certain limitations. The mixed method enables one to surmount the limitations of other approaches and offers numerous advantages, such as augmenting the validity and reliability of data derived from multiple sources (Bryman, 2007). The application of this technique has been employed by numerous authors, including Bui et al. (2021); Chhimwal et al. (2022); Tirkolaee et al. (2020) within the domain of Sustainable supply chain and Circular Economy.

The research work has made use of the survey method, the case study method, as well as methodologies for the development of models and decision frameworks. To begin with, data was gathered through a survey conducted on the Indian manufacturing industry by means of a questionnaire, and hypotheses were tested and results were analyzed. In the second phase, the case study method was employed, which involved the collection of qualitative data through semi-structured interviews, and the findings from the survey were validated through a thorough analysis of the case study. It was observed that the survey method and case study method are the predominant methodologies for examining drivers, barriers, practices, risks and key challenges in the Circular Supply Chain (CSC). Furthermore, this chapter discusses the various methodologies employed for the development of statistical models and decision frameworks.

3.2 Research objectives

Keeping in mind the research gap mentioned in the previous chapter, this study aims to fill these gaps by considering the following objectives:

- To explore and analyze various CSC practices in manufacturing industry.
- To develop a framework for the adoption and implementation of CSC practices in manufacturing industry.
- To analyze the role of co-ordination among different stake holders of CSC.
- To explore the various outsourcing issues and develop an outsourcing decision model for CSC activities.
- To develop a model for benchmarking CSC measures in manufacturing industry.
- To develop and validate the findings of the research through case studies.

To accomplish these objectives, a research methodology workflow was devised, as depicted in Fig. 3.1. In order to enhance the questionnaire's quality and content, a questionnaire was formulated and subjected to pilot testing. Through a literature review and expert consultations, significant practices, challenges, risks and other issues were identified. A model has been developed to prioritize the key challenges faced by the Indian manufacturing industry. These elements aided in comprehending the manufacturing industry and the formulation of the questionnaire. A survey was conducted to gather information regarding various factors and the strategic development of CSC in the Indian manufacturing industry. The selected factors for the research study were examined through hypotheses testing based on the theoretical development of these factors. Subsequently, a case study was conducted to validate the findings pertaining to these factors. Numerous models and decision frameworks have been created to address these specific issues. The research methodology will be elaborated upon in the subsequent sections.

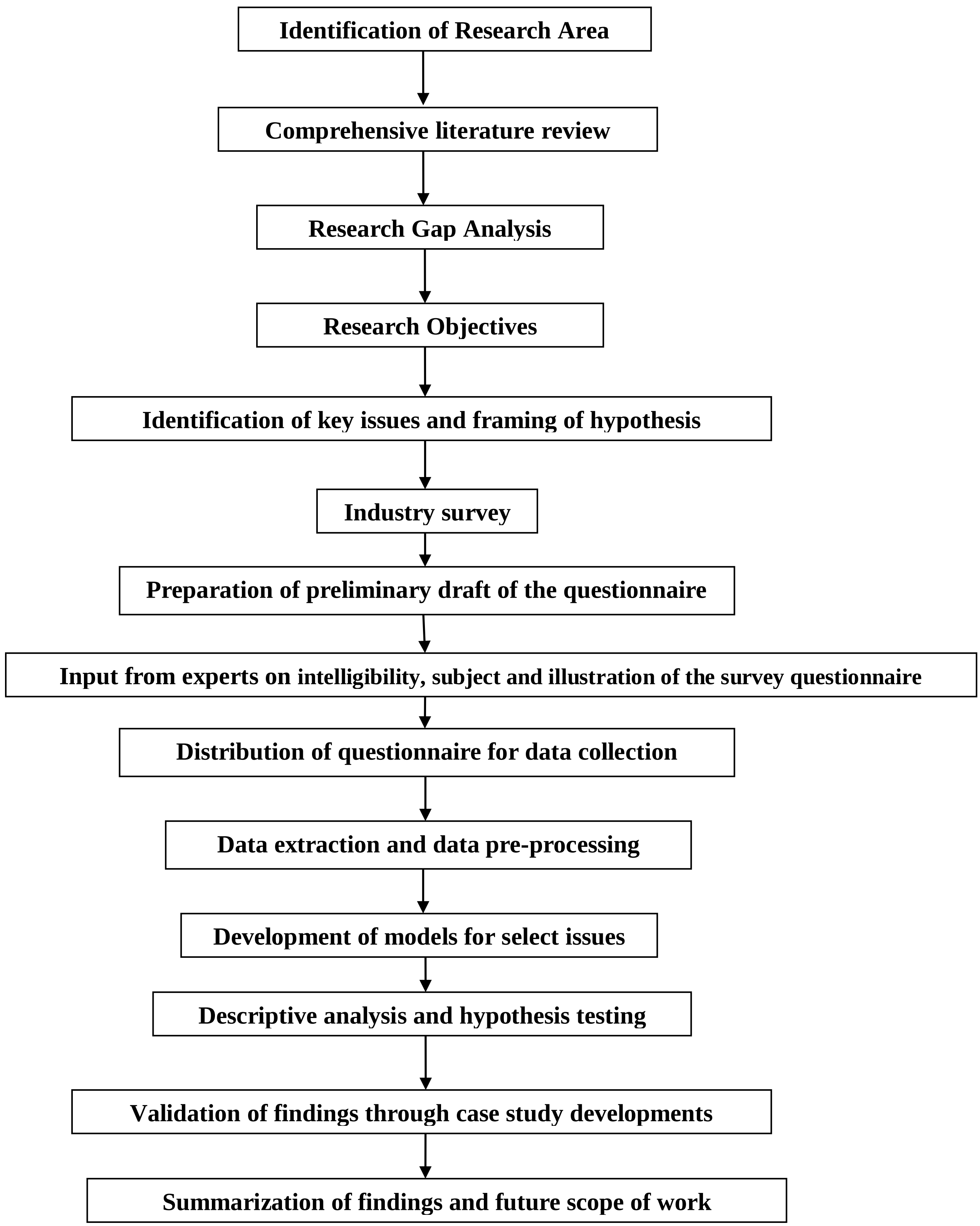

Fig. 3.1 Research flowchart

3.3 Methodology for literature review

A methodical examination of existing literature was undertaken, leading to the identification of areas where research is lacking. The objectives of the research were derived from an analysis of these gaps in knowledge. The systematic approach employed in this research work served as a framework for reaching a set of conclusions pertaining to these objectives. According to the findings of Saunders et al. (2011), the research methodology consists of six distinct steps. The subsequent paragraphs provide a description of each of these steps in the research methodology.

3.3.1 Research philosophy

The initial stage of the research methodology encompasses crucial assumptions, facts, theories, and frameworks. The selected philosophy plays a significant role in shaping the interpretations made by the researchers. As stated by Saunder et al. (2011), the research philosophy encompasses positivism, realism, subjectivism, objectivism, and pragmatism. The current study adopts the research philosophy of pragmatism, as it serves as the primary determinant of the research objectives.

3.3.2 Research approach

According to the comprehensive review of scholarly literature, two distinct research methodologies were identified, namely deductive and inductive. The deductive approach entails the formulation of theories and hypotheses, as well as the design of a test strategy to assess these hypotheses. On the other hand, the inductive approach focuses on data collection and the development of theories based on the analysis of said data. In the current study, the deductive approach was adopted, employing a multi-method approach. Initially, data were gathered through scholarly articles, books, and chapters.

3.3.3 Data collection

The current approach encompasses both quantitative and qualitative techniques for gathering information. The gathering of primary data involved conducting a survey within the Indian manufacturing industry through the use of questionnaires, personal interviews, and the mailing of said questionnaires. The findings of the study were thoroughly analyzed and employed for the case methodology. In the subsequent phase, the case study method was employed, which entailed collecting qualitative data through semi-structured interviews. Both primary and secondary sources were utilized for the collection and validation of data. A comprehensive discussion regarding the collection and analysis of data can be found within the respective chapters.

3.3.4 Time horizons

According to Saunders (2011), a longitudinal investigation pertains to alterations and advancement throughout a designated duration, whereas a cross-sectional investigation pertains to the scrutiny of a particular occurrence at a precise moment. The preponderance of research undertakings finalized for academic courses necessitates temporal restrictions. Hence, the research endeavor has employed a cross-sectional study.

3.3.5 Research methods

Saunders (2011) has proposed a variety of research strategies. The research entails the utilization of survey and case study methods, as well as diverse methodologies for constructing models and frameworks. The survey method facilitated the quantitative evaluation of the present CSC practices, as well as the issues associated with CSC within the Indian manufacturing industry. Conversely, the case study method enabled a qualitative and thorough assessment of a limited number of cases. While it is recommended to use a single case for the case method when the researchers are affiliated with the organization (Yin, 2003), the single case study can be employed in conjunction with the survey method for a more comprehensive clarification of certain survey results. The research work has employed both a survey method and a single case study.

3.3.5.1 Survey method

The survey method was employed in order to investigate the present practices and challenges pertaining to CSC in the Indian manufacturing industry, as well as to assess and substantiate the hypotheses through statistical analysis. The utilization of surveys is the most prevalent approach to identify the prevailing issues in the manufacturing industry (Hussain and Malik, 2020; Khan et al., 2021). It relies on empirical data and enables the collection of a sufficiently large dataset in an economical manner through the use of questionnaires. In order to collect data, a survey was conducted within the Indian manufacturing industry, employing a questionnaire. The questionnaire was formulated and administered via google forms, with the responses being collected within the same platform. The validity and reliability of the questionnaire were ensured by addressing non-response bias and employing other statistical measures. The collected data were examined to explore the current practices of CE in the Indian manufacturing industry, and select factors were analyzed in terms of their interrelationships. The hypotheses were tested using the likelihood ratio test. The comprehensive and methodical procedure and utilization of the survey technique for the research process are deliberated in Chapter 4.

3.3.5.2 Case study method

Case study is included in the research to have a deeper insight of the issues faced by the industry and analyzing them through empirical results. Case study is conducted to provide academic based solutions to industries facing problems at strategic and operational levels. This section comprises of the application of the proposed technique in solving sustainability issues for an automobile manufacturing company located in Delhi–NCR in India. In this section, a detailed description of the case study, problem formulation, and data collection is provided.

India being a developing nation, hence sustainability becomes a major issue to meet the demand of majority of population. Therefore, it is the right time to examine the research and novel activities to help Indian manufacturing sector in developing their approach and the essential techniques/methods to adopt circular models effectively. An attempt has been made to explore and identify the challenges and risks related to the implementation of CE practices in Indian manufacturing context. This study considered different case example from the Indian manufacturing sector illustrating issues pertaining to the adoption and implementation of CE practices. On a broader spectrum, Indian manufacturing sector is chosen as the field of study because this is a growing sector and it involves a lot of issues that need to be addressed in a systematic way. The step-by-step approach and illustration of case related to research work are discussed in Chapter 6.

3.3.5.3 Modeling based approaches

The research methodologies used for model development and decision framework are discussed in the following section.

3.3.5.3.1 Fuzzy DEMATEL approach

In this research work, effort has been made to explore and analyze the challenges pertaining to the implementation of CE concept in Indian manufacturing industry. For the identification of significant challenges Pareto approach is incorporated in the study. Pareto analysis is a statistical tool which is used for the ranking of the factors according to their frequency of occurrence (Craft and Leake, 2002). Fuzzy logic is applied along with Decision Making Trial and Evaluation laboratory (DEMATEL) approach to prioritize the significant CE challenges for the implementation in manufacturing industry. The concept of fuzzy logic is used to remove uncertainty in the data arising from human judgment (Azadegan et al., 2011). The purpose of using DEMATEL approach is to reflect causal relationship among the challenges (Rajput and Singh, 2019).

Multi Criteria Decision Making (MCDM) techniques such as Analytical Hierarchy Process (AHP), Analytic Network Process (ANP), Vlse Kriterijumska OptimizacijaI Kompromisno Resenje (VIKOR), Technique for order of preference by similarity to ideal solution (TOPSIS) have been used in the past to rank the factors but none of the techniques can classify the factors into cause and effect groups (Chandra and Kumar, 2020; Khalilzadeh et al., 2020; Rashidi, 2020). DEMATEL is used as a MCDM technique as this approach can transform the cause and effect relationship of the factors into an intelligent structural model of the system (Tian et al., 2019). This approach aims to identify the most important criteria which can severely affect other criteria in the system (Jaiswal et al., 2020). It is based on digraph or directional graph. Digraphs are used to represent the contextual relations among the factors of the system and each value on the digraph shows the degree of influence of individual factor (Singh et al., 2020). Fuzzy set theory is used along with DEMATEL approach to avoid loss of information owing to the uncertainty arising from human judgment thus removing ambiguity from the data collected (Chang et al., 1998; Chen and Chiou, 1999).

The concept of Triangular Fuzzy Number (TFN) has been used to find idyllic solutions from group decision-making. A TFN is represented by its height, spread, shape and its relative position on the x-axis (Chen and Hwang, 1992). Defuzzification is a process to convert uncertain spatial data into crisp values which consider all the parameters as stated by (Chen and Hwang, 1992). Defuzzification can be generally performed by centroid or center-of-gravity method. The centroid method cannot differentiate among two fuzzy numbers with equivalent crisp value, even if the shape of the fuzzy numbers is different (Opricovic and Tzeng, 2003). Instead, Converting Fuzzy data into Crisp Scores (CFCS) defuzzification method is used to obtain a better crisp value. In this method, the equivalent fuzzy scores are converted into crisp numbers involving the computation of right and left score by the fuzzy maximum and fuzzy minimum, respectively and the total score is computed by calculating the average weight according to the membership functions (Opricovic and Tzeng, 2003).

In most of the studies, DEMATEL has been applied on crisp data while this research work consists of the application of DEMATEL approach which has been extended on the data gathered through human perception.

3.3.5.3.2 Bayesian Network Approach

The Bayesian network (BN) model was first proposed by (Caudill, 2003), who employed this model in solving the issues of uncertainty and risk in the supply chain. This modeling technique has been in existence for the last two decades, and many researchers have used this technique to model risk in different fields of the SC. For example, there are numerous studies that make use of this technique in decision support systems (Shevtshenko and Wang, 2009). Chen et al. (2010) demonstrated how the BN can be used to manage supply chain uncertainty. The BN has also been used in the field of operation management, to model risk that is related to the threat of IT infrastructure (Duchessi, 2007), business lines, construction project schedules (Luu et al., 2009), and due-date assignments (Yelland et al., 2010). The BN is also used with some of the forecasting techniques, to mitigate risk in the SC (Rahman et al., 2011). Risk mitigation analysis in the marketing sector has also seen the application of the BN technique (Cui et al., 2006). Service sectors that are exposed to risk, owing to weak profit dissemination throughout their chain of workers, utilize the BN model for improving their coordination mechanisms (Anderson et al., 2004). While the application of the BN has flourished in diverse areas of risk management, in the field of CSC only a few models are proposed. Most of the SCRM studies utilizing BN models were not able to map specific risk at specific locations throughout the network of SC, and did not clearly demonstrate the dependencies, proliferation and consequences of these risks

For the purpose of risk analysis, the BN methodology is used to generate a risk profile of each of the CSC partners. This network model is used to compute the probability of risk impact that an individual partner could have on the complete supply chain. Economic, environmental, social, technological, waste management, agile vulnerability, and risk of cannibalization are some of the risk categories that were identified through the extensive literature review.

The risk assessment model consists of a cluster of measures and scales, used to compute the probability of the occurrence of each risk construct. The measures of each risk category were incorporated, taking the key events that could have a direct impact on the risk into consideration. Further, these risk measures and scales are utilized to generate the risk profile of individual CSC partners. The risk profile represents the disruption caused by a particular CSC partner when a cluster of risk events occurs under a certain condition. The disruption not only affects the individual partner, but has an impact on the complete supply chain. In the case of the circular supply chain, all the partners are connected through a cycle. Therefore, if any disruptive event occurs, it will affect each of the partners that are involved in the cycle. In the study, certain parameters that may be used to check the performance of the CSC are considered, with regards to the risk assessment model under consideration. These are the partners risk impact on SC revenue, lost sales, and inventory holding cost. The probability of risk impact of an individual partner is used to analyze the effect on these performance parameters. Each individual partner has a distinctive effect on these parameters that illustrate the performance of the CSC.

3.3.5.3.3 Markov Chain Approach

The Markov method is used for the analysis of complex systems with dynamic effects. A Markov process is one which satisfies the Markov property. A process is said to satisfy the Markov property when the prediction of the occurrence of its future state solely depends on the immediate preceding state, independent of the history of past states. Since in a Markov Process, its future state solely depends on the present state, there is no connection between the future and past states. Therefore, a Markov Process is sometimes referred to as a memory-less process. This helps in calculating the conditional probability where the process is assumed to have a finite number of states and time is continuous.

Markov chain is used for modeling the material flow in a circular network of supply chain as the material movement to the next state solely depends on the immediate preceding state. Let us assume, the EoL stage (disposal or recycling) is solely based on its consumption stage and the material movement towards the customer primarily relies on the recycling or production stage. Accurate prediction can be made using MC model if the movement of the material is steady. Therefore, while using MC modeling technique to analyze the circularity of Aluminium, this study assumes that the amount of Aluminium circulated in the Indian economy is constant over a long time span.

There are two types of processes which can generally be related to the flow of a material. One that is cyclic in nature and the other which is absorbed after certain time period. The processes in a MC, which comes to an end after a particular time are represented as absorbing states. If material flow is seen as a stochastic process, then some of the stages are classified as absorbing states, such as landfill. Because once the material enters the absorbing states, its movement to other states is restricted. Stages like production, consumption and recycling are considered as transient states, because material movement is possible through these states.

A Markov Chain is said to be an absorbing chain if.

- There is atleast one absorbing state (there can be more than one absorbing state also).
- Movement from any state to atleast one absorbing state is possible in a finite number of steps.

A Markov chain containing an absorbing state is not the only and sufficient condition for the chain to be called as Absorbing Markov Chain (AMC). It must also comprise of states that eventually reach an absorbing state with probability equal to 1. The states which are not absorbing are called transient states. Hence, in an AMC, there are absorbing states or transient states.

3.3.5.3.4 Graph Theory and Matrix Approach

Selection of SC partners based on CE perspectives is one of the crucial problems of circular supply chain management (CSCM) that is yet to be addressed. During the selection of suitable partners the sustainability aspect need to be integrated due to stringent environment norms, strict government policies and economic interest (Mao et al., 2020). Therefore, the ultimate objective of the proposed research work is to prepare a framework for the selection of suitable actors of CSC. Therefore, in this work an approach has been incorporated that best describes the role of individual partners in achieving the desired objective Graph Theory and Matrix approach (GTMA) has been utilized as a selection methodology as this approach comprehensively evaluates all the selection criteria and the interdependencies among them. The selection criteria were identified based on extensive literature review and through discussion with supply chain experts. Thereafter selection index was determined for the various SC alternatives used to select suitable actors of CSC. Selection index is the value obtained through a permanent function using GTMA. Higher the value of selection index, better is the alternative chosen. The selection index values were compared and best SC alternative was selected.

GTMA is a simplified logical decision making approach. It is a matrix approach which consists of directional graphs depicting relationships among attributes. GTMA is used when there is larger number of nodes and it is difficult to analyze and compute the solution through other graphical techniques. GTMA provides a simple and generic way to solve a problem with less computation. GTMA consists of algorithm and theorem through which one can represent the system behavior in systematic way. Various software tools are present for the ease of analysis and computation of matrices. However, in case of critical analysis GTMA can be utilized even if the number of attributes is large. The concept of permanent function helps in detailed characterization as it comprises of all the attribute components. The value generated by the permanent function can significantly vary even if there is a small change in the value of the attribute. Therefore it becomes easy to rank the alternatives as there is a significant difference in the value generated by the permanent function. Further, the relative importance of the attributes and the importance of attributes for each alternative is used together for the improved evaluation of the alternatives. Because of all the above advantages, the proposed study has incorporated GTMA as the solution methodology.

3.6 Concluding remarks

A research framework has been formulated in this chapter to accomplish the research objectives. The research stages, including research philosophy, research approach, data collection, time horizon, and research methods, have been duly justified and established for the research work. The research work examines the noteworthy characteristics of mixed research, which encompasses the survey method and case method. Additionally, a methodical approach for validating the findings of the survey method through the case study method and subsequently developing models and decision frameworks is also discussed. The chapter also delves into the justification of various methodologies employed in the development of models and decision frameworks pertaining to select issues in the field of CSC. The utilization of Pareto analysis and Fuzzy-DEMATEL methodology for the identification and prioritization of significant factors in CSC, as well as their classification into cause and effect groups, is thoroughly addressed. Furthermore, the adoption of the Markov chain approach for the development of decision frameworks concerning circularity decisions and the percentage of circularity is elucidated. The GTMA has been employed to ascertain the value of the coordination index under different scenarios. The chapter provides justifications for the use of these methodologies in the development of decision frameworks, along with their historical application in previous research endeavors within the realm of CSC. In the subsequent chapter, the identification and prioritization of challenges for the implementation of CSC concept in Indian manufacturing industry are discussed.

CHAPTER 4

DESCRIPTIVE ANALYSIS AND HYPOTHESES TESTING

4.1 Introduction

The literature review reveals that CE plays a significant role in effectively managing both end-of-life product returns and discarded products. This chapter delves into the present practices, challenges, and risks associated with the implementation of the CSC concept in the Indian manufacturing industry and assess the various industry factors. According to (Diaz et al., 2021), the survey method serves as an appropriate tool for exploring an Industry and CSC activities. To explore the current trends, status, and factors related to CE, a survey was conducted in the Indian manufacturing industry. The study delved into CSC issues related to key factors, coordination decisions, and circularity implementation, and hypotheses were formulated to examine the association of these issues with the economic, environmental, and social performance of CSC. The hypotheses were then tested after evaluating the fitness of the data through a measurement model. The complexities of relationships were analyzed using the Likelihood Ratio Test approach, which considers the causal relationship among variables. The following sections provide an explanation of the hypotheses development, observations from the survey, hypotheses testing, and the study's findings.

4.2 Hypotheses development

Formerly, Circular Economy (CE) was regarded as an activity driven by costs and primarily focused on the economic aspects of performance. In a study conducted on the Indian manufacturing sector, Bag et al. (2020) discovered that organizations are adopting CE practices to enhance sustainable manufacturing capabilities. Presently, organizations are also addressing environmental and social concerns through the implementation of CE. The integration of CE principles in the supply chain operations can have a notable impact on an organization's sustainable performance (Kamble and Gunasekaran (2023). Rajput and Singh (2020) stated in their study on CE that there is a necessity to delve into CE planning and decision-making processes to enhance an organization's sustainability performance. Nonetheless, limited research has been conducted on the social dimensions of CE (Baah et al., 2023). The study examines all three sustainability perspectives and assesses how various factors influence the economic, environmental, and social performance of CE. Numerous challenges within CE affect its overall performance. Past research reveals that circular supply chain practices, challenges, and risks have not been extensively explored. Consequently, the study formulated hypotheses regarding these factors to gauge their effects on the economic, environmental, and social performances of CE. These hypotheses were then tested to determine the relationship between these issues and the economic, environmental, and social performance of CE based on a survey conducted within the Indian manufacturing industry. The development of hypotheses is elaborated upon in the subsequent subsection.

4.2.1 Hypotheses associated with CSC implementation

According to literature review, Circular Supply Chain (CSC) plays an important role in handling of product returns and end-of-life products. The preceding section lays the foundation for framing of the hypothesis which depicts the relationship between various issues of CSC implementation and their impact on sustainable performance of CSC. This study sought to investigate CSC practices in the Indian manufacturing industry, as well as the challenges and risks involved with their implementation. A survey of the Indian manufacturing industry was done to investigate present CSC practices, challenges, and risks. Issues related to the adoption and implementation of CSC practices, challenges or barriers during the implementation phase and risks associated with its adoption were explored and hypothesis was developed to test the effect on environmental, economic and social performance of CSC. The hypothesis was examined subsequent to evaluating the adequacy of the data using a measurement model. The investigation of the likelihood of these challenges and risks arising during the execution of CSC practices is examined through the application of the Likelihood Ratio Test (LRT) method, which considers the probability of these factors occurring, when comparing the fits of two nested statistical models. The likelihood ratio test (LRT) is a statistical test that is commonly employed in the context of hypothesis testing in statistical inference. In a nested model, one model is a simplified version of the other, obtained by constraining certain parameters to fixed values. The LRT is used to assess whether the more complex model, which allows for more flexibility in parameter estimation, provides a significantly better fit to the data compared to the simpler model. The framework of hypothesis is developed based upon the observations from the comprehensive review of literature which is shown in Fig. 4.1.

In the past, CSC was considered a cost-driven strategy that prioritized the financial aspects of its implementation. In their research on the Indian manufacturing sector, Ravi and Shankar (2015) discovered that businesses are adopting sustainable practices in order to generate financial gains. Organizations are presently endeavoring to tackle the environmental concerns by means of the contribution of CSC. CSC has the capacity to render a substantial contribution towards the sustainable development of an organization. According to Govindan et al. (2015), it is necessary to explore the practices, challenges and risks associated with the implementation of CSC in order to enhance an organization's sustainability performance. However, research on the social dimensions of CSC is scarce. The research study takes into account all three elements of sustainability and investigates how specific issues affect the environmental, social, and economic performance of CSC. There are numerous issues of CSC that impact its overall performance. The analysis of research gaps reveals that there has been limited exploration into the practices, challenges, and risks pertaining to CSC. Thus, in order to evaluate their impact on the environmental, economic, and social performances of CSC, the hypothesis was developed based on these concerns. Based on a survey carried out in the Indian manufacturing industry, hypotheses are evaluated to determine the association between these concerns and the environmental, economic, and social performance of CSC. The hypothesis development is explained subsequently.

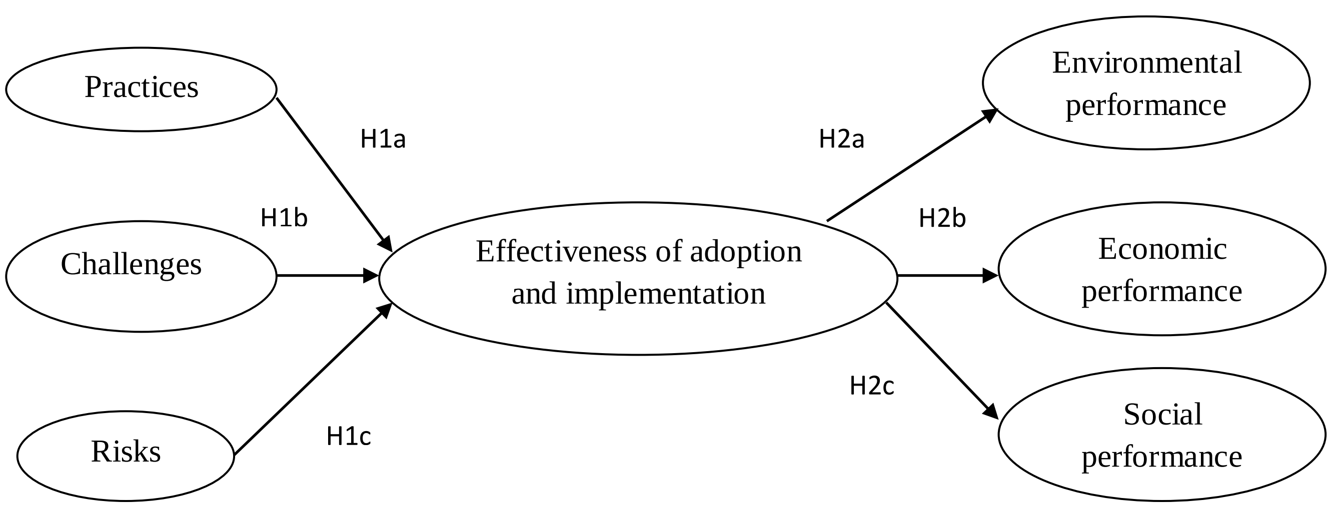

Fig. 4.1 Hypothesis framework

H1a. Practices identified in the study are positively effecting the adoption and implementation of CSC.

H1b. Challenges identified in the study are directly influencing the adoption and implementation of CSC.

H1c. Risks identified in the study are directly influencing the adoption and implementation of CSC.

Based on comprehensive review of literature, it can be inferred that an organization could ensure sustainability through the adoption of CSC practices. The study investigates whether these practices have a positive impact on the economic, environmental, and social performance of the organization. The purpose of the hypothesis is to evaluate the relationship between the organization's social, environmental, and economic performance and the advantages that come from CSC activities. A questionnaire was used to collect data in order to evaluate the hypothesis. Additionally, the following is a list of the hypotheses that were put forth.

H2a. The environmental performance of CSC is positively correlated with the effectiveness of adoption and implementation.

H2b. The economic performance of CSC is positively correlated with the effectiveness of adoption and execution.

H2c. The social performance of CSC is positively correlated with the effectiveness of adoption and implementation.

4.3 Data Collection

The data collection process using the survey method entails adhering to the subsequent procedures.

4.3.1 Questionnaire development

A survey questionnaire was created based on an extensive review of the literature and an analysis of the research gap. The purpose of the survey was to collect information from the Indian manufacturing industry regarding current practices, challenges, and risks in order to assess the theoretical constructs of CSC. A preliminary draft of the questionnaire was reviewed by five practitioners from the Indian manufacturing industry and four experts from academia prior to distribution for data collection. These reviewers assessed the clarity and content representativeness of the questionnaire and provided feedback. The suggestions provided by the reviewers were incorporated to improve the questionnaire. The questionnaire was created with Google Forms and is attached in the Appendix I. Individual responses and associated information will be treated as confidential.

4.3.2 Questionnaire administration

A method of data collection known as a cross-sectional quantitative survey has been employed in the specific context of the manufacturing industry in India. This particular industry has been chosen due to its emphasis on sustainability performance and the development of circular frameworks. In order to gather the necessary data, a survey was distributed to 390 manufacturing companies via Google Forms, all of which have implemented sustainable and environmentally-friendly practices within their organizations. Moreover, the survey also targeted companies that have previously utilized circular concepts in their operations. In addition to this, an additional 50 emails were sent to academia and researchers specializing in this field. Overall, a total of 440 emails were dispatched for the purpose of conducting the survey. Out of these 440 email correspondences, it was discovered that 240 responses were fully completed, whereas 200 were deemed incomplete and subsequently excluded from the analysis. Consequently, the response rate for the questionnaire stands at approximately 54.5%. Notably, (Malhotra and Grover, 1998) have recommended that operational management research should aim for a response rate of more than 20%.

4.3.3 Respondent profile

To gather information through a survey, 440 emails in total were sent to different companies in the Indian manufacturing sector over two different periods. A total of 240 answers were considered appropriate for the study. Table 4.1 displays the demographic characteristics of the participants. The profiles of both the organizations and the respondents are visually represented in Fig. 4.2, 4.3, and 4.4. The number of employees can be seen in Fig. 4.2, while the sectors in which they are employed are illustrated in Fig. 4.3. The organizations that willingly participated in the survey encompass a range of sizes, spanning from low to medium to large, as evidenced by the turnover displayed in Fig. 4.4. The respondents who actively took part in this survey hail from a variety of departments, including Design and Development, Procurement, Production, Human Resources, Marketing and Sales, as well as Corporate Social Responsibility.

Table 4.1 Demographic characteristics of the respondents

Type of manufacturing organization	**Numbers**	**Percentage**
Food products and beverages	24	10
Automobile Sector	72	30
Electrical and electronics equipment	32	13.33
Non-ferrous metal products	44	18.33
Medical and pharmaceuticals	18	7.5
Machine tool equipments	30	12.5
Others	20	8.33
Annual Turnover (in million dollars) of the organization.		
<100	90	37.5
100 to 300	74	30.83
300 to 500	46	19.16
>500	30	12.5
Number of employees in the organization		
<200	124	51.66
200 to 500	68	28.33
500 to 1000	32	13.33
>1000	16	6.66
Product/Services offered by the organization		
Service based	60	25
Product based	180	75
Total Industrial Experience		

Less than or equal to 5 years	90	37.5
5 to 10 years	65	27
10 to 15 years	45	18.75
Greater than or equal to 15 years	40	16.66

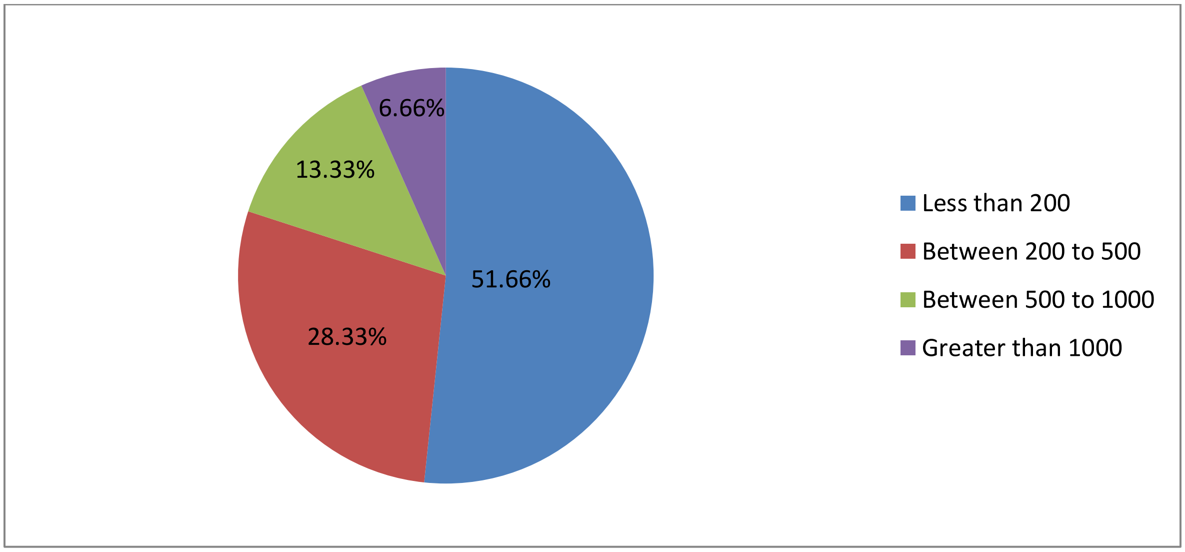

Fig. 4.2 Distribution of organization according to number of employees

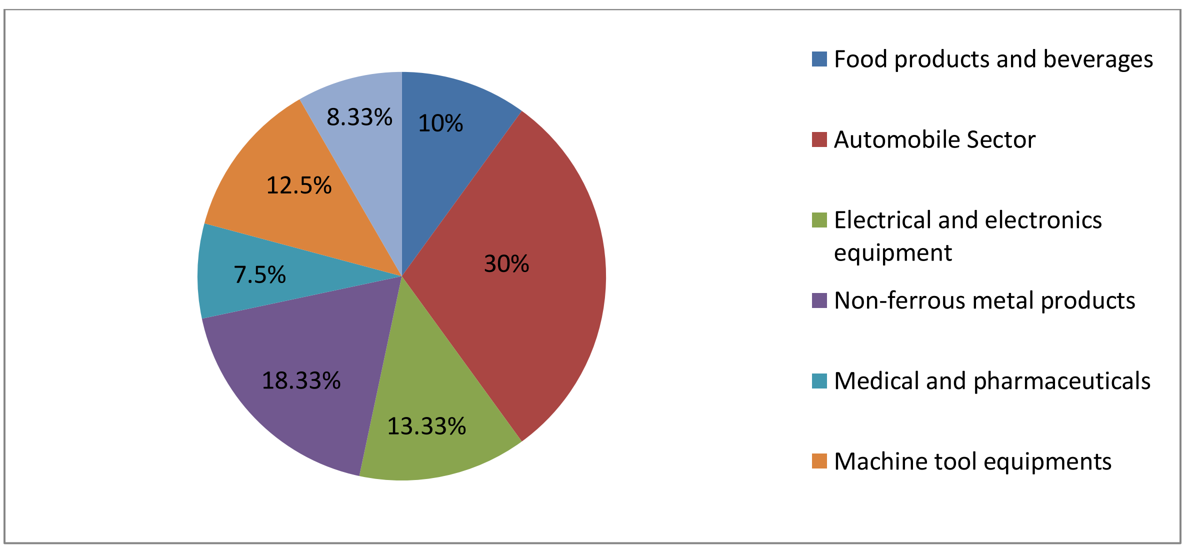

Fig. 4.3 Type of manufacturing organization

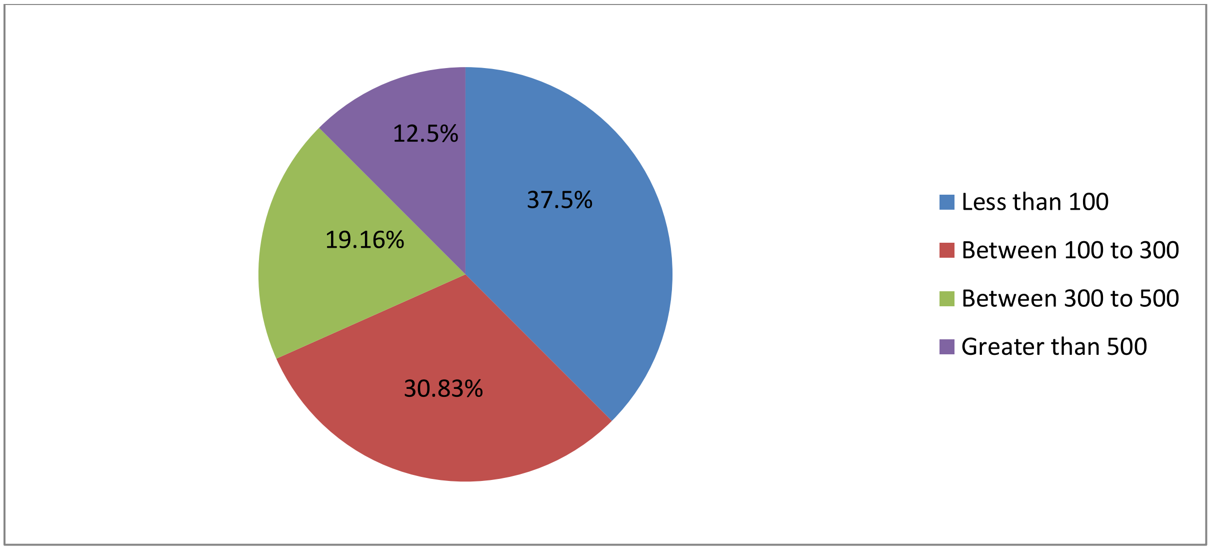

Fig. 4.4 Annual Turnover (in million dollars) of the organization

4.4 Observations from the survey

Observations derived from the survey of Indian manufacturing industry have been thoroughly examined in order to comprehend the prevailing practices, challenges, and risks associated with the adoption and implementation of CSC. Participants were requested to articulate their viewpoints using a Likert scale comprising five points, wherein a score of 5 indicated a highly significant level of agreement, 4 denoted a moderately significant level of agreement, 3 represented an absolutely significant level of agreement, 2 implied a significant level of agreement, and 1 indicated a minimally significant level of agreement. The observations from the survey are examined and discussed in the subsequent section. The mean and standard deviation values are displayed in the corresponding Figures. The standard deviation value is calculated to facilitate comprehension of diversification among viewpoints and for potential additional analysis.

4.4.1 Significant developments in Indian Manufacturing Industry

A total of nine CSC practices were found in order to examine the most recent developments in the Indian manufacturing sector. The evaluation of practices was based on their orientation towards CSC. Fig. 4.5 displays mean values and standard deviation. Cleaner production has the highest mean value (3.86) and standard deviation (0.92), according to the survey data.

Unnikrishnan and Hegde (2007) also reported that Indian manufacturing industry requires more of cleaner production practices to be adopted at micro-level. The importance of green consumption and green public procurement is the second highest with mean 3.72 as it involves setting of responsibility of individual stakeholders. Industrial symbiosis is another important practice (mean = 3.48) which leads to the formation of eco-industrial parks and sustainable exchange of material and energy (Bain et al., 2010). This could only be possible when there are stringent policies for eco-industrial parks (mean=3.25) which requires continuous monitoring of carbon emissions and optimizing exchange of material and energy (Patnaik and Poyyamoli, 2015). Also regional level collaboration of eco-industrial parks (mean = 2.96) strengthens regional markets for recycled materials and helps in reducing the risk of under utilization of local material (Bueren et al., 2023). Establishing waste trade markets is another important practice (mean = 2.75) which requires thorough analysis of secondary market and an important customer connect (Su et al., 2013). Sustainable development can be achieved by creating a recycling oriented society (mean = 2.45) which requires spreading awareness and technical know-how for circular activities (Franklin-johnson et al., 2016). Strong policies on product recycling and reuse (mean = 2.25) directly influence standardization of secondary products and ultimately lead to monetary gains (Mukhopadhyay and Setaputra, 2011). Collaborative business models (mean = 2.1) represent another crucial practice that necessitates not only the involvement of top management in joint decision-making, but also the adoption of risk, resource, and revenue sharing to enhance the coordination among business partners (He, 2017).

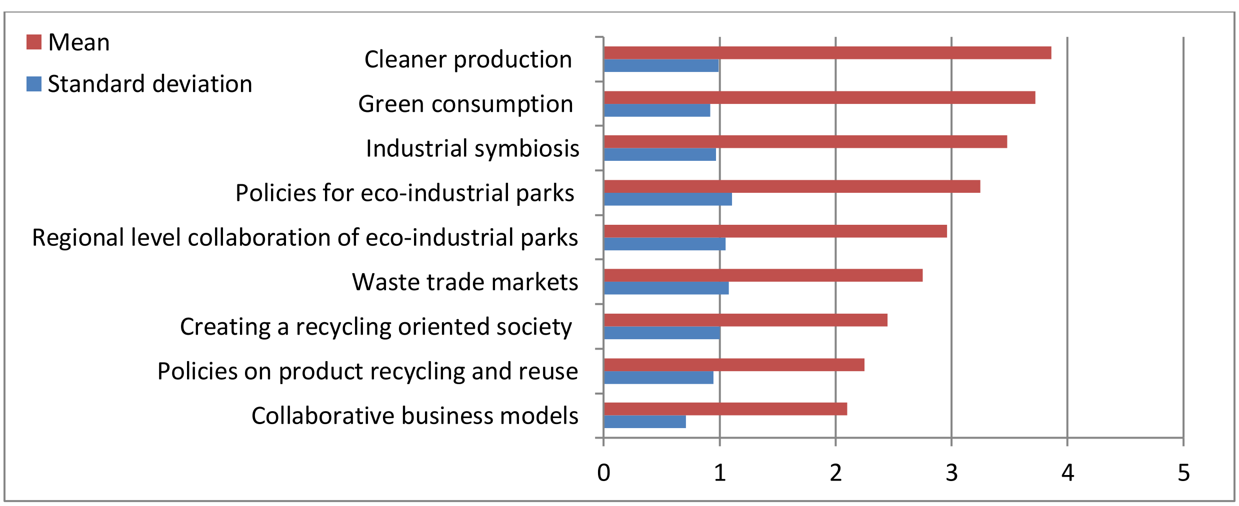

Fig. 4.5 Important practices in Indian manufacturing industry

A proposed conceptual framework is presented in Fig. 4.6, which is based on hypothetic-deductive reasoning for empirical testing, and is developed through the identification and classification of the relevant factors.

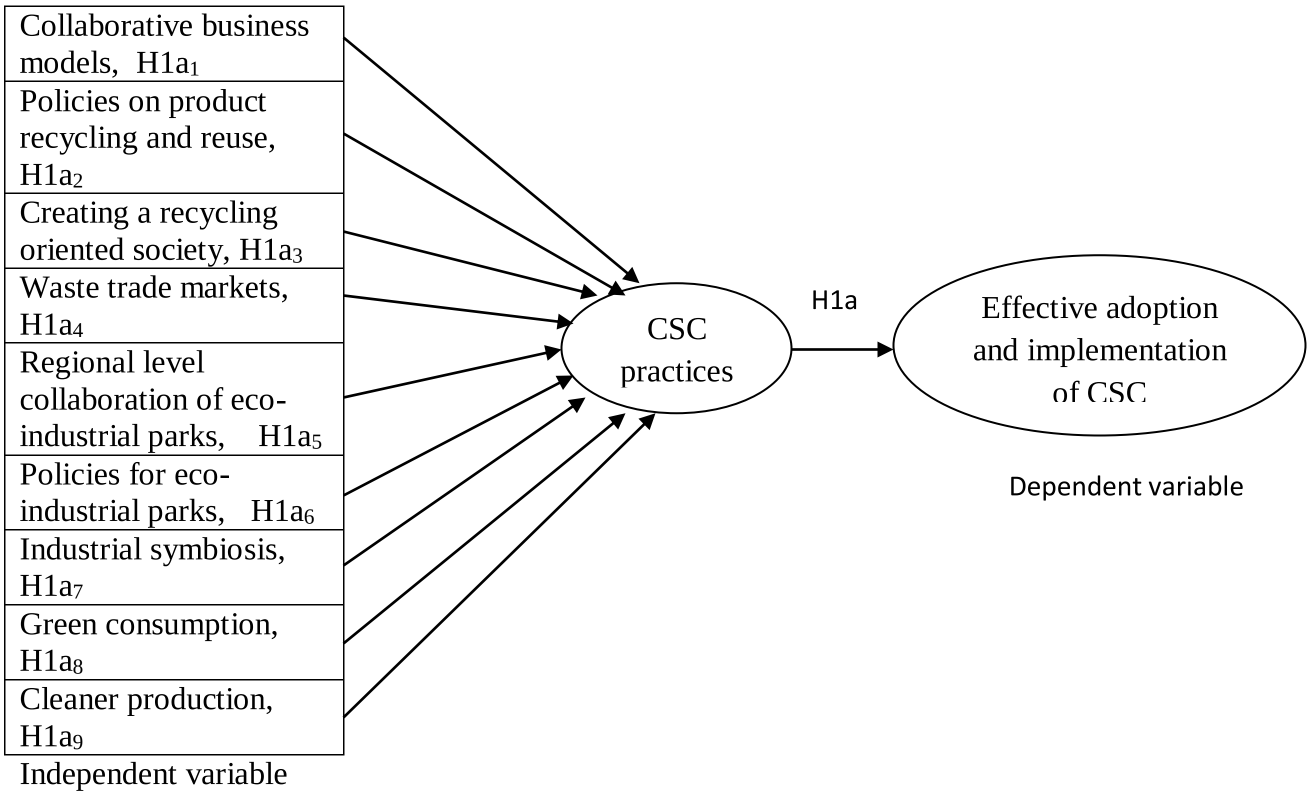

Fig. 4.6 Proposed theoretical model for empirical validation of CSC practices

The adoption of CSC practices entails several challenges that need to be addressed in a systematic way. Shi et al. (2008) identified the challenges encountered while integrating cleaner production practices into the operations of Chinese SMEs and determined their order of importance. Their study revealed that the foremost challenges consist of the absence of policies concerning economic incentives (mean = 3.85), inadequate implementation of environmental taxes (mean = 3.76), and the substantial upfront capital investment required (mean = 3.65). Zhijun and Nailing (2007) identified some major challenges during green consumption and green public procurement. Setting up responsibility of individual stakeholders (mean = 3.57) and complying to the regulations (mean= 3.36) with a scientific development philosophy are some of the significant challenges that need to be addressed. The government formulates policies concerning the recycling and reutilization of products, however their implementation is hindered by financial limitations (mean=3.28) and a resistance to embrace change (mean=3.15). The implementation of the concept of waste trade markets necessitates a comprehensive examination of the secondary market (mean=3.15) and a robust connection with customers (mean=3.45). The effective implementation of the policies for eco-industrial parks requires capacity enhancement through social integrity (mean= 2.75) and continuous monitoring of carbon emissions (mean= 2.59). Regional level collaboration of eco-industrial parks necessitates strengthening of regional markets for recycled materials (mean= 2.56) and sustainable accounting of resources (mean= 2.45). In addition, the establishment of a society with a focus on recycling necessitates the dissemination of knowledge amongst a wide range of individuals (mean= 3.57) as well as technical expertise in circular endeavors (mean= 2.96). Collaborative business models are inevitable part of circular supply chain necessitating the confluence of decision-making processes (mean= 3.25), resource allocation (mean= 2.25), and risk distribution (mean = 3.14). Total 18 challenges have been identified that pose a significant effect on the adoption and implementation of 9 CSC practices which can be estimated by observing important trends in Indian Manufacturing industry. Mean value and standard deviation for the challenges are presented through a bar graph shown in Fig. 4.7.

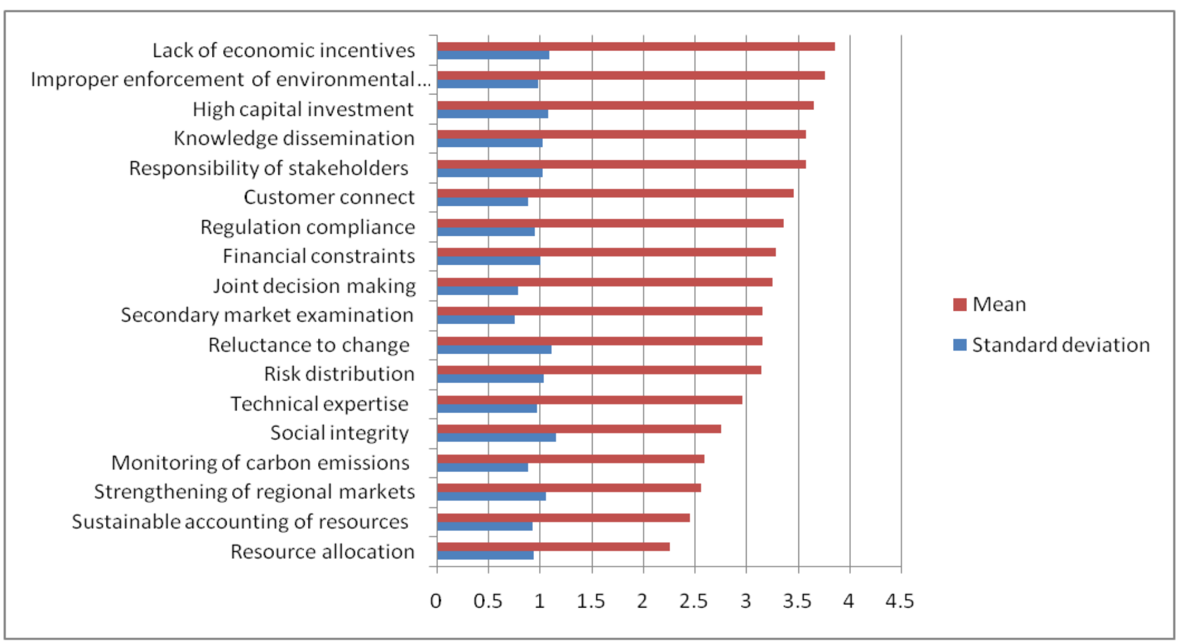

Fig. 4.7 Significant challenges in Indian manufacturing industry

Fig. 4.8 shows the hypothetical model for the empirical validation of these challenges by the observations made through the survey of Indian manufacturing industry.

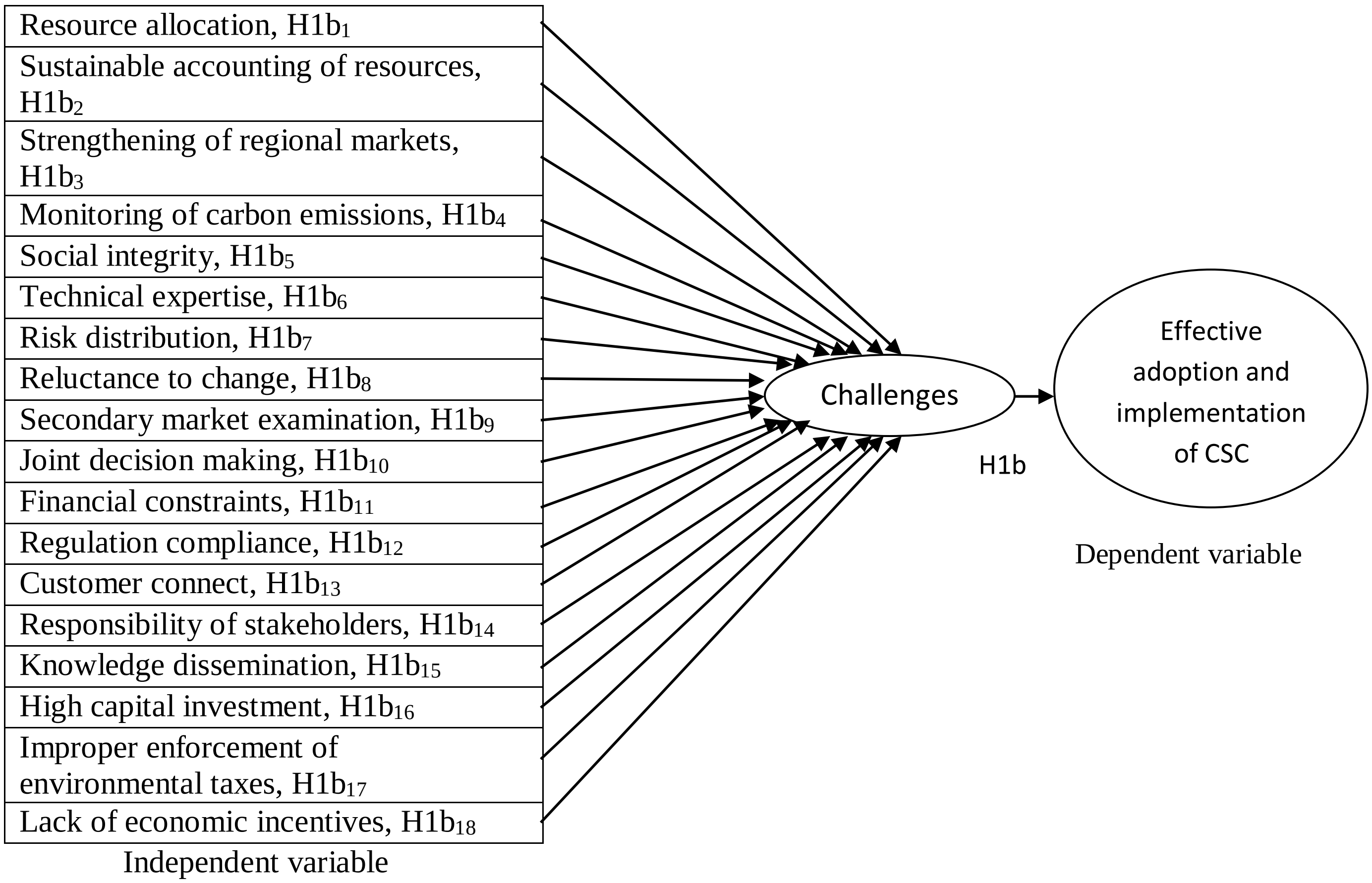

Fig. 4.8 Proposed theoretical model for empirical validation of CSC challenges

Apart from various challenges faced during the adoption and implementation of CSC practices, the organization is also exposed to a variety of risks that need to be considered prior to its implementation phase. Recently, researchers have been increasingly focusing their attention on the recognition of risk in the execution of circular economy in the supply chain. This stems from the significant economic benefits it offers and the reduced harm it inflicts on the environment (Kazancoglu et al., 2020). The achievement of a high level of circularity in the supply chain requires the implementation of risk management. This involves the process of identifying, modeling, and mitigating risks at different levels of the supply chain. The existing literature lacks in terms of measuring disruptions in the circular supply chain and their impact on sustainable performance. Therefore, a thorough analysis of supply chain risk management literature in relation to circular economy reveals gaps and provides a foundation for further research in the field of circular supply chain.

Fragmented policies for product recycling and reuse raise concerns regarding the impact on product standardization (mean=3.75). Collaboration at the regional level among eco-industrial parks has the potential to mitigate the possibility of local resource underutilization (mean=2.54), while simultaneously impacting global material trade (mean=2.69). CSC face a wide range of coordination risk (mean=2.88) which include distortion of information, building of trust, lack of commitment and sharing of risk among partners. Due to the presence of multiple supply chain (SC) partners in a circular supply chain (CSC), it becomes essential to establish a robust coordination mechanism in order to enhance the circularity of material flow. In the circular supply chain, the execution of the 6R (reuse, repair, refurbish, remanufacture, recycle, redesign) operations can be carried out internally or contracted to a specialized outsourcing collaborator. The outsourcing of said operations entails a multitude of risks (mean=3.25), encompassing disruptions to internal activities, depletion of the competitive foundation, the manifestation of opportunistic behaviors, the escalation of transaction and coordination expenses, as well as augmented procurement costs (Chhimwal et al., 2021b). Supply risk, flawed incentive structures and high investment are some of the major economic risks (mean=2.98) a company may face while implementing the concept of CE in supply chain. The occurrence of environmental risk (mean= 3.45) may be heightened by several factors, including a restricted supply of natural resources, an unequal geographical allocation, and limited assimilative capacities of ecosystems. The impact on the local geographical ecosystem, the establishment of health standard protocols, and the influx of large-scale immigration pose significant risks to society (mean=3.08). Swift response to agile changes and flexibility in production process may reduce demand related risks (mean=2.75). Deregulated markets and problematic ownership structures give rise to risk of cannibalization (mean=3.13). Risk encountered during the implementation of CE concept pose a significant effect on its adoption and its thorough analysis could lead to improved sustainable performance. Fig. 4.9 presents a bar graph illustrating the mean and standard deviation of various risks associated with the adoption and implementation of CSC.

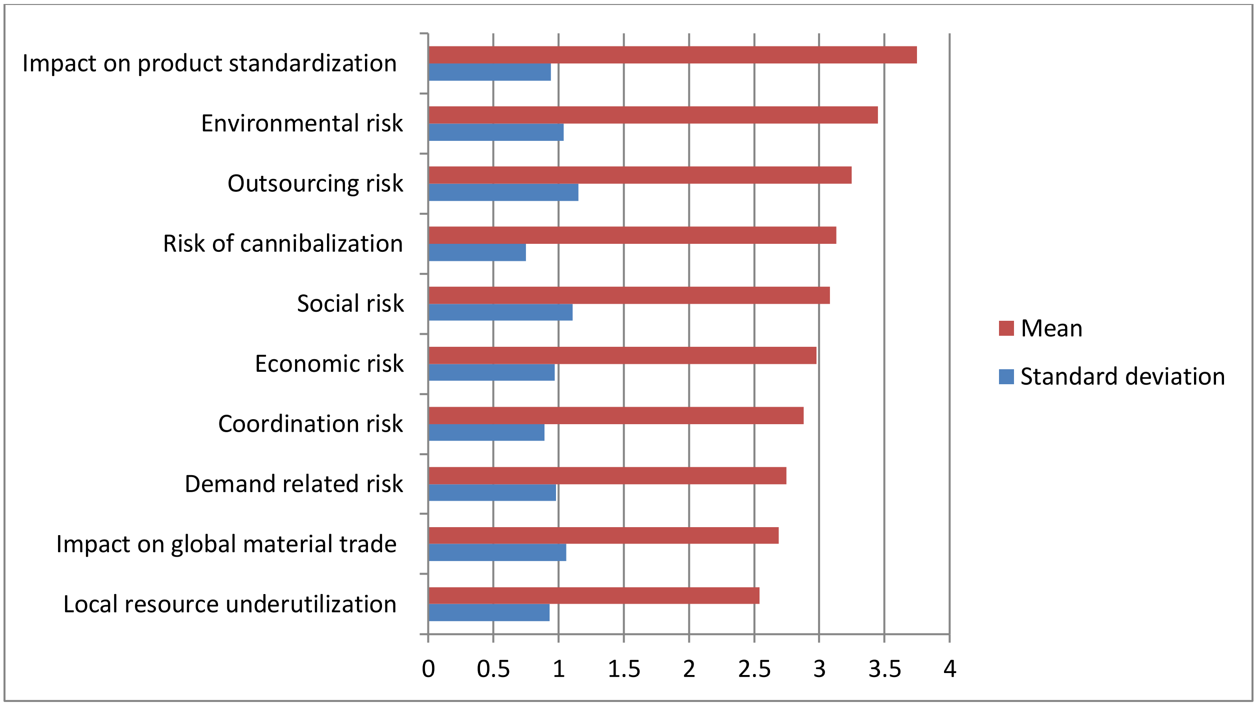

Fig. 4.9 Risk associated with CE implementation

Fig. 4.10 shows the hypothetical model for the empirical investigation of the risk associated with the adoption and implementation of CE concept in the Indian manufacturing industry.

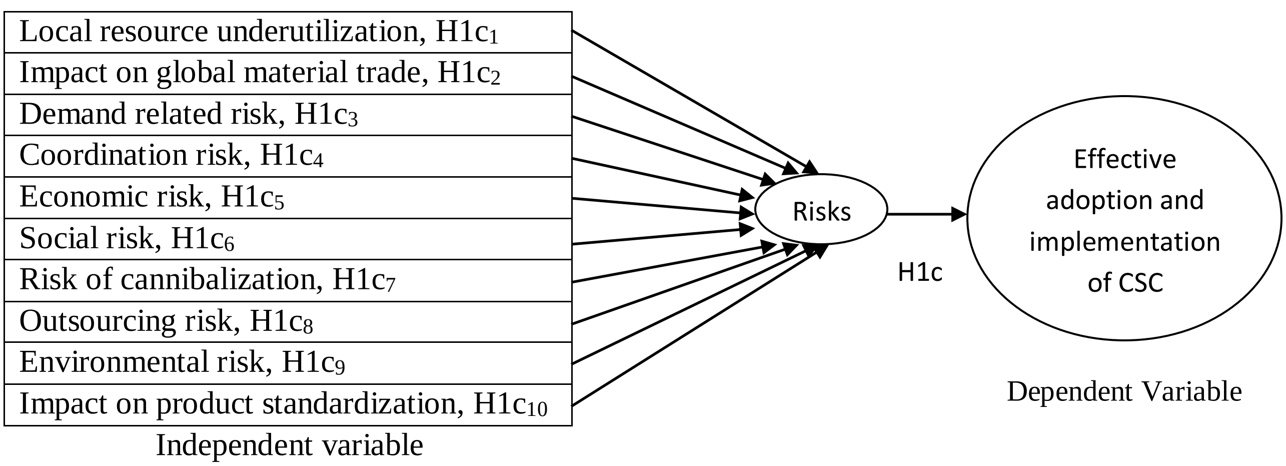

Fig. 4.10 Proposed theoretical model for empirical validation of CSC risks

4.5 Hypotheses testing methodology

The formulation of a theory of hypothesis testing (as opposed to the examination of specific instances) can be traced back to the pioneering book authored by Neyman and Pearson (1928). In this seminal work, they highlight the crucial fact that when selecting an appropriate test, one must consider not only the hypothesis itself but also the alternative scenarios against which the hypothesis is to be evaluated. Building upon this insight, they propose the likelihood ratio principle as a universally applicable criterion. This principle has proven to be remarkably successful, as the majority of currently employed tests for testing parametric hypotheses are likelihood ratio tests (for an expansion to the non-parametric case, refer to (Statistics, 2016)). Additionally, many of these tests have been demonstrated to possess various optimal properties.

In the parametric case, the likelihood ratio test exhibits a multitude of desirable characteristics. These include:

(i) Frequently, it is a straightforward and rational test to apply, yielding a definitive outcome.

(ii) In instances where the sample size is substantial and specific regularity conditions are met, it is possible to derive an approximate solution for the distribution problems that arise in determining the size and power of the test (King, 1930; Wald, 1943). In fact, if we denote the likelihood ratio as λ, $-2 \log \lambda$ can be approximated to have a central chi-square distribution under the null hypothesis, and a non-central chi-square distribution under the alternative hypotheses. The degrees of freedom in these distributions correspond to the number of constraints imposed by the hypothesis.

(iii) As demonstrated by (Wald, 1943), the likelihood ratio test exhibits various favorable properties in larger sample sizes, subject to certain restrictions.

Suppose we are presented with a set of random variables $X_1, \ldots, X_n$, which are distributed normally with a mean of μ and a variance of σ^2. In this scenario, both the mean and the variance are unknown. Our objective is to conduct a hypothesis test in order to evaluate the validity of certain propositions.

$$H_0 : \sigma^2 = \sigma_0^2 \text{ vs. } Ha : \sigma^2 \neq \sigma_0^2$$

at the level α.

The parameter θ is defined as $\theta = (\mu, \sigma^2)$. It is important to note that θ_o represents the set $\{(\mu, \sigma_o^2) : -\infty < \mu < \infty\}$, while θ_a is given by $\{(\mu, \sigma^2) : -\infty < \mu < \infty, \sigma^2 \neq \sigma_0^2\}$. Combining these sets, we have $\theta = \theta_o \cup \theta_a = \{(\mu, \sigma^2) : -\infty < \mu < \infty, \sigma^2 > 0\}$. In order to proceed, it is necessary to determine $L(\widehat{\theta o})$ and $L(\widehat{\theta a})$.

In reference to the normal distribution, we have

$$L(\theta) = L(\mu, \sigma^2) = \left(\frac{1}{\sqrt{2\Pi\sigma}}\right)^n \exp\left[-\sum_{i=1}^{n} \frac{(X_i-\mu)^2}{2\sigma^2}\right] \quad (4.1)$$

In the subset θ_o, the variance σ^2 is equal to σ_0^2, and the determination of the value of μ that maximizes the likelihood $L(\mu, \sigma^2)$ is possible if we can find $L(\theta_o)$ under the condition that $\sigma^2 = \sigma_0^2$. It can be observed that the value of μ that maximizes $L(\mu, \sigma_0^2)$ is easily identifiable as $\widehat{\mu_o} = \bar{X}$. Consequently, by substituting μ with $\widehat{\mu_o}$ and σ^2 with σ_0^2 in $L(\mu, \sigma^2)$, $L(\widehat{\theta o})$ can be derived.

$$L(\widehat{\theta o}) = \left(\frac{1}{\sqrt{2\Pi\sigma_o}}\right)^n \exp\left[-\sum_{i=1}^{n} \frac{(X_i-\widehat{\mu_o})^2}{2{\sigma_o}^2}\right] \quad (4.2)$$

Next, the value of is $L(\hat{\theta})$ determined. Suppose $(\hat{\mu}, \hat{\sigma}^2)$ is the element in the set θ that maximizes the likelihood function $L(\mu, \sigma^2)$ through the utilization of the maximum likelihood estimation method. Thus, we obtain.

$$\hat{\mu} = \bar{X} \quad \text{and} \quad \hat{\sigma}^2 = \frac{1}{n}\sum_{i=1}^{n}(X_i - \hat{\mu})^2$$

Then $L(\hat{\theta})$ is acquired by substituting μ with $\hat{\mu}$ and σ^2 with $\hat{\sigma}^2$,thereby providing.

$$L(\hat{\theta}) = \left(\frac{1}{\sqrt{2\Pi\hat{\sigma}}}\right)^n \exp\left[-\sum_{i=1}^{n} \frac{(X_i-\hat{\mu})^2}{2\hat{\sigma}^2}\right] = \left(\frac{1}{\sqrt{2\Pi\hat{\sigma}}}\right)^n e^{-n/2} \quad (4.3)$$

The calculation of the likelihood ratio is thus determined.

$$\lambda = \frac{L(\widehat{\theta o})}{L(\hat{\theta})} = \frac{\left(\frac{1}{\sqrt{2\Pi\sigma_o}}\right)^n \exp\left[-\sum_{i=1}^{n} \frac{(X_i-\widehat{\mu_o})^2}{2{\sigma_o}^2}\right]}{\left(\frac{1}{\sqrt{2\Pi\hat{\sigma}}}\right)^n e^{-n/2}} = e^{n/2}\left(\frac{\hat{\sigma}^2}{{\sigma_o}^2}\right)^{n/2} \exp\left[-\frac{n}{2}\frac{\hat{\sigma}^2}{{\sigma_o}^2}\right] \quad (4.4)$$

It is important to observe that the value of λ falls within the range of 0 to 1, where λ is less than or equal to 1, due to the inclusion of θo within the set θ. Consequently, in cases where λ is less than the constant k, we would proceed to reject the null hypothesis H_0. Here, k is a constant that is less than 1. The rejection region, denoted as $\lambda < k$, is essentially synonymous with.

$$\left(\frac{\hat{\sigma}^2}{{\sigma_o}^2}\right)^{n/2} exp\left[-\frac{n}{2}\frac{\hat{\sigma}^2}{{\sigma_o}^2}\right] < ke^{-n/2} = k' \tag{4.5}$$

When looking at the function of $\hat{\sigma}^2/{\sigma_o}^2$ on the left hand side, the inequality mentioned above holds true if $\hat{\sigma}^2/{\sigma_o}^2$ is either too large or too small, in other words.

$$\frac{\hat{\sigma}^2}{{\sigma_o}^2} < a \text{ or } \frac{\hat{\sigma}^2}{{\sigma_o}^2} > \text{b}$$

This inequality is the same as

$$n\frac{\hat{\sigma}^2}{{\sigma_o}^2} < na \text{ or } n\frac{\hat{\sigma}^2}{{\sigma_o}^2} > \text{nb}$$

We are able to discern that $n\hat{\sigma}^2/{\sigma_o}^2$ represent the χ 2 statistic and the decision rule remains unchanged. As a result, in this particular scenario, the likelihood ratio test is synonymous with the χ 2 test.

The likelihood function, which measures how well a statistical model explains observed data, underpins the Likelihood Ratio Test (LRT). To estimate the model parameters, the likelihood function is maximized, and the likelihood ratio is calculated as the ratio of the likelihoods of two models. The LRT statistic is based on a chi-squared distribution, and its significance is determined by comparing it to a critical value from the chi-squared distribution with a given number of degrees of freedom. The following are the general steps for performing a likelihood ratio test :

Step 1: Formulate the null hypothesis (H0) and the alternative hypothesis (H1). The null hypothesis typically represents the simpler model with certain parameters constrained, while the alternative hypothesis represents the more complex model with more flexibility in parameter estimation.

Hypothesis has already been stated and provided in section 4.2.1.

Step 2: Estimate the parameters of both the null and alternative models using maximum likelihood estimation (MLE) method.

It is possible to determine the parameters of both the null and alternative hypotheses by looking at significant trends in the Indian manufacturing sector.

Step 3: Calculate the likelihoods of the data under both the null and alternative models. This involves evaluating the likelihood function for each model using the estimated parameters and the observed data.

As discussed in the previous section, when the sample size is substantially large and primary conditions are met, the likelihood ratio test exhibits similar properties as that of chi-square distribution and the value of -2log λ can be approximated to have a central chi-square distribution under the null hypothesis, and a non-central chi-square distribution under the alternative hypotheses. In this specific scenario, the likelihood ratio test is equivalent to the χ 2 test. This study constitutes testing of three models. All the three models are tested to ascertain the association between the issues and the performance outcomes. Each model is tested for the observed data and the estimated parameters using the latest version of Minitab. For each model, the value of level of significance i.e. α is considered to be 0.05, which is also sometimes referred to as the chances of making Type-1 error during testing of hypothesis. Here, α denotes the risk of concluding that there are differences among the outcome percentage profiles when in fact there are not, is 0.05. If the p-value is less than 0.05, you can conclude there are differences at the 0.05 level of significance.

4.6 Results

The results of chi-square test for each model as obtained from Minitab software are shown in the Fig. 4.11, 4.12 and 4.13 respectively.

Fig. 4.11(a) Validity of test for association: Performance by Practices

Chi-Square Test for Association: Performance by Practices
Diagnostic Report

Observed and Expected Counts

	Cleaner prod		Green consum		Industrial s		Policies for		Collaborativ		Policies on	
	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp
Environment	140	105	80	105	120	105	130	105	60	105	100	105
Economic	40	82	60	82	80	82	70	82	140	82	100	82
Social	60	53	100	53	40	53	40	53	40	53	40	53
Total	240		240		240		240		240		240	

Expected counts should be at least 1 to ensure the validity of the p-value for the test.

Fig. 4.11(b) Observed vs. Expected counts for association: Performance by Practices

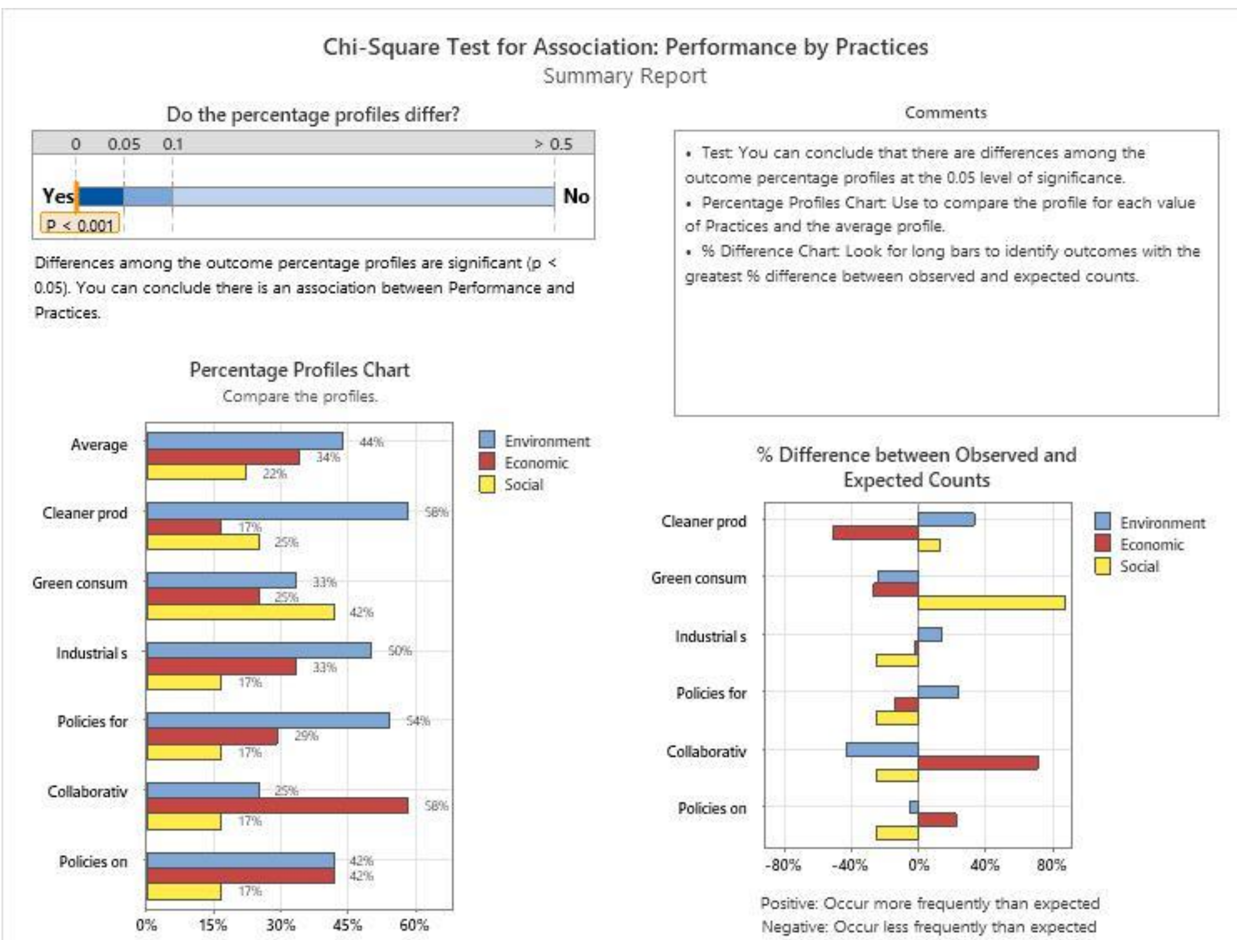

Fig. 4.11(c) Hypothesis testing results for association: Performance by Practices

Chi-Square Test for Association: Performances by Challenges
Report Card

Check	Status	Description
Validity of Test	✓	All samples are large enough to obtain sufficient expected counts. The p-value for the test should be accurate.

Fig. 4.13(a) Validity of test for association: Performance by Challenges

Chi-Square Test for Association: Performances by Challenges
Diagnostic Report

Observed and Expected Counts

	Resource all		Sustainable		Strengthenin		Monitoring o		Social integ		Technical ex	
	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp
Environment	80	77	60	77	40	77	100	77	80	77	100	77
Economic	100	80	80	80	60	80	100	80	40	80	100	80
Social	60	83	100	83	140	83	40	83	120	83	40	83
Total	240		240		240		240		240		240	

Expected counts should be at least 1 to ensure the validity of the p-value for the test.

Fig. 4.12(b) Observed vs. Expected counts for association: Performance by Challenges

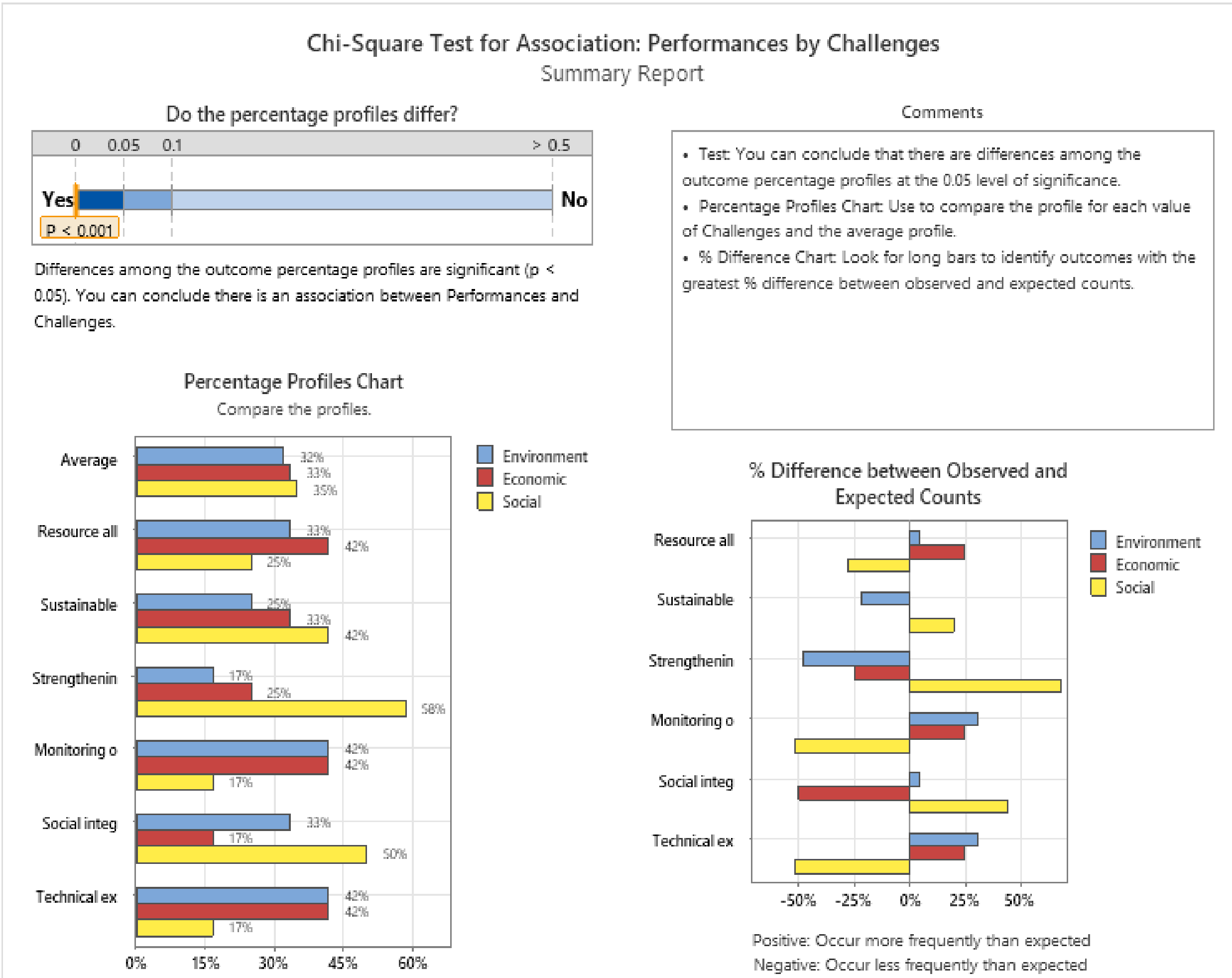

Fig. 4.12(c) Hypothesis testing results for association: Performance by Challenges

Fig. 4.14(a) Validity of test for association: Performance by Risks

Chi-Square Test for Association: Performances by Risks
Diagnostic Report

Observed and Expected Counts

	Product stan		Risk of cann		Outsourcing		Coordination		Demand relat		Resource und	
	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp	Obs	Exp
Environment	60	63	60	63	70	63	60	63	50	63	80	63
Economic	80	93	100	93	70	93	90	93	120	93	100	93
Social	100	83	80	83	100	83	90	83	70	83	60	83
Total	240		240		240		240		240		240	

Expected counts should be at least 1 to ensure the validity of the p-value for the test.

Fig. 4.13(b) Observed vs. Expected counts for association: Performance by Risks

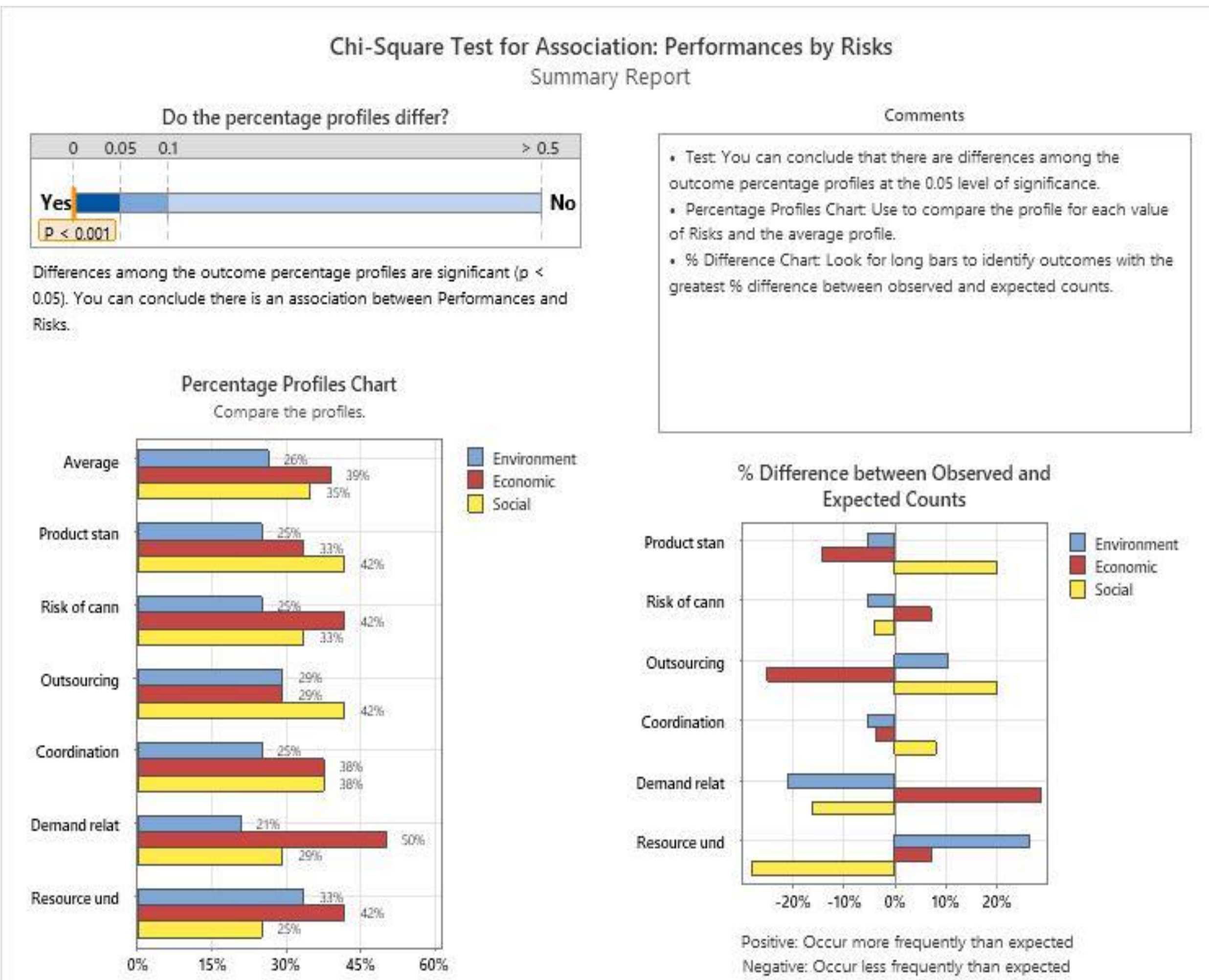

Fig. 4.13(c) Hypothesis testing results for association: Performance by Risks

4.7 Discussion and Concluding remarks

The selection of technique to test the hypothesis along with test statistics and test situations is discussed in the previous section. The likelihood ratio test is selected as a suitable approach for conducting hypothesis testing due to its consideration of the complete parametric space for evaluating the adequacy of the sample data against the developed model. The test results for association between performance and practices obtained through Minitab software shows that all samples are large enough to yield adequate expected counts. Also p-value considered for the test is less than 0.05 which shows differences between outcome percentage profiles are significant. This suggests that there is a relationship between practices and performance. There are variations in the outcome percentage profiles at the 0.05 level of significance, as indicated by the percentage profile chart in Fig. 4.11(c), which is utilized to compare the profiles for each value of practices and the average profiles. Therefore, it can be inferred from the chart that the performance outcomes significantly vary according to the practice adopted in particular situation. For example, the environmental aspect of performance of Circular Supply Chain (CSC) will be significantly affected by the adoption of cleaner production as a sustainable practice. In order to find outcomes with the biggest percentage difference between actual and expected counts, the percentage difference chart searches for long bars. For example, from the percentage difference chart shown in Fig. 4.11(c) it can be observed that adopting green consumption practice can significantly affect the social aspect of CSC performance. From the percentage difference chart, it is also observed that there is a positive association between practices and performances and therefore, the practices identified in the study are positively effecting the adoption and implementation of CSC.

Similarly, to test the association between the challenges identified in the study and the performance outcomes, the validity of the test holds good as all the samples are large enough to obtain sufficient expected counts. In this case, also the p-value is less than 0.05 which shows difference among outcome percentage profiles are significant. This leads to the conclusion that there is an association between performance and challenges. From the percentage profile chart shown in Fig. 4.12(c), it can be concluded that the average effect of the challenges on three performance outcome i.e. environmental, economic and social is almost equal. Therefore, it can be concluded that the challenges identified in the study will have a similar effect on all the three aspects of CSC performance. From the percentage difference chart shown in Fig. 4.12(c) it can be observed that the social aspect of performance has a significant percentage difference between observed and expected counts. Therefore, it can be concluded that while addressing these challenges the organization need to give due consideration to the social aspect of CSC performance. From Fig. 4.12(c), it can also be observed that challenges identified in the study are directly affecting the adoption and implementation of CSC and have a positive association with performance outcomes. Likewise, the test results to check for the association between the risks identified and the performance outcomes provide similar insights. From Fig. 4.13(c), it is observed that the risks identified in the study have a significant impact on the economic performance of CSC. Therefore, risk identification, analysis and mitigation is an important strategy to deal with the economic performance of CSC. From Fig. 4.13(c), it can be deduced that the risks that were identified in the study are directly influencing the adoption and implementation of CSC and exhibit a favorable correlation with performance outcomes.

The findings of this study have yielded similar results with the recent studies targeting the issues of sustainable manufacturing. In their study, Ahmad et al. (2023) discovered that the environmental dimension was more frequently taken into account compared to the economic and social dimensions in most of the examined methods. From the perspective of indicators, the majority of the tools that were examined relied on a small set of indicators, without considering their relative importance or receiving validation from experts. In order to address these challenges, future research directions were identified to enhance the inclusiveness and reliability of these methods. Additionally, there is a need to place greater emphasis on the economic and social dimensions. The outcomes of the investigation carried out by Baah et al. (2023), pertaining to the adoption and implementation of circular approaches, have primarily concentrated on the economic and environmental aspects. However, there is a scarcity of literature pertaining to the social consequences of the circular economy. Kamble and Gunasekaran (2023) found in their study that the relationship between Industry 4.0 technologies, Circular Economy and sustainable performance is still unexamined and a more conceptual and empirical examination is required to comprehend the ways in which the Industry 4.0 technologies facilitate the transition towards CE practices and the collective impact they exert on sustainable performance.

The likelihood ratio test was used in this study as an appropriate statistical approach to investigate the potential association between variables and performance outcomes. Many statistical applications, including analysis of variance (ANOVA), logistic regression, and linear regression, make extensive use of the likelihood ratio test. It provides a formal and widely accepted method for comparing the fit of nested models and making statistical inferences about model parameters. However, it has assumptions and limitations, and its application should be done carefully and in accordance with appropriate statistical principles. The t test and f test, which are employed for hypothesis testing problems involving two samples, can be recast as a likelihood ratio test. However, the likelihood ratio approach does not always produce a test statistic with a known probability distribution. Nonetheless, if the sample size is high enough, we can approximate the distribution under some reasonable regularity constraints that the population distributions under consideration satisfy. The existence of derivatives of the probability function with respect to the parameters is often required for these regularity criteria. Another critical need is that the region where the likelihood function is positive not be dependent on unknown parameter values.

The research work has attempted to address the select issues of Circular Supply Chain (CSC), identified based on the comprehensive literature review and exploration of Circular Economy (CE), especially in the context of Indian manufacturing industry. The work reported has explored the various issues of CSC such as practices, challenges and risks and proposed the solution methodologies by developing models, framework for evaluating performance of CSC that are discussed in the subsequent chapters. Some of the significant contributions of the research work are enumerated as follows.

- A thorough analysis of the literature on important CSC practices, challenges, and risks has been conducted in order to build the transition framework and provide other researchers with a pathway for research. The study has successfully highlighted the research gaps and connected them to the topics that need further investigation.
- A hypothetical framework has been developed to establish the relationship between the issues of adoption and implementation of CSC and the performance outcomes.
- Survey method was used to analyze the recent developments in the CE of Indian manufacturing industry through descriptive analysis and hypothesis testing.

CHAPTER 5

IDENTIFICATION AND PRIORITIZATION OF CIRCULAR ECONOMY CHALLENGES

5.1 Introduction

The adoption and implementation of CSC encompass various factors, which are instrumental in the process of decision-making and enhancing the effectiveness of CSC. A critical analysis of the challenges affecting CE application and their mutual interaction can facilitate the manufacturing sector of emerging economies in the smooth transition from linear to circular business model. Therefore, a comprehensive review of literature is conducted to explore the challenges and solutions during CE implementation. This chapter focuses on the identification of significant challenges and their prioritization for the implementation of a novel concept in a developing economy like India. Subsequent section presents the methodologies adopted in the study for the identification and prioritization of significant challenges related to CE implementation in manufacturing industry. The use of Pareto analysis for the identification of significant challenges is illustrated in the section 5.2. Section 5.3 deals with the application of Fuzzy logic along with DEMATEL approach to prioritize the significant CE challenges for the implementation in manufacturing industry. A research framework portraying the various steps involved in this study and the methods adopted for the generation of fruitful results is shown in Fig. 5.1.

5.2 Pareto Analysis

The selection of significant challenges from those identified through literature survey is done using Pareto analysis. It is also sometimes referred to as 80/20 rule. Regarding this 80/ 20 principle, Svensson and Wood (2006) in their theory stated that “a small percentage of a total is responsible for a large proportion of total outcome.” However, this concept has its own limitations. As a small percentage of key inputs is responsible for a large percentage of output, so companies should not narrow down their operations just by relying on the key inputs rather they should also consider the other input variables depending upon the application and requirement of variables (Craft and Leake, 2002). Empirical observation is the fundamental basis for the application of Pareto analysis and should not be considered as a mandatory rule for actions. Pareto analysis is widely used by academicians and industry practitioners. Talib et al. (2015)

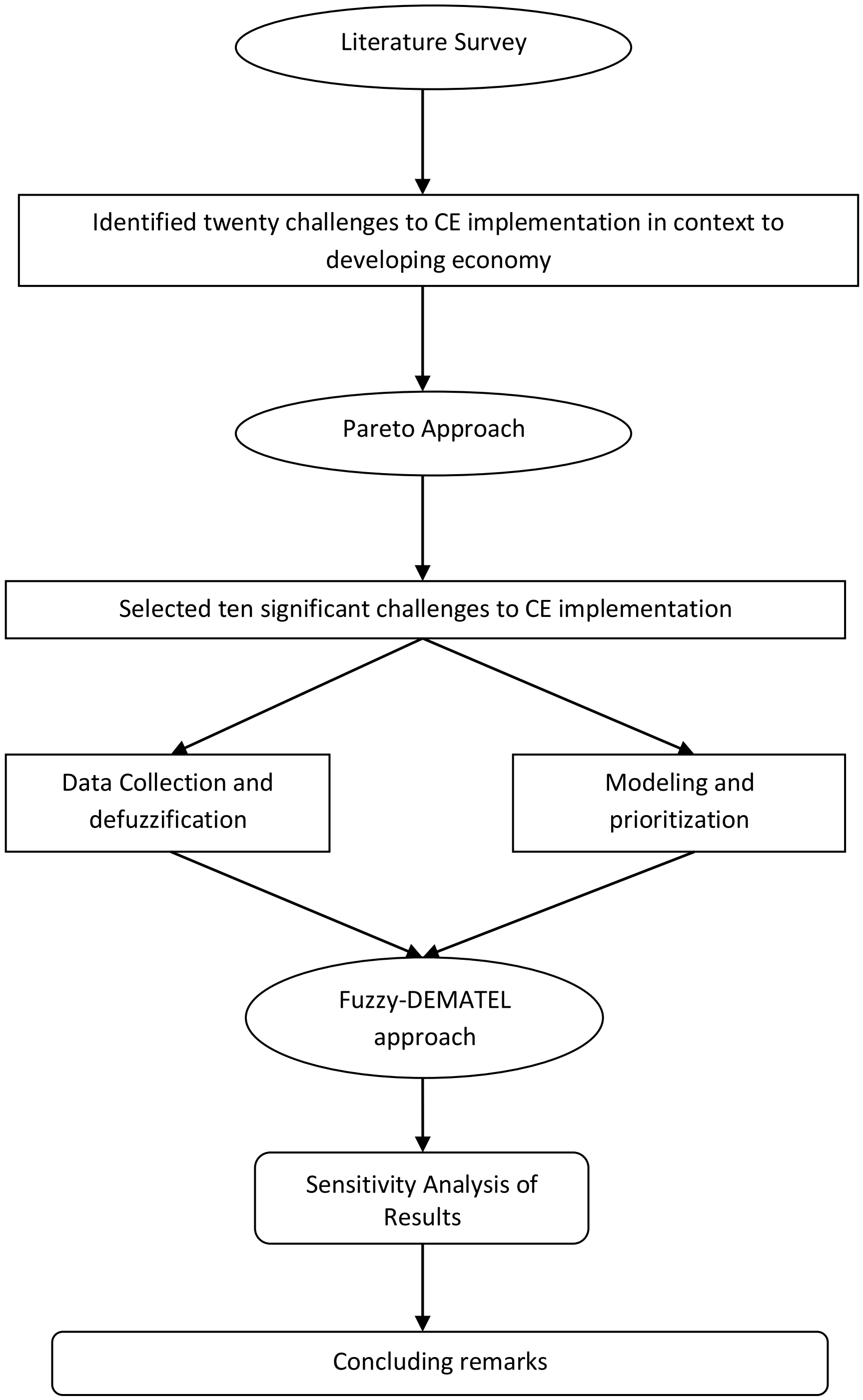

Fig. 5.1 Research framework

used Pareto approach to trace the frequency of occurrence of every possible critical success factors (CSF's) in SCM literature. Kumar et al. (2019b) used "Pareto Analysis" tool to shortlist and arrange the critical factors for the smooth implementation of agile manufacturing. Karuppusami and Gandhinathan (2006) used "Pareto analysis" as a quality tool to sort and arrange the CSF's of total quality management according to the order of criticality. Fotopoulos et al. (2011) and Bamford and Greatbanks (2005) studies establish that Pareto analysis can be regarded as a proven useful selection technique in management decision-making. According to Garg and Garg (2013), Pareto analysis can be used by managers as an improvement technique to select vital few from the useful many. The current study is framed to identify the significant challenges for implementation of CE principles in Indian Manufacturing industry. This study takes into consideration the exploratory and the descriptive nature of analysis. To achieve the desired research objectives, this study is conducted in two phases. First, a comprehensive literature survey is undertaken to ensure that no important challenge is ignored. Second, Pareto analysis approach is applied to shortlist the important challenges identified through literature survey which are prioritized using Fuzzy-DEMATEL approach.

The main literature sources are the online databases, namely, Web of Science, Google Scholar, Science-Direct, Scopus, Springer, Emerald, Taylor and Francis, Wiley and Inderscience. Time-explicit and term sensitive search criteria is applied to yield the desired literature. The time frame chosen to gather the relevant literature is from the year 2000 to 2023 as research toward the implementation of environmental oriented techniques was mainly conducted in past two decades. The keywords used to extract the suitable papers are: barriers, challenges, CE barriers, circular supply chain barriers, CE challenges, close loop supply chain barriers, CE implementation.

There are several challenges to the application of CE (already discussed in Chapter 2: literature review) that are further analyzed using Pareto Analysis to separate the "Vital Few" from the "Useful Many" by prioritizing the frequency of occurrence. The four steps of Pareto Analysis, as suggested by Swink et al. (2014) are as follows:

- identify the CE challenge categories;
- classify the CE challenges and calculate their individual percentage of occurrence;
- sort the CE challenges in descending order based on their individual percentage of occurrence; and

- represent the data graphically and recognize the significant CE challenges from those identified through literature survey.

In order to obtain desired results, this study incorporates empirically tested challenges as they are more reliable and valid. Further, a judgmental procedure is applied where the challenges with almost the same connotation are grouped and assigned a single domain name. Finally, twenty challenges were selected for Pareto Analysis with a total occurrence of 103. Table 5.1 shows the individual occurrence of challenges along with the source of literature.

Table 5.2 Grouping of CE challenges

Challenges	References	Occurrence
1. Lack of standardization system	Elia et al. 2017; Su et al. 2013; Geng et al. 2012; Kirchherr et al. 2018; Ivanovic (2019); Saroha et al. 2018;Hughes (2017); Kumar and Suganya (2019); Li and Yu (2011); Pauliuk, 2018);Muradin and Foltynowicz (2019); Goyal et al. 2016;Venkatesh and Luthra (2016); Zhu et al. 2017	14
2. Non compliance of environmental laws	Ma and Ortolano (2000); Elia et al. 2017; Geng et al. 2012; Kirchherr et al. 2018; Ivanovic (2019); Saroha et al. 2018; Hughes et al. 2017; Muradin and Foltynowicz (2019); Pauliuk (2018); Kumar and Suganya (2019); Li and Yu (2011); Goyal et al. 2016;Venkatesh and Luthra (2016); Zhu et al. 2017	14
3. Lack of economic inducement	Shi et al. 2008; Su et al. 2013; Geng et al. 2012; Kirchherr et al. 2018; Ivanovic (2019); Saroha et al. 2018; Hughes et al. 2017; Muradin and Foltynowicz (2019); Pauliuk (2018); Kumar and Suganya (2019); Goyal et al. 2016;Venkatesh and Luthra (2016); Zhu et al. 2017	13
4. High capital investment cost	Geng and Doberstein (2008); Shi et al. 2008; Kirchherr et al. 2018; Ivanovic (2019); Saroha et al. 2018; Hughes et al. 2017; Muradin and Foltynowicz (2019); Pauliuk	12

	(2018); Kumar and Suganya (2019); Goyal et al. 2016;Venkatesh and Luthra (2016); Zhu et al. 2017	
5. Design issues due to technological limitations	Geng and Doberstein (2008); Su et al. 2013; Geng et al. 2012; Kirchherr et al. 2018; Ivanovic (2019); Saroha et al. 2018; Hughes et al. 2017; Muradin and Foltynowicz (2019)	8
6. Lack of infrastructure and unavailability of advance tool.	Su et al. 2013; Geng et al. 2012; Kirchherr et al. 2018; Ivanovic (2019); Saroha et al. 2018; Hughes et al. 2017	6
7. Less preference to reused or refurbished products	Kirchherr et al. 2018; Ivanovic (2019); Saroha et al. 2018; Hughes et al. 2017; Muradin and Foltynowicz (2019)	5
8. Coordination with supply chain partners	Cezarino (et al. 2019); Kirchherr et al. 2018; Ivanovic (2019); Saroha et al. 2018; Hughes et al. 2017	5
9. Managing product quality through recovered parts	Geng et al. 2012; Saroha et al. 2018; Hughes et al. 2017; Muradin and Foltynowicz (2019)	4
10. Revenue generation	Muradin and Foltynowicz (2019); Pauliuk (2018); Kumar and Suganya (2019); Ivanovic (2019)	4
11. Inadequate implementation of CE laws	Jaeger and Upadhyay (2020); Li and Yu (2009), Su et al. (2013); Pauliuk (2018)	4
12. Lack of information sharing	Jaeger and Upadhyay (2020); Geng et al. 2012; Kumar and Suganya (2019)	3
13 Complexity in deciding final price of product	Leider and Rashid (2016); Kirchherr et al. 2018	2
14. Fallacious information	Su et al. 2013; Muradin and Foltynowicz (2019)	2
15. Improper mapping of the environment laws with CE Practices	Moktadir et al. 2018; Geng et al. 2012	2

16. Unproductive management and poor administration	Su et al. (2013)	1
17. Uneven distribution of work	Shahbazi et al. (2016)	1
18. Inefficient take back mechanism	Ghisellini et al. (2016)	1
19. Lack of Standardization of refurbished or remanufactured products	Weelden et al. (2016)	1
20. Environmental awareness among the stakeholders	Agyemang et al. 2019	1

Table 5.2 shows the CE challenges occurrence percentage in descending order. Applying the Pareto analysis approach, the first ten challenges which accounted for 82 percent of the total occurrence are represented as the ‘vital few’ while the remaining ten challenges which hold only 18 percent of the total occurrence are regarded as ‘useful many’. The outcome of Pareto Analysis did not exactly yield into 80/20 split as (Christopher and Holweg, 2011) suggests that market business may vary depending upon the strategy applied.

To sum up the findings of Pareto Analysis, these ’10 vital CE challenges’ are extremely important because in order to effectively implement CE nationwide one must distinguish the ‘vital few’ from the ‘useful many’ which are responsible for a larger impact on the industry as compared to the other ’10 useful many challenges’. This will not only help the supply chain managers in effective decision making but will also save time and resources as they need to focus their efforts only on the ’10 vital CE challenges’. Fig. 5.2 represents the individual occurrence percentage and the total percentage of occurrence of ‘vital CE challenges’ and the ‘useful many CE challenges’.

Table 5.3 Vital Few and Useful Many CE Challenges

S. No.	Challenge	Occurrence	Percentage of occurrence (%)	Collective Percentage of occurrence (%)
1	Lack of standardization system	14	13.59	13.59
2	Non compliance of environmental laws	14	13.59	27.18
3	Lack of economic inducement	13	12.62	39.8
4	High capital investment cost	12	11.65	51.45
5	Design issues due to technological limitations	8	7.7	59.15
6	Lack of infrastructure and unavailability of advance tool.	6	5.82	64.97
7	Less preference to reused or refurbished products	5	4.85	69.82
8	Coordination with supply chain partners	5	4.85	74.67
9	Managing product quality through recovered parts	4	3.88	78.55
10	Revenue generation	4	3.88	82.43
11	Inadequate implementation of CE laws	4	3.88	86.31
12	Lack of information sharing	3	2.91	89.22
13	Complexity in deciding final price of product	2	1.94	91.16
14	Fallacious information	2	1.94	93.1
15	Improper mapping of the environment laws with CE Practices	2	1.94	95.04
16	Unproductive management and poor administration	1	0.97	96.01
17	Uneven distribution of work	1	0.97	96.98
18	Inefficient take back mechanism	1	0.97	97.95
19	Lack of Standardization of refurbished or remanufactured products	1	0.97	98.92
20	Environmental awareness among the stakeholders	1	0.97	100

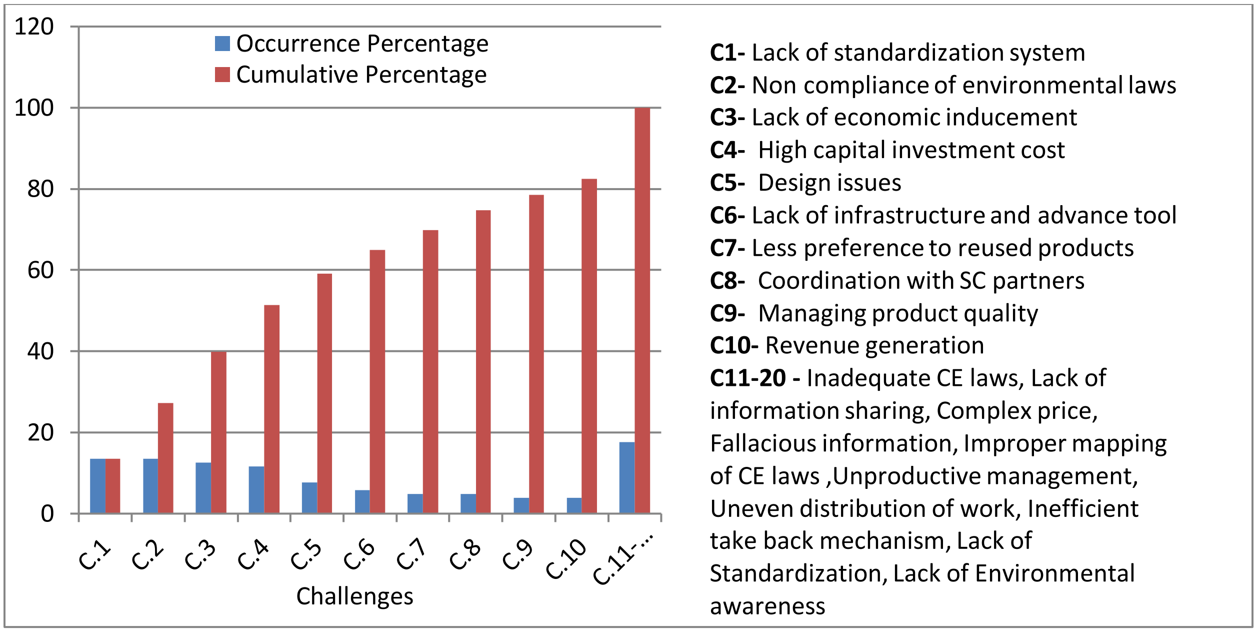

Fig. 5.2 Pareto Analysis of CE challenges

5.3 Fuzzy DEMATEL approach

The Fuzzy DEMATEL approach has been applied in the proposed study. Fuzzy set, F in Y is an ordered set of pairs i.e. F = {(y, μF(y))}, y ϵ Y; where μF(y) denotes the membership of the function, and Y = {y} relates to a set of points represented by y (Bellman and Zadeh, 1970). The membership function μF(y) signifies the measure of acceptance that y is an element belonging to F. It is presumed that μF(y) ϵ [0, 1], where μF{y}=1 depicts that y is definitely an element in F, while μF{y}=0 represents *y* is not an element of A. A fuzzy number $\widehat{N}$ corresponds to a fuzzy set {(y, $\mu_{\widehat{N}}$(y))}, where the value of y always lie on the real line and $\mu_{\widehat{N}}$(y) is the membership function which shows the probability of the fuzzy number N lying within the real interval [l, r].

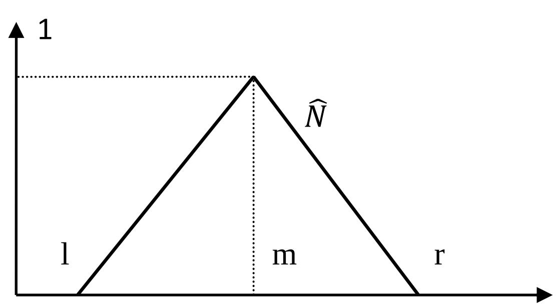

Fig. 5.3 Triangular Fuzzy Number

Triangular fuzzy number (TFN) $\widehat{N}$ is represented as a set of (l, m, r) and $\mu_{\widehat{N}}$ is the membership function denoted as in Fig. 5.3. The different values of the membership function can be expressed as per Eqn. 5.1.

$$\mu_{\widehat{N}}(y) = \begin{Bmatrix} 0, & y < a \\ (y-a)/(b-a), & a \le y \le b \\ (c-y)/(c-b), & b \le y \le c \\ 0 & y > c \end{Bmatrix} \quad (5.1)$$

The concept of TFN has been employed to find idyllic solutions from group decision-making. A TFN is represented by its height, spread, shape, and its relative position on the x-axis (Chen and Hwang, 1992). Defuzzification is a process to convert uncertain spatial data into crisp values which consider all the parameters as stated by Chen and Hwang (1992). Defuzzification can be generally performed by centroid or center-of-gravity method. The centroid method cannot differentiate among two fuzzy numbers with equivalent crisp value, even if the shape of the fuzzy numbers is different (Opricovic and Tzeng, 2003). Instead, Converting Fuzzy data into Crisp Scores (CFCS) defuzzification method is used to obtain a better crisp value (Opricovic and Tzeng, 2003). In this method, the equivalent fuzzy scores are converted into crisp numbers involving the computation of right and left score by the fuzzy maximum and fuzzy minimum, respectively and the total score is computed by calculating the average weight according to the membership functions (Opricovic and Tzeng, 2003). The step wise defuzzification process is presented below:

Step 1. Compute normalized values of the Triangular fuzzy matrix with fuzzy number (l_{ij}, m_{ij}, r_{ij}) using Eqns. 5.2 to 5.4.

$$r_i^{max} = \max r_{ij}\ ,\ l_i^{min} = \min l_{ij},$$

$$\Delta_{min}^{max} = r_i^{max} - l_i^{min}$$

Compute for all alternatives *as*, $a_j = 1, 2, 3, ..., J$

$$y_{lj} = (l_{ij} - l_i^{min}) / \Delta_{min}^{max} \quad (5.2)$$

$$y_{mj} = (m_{ij} - l_i^{min}) / \Delta_{min}^{max} \quad (5.3)$$

$$y_{rj} = (r_{ij} - l_i^{min}) / \Delta_{min}^{max} \tag{5.4}$$

Step 2. Compute left (ls) and right (rs) normalized values, for j=1, 2, ...J using Eqns. 5.5 and 5.6.

$$y_j^{ls} = y_{mj}\,(1 + y_{mj} - y_{lj}) \tag{5.5}$$

$$y_j^{rs} = y_{rj}\,(1 + y_{rj} - y_{mj}) \tag{5.6}$$

Step 3. Compute total normalized crisp value, for j=1,2,...,J using Eqn. 5.7.

$$y_j^{crisp} = \left[y_j^{ls}\left(1 - y_j^{ls}\right) + y_j^{rs} y_j^{rs}\right] / \left[1 - y_j^{ls} + y_j^{rs}\right] \tag{5.7}$$

Step 4. Compute crisp values, for j= l,2,...,J using Eqn. 5.8

$$f_{ij} = l_i^{min} + y_j^{crisp}\,\Delta_{min}^{max} \tag{5.8}$$

Following the above process, each of the allocated fuzzy numbers is converted into crisp value. A performance matrix containing fuzzy elements, $\tilde{f}_{ij} = (l_{ij}, m_{ij}, r_{ij})$, j=1,2...J, i ϵ $\tilde{n}$, is converted into crisp numbers f_{ij}, j=1,2...J, $i=1,...,n$, (where n represents the total number of criteria, $n>\tilde{n}$). In most of the studies, DEMATEL has been applied on crisp data while in the proposed study the application of DEMATEL approach has been extended on the data gathered through human perception. Further, the DEMATEL method comprises of the following (Fontela and Gabus, 1976):

Step 1. Development of Direct-Relation Matrix

Develop a matrix of direct relations by tabulating the responses of various experts. 'Direct Relation Matrix' $A_{n\times n}$ (where n stands for the total number of factors) is constructed by establishing a pairwise comparison among factors. Each value of matrix $A_{n\times n}$ is represented by a_{ij} which depicts the level of influence of criterion i on j. The averaged value of matrice A is developed by calculating the mean scores of all the 'H' experts where 'w_k' denotes the significant weight of k^{th} expert (Refer Eqn. 5.9).

$$a_{ij} = \frac{\sum_{k=1}^{H} w_k\, y_{ij}^k}{\sum_{k=1}^{H} w_k} \tag{5.9}$$

Step 2. Representation of triangular fuzzy numbers

Responses are expressed in linguistic terms. According to Li (1999), the linguistic variable may be classified as no influence, very less influence, less influence, moderate influence and high influence. These linguistic terms are assigned an influence score which is represented in the form of TFNs. The value of influence score varies from 0 to 4 with no influence being assigned 0 value and high influence is represented with a score of 4. The score of influence of various linguistic terms with their corresponding TFN is shown in Table 5.5.

Step 3. Convert the triangular fuzzy numbers into initial direct relation matrix

TFNs can be used to assign values to fuzzy linguistic variables which are then converted into crisp values using the CFCS method. The crisp value in the initial direct relation matrix can be calculated by following the Eqns. 5.2 to 5.8 using CFCS defuzzification method.

Step 4. Normalizing the direct relation matrix

To normalize the matrix of direct relation Eqn. 5.10 and 5.11 are applied. This results in the formation of an averaged direct relation matrix.

$$Y = k \times A \tag{5.10}$$

$$k = \frac{1}{\max \sum_{j=1}^{n} a_{ij}}, \; 1 \le i \le n \tag{5.11}$$

Step 5. Construct total relation matrix

The matrix of total relation 'T' can be obtained by using the Eqn. 5.12. The corresponding identity matrix is represented by 'I'.

$$T = Y\,(I-Y)^{-1} \tag{5.12}$$

Step 6. Generating the causal diagram

The causal diagram is generated by the values of summation of rows and summation of columns for each criterion which is represented as D and R respectively. To obtain the values of D and R for each row and column, Eqns. 5.13 to 5.15 are used

$$T = [t_{ij}]_{n\times n} \quad i,j=1,2,\ldots,n \tag{5.13}$$

$$D = [\sum_{j=1}^{n} t_{ij}]_{n\times 1} = [t_i]_{n\times 1} \tag{5.14}$$

$$R = [\sum_{i=1}^{n} t_{ij}]_{1\times n} = [t_j]_{1\times n} \tag{5.15}$$

A cause and effect diagram is obtained by plotting the data set of (D+R, D-R), where (D + R) represents the horizontal axis vector or ‘‘Prominence’’ which is used to obtain the ranking of the criterion and (D-R) depicts the vertical axis which shows the category in which the criteria will fall.

5.4 Case illustration

This section comprises of the discussion related to the application of proposed methodology in the adoption of CE practices in the Indian manufacturing context.

5.4.1 Indian Manufacturing Industry

Rise in the per capita income, growth in population, rapid urbanization and changing lifestyle ensures a strong building up of manufacturing sector in India. According to a report published by IBEF, India will come out as world’s fifth largest consumer market by 2025 with an average consumption expected to rise by four times during 2005-2025. The Indian government aims to achieve 25 percent of its GDP share by manufacturing sectors till 2025 as against 16 percent current share (IBEF, 2023). This will attract manufacturers from all over the world to invest and establish their manufacturing unit in India thus creating 100 million new employment opportunities in this sector by 2025 and making India a global manufacturing hub.

India being a developing nation, hence sustainability becomes a major issue in order to meet the demand of majority of population. Therefore, it is the right time to examine the research and novel activities to help Indian manufacturing sector in developing their approach and the essential techniques/ methods to adopt circular models effectively. An attempt has been made to explore and identify the challenges related to the implementation of CE practices in Indian manufacturing context by using Fuzzy-DEMATEL as the method for the prioritization of these challenges.

5.4.2 Data Collection

This study utilizes survey method to collect data from different experts by distributing a questionnaire among the supply chain professionals of 75 different manufacturing organizations located in the National Capital Region (NCR) of India. Three experts each from academia and manufacturing based multi-national companies located in Delhi-NCR reviewed the preliminary draft of the questionnaire. Experts commented on the intelligibility, subject and illustration of the survey questionnaire. Suggestions were incorporated and improvements in the questionnaire were completed before distributing for data collection. Google form was used to develop the questionnaire. This questionnaire consists of all the ten significant challenges identified through extensive literature survey after applying Pareto analysis approach. The professionals were asked to rate these challenges on a five point Likert scale (e.g. 1 = no influence and 5 = extremely high influence) illustrating the influence of each challenge on the implementation of CE principle in their manufacturing organization.

The second stage comprises of the filling up of pair-wise comparison matrix consisting of ten significant challenges. Six experts from Operation, Environment, Logistics, Procurement, Store and Marketing department were selected to fill the responses. The experts were chosen in a way so that every domain of the circular economy is included while gathering the information related to its implementation. Therefore, the experts are selected from the operations, logistics, procurement, store, marketing and environment fields. These experts were selected from industry, academia and not for profit organizations to reflect their knowledge and experience in the outcome of the study and provide better solutions to its implementation. The weight of each expert was expressed as a linguistic value shown in Table 5.3.

Table 5.3 Importance weight of experts

Experts	Linguistic Variable	Significance Weight	Crisp Weights
Expert 1 (Operation Dept)	Medium	(0.3, 0.5, 0.7)	0.5
Expert 2 (Environment Dept)	High	(0.5, 0.7, 0.9)	0.7
Expert 3 (Logistics Dept)	Medium	(0.3, 0.5, 0.7)	0.5
Expert 4 (Procurement Dept)	Low	(0.1, 0.3, 0.5)	0.3
Expert 5 (Store Dept)	Low	(0.1, 0.3, 0.5)	0.3
Expert 6 (Marketing Dept)	High	(0.5, 0.7, 0.9)	0.7

In this study the questionnaire was distributed among the supply chain professionals in two phases. Firstly a total of 200 emails were sent to the professionals of different manufacturing organization and responses received were analyzed. Additionally, 100 emails were sent to the other organization to gather sufficient number of responses. A total of 300 emails were sent to the companies engaged in the manufacturing sector which are having a minimum annual turnover of 100 million Indian rupees and employees ranging between 200 to 1000. Out of 90 responses received 15 were incomplete and therefore not considered for evaluation. Overall 75 responses were used for the purpose of analysis with a response rate of 25 percent. Most of the respondents either belonged to middle level management or top management of the organization which are dealing with strategic part of management. A non response bias was checked by splitting the responses into two groups based upon the date on which response is received. 40 responses were received before the due date and 35 were received after. A t-test was performed to check for any significant difference in the samples of the two groups. With a p value greater than 0.05 ($p > 0.05$) the results did not yield any significant difference between the samples of both the groups in terms of annual turnover, number of employees and their designation.

5.5 Results and Discussion

The fuzzy DEMATEL approach is used to evaluate the relative weightage of the challenges. Ten significant challenges to the application of CE in the perspective of the manufacturing industry were selected through literature survey and responses obtained from survey questionnaire. They are classified as: (C.1) Lack of standardization system, (C.2) Non compliance of environmental laws, (C.3) Lack of economic inducement, (C.4) High capital investment cost, (C.5) Design issues due to technological limitation, (C.6) Lack of infrastructure and unavailability of advance tool., (C.7) Less preference to refurbish and reused product (C.8) Coordination with neighborhood organization, (C.9) Managing product quality through recovered parts and (C.10) Revenue generation.

The responses of the experts were tabulated in the form of pairwise comparison matrix to evaluate the influence of each challenge. This yields to a Direct Relation Matrix presented in Table 5.4 which shows the interrelationship between challenges.

Table 5.4 Direct-Relation Matrix

	C.1	C.2	C.3	C.4	C.5	C.6	C.7	C.8	C.9	C.10
C.1	0	2	3	1	3	4	3	1	2	3
C.2	1	0	4	1	1	4	3	1	1	4
C.3	0	3	0	0	0	2	4	0	0	4
C.4	3	1	1	0	4	1	3	0	4	3
C.5	4	3	3	2	0	4	4	3	0	4
C.6	0	2	3	1	1	0	3	2	0	3
C.7	0	3	1	0	2	2	0	3	1	3
C.8	1	2	0	1	3	1	3	0	1	1
C.9	4	1	4	3	3	4	3	3	0	4
C.10	1	3	3	0	3	4	3	0	0	0

The linguistic term used for the corresponding influence score are shown as TFNs in Table 5.5

Table 5.5 Linguistic Terms and corresponding Triangular Fuzzy Number

Linguistic Term	Influence Score	Triangular Fuzzy Number
no influence	0	(0.0, 0.1, 0.3)
very less influence	1	(0.1, 0.3, 0.5)
less influence	2	(0.3, 0.5, 0.7)
moderate influence	3	(0.5, 0.7, 0.9)
high influence	4	(0.7, 0.9, 1.0)

The data elements of direct relation matrix are shown as corresponding TFNs in Table 5.6. The responses that are shown as TFNs are defuzzified into a crisp value which obtains the f_{ij}. The logical formulae as given in the equations (2) to (8) are used to compute the initial direct-relation matrix.

Table 5.6 Triangular Fuzzy Numbers

	C.1	C.2	C.3	C.4	C.5	C.6	C.7	C.8	C.9	C.10
C.1	0	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(0.7,0.9,1.0)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.5,0.7,0.9)
C.2	(0.1,0.3,0.5)	0	(0.7,0.9,1.0)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.7,0.9,1.0)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	(0.7,0.9,1.0)
C.3	(0.0,0.1,0.3)	(0.5,0.7,0.9)	0	(0.0,0.1,0.3)	(0.0,0.1,0.3)	(0.3,0.5,0.7)	(0.7,0.9,1.0)	(0.0,0.1,0.3)	(0.0,0.1,0.3)	(0.7,0.9,1.0)
C.4	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	0	(0.7,0.9,1.0)	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(0.0,0.1,0.3)	(0.7,0.9,1.0)	(0.5,0.7,0.9)
C.5	(0.7,0.9,1.0)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	0	(0.7,0.9,1.0)	(0.7,0.9,1.0)	(0.5,0.7,0.9)	(0.0,0.1,0.3)	(0.7,0.9,1.0)
C.6	(0.0,0.1,0.3)	(0.3,0.5,0.7)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.1,0.3,0.5)	0	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.0,0.1,0.3)	(0.5,0.7,0.9)
C.7	(0.0,0.1,0.3)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.0,0.1,0.3)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	0	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.5,0.7,0.9)
C.8	(0.1,0.3,0.5)	(0.3,0.5,0.7)	(0.0,0.1,0.3)	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(0.1,0.3,0.5)	(0.5,0.7,0.9)	0	(0.1,0.3,0.5)	(0.1,0.3,0.5)
C.9	(0.7,0.9,1.0)	(0.1,0.3,0.5)	(0.7,0.9,1.0)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.7,0.9,1.0)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	0	(0.7,0.9,1.0)
C.10	(0.1,0.3,0.5)	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.0,0.1,0.3)	(0.5,0.7,0.9)	(0.7,0.9,1.0)	(0.5,0.7,0.9)	(0.0,0.1,0.3)	(0.0,0.1,0.3)	0

The next step is normalizing the initial direct relation matrix using the equation (10) and (11). This results in the formation of a generalized direct relation matrix. The total relation matrix can be acquired from the generalized direct relation matrix by following equation (12). The total relation matrix is presented as Table 5.7.

Table 5.7 Total Relation Matrix

	C.1	C.2	C.3	C.4	C.5	C.6	C.7	C.8	C.9	C.10
C.1	0.1915	0.4071	0.3501	0.1994	0.3250	0.4359	0.3996	0.2479	0.2311	0.4136
C.2	0.2151	0.3045	0.3309	0.1832	0.2559	0.4043	0.3698	0.2269	0.2142	0.3886
C.3	0.1829	0.4017	0.2075	0.1563	0.2149	0.3633	0.3473	0.1963	0.1592	0.3686
C.4	0.3030	0.4110	0.3064	0.1588	0.3391	0.3711	0.3971	0.2403	0.2771	0.4191
C.5	0.3505	0.5244	0.3912	0.2548	0.2752	0.4909	0.4669	0.3366	0.2264	0.4882
C.6	0.1844	0.3742	0.3015	0.1687	0.2369	0.2589	0.3446	0.2348	0.1637	0.3603
C.7	0.1995	0.4187	0.2725	0.1671	0.2854	0.3606	0.2688	0.2754	0.1870	0.3876
C.8	0.1962	0.3534	0.2245	0.1652	0.2704	0.2920	0.3292	0.1582	0.1832	0.2902
C.9	0.3627	0.4817	0.4062	0.2884	0.3835	0.5059	0.4703	0.3448	0.2017	0.5032
C.10	0.2188	0.4337	0.3231	0.1732	0.2953	0.4052	0.3671	0.2180	0.1798	0.2900

The sum of each row and sum of each column of the total relation matrix are separately computed using equation (13) to (15) and are denoted as D and R respectively. If (D-R) is positive, criterion belongs to the cause category and if the value comes out to be negative, the criterion falls into the effect group. The horizontal axis of the causal diagram is represented by 'D+R' which illustrates the relative significance of a criterion. (D+R) signifies the "Prominence" and (D-R) attributes to the "relation" of a criterion. Table 5.8 shows the corresponding value of (D+R) and (D-R) for the ten challenges considered.

Table 5.8 The Prominence and Relation vectors (CASE 1)

Challenges	D	R	D-R	D+R	Rank(D+R)
C.1	3.2012	2.4047	0.7965	5.6059	8
C.2	2.8934	4.1103	-1.2169	7.0037	1
C.3	2.5979	3.1138	-0.5159	5.7117	7
C.4	3.2231	1.9149	1.3082	5.138	9
C.5	3.805	2.8815	0.9235	6.6865	3

C.6	2.6279	3.888	-1.2601	6.5159	5
C.7	2.8226	3.7608	-0.9382	6.5834	4
C.8	2.4626	2.4793	-0.0167	4.9419	10
C.9	3.9482	2.0236	1.9246	5.9718	6
C.10	2.9043	3.9094	-1.0051	6.8137	2

Therefore, the causal diagram is generated by plotting the dataset of (D+R, D-R), shown in Fig. 5.4. The causal diagram provides the ability to understand how far the individual challenges affect the application of Circular Economy principles in the manufacturing industry.

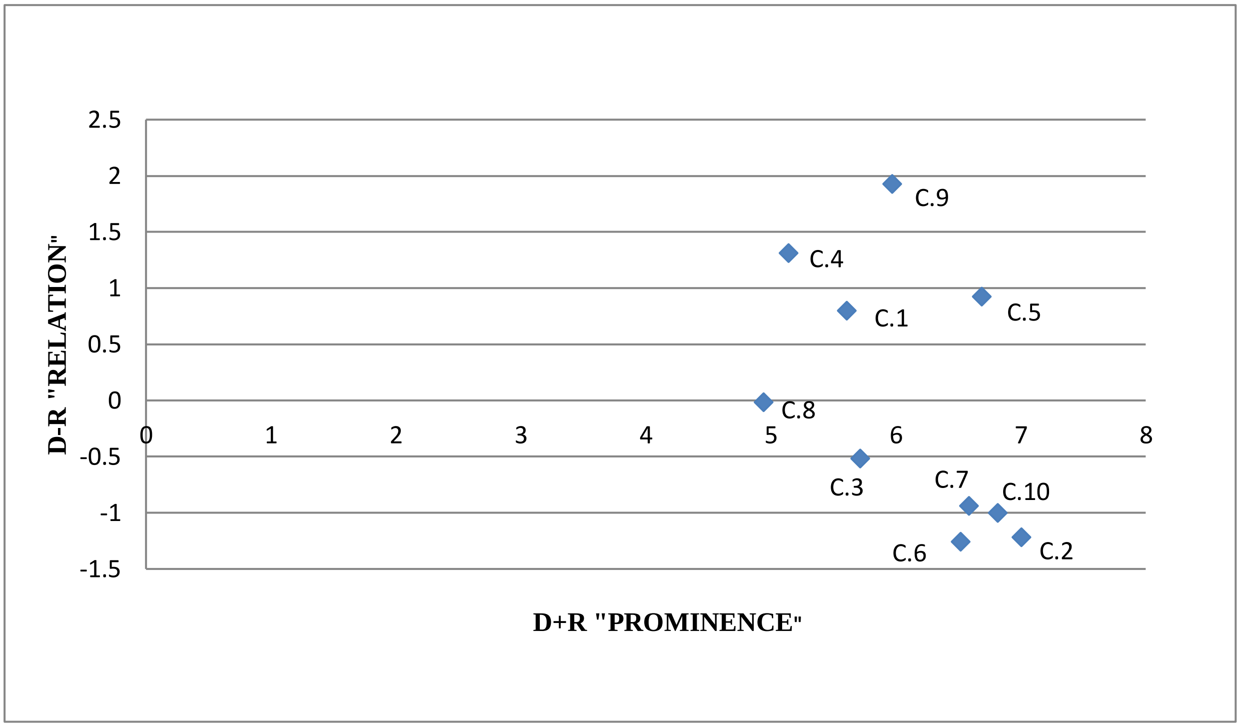

Fig. 5.4 CAUSAL Diagram

Findings revealed that challenges such as Non compliance of environmental laws (C.2), Lack of economic inducement (C.3), Lack of infrastructure and unavailability of advance tool (C.6), Less preference to refurbish and reused product (C.7), Coordination with neighborhood organization (C.8) and Revenue generation (C.10) fall into the effect group because these challenges are easily influenced by the rest of the challenges as the individual value of (D-R) for each challenge is negative. While Lack of standardization system (C.1), High capital investment cost (C.4), Design issues due to technological limitation (C.5) and Managing product quality through recovered parts (C.9) belong to the cause category because these challenges have a larger value of (D) in comparison to the value of (R). (D+R) score signifies the relative importance, as value of D denotes how much it influences other factors and R depicts the degree to which it is influenced by others. Non compliance of environmental laws (C.2) has the highest (D+R) score therefore should be considered as the major challenge in the CE application. Revenue generation (C.10), Design issues due to technological limitation (C.5), Less preference to refurbish and reused product (C.7) and Lack of infrastructure and unavailability of advance tool (C.6) rank after Non compliance of environmental laws (C.2) in the (D+R) ranking, therefore these are considered as relatively less important challenges. Furthermore, the (D-R) score of managing product quality through recovered parts (C.9) is the highest in the causal diagram (Fig. 5.4) which means that it will greatly influence other challenges during the application of CE practices in the manufacturing industry. High capital investment cost (C.4), Design issues due to technological limitation (C.5) and Lack of Standardization System (C.1) are having less influence on other challenges as compared to managing product quality through recovered parts (C.9). The overall prioritization of the challenges is as:

C.2>C.10>C.5>C.7>C.6>C.9>C.3>C.1>C.4>C.8

The finding of the study is also supported by earlier research. Lieder and Rashid (2016) found Non compliance of environmental laws as the major challenge towards CE application in the manufacturing industry. Geng and Doberstein (2008) in their article on the application of CE concept at the regional level in China, revealed that weak economic inducement from the government make it difficult for the small and medium enterprises to implement CE practices at the regional level.

Franklin-johnson et al. (2016) suggested that the amount of revenue generated by the application of CE practices in the supply chain could be considered as one of the major challenges because cost incurred in recycling and remanufacturing of the products is quite high. Technological limitations due to complex design and material composition of a product make it a greater challenge for the successful and cost-effective recovery and reuse of a product (Pringle et al., 2016). Shahbazi et al. (2016) revealed that managing product quality through recovered parts is one of the major challenge that increase the chances of lack of interest among the employees towards the CE application. Pan et al. (2014) found that higher initial cost related to the investment in the area of cutting-edge technology, skilled manpower, and better facilities for production are significantly becoming major challenge towards the application of CE. Su et al. (2013) suggests that lack of standardization system to measure the performance of CE oriented practices could create obstruction in its application globally. Ghisellini et al. (2016) considers inefficient take-back mechanism as a major market issue. To overcome this barrier it is necessary to have an effective coordination among the supply chain partners and full support of all the stakeholders. The findings of Agyemang et al. (2019) revealed that unawareness, financial constraint and lack of expertise are the top three challenges in implementing CE in the automobile industry of Pakistan. Cezarino et al. (2019) identified lack of communication between public and private institutions, ineffectiveness in consolidating industrial policies and investment in remanufacturing process are some of the major challenges to CE implementation in the Brazilian manufacturing industry. The study conducted by Moktadir et al. (2018) focusing on CE implementation in leather industry of Bangladesh found that the knowledge of CE is essential for its implementation. The findings of this study are similar to the other studies identifying challenges to CE implementation and therefore the results are generalized in context to emerging economies.

5.6 Sensitivity analysis

Sensitivity analysis is performed by varying the weight assigned to a particular expert or by changing the influential rating among various CE challenges so as to check the robustness of the model. In this study, sensitivity analysis is carried out for Fuzzy-DEMATEL results by altering the weight of expert 1. Primarily expert 1 is assigned “medium” (0.3, 0.5, 0.7) significance weight. This situation is represented by ‘Case 1’. During the sensitivity analysis of the above model the significance weight of Expert 1 is modified to “low” (0.1, 0.3, 0.5) and we call it ‘Case 2’. In another situation, the weight of Expert 1 is changed to “high” (0.5, 0.7, 0.9) and represent it as ‘Case 3’ without altering the weight of the remaining experts. The outcomes of the other two cases are shown in Table 5.9. Fig. 5.5 portrays the steadiness of the model. From the results of sensitivity analysis as represented in Fig. 5.5, it is interpreted that the peak and trough in each of the cases remain same. Since there is no considerable change occurring in the ranking of the most important challenges to CE, the model has least sensitivity to the alteration in the weight of expert 1. In the future, sensitivity analysis can be performed by altering the weights of remaining experts.

Table 5.9 Prominence and Relation Vector (CASE 2 and 3)

	CASE 2		CASE 3	
Challenges	D+R	Rank	D+R	Rank
C.1	5.4868	8	6.777768	7
C.2	6.815395	1	8.136412	1
C.3	5.568633	7	6.694243	8
C.4	5.051109	9	6.243098	9
C.5	6.546153	3	7.838396	3
C.6	6.383685	5	7.700172	5
C.7	6.435442	4	7.824168	4
C.8	4.825126	10	5.963813	10
C.9	5.871386	6	7.078272	6
C.10	6.664718	2	7.848311	2

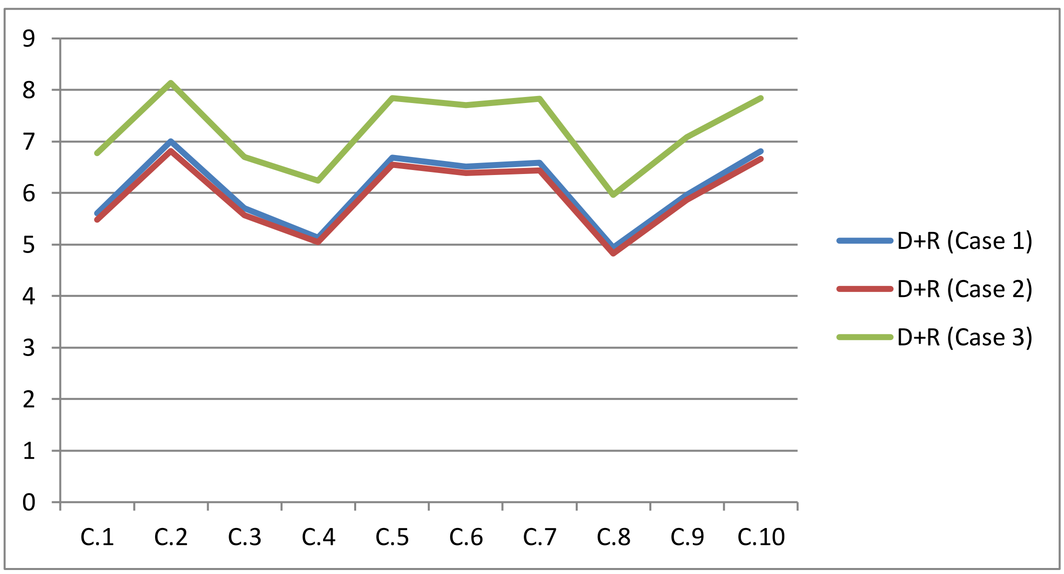

Fig. 5.5 Sensitivity analysis of the ranking of the challenges corresponding to the change of 'significance weight' of Expert 1

5.7 Concluding remarks

The concept of Circular Economy is in nascent stage and requires utmost attention by the researchers and practitioners for its successful application in the manufacturing industry. This concept is a solution to many serious problems like waste generation, resource scarcity, and sustainable economic benefits. Application of CE in the manufacturing industry entails serious challenges to the enterprise and researchers need to find ways for its successful application. Therefore this study is focused to a developing economy having a huge customer base and manufacturing sector almost contributing one fourth in the GDP. It is necessary for a country like India to implement such business models in the manufacturing sector that could foster towards a sustainable development.

This study selected ten challenges for the CE application in the manufacturing industry of India. Based on the exhaustive literature review it has been seen that very limited work has been conducted in the context to developing economies. Analysis of the findings revealed that non compliance of environmental laws, revenue generation, design issues due to technological limitation and inefficient take-back mechanism are some of the major challenges to the application of CE practices in the Indian manufacturing industry. The findings of this study is significant to Indian context, however studies related to the challenges in CE implementation have yielded similar results in context to other emerging economies (Agyemang et al., 2019; Cezarino et al., 2019; Jaeger & Upadhyay, 2020; Moktadir et al., 2018).

The novelty of this study and the contribution made to the literature is summarized as follows:

- The study contributes to the identification of sustainability related challenges faced during the implementation of a CE concept by a developing economy.
- This study also includes the prioritization of significant challenges to CE implementation faced by the manufacturing industry of a developing economy.
- This research also proposed a methodology that could evaluate and explore these challenges for CE application.

Finally, the findings of this research will help the researchers and managers to develop a framework for the successful application of Circular Economy in the context of manufacturing industry. The implementation of this novel concept is not just seen as a trillion dollar business but will also create several million job opportunities that will be regarded as a major upliftment for the society. Therefore, manufacturing organization should take prior action in this direction in order to prevent the obstruction caused by these challenges on the implementation of the CE concept in the Indian manufacturing industry.

CHAPTER 6

CASE STUDY

6.1 Introduction

This chapter includes the case study focusing on the exploration of current practices, challenges, and risks associated with the implementation of the Circular Economy concept in the Indian Manufacturing Industry. In this chapter, case study pertaining to the product as well as the process to which it pertains is discussed. Firstly the case study talks about the challenges in the implementation of Circular Economy faced by the manufacturing sector in the context of developing economy. In this regard, the study considers certain number of organizations which are directly or indirectly involved with the manufacturing sector. The second case study talks about making the process of manufacturing more sustainable. This case specifically focuses on the manufacturing process and how circular practices can be incorporated in the manufacturing environment. The case studies are chosen in such a way that circularity at product level as well as process level are addressed for a manufacturing organization in the context of developing economy.

6.2 Case Study method

Case study is included in the research to have a deeper insight of the issues faced by the industry and analyzing them through empirical results. Case study is conducted to provide academic based solutions to industries facing problems at strategic and operational levels. This section comprises of the application of the proposed technique in solving sustainability issues for an automobile manufacturing company located in Delhi–NCR in India. In this section, a detailed description of the case study, problem formulation, and data collection is provided.

India being a developing nation, hence sustainability becomes a major issue to meet the demand of majority of population. Therefore, it is the right time to examine the research and novel activities to help Indian manufacturing sector in developing their approach and the essential techniques/methods to adopt circular models effectively. An attempt has been made to explore and identify the challenges and risks related to the implementation of CE practices in Indian manufacturing context. This study considered different case example from the Indian manufacturing sector illustrating issues pertaining to the adoption and implementation of CE practices. On a broader spectrum, Indian manufacturing sector is chosen as the field of study because this is a growing sector and it involves a lot of issues that need to be addressed in a systematic way. The research methodology adopted for the study is founded on an extensive review of literature and consultations with senior executives of the company. Interactions with executives offered a practical view of CSC in the Indian manufacturing sector, highlighting specific issues. A methodical framework for this case study is formulated using the research methods outlined in previous literature. These steps are as follows.

Step 1: Definition of research question:

The initial phase of case research methodology entails the articulation of the research question. This question is elucidated as "Study of select issues in Circular Supply Chain." In this case study, the focus will be on addressing the questions related to a manufacturing organization, specifically XYZ Ltd.

- What are the major Circular Supply Chain practices performed by the organization?
- What are the challenges for Circular Supply Chain implementation?
- What are the major Circular Supply Chain risks faced during implementation?
- What are the major Circular Supply Chain activities outsourced by the organization?
- What are the major coordination issues faced by the organization?
- How the organization measures performance of Circular Supply Chain?

Step 2: Instrument development

The next stage in case research methodology involves creating a research instrument and choosing the field site. One particular case containing underlying issues was chosen to represent a larger group of cases in the study. The organization selected for the research is based on its revenue size and its location in NCR Delhi, India, which is convenient for the researchers.

Step 3: Data Collection

In data collection method in-depth interviews are conducted with the functional heads or the top executives of the organization to collect data pertaining to various issues related to CE implementation. The experts were chosen in a way so that every domain of the CE is included while gathering the information related to its implementation. Therefore, the experts are selected from the operations, logistics, procurement, store, marketing and environment fields. These experts were selected to reflect their knowledge and experience in the outcome of the study and provide better solutions to its implementation.

Step 4: Data Analysis

Information and data gathered during field visits to the organization, as well as other secondary sources, were utilized for the analysis of the issues in CSC.

Step 5: Dissemination

Case investigation is a valuable approach for thorough comprehension and examination of these matters. As stated by Yin (2003), a case study is a methodical inquiry that delves into a contemporary phenomenon within its authentic setting, particularly when the boundaries between the phenomenon and its context are ambiguous. The utilization of a case study as a research technique is dependent on the consideration of contextual elements, while simultaneously constraining the scope of the analysis. The application of a versatile, occasionally even serendipitous research approach is a key advantage of this method, but it could also serve as a significant drawback of case study research, especially if the methodology lacks thorough documentation.

6.3 Profile of the organization

This study constitutes a case example of an XYZ automobile manufacturing company that is involved in the manufacturing and assembling of farm tractors, with all its plants located in the Delhi–NCR region. The company is a leading manufacturer of farm tractors, with a manufacturing capacity of 98,940 tractors/annum, which is the highest in Asia at one location. The Indian tractor industry plays a vital role in India's agricultural sector, constituting approximately 17% of the country's GDP and engaging around 50% of the nation's labor force. It is anticipated that the sector will sustain its expansion path, and XYZ Limited, being a prominent participant, is in a favorable position to leverage the opportunities for growth. In a dynamic business environment, it is essential for businesses to remain current by recognizing potential risks, opportunities, and strategically positioning themselves. The significance of this method is acknowledged by XYZ Limited, which endeavors to gain a competitive advantage by consistently evaluating their operational environment and positioning themselves to optimize growth opportunities. Therefore, this study aims to provide sustainability-based CE solutions to minimize the uncertainties that are faced by the company, due to rapid product innovations and scarcity of resources.

6.4 Problem Description

The manufacturing and assembly operations are divided as per the following three plants: component plant, tractor assembly plant, and crankshaft and hydraulic plant. This study considers gear manufacturing as a major sustainability concern for the company, as it involves some intricate machining processes, and the company is facing some serious challenges related to wastage minimization and optimizing resource input. The complex industrial environment demands a manufacturing system to rapidly adjust itself to uncertainties and changes

The process of the manufacturing of gears involves some intricate manufacturing processes. For the purpose of economic and environmental benefits, the reusability of production waste is highly desirous to overcome sustainability-related challenges during manufacturing operations. The interconnected flow of material in the day-to-day manufacturing and SC operations is one of the CE initiatives to help overcome sustainability issues. The adoption of CE in manufacturing and SC operations can encourage the reuse and recycling of material, and simultaneously reduce the wastage of resources. The entire manufacturing and supply chain operation is interconnected by developing a circular loop of material flow (Fig. 6.1) using 6Ds (design, develop, deliver, detect, dismantle, discard) and 6Rs (reuse, repair, refurbish, redesign, remanufacture and recycle). By adopting circularity into the production and supply chain operations, using 6Ds and 6Rs, the wastage of resources can be minimized, and the company can easily deal with the uncertainties arising due to economic, environmental and social issues.

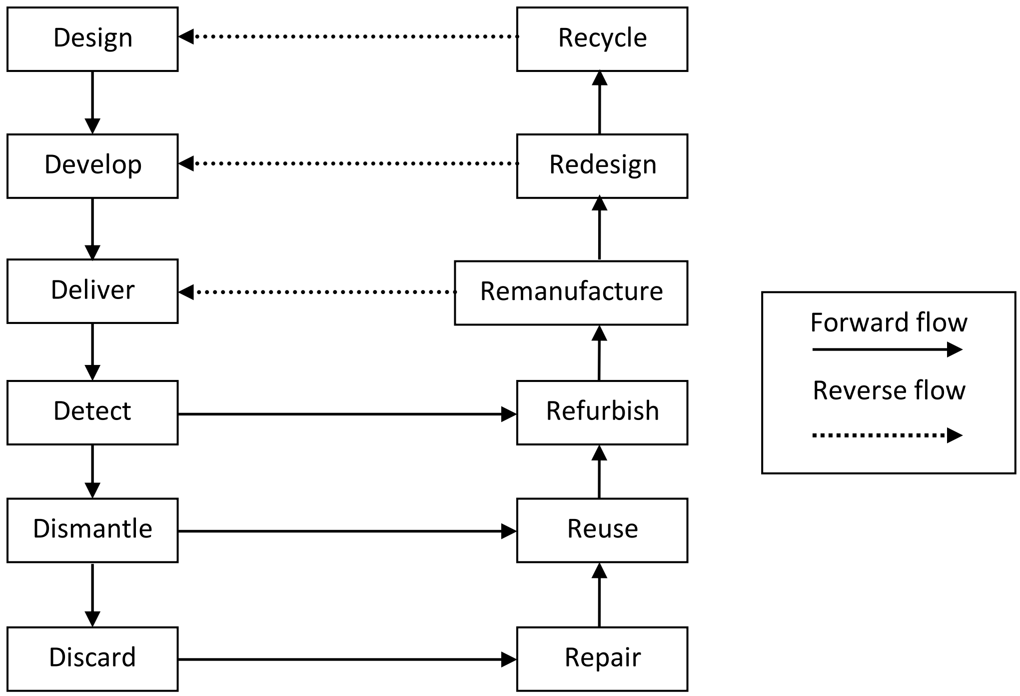

Fig. 6.1 Circular flow of product

6.5 Sustainable and strategic development initiatives adopted by XYZ Ltd.

XYZ Ltd. is dedicated to incorporating Environmental, Social, and Economic principles into their business practices in order to provide sustainable and enduring benefits for their stakeholders, such as customers, employees, investors, suppliers, and communities. The company acknowledges the significance of harmonizing non-financial and social dimensions, including environmental impact, social responsibility, ethical behavior, and corporate governance, with their financial results, in order to augment their credibility and standing in the marketplace and society.

The formulation of their strategy is propelled by their Vision to emerge as a leading entity in the tractor manufacturing sector, their Mission to offer innovative and top-notch solutions to their clientele, and their Core & Strategic values encompassing excellence, agility, innovation, customer-centric approach, and teamwork. In addition to these guiding principles, they receive strategic direction from their Board of Directors and Senior management team, who possess vast experience and expertise in the field. They scrutinize both external and internal business landscapes, including market trends, customer requirements, competitor strategies, regulatory modifications, technological advancements, and operational capacities, while pinpointing potential risks that could impact the industry or their operations. The alignment of their long-term and yearly business goals and overarching strategy with the distinct objectives and functions of each department throughout the organization is ensured by the company. The organization guarantees that every department is bestowed with well-defined responsibilities and obligations to attain their objectives and contribute to the overall vision and mission. Moreover, the company undertakes regular monitoring and assessment of the advancement and performance of each department, providing necessary feedback and assistance when required.

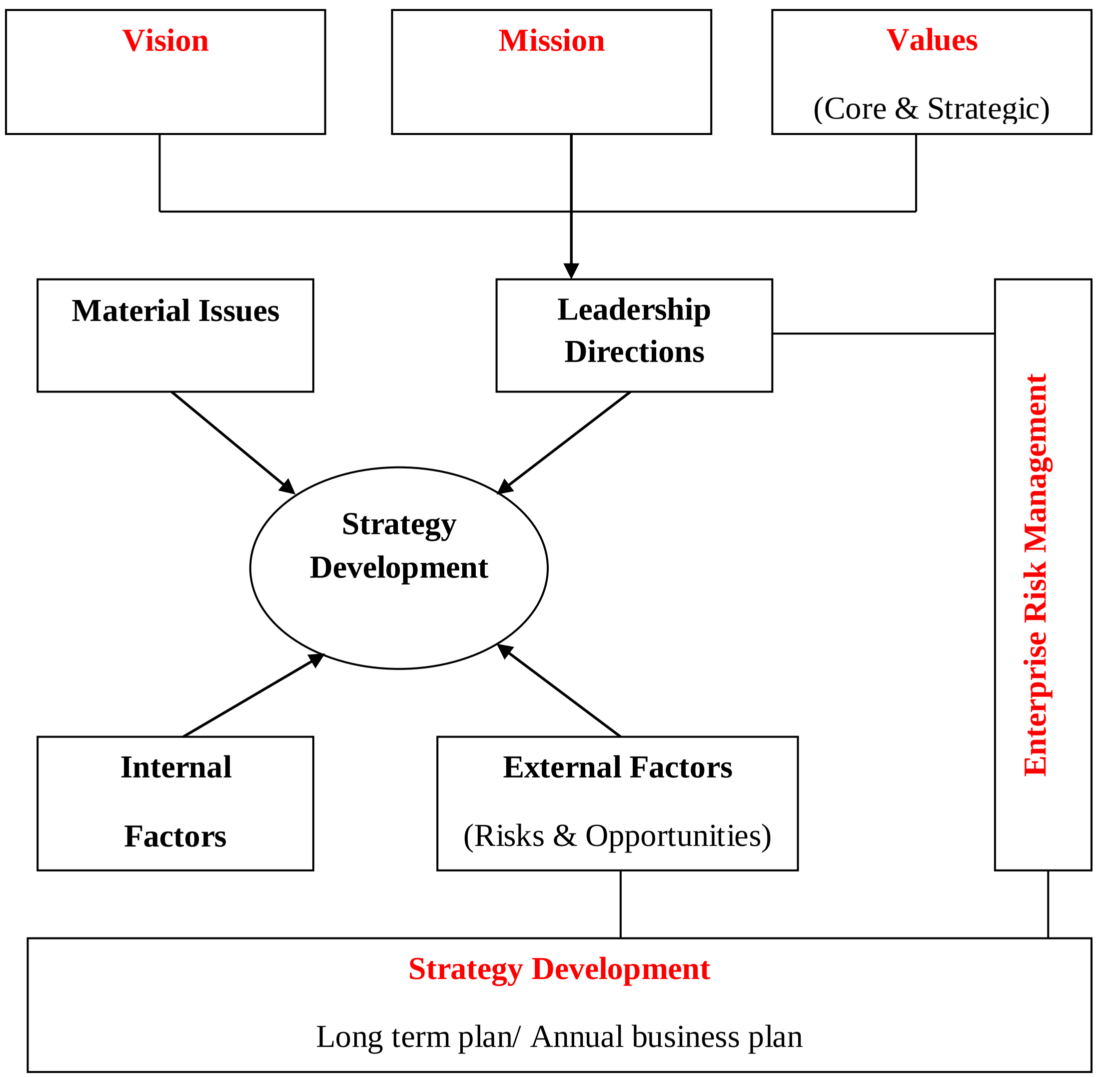

Fig. 6.2 Strategic Planning chart

XYZ has embedded sustainability throughout its business activities and endeavors to make a positive impact on society in a socially, ethically, and environmentally conscious manner. This includes fostering a community where the needs of all individuals are satisfied while ensuring that the resources can be sustained for the benefit of current and future generations.

6.5.1 Decarbonisation

With the escalation of global temperatures and the increasingly apparent impacts of climate change, there exists a pressing need for immediate action. Recognizing these shifts and the inherent nature of their operations, they are of the opinion that their decarbonization strategy will facilitate our contribution to the worldwide endeavor of capping global temperature increase at 1.5 degrees Celsius. Their endeavor towards achieving Net Carbon Neutrality has commenced, with a target of achieving substantial reductions in carbon emissions to align themselves with the company's of carbon neutrality by the year 2050. In accordance with this objective, they are striving to realize a 25% reduction in CO_2 emissions by the year 2030 compared to the base year of 2023. The pursuit of decarbonization has unveiled an array of opportunities for them to explore. The key mechanisms on which they are reliant for decarbonization include the diversification of their energy mix and enhancement of energy efficiency, with a heightened emphasis on Renewable Energy adoption and the reduction of CO_2 emissions through the transition from Diesel gensets to Gas gensets. XYZ Ltd. has already made the transition from Diesel gensets to Gas gensets for the majority of its operations. They are actively seeking out prospects for expanded renewable energy generation and enhancing energy efficiency through innovative product design tailored to meet the needs of emerging markets.

6.5.2 Promoting Resource Recycling

XYZ Ltd. produces both hazardous and non-hazardous waste in various forms and quantities. In order to handle these wastes, they have implemented an effective waste management system that takes into account environmental impact, social implications, and economic feasibility. With the commencement of the fiscal year 2023-24, the company has initiated their sustainability commitment towards achieving "Zero Waste to Landfill by 2026" to effectively manage their waste. Currently, they are conducting a Prefeasibility study to formulate a plan of action for reducing waste generation in order to reach the goal of "Zero Waste to Landfill".

6.5.3 Water Positive Organisation by 2030

Water is considered one of the most valuable and commonly shared natural resources on which the operations of the company rely. Within the premises of XYZ Ltd., a proficient management of water resources is carried out. With the objective of achieving water positivity by the year 2030 as part of their Sustainable Development Goals, various strategies are being implemented, including but not limited to Zero Liquid Discharge initiatives, water reuse and recycling, and Rainwater harvesting. The company will monitor its progress by utilizing specific metrics such as freshwater extraction, water usage, water recycling, and water replenishment to ensure the attainment of this goal.

6.5.4 Improvement in Renewable Energy Share

On a global scale, a distinct shift towards cleaner energy and fuels is evident. This presents a valuable opportunity for manufacturing sectors to reassess their energy sources and guarantee energy adequacy for the times ahead. Within the premises of XYZ Ltd., cutting-edge and energy-efficient technologies and methodologies have been implemented throughout all activities. Moreover, in alignment with their Sustainable Development Goals (SDGs), there is a targeted effort to enhance their renewable energy share by over 3% by upgrading solar power arrays. The initial phase of solar panel installation, boasting a capacity of 170 KWh, has already been successfully finalized by the company. The next step involves harnessing 3% of their energy requirements from this sustainable source, aiding in the continuous preservation of resources and energy, thus effectively managing their operational costs.

6.5.5 Environment Protection

Protection of the environment is their foremost concern, and they are persistently striving for the sustainable management of waste. This is achieved through their Extended Producer Responsibility initiatives for batteries and plastics, as well as by minimizing the emissions of volatile organic compounds from their operations.

6.5.6 Greenfield expansion with Green Building Certification

XYZ Ltd. acknowledges that climate change and resource scarcity are compelling factors necessitating the development of solutions to harmonize increasing demands with environmental concerns. Throughout the fiscal year 2023-24, the company intends to evaluate the manufacturing facilities for Green Building Certification.

6.6 SWOT analysis of XYZ Limited

XYZ aims to achieve future readiness concerning their structure, finances, and culture, with the aspiration to emerge as the most esteemed and valued engineering firm in the Indian market. The six key areas of focus they emphasize, in accordance with the UN Sustainable Development Goals, demonstrate their holistic approach, connecting their mission of offering innovative and high-quality engineering services to clients with the objective of ensuring sustainable and lucrative progress for all stakeholders.

In order to attain their goals, they utilize their strengths, such as strategic partnerships, strong brand recognition, a diversified product portfolio, and a skilled workforce. They seize opportunities stemming from the increasing demand for mechanization, favorable government policies, and emerging trends in digitalization and automation. Moreover, they mitigate risks associated with raw material prices, competition, and environmental impacts. By adjusting to customer requirements, improving efficiency, investing in research and development, and broadening their market presence, they navigate through business cycles and prioritize the interests of stakeholders. By demonstrating unwavering dedication to excellence and customer satisfaction, the company generates value for their customers, shareholders, employees, and communities. The company's commitment to developing solutions that promote sustainable growth establishes them as a reputable leader in the industry, delivering significant outcomes for all stakeholders involved.

The company will significantly augment the range of products and introduce collaboratively developed products for all the brands. In terms of the sales channel, customer-centric sales policies and practices will be implemented in India and global markets. Drawing from feedback provided by dealers and customers, enhancements will be made to products, supply chain, and services, with a further emphasis on fortifying the sales network in both quantity and quality. Moreover, enhancements will be made to the retail finance and training systems. In the realm of exports, close collaboration with partner companies will be pursued to deliver Indian-made products to the global market at competitive prices and high quality, aiming to establish a leading position in exports led by India. Another significant area of focus will be the reinforcement of retail finance.

The company intends to redesign the layout, incorporating the green area, as well as expanding capacity and business operations. In line with their growth objectives, they aim to set up a cutting-edge Engine Manufacturing Facility. This move establishes them as a worldwide center for cost-effective manufacturing, while also preparing for BS-VI compliance to adhere to strict emission standards, demonstrating their dedication to environmental sustainability. Furthermore, by embracing initiatives for digital transformation, they will achieve enhanced efficiency and consistent quality. The strengths, weakness, opportunities and threats are summarized in the following sub-sections.

6.6.1 Strengths

The strengths of the company are summarized as follows:

- One of the most ancient and esteemed players in the market, boasting a considerable market share and brand value.
- Continuously evolving to meet the growing demand for supply.
- Continuously expanding its product portfolio tailored to specific markets, leading to enhanced market reach.
- Establishing a comprehensive framework for risk management to incorporate sustainability practices.
- Venturing into new markets and fortifying distribution channels through strategic partnerships and alliances.
- Addressing climate change by implementing initiatives that significantly reduce our carbon footprint.

6.6.2 Weakness

The weaknesses of the company are summarized as follows:

- Government intervention and abrupt policy modifications may impede the short-term expansion of businesses.

- Disruptions in the supply chain can have a negative effect on production.

6.6.3 Opportunities

The opportunities for the company are summarized as follows:

- The government offers substantial incentives to enhance the manufacturing and allied sector within the nation.
- The government maintains a consistent emphasis on boosting demand through the augmentation of people's purchasing power.
- The rise in the literacy rate among the population contributes to improved economic growth and heightened demand.
- The projected economic growth is anticipated to result in escalated urbanization and increased demand.

6.6.4 Threats

The threats the company may face are summarized as follows:

- New entrants and established participants have the potential to thrive amidst the ongoing expansion of the market sector, resulting in pricing pressures.
- The agricultural domain exhibits a strong dependence on meteorological patterns and atmospheric conditions. Adverse weather phenomena have the capacity to diminish crop output, consequently causing fluctuations in the availability of goods.
- Geopolitical determinations possess the ability to significantly influence the supply and demand dynamics of various commodities.

6.7 Risks faced by the company

The organization's various business operations face a range of risks due to their global presence. In order to detect and handle crucial risks in a proactive manner to accomplish their strategic goals, they have established a clearly outlined Enterprise Risk Management (ERM) framework. This framework ensures that the company's operational controls are in line with the overall vision and mission, enabling the achievement of strategic objectives.

6.7.1 Operational Risks

6.7.1.1 Impact

The operations conducted by the organization may be influenced by various circumstances that are not entirely under the purview of the Company. These factors encompass instances such as equipment or infrastructure damage, unforeseen geological changes or technical challenges, severe weather conditions, and occurrences of natural disasters - all of which have the potential to negatively impact production output and associated expenses.

6.7.1.2 Mitigation Strategies

- Crisis management and business continuity plans are established throughout the organization and undergo regular testing.
- Simulation exercises are conducted to verify the readiness of fire safety systems and personnel in case of fire or seismic activities.
- An emergency response system is in place to enforce optimal accident prevention strategies in all operational locations.
- Ongoing surveillance and regular assessment of security operations are carried out.
- The emphasis remains on enhancing the Company's capabilities through continuous development.

6.7.2 Compliance Risks

6.7.2.1 Impact

The operations of the organization may face disruptions due to changes in legal and regulatory frameworks in the geographical areas of operation, leading to increased operational expenses, limitations, and sanctions.

6.7.2.2 Mitigation Strategies

- The company maintains a continuous surveillance of regulatory changes.
- Operational units at the business level recognize and fulfill regulatory duties and adapt to emerging mandates.

- Upholding a strong commitment to sustainability is demonstrated through proactive adoption of environmental, safety, and corporate social responsibility practices.
- Installation of cutting-edge machinery and technology in our facilities, in accordance with recommendations from the Pollution Control Board.
- Employee training and awareness campaigns on environmental regulations and standards.
- Regular inspections conducted to ensure adherence to relevant environmental, health, and safety laws.
- Implementation of a disaster management system to execute optimal accident prevention strategies at all operational locations.
- Compulsory utilization of personal protective gear by all on-site personnel.

6.7.3 Strategic Risks

6.7.3.1 Impact

Failure to build innovative products, business ventures, and technologies to seize opportunities in the market.

6.7.3.2 Mitigation Strategies

- Adequate financial resources allocated for the development of novel products, expansion of market reach, provision of customer-focused products and services, improvement of customer satisfaction, and establishment of our brand.
- Investment and enhancement of capabilities in emerging digital technologies.
- Establishment of strategic partnerships to boost competitive advantage.
- Provision of continual product updates and introduction of cutting-edge technology.
- Active pursuit of advancements in the Electric Vehicle (EV) sector, products, and technology.

6.7.4 Financial Risks

6.7.4.1 Impact

Prices and demand for the products may continue to exhibit volatility and uncertainty, subject to influences such as economic conditions, natural disasters, weather patterns, pandemics, political instability, among others. The fluctuation in commodity prices and demand has the potential to adversely impact our earnings and cash flow.

6.7.4.2 Mitigation Strategies

• The ongoing effort to mitigate the inflationary effects is being pursued through the implementation of 'Commodity Risk Management', as well as cost re-engineering and value engineering initiatives.

• Capitalizing on opportunities presented by reductions in commodity prices to achieve a decrease in material costs is an important strategy to leverage.

6.8 Concluding Remarks

- At XYZ Ltd., the organization prioritizes long-term financial viability, possesses a solid balance sheet free of debt, and emphasizes strategic capital distribution. The primary goal is to deliver optimal returns to their financial stakeholders while also directing additional capital towards the exploration and advancement of opportunities and products within their Mid Term Business Plan 2028. XYZ Ltd. implements a rigorous financial management procedure that evaluates fund necessities for sustainable business activities and investment in initiatives that support business resilience and expansion. There is a notable emphasis on heightened productivity, inventive customer offerings to maintain ongoing client satisfaction, maintenance of robust financial performance indicators to bolster investor confidence, and fostering fruitful collaborations with enterprises well-versed in sectors pertinent to their operations.
- XYZ acknowledge's the significance of partnerships and place a strong emphasis on collaborations with academic institutions, technology specialists, research entities, and other relevant stakeholders who are aligned with our commitment to advancing farm mechanization, contemporary construction, and efficient railway transportation in both the domestic and international contexts. Over the recent years, they have established several noteworthy partnerships to capitalize on synergies in the manufacturing of tractors, as well as our partnership aimed at enhancing our portfolio of cutting-edge agricultural mechanization solutions.

- Enhancing the ecological impact reduction throughout XYZ's enterprises is crucial for its operational efficiency. The organization's commitment to environmental and sustainability stewardship guarantees that all production facilities adhere to consent terms and environmental regulations that go beyond mere compliance. Adherence to all relevant laws and regulations is ensured, with periodic audits conducted to verify compliance. Installation of Magnetic flow meters at various water consumption points allows for real-time monitoring of water usage, enhancing resource utilization. Additionally, during the previous year, an Environmental laboratory was established to monitor various parameters for better management of water recycling. To monitor their environmental progress, an internal Plant Sustainability Index has been implemented to oversee the performance of their facilities. Regular training sessions and updates on evolving laws and regulations are provided to all employees, focusing on pollution prevention, waste minimization, and other strategies to mitigate environmental impact.
- Business longevity is contingent upon the satisfaction of customers. It is imperative for businesses to comprehend consumer needs and adapt to market conditions for achieving success. Interactions with customers on a regular basis facilitate the enhancement of products and processes to cater to their ever-evolving needs. The company is dedicated to the continuous improvement of safe and sustainable products, ensuring the provision of high quality and unparalleled experience. XYZ prioritizes its customers and actively engages with them through various channels such as Customer Empathy index and Service Quality index to gain insights into their needs, preferences, and interests.
- XYZ has consistently made investment choices founded on enduring fundamental factors such as market potential, technology, and their customers. The company's dominant position in crucial business sectors has been attained through strategic yet measured long-range investments. With the intrinsic advantages of the organization, they find themselves once more in a juncture where they have a distinctive advantage to allocate funds towards sustained long-range expansion and enduring value creation for all stakeholders, while also embracing novel paradigms and emerging opportunities.

CHAPTER 7

DEVELOPMENT OF DECISIONS FRAMEWORK IN CIRCULAR SUPPLY CHAIN

7.1 Introduction

Examination of literature, the survey of the Indian Manufacturing industry, and a case study have led to the conclusion that numerous issues such as risk management, coordination, and circularity decisions are positively linked to the performance of CSC. The impacts of decisions concerning these issues will not only affect the organization but also various other stakeholders. This chapter presents the decision framework for risk management and coordination-related decisions in CSC. The sequence of the chapter is depicted in Fig. 7.1. Decision frameworks have been formulated utilizing diverse research methodologies, and each framework has been verified through a case illustration of an Indian manufacturing organization. The decision frameworks have been established and deliberated in the subsequent sections.

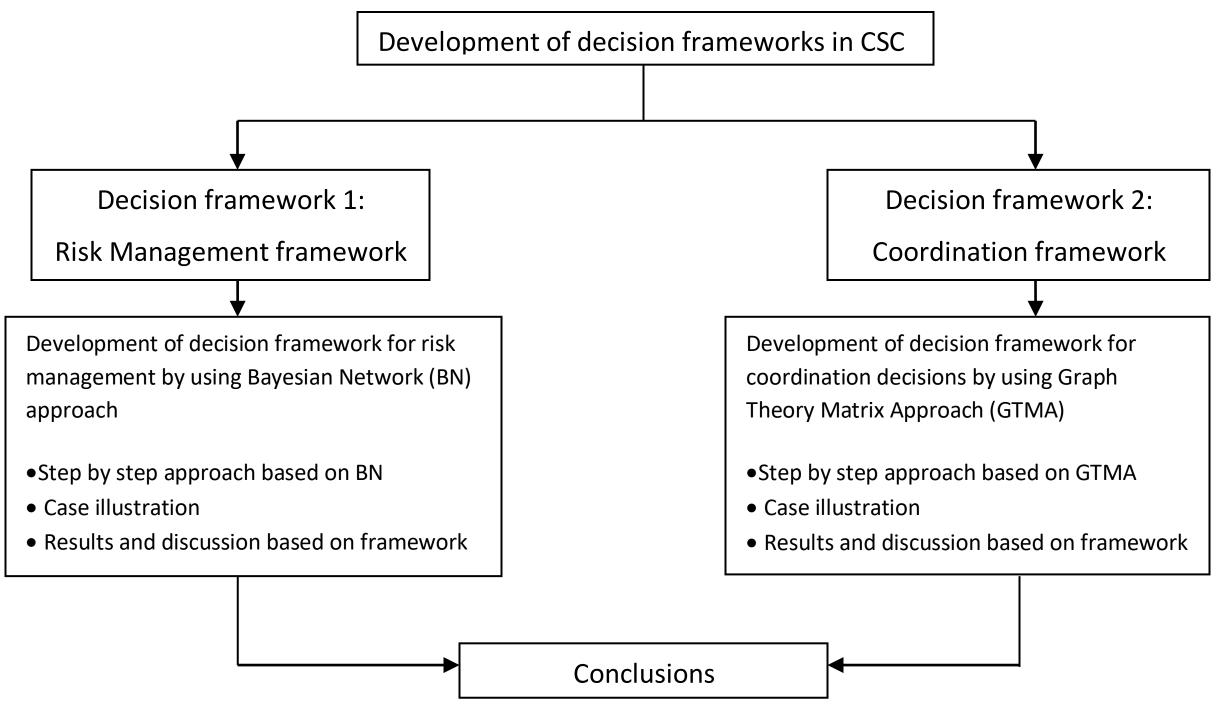

Fig. 7.1 Workflow for the development of decision frameworks

7.2 Decision framework 1: Risk Management framework

The concept of CSC is novel, and is seen as a major research interest among the supply chain practitioners, academicians, and industry experts (De Angelis, 2020; Fiksel et al., 2021; Lahane et al., 2020). CSC involves the forward, as well as reverse, flow of product constituting a cycle comprising various supply chain partners (Genovese et al., 2017). Enterprises planning to switch towards CSC need to involve more partners, thus exposing the supply chain to several risks (Bui et al., 2021). Risk is unpredictable by nature, and firms need to be aware of its occurrence and severity. It may originate at one branch of the supply chain and create a cascading effect on sub-branches, generating further risk with severe impacts (Koh et al., 2017). This cascading phenomenon of disruption propagation along the chain of network is known as a ripple effect Pan et al. (2014). Failure, due to risk encountered at any node, can cause the entire system of SC to collapse (Ethirajan et al., 2020). Therefore, enterprises should understand the interdependency among the partners, plan for these disruptions, and redesign their SC accordingly.

Risk management is inevitable for achieving a high degree of circularity in SC. Risk management involves the identification, modeling and mitigation of risk at various levels of SC. Measuring circular supply chain (CSC) disruptions, and the impact on the sustainable performance of the CSC, is still lacking in the existing literature (Spekman and Davis, 2004). Therefore a comprehensive review of the literature on supply chain risk management (SCRM), pertaining to CE, leads to the identification of gaps and a basis of research in the novel area of CSC. Tang (2006) reviewed various quantitative models for managing forward supply chain risk. The authors also related various SCRM strategies that were examined in the literature with actual practices. Jüttner et al. (2003) reviewed the literature on supply chain vulnerability and the management of forward supply chain risk, and compared the findings to develop suitable SCRM strategies. Fan and Stevenson (2018) provided a broad and contemporary understanding of SCRM, and presented a comprehensive definition, covering the process, pathway, and objectives of SCRM, leading to a conceptual framework. Past research reveals that risk management approaches have only been applied in the forward direction of the supply chain (Li and Zobel, 2020). Risk identification and propagation in the reverse direction is still missing in the current literature of SCRM. Therefore, an effort has been made to identify and analyze the various kinds of risk, their probability of occurrence, and their impact on the SC performance in the forward, as well as in the reverse, direction. In this regard, a circular supply chain (CSC) risk framework has been developed, in order to generate risk profiles of the various partners involved. Hence, the research aims to present the holistic view of risk propagation in the circular supply chain network.

7.2.1 Bayesian Network methodology for the modeling of Circular Supply Chain risk

In this study, the Bayesian network (BN) methodology is adopted, to develop a probabilistic graphical model using the empirical data obtained from the interviews conducted with the risk experts of ten CSC partners of an Indian auto parts manufacturing company. The main reason to incorporate the BN methodology is to develop a framework of risk assessment, by generating individual risk profiles of all the CSC partners involved with the SC of the company. Most of the applications of BN have flourished in other areas of risk aversion, but in the field of supply chain risk management, only a few models are proposed (Ojha et al., 2018). Through the application of the BN methodology, the study is able to demonstrate how risk propagation takes place across the CSC network, and the disruption caused at individual SC nodes. It is observed that the BN methodology has a few applications in the area of SCRM (Garvey et al., 2015; Sharma and Sharma, 2015; Ojha et al., 2018). The BN methodology can be applied for the assessment of the cascading effect of disruptive events (Hosseini and Ivanov, 2019; Liu et al., 2021). The unique ability of this approach to model the network of risk in an interconnected structure of complex SC system, encourages its adaptation as a preferred research methodology for the modeling of CSC risk.

7.2.2 Bayesian Network Approach

The Bayesian Network (BN) can be understood as a directed graphical model or a probabilistic dependency model, illustrating a causal relationship among variables and key factors, which finally leads to one or more outcomes in a system (Sharma and Sharma, 2015). The BN model consists of finite nodes that are connected through directed arcs, which show the conditional probability dependence of individual factors on the dependent variable. An arc connects an independent variable X to a dependent variable Y, and is represented as (X,Y), which implies the direction of the arc from X to Y. In this causal relationship, the independent variable X is also sometimes called the parent node, and the dependent variable Y is termed as the child node.

Nodes are considered to be an independent random variable, as their value depends on the situation (system state) in which they arise. An independent variable may consist of any number of possible states. It is advisable to use as few as possible to make the computation of the problem simpler. The node can be a latent variable or it may be hypothetically derived.

BN analysis may be qualitative, quantitative, or both, depending on the scope of analysis. The BN typically consists of the following two primary components: a subjective causal relationship and objective conditions that are fulfilled using probability distribution. Continuous probability distribution can also be used in a Bayesian network, but it will make the problem more complex. An important advantage of using Bayesian methodology is the flexibility to update the subjective probability with the increase in the number of evidences. Subjective probability is a measure of an individual belief in the occurrence of an event. This probability is divided into two phases, and is given the name prior probability and posterior probability.

An important advantage of using Bayesian methodology is the flexibility to update the subjective probability with the increase in the number of evidences. Subjective probability is a measure of an individual belief in the occurrence of an event. This probability is divided into two phases, and is given the name prior probability and posterior probability. Let us assume that the subjective probability of the occurrence of an event E is represented as Pr(E). This is called the prior probability of occurrence, or degree of belief of an event E before the analyzer gets access to additional data D1. On gaining access to the data D1 that contains information pertaining to event E, the analyzer can quote the updated probability by using Baye's formula given in Eqn.7.1.

$$\Pr(E|D1) = \Pr(E).\Pr(D1|E)/\Pr(D1) \tag{7.1}$$

This updated subjective probability of occurrence, which is represented as Pr(E|D1), is called posterior probability. The main reason to incorporate the Bayesian methodology into the study of risk analysis is to model the network of influencing factors, which can lead to a single outcome that will help in generating an individual risk index for the various partners involved in a circular supply chain.

7.2.3 Case illustration

This section comprises the application of the proposed technique in solving sustainability issues for an automobile manufacturing company located in Delhi–NCR in India. In this section, a brief overview of the company's profile and process of data collection is provided.

7.2.3.1 Profile of the organization

XYZ Limited is considered to be among the foremost engineering conglomerates in India, engaged in the burgeoning sectors of agri-machinery, construction & material handling equipment, railway equipment, and auto components. With a noteworthy presence of over 1 million tractors in active operation within India, along with 16,000 units of construction and material handling equipment, and an impressive production of 5 million auto-components to date, XYZ Ltd. is effectively capitalizing on its engineering proficiency and role as a catalyst for change in the fields of agriculture, construction equipment, and automotive components.

XYZ Ltd. possesses three essential mission statements: Sustainability, Contribution, and Solution. The initial statement entails striving for growth that is sustainable, while the second involves contributing to the enhancement of the living environment, specifically for individuals such as farmers, women, and socially vulnerable populations, to ensure their comfort. The third mission is focused on advancing mechanization and delivering comprehensive solutions to fulfill the needs of our customers. In a constantly evolving business environment, it is imperative for enterprises to remain abreast of the latest developments through the identification of potential threats and opportunities, as well as by strategically positioning themselves. The importance of this strategy is acknowledged at XYZ Limited, where efforts are made to gain a competitive advantage through ongoing evaluations of their operational environment and optimal positioning for maximizing opportunities for growth.

7.2.3.2 Data Collection

The data were gathered by a group of representatives of ten CSC partners, which included four manufacturers, three retailers/sellers, and three recyclers, in the Indian automobile parts manufacturing industry. These CSC partners were located in the National Capital Region (NCR) of India. These partners have a close connection, and are collectively working to improve the sustainability of production and consumption in the automobile parts manufacturing industry. The period of data collection was from November 2020 to March 2021. The data collection was conducted in three stages. In the first stage, the partners were informed about the benefits of implementing circular strategies in their SC operations. Secondly, a self-assessment online data collection platform was created and distributed among the partners through e-mail. The third stage of data collection consisted of conducting interviews with the supply chain managers of the manufacturing company working in the area of risk management. These interviews were conducted online, in order to cross-verify with the data that were collected through the supply chain experts. Finally, a five-point Likert scale was used to rate the different risk measures that were taken into consideration in the study, and, thereafter, a risk profile was generated for each of the partners involved in the CSC operations.

7.2.4 Results and discussion based on the model

This section is divided into three sub sections. The first sub section consists of the formulation and analysis of the BN model that was used to generate the risk profiles of various CSC partners. The next sub section consists of the effect analysis of these risks on the various performance parameters of the CSC. The last sub section comprises the risk exposure index (REI) that indicates the extent to which an individual CSC partner is exposed to various categories of risk.

7.2.4.1 Risk Measurement Model

The risk assessment model consists of a cluster of measures and scales, used to compute the probability of the occurrence of each risk construct. The measures of each risk category were incorporated, taking the key events that could have a direct impact on the risk into consideration. Further, these risk measures and scales are utilized to generate the risk profile of individual CSC partners. The risk profile represents the disruption caused by a particular CSC partner when a cluster of risk events occurs under a certain condition. The disruption not only affects the individual partner, but has an impact on the complete supply chain. In the case of the circular supply chain, all the partners are connected through a cycle. Therefore, if any disruptive event occurs, it will affect each of the partners that are involved in the cycle. In the study, certain parameters that may be used to check the performance of the CSC are considered, with regards to the risk assessment model under consideration. These are the partners risk impact on SC revenue, lost sales, and inventory holding cost. The probability of risk impact of an individual partner is used to analyze the effect on these performance parameters. Each individual partner has a distinctive effect on these parameters that illustrate the performance of the CSC.

For the purpose of risk analysis, the BN methodology is used to generate a risk profile of each of the CSC partners. This network model is used to compute the probability of risk impact that an individual partner could have on the complete supply chain. Economic, environmental, social, technological, waste management, agile vulnerability, and risk of cannibalization are some of the risk categories that were identified through the extensive literature review that is provided in Table 7.1. The level of risk for each risk category was computed using the prior probabilities of individual risk events. Finally, the estimated subjective probability of each category of risk was used to generate the risk profile of the CSC partners. A schematic diagram of the BN model is shown in Fig. 7.2.

The first and foremost task in the development of the Bayesian model is to identify the end nodes in a clear and explicit way. These end nodes contain the various categories of risk that have been identified through a comprehensive literature survey. Each category of risk is a function of certain risk events. These risk events are further dependent on the risk measure. These risk measures are the backbone of the BN model, and are sometimes referred to as the parent node. Table 7.1 depicts the hierarchal structure of the BN model, comprising various categories of risk, their individual risk events, and the risk measuring factors.

Table 7.1 CSC Risk hierarchy for Bayesian Analysis

Risk Category	Risk Event	Risk Measure	References
Economic risk (RC1)	Supply risk (RE1),	Failure in delivering the right quality and quantity of product Misalignment of interest between supplier and company Accreditation of suppliers	Tofighi et al. (2016); Chopra and Sodhi (2004)
	Flawed incentive structures (RE2),	Revenue generation of company Return on investment Financial instability due to fluctuating market demand	Li and Zobel (2020)
	High investment (RE3)	Portfolio of Customer Market trend Profit percentage Product Sale	Tofighi et al. (2016)

Environmental Risk (RC2)	Limited store of resources (RE1),	Supplier licensing Disaster Mitigation Check on resource extraction	DuHadway et al. (2019)
	Uneven geographical distribution of resources (RE2),	Transportation challenges Routing and allocation Planning and optimization	Giunipero and Eltantawy (2003)
	Limited assimilative capacities of ecosystems (RE3)	Regularity check Accreditation and adoption Policies supporting CE adoption	Georgescu-Roegen (1977); Daly and Townsend (1993)
Social Risk (RC3)	Excessive working time of the employees (RE1),	Accurate forecasting Social Responsibility Mass immigration	Gouda and Saranga (2018)
	Unfair wages (RE2),	Revenue generation Profit sharing Management involvement	Song et al. (2017); Tofighi et al. (2016)
	Work-life imbalance (RE3)	Conducive working environment Health standards Work load distribution	Song et al. (2017)
Technological Risk (RC4)	Threat of implementing newer/complex technology (RE1),	Fulfillment of desired objectives Revenue generation Environmental effect	Ivanov et al. (2019); Song et al. (2017)
	Compatibility issues with existing systems (RE2)	Product Performance Likelihood of process change Generation of defects Value embedded	Kauppi et al. (2016); Song et al. (2017)
Waste management Risk (RC5)	Health-associated risk to the society (RE1)	Effect on local geographical ecosystem Framing of Health Standard protocols Loss of credibility	Maria et al. (2013); Sodhi and Tang (2019)
	Penalties involving improper disposal of waste (RE2)	Financial Losses Intricacy in receiving accreditation	Maria et al. (2013); Agrawal et al. (2015)
Agile Vulnerability (RC6)	Swift response to agile changes (RE1),	Market Demand Piling up of Inventory Lost Sales Profit Generation	Monte et al. (2009); Tofighi et al. (2016)
	Flexibility in production process (RE2)	Frequent technological upgradation Loss of production Customer Satisfaction	Gunasekaran (1999); Hafezalkotob and Makui (2012)
Risk of Cannibalization (RC7)	Deregulated markets (RE1),	Compliance with market norms Monopolization Market Share	Guiltinan (2009); Monte et al. (2009); Okorie et al. (2021)
	Problematic ownership structures (RE2)	Customer Satisfaction Service life of product Product Return Market Credibility	Llerena (2011); Sodhi and Tang (2019)

When the state of every individual node is defined, the arc needs to be drawn, connecting the nodes, and the probability should be assigned to the individual node. The process of assigning probability should start from the root node. After the root nodes are completely assigned, the process of assignment should move to the next level. The conditional probability table (CPT) of these nodes is computed, with the help of the probabilities assigned to the parent node. This process continues until all the nodes of each level are assigned with a conditional probability. With the establishment of all the CPTs of each node, this process gets completed. The value of the CPT that is assigned to the root node may come from an expert judgment, from an external data source, or a combination of both.

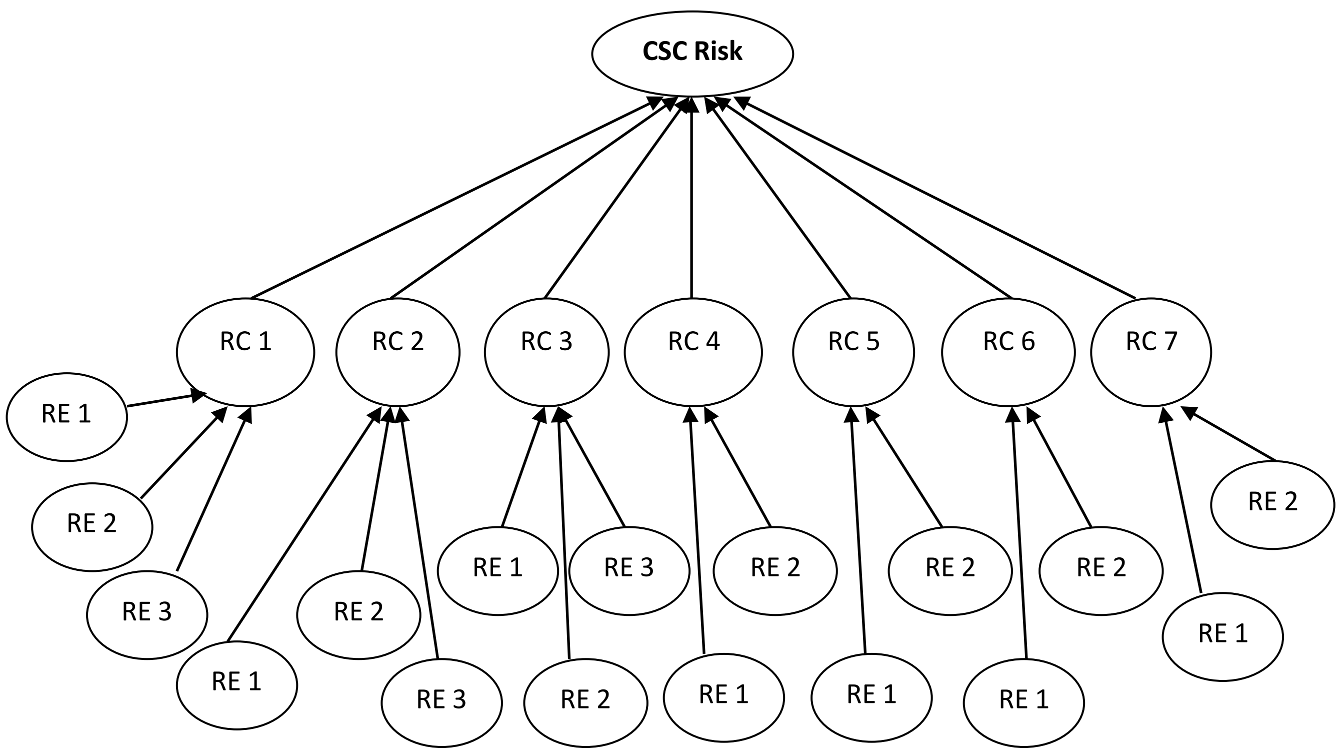

Fig. 7.2 CSC risk network framework

7.2.4.2 Result Analysis

The priori probability for each of the risk events depends on the value of the individual risk measure. These risk measures are assigned values, through various experts and supply chain managers. The probabilities for 17 supply chain risk events that affect economic, environmental, social, technological, waste management, agile vulnerability, and risk of cannibalization, are presented in Table 7.2, for each CSC partner. The values of the probability of individual risk events are used to generate the risk profile, using the Bayesian network. Table 7.3 provides the occurrence probability of each of the categories of risk for the individual CSC partners.

Table 7.2 A Priori probabilities for 17 circular supply chain risk events

Risk	**Economic Risk**			**Environmental Risk**			**Social Risk**			**Techno-logical Risk**		**Waste Management Risk**		**Agile Vulnerability**		**Risk of Cannibalization**	
Risk event	**Supply Risk**	**Flawed incentive structures**	**High investment**	**Limited Resources**	**Uneven geographical distribution**	**Assimilative capacity of ecosystem**	**Excessive working time of employees**	**Unfair wages**	**Work-life imbalance**	**Threat of implementing new technology**	**Compatibility with existing systems**	**Health-associated risk**	**Improper disposal of waste**	**Swift response to agile changes**	**Lack of flexibility**	**Deregulated markets**	**Problematic ownership structures**
M1	0.65	0.40	0.75	0.60	0.15	0.80	0.76	0.32	0.65	0.68	0.55	0.42	0.75	0.15	0.10	0.78	0.52
M2	0.45	0.55	0.65	0.50	0.25	0.62	0.25	0.67	0.35	0.64	0.69	0.49	0.78	0.16	0.31	0.54	0.78
M3	0.62	0.25	0.67	0.35	0.64	0.69	0.49	0.78	0.15	0.80	0.76	0.32	0.65	0.68	0.55	0.42	0.75
M4	0.64	0.69	0.49	0.78	0.15	0.80	0.76	0.32	0.65	0.55	0.65	0.50	0.25	0.62	0.25	0.67	0.35
Rt1	0.65	0.68	0.55	0.42	0.75	0.15	0.10	0.78	0.52	0.35	0.26	0.29	0.49	0.78	0.15	0.20	0.26
Rt2	0.35	0.64	0.69	0.49	0.78	0.15	0.80	0.76	0.62	0.25	0.67	0.35	0.24	0.29	0.49	0.38	0.29
Rt3	0.78	0.15	0.80	0.76	0.32	0.65	0.55	0.65	0.50	0.65	0.50	0.25	0.62	0.25	0.67	0.35	0.44
Re1	0.64	0.69	0.49	0.78	0.15	0.80	0.76	0.32	0.65	0.75	0.15	0.670	0.78	0.52	0.35	0.64	0.69
Re2	0.65	0.55	0.65	0.50	0.65	0.50	0.25	0.62	0.25	0.69	0.49	0.78	0.15	0.80	0.76	0.62	0.25
Re3	0.78	0.52	0.35	0.64	0.69	0.49	0.78	0.15	0.80	0.65	0.68	0.55	0.42	0.75	0.15	0.60	0.54

*Manufacturer 1 (M1); Manufacturer 2 (M2); Manufacturer 3 (M3); Manufacturer 4 (M4); Retailer 1 (Rt1); Retailer 2 (Rt2); Retailer 3 (Rt3); Recycler 1 (Re1); Recycler 2 (Re2); Recycler 3 (Re3).

The occurrence probability of each risk is based upon the scenario in which the events of risk occur. The combination of parent risk events associated with a child node is called a scenario. The total number of scenarios associated with a node is 2^n, where n represents the total number of risk events that are linked to the node. For example, in order to compute the occurrence probability of the economic risk associated with manufacturer 1 (M1), the total number of possible scenarios is 2^3, i.e., eight, since there are three risk events that define economic risk. Therefore, a combination of eight scenarios (000, 001, 010, 011, 100, 101, 110, 111) is possible, which is used to compute the probability of the occurrence of economic risk. These eight scenarios can be represented as a combination set, comprising of zero and one. Zero denotes that the event of risk has not occurred, while one denotes that the risk event has occurred. This study incorporates the scenario in which all the risk events have occurred simultaneously, pertaining to a particular category of risk. This combination is chosen in order to compute the maximum possible disruption a particular type of risk could cause to a supply chain. The probability of the occurrence of economic risk for manufacturer 1 can be computed using Eqn. 7.2:

$$\mathrm{P(EconomicRisk)} = \frac{\sum(\text{Probability of economic risk event})\times\sum(\text{Probability of event occurrence})}{\sum(\text{Probability of event occurrence})} \tag{7.2}$$

$$\mathrm{P(Economic\ Risk)} = \frac{[(0.65\times1)+(0.40\times1)+(0.75\times1)]}{1+1+1} = 0.6$$

The above equation can also be used to compute the probability of occurrence of other categories of risk associated with different CSC partners. Table 7.3 reveals that manufacturer 3 (M3) and recycler 1 (Re1) have the highest overall probability of risk impact on the performance of CSC. While retailer 1 (Rt1) has the lowest probability of risk impact. From Table 7.3, it can be concluded that recyclers have a greater risk impact on the overall performance of CSC and therefore, they need special attention from the perspective of risk mitigation.

Table 7.3 CSC partner risk profiles.

CSC Partner	Economic	Environmental	Social	Technological	Waste Management	Agile Vulnerability	Risk of Cannibalization	Overall Probability of risk impact
	Risk Probability							
M1	0.6	0.51	0.57	0.61	0.59	0.12	0.65	0.52
M2	0.55	0.45	0.42	0.66	0.64	0.23	0.66	0.51
M3	0.51	0.56	0.47	0.78	0.49	0.62	0.59	0.57
M4	0.6	0.58	0.58	0.6	0.38	0.44	0.51	0.53
Rt1	0.63	0.44	0.47	0.30	0.39	0.47	0.23	0.42
Rt2	0.56	0.47	0.73	0.41	0.29	0.39	0.34	0.45
Rt3	0.58	0.58	0.57	0.58	0.44	0.46	0.38	0.51
Re1	0.6	0.58	0.58	0.45	0.44	0.74	0.67	0.58
Re 2	0.62	0.55	0.37	0.59	0.47	0.78	0.44	0.54
Re3	0.55	0.60	0.58	0.67	0.49	0.45	0.56	0.55

7.2.4.3 Risks impact analysis and discussion

This subsection includes the effect analysis of the risk encountered during the implementation of the concept of circularity, on various performance parameters of the supply chain of the Indian automobile organization that was considered as the case illustration. For the purpose of analysis, a multi-echelon system is chosen, consisting of a group of manufacturers, retailers, and recyclers that are part of circular supply chain of a leading automotive organization in India. The following parameters are analyzed for the comprehensive understanding of the disruption caused due to various risk on CSC performance.

7.2.4.3.1 Inventory Holding Cost

In a conventional multi-echelon system, having linear flow of material, the inventory holding cost increases as we move downstream in the supply chain (Chopra and Sodhi, 2004). The holding cost of raw material or work in process inventory is lesser than the cost incurred in holding finished goods inventories; while in the circular supply chain, the holding cost of recycled raw material on the reverse side is comparatively more, as it includes the cost of the collection and sorting of material from used products, and the cost of recycling operations. Any disruption caused on the reverse side of the supply chain will affect the production of recycled raw material, ultimately leading to a shortage of raw material for the manufacturer. Therefore, the bottleneck (at recycler end) has a higher backup of inventory (used products), as disruption propagates from the recycler to the manufacturer and the retailer. In the case of the CSC, the inventory holding cost for each of the retailers is found to be minimum (Fig. 7.3(a)), because they have the least disruption impact on the overall performance, and, therefore, the requirement of an inventory is also low at the retailer end. Let us take an example of retailer 2. It can be seen from Table 7.3, the 'overall probability of risk impact' for retailer 2 is 0.45. Now, taking the values of the 'annual demand rate' and 'inventory holding cost per unit' for 'Retailer 2', from the risk register of the organization, is considered as the case illustration. The total inventory holding cost (TIHC) per year for 'Retailer 2' can be computed using Eqn. 7.3:

$$\text{TIHC} = \text{overall disruption probability of retailer 2} \times \text{annual demand rate} \times \text{inventory holding cost per unit} \tag{7.3}$$

$$\text{TIHC} = 0.45 \times 10{,}000 \times 2.7;$$

$$\text{TIHC} = 12{,}150.$$

Similarly, the value of TIHC for other CSC partners can be obtained by applying the same formula. The value of TIHC for each of the CSC partners is shown in Fig. 7.3(a). A similar method can be applied to compute the values of the other two performance parameters that are discussed in the subsequent section.

7.2.4.3.2 Impact of Partner's Risk on SC Revenue

The impact of partner's risk on supply chain revenue can be defined as the expected increase in the cost of the SC when an uncertain event or a group of events occurs (Chopra and Sodhi, 2004). The disruptions in the networks, which are more localized, often have less impact on the SC revenue. Since in a CSC, the disruption propagates from the reverse to the forward side, so any disruption caused to the recycler may have a huge impact on the total SC revenue. Since the impact of the partner's risk on the SC revenue is dependent on the probability of disruption, it does not vary much with the change in the inventory level. It can be seen from Table 7.3 that the disruption probability of the recyclers for each of the categories of risk is greater as compared to the manufacturers and retailers; therefore, any disruption occurring on the recycler side can have a huge impact on the revenue of the CSC (Fig. 7.3(b)).

7.2.4.3.3 Lost Sales

A loss in sales may take place due to the disruption occurring at the individual nodes. A loss in the sale of the product is mainly because of the imbalance between supply and demand. Firstly, if the demand of the product in the market is high, and the company's SC is not able to meet the required demand, then it leads to a loss in the expected sales. A loss in sales may also happen if the demand of the product in the market is low, while comparing it to the production capacity of the company. In both the cases, there is a loss in the net SC revenue. These results can be well attributed to the smooth functioning of the CSC. In the case of the CSC, the demand of a product is not only related to the generation of recycled raw material, but it also has a major contribution to the circular flow of economy. In the case of the circular flow of a product, the dependency in fresh raw material is minimized, so the chance of a shortage of raw material for the production is also less. This, in turn, creates a balance between supply and demand. The risk propagation of the loss in sales is, again, from the recycler to the manufacturer and retailer. Any disruption occurring at the recycler will affect the production of recycled raw material, which will further affect the manufacturer's performance, due to a shortage of input material. This will lead to a shortage of finished products at the retailer, thereby leading to a loss in sales. So, a high inventory of used products should be kept by the recycler, in order to reduce the disruption over the entire cycle. The level of inventory may decrease from the reverse to the forward side (Fig. 7.3(c)).

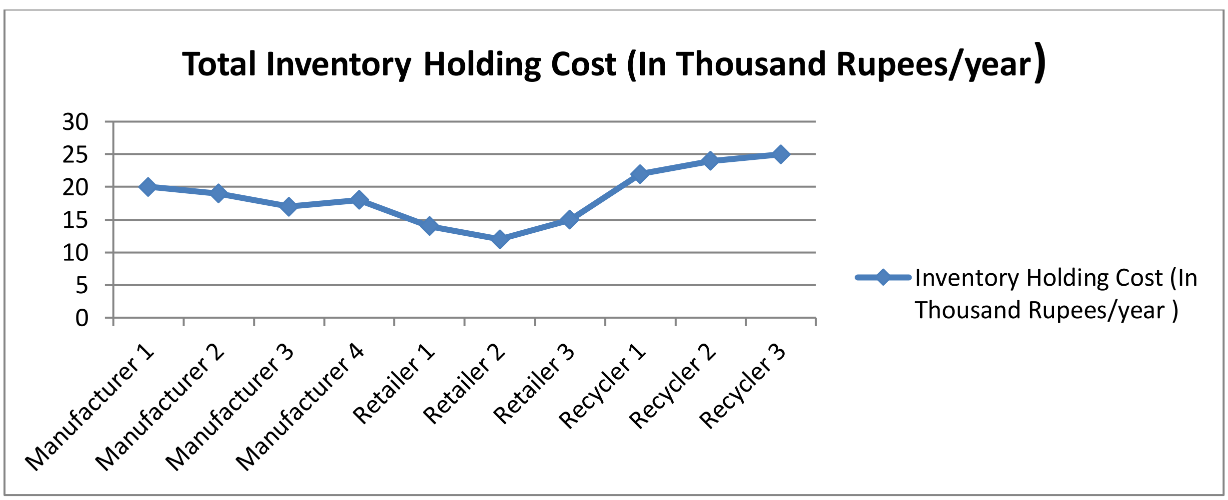

Fig. 7.3(a) Holding cost for CSC partner

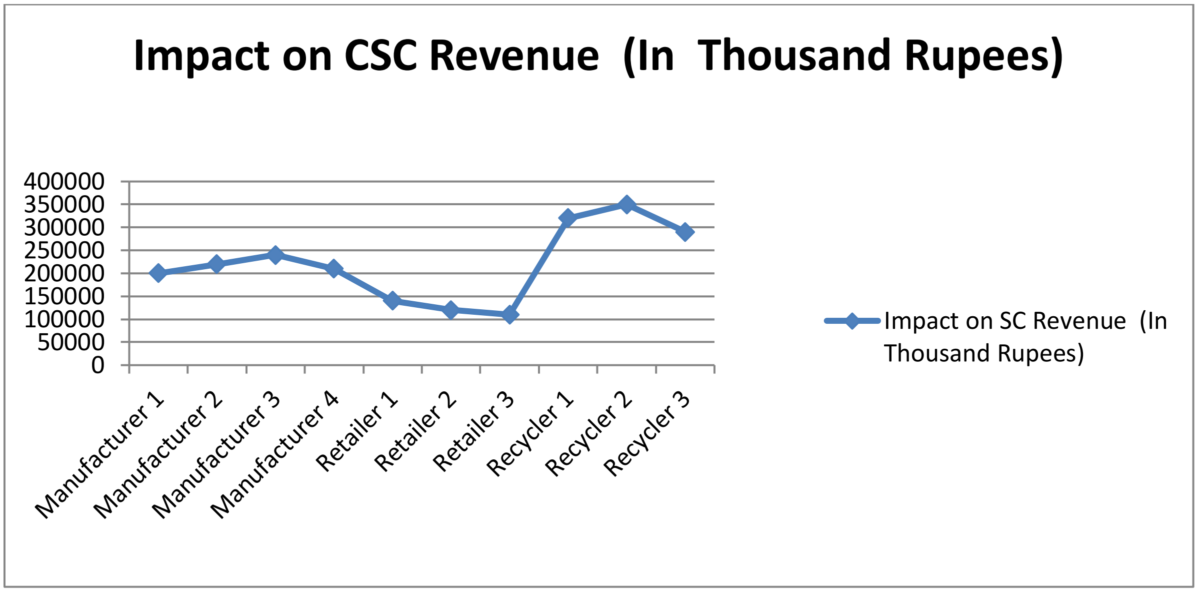

Fig. 7.3(b) Impact of partner's risk on CSC revenue

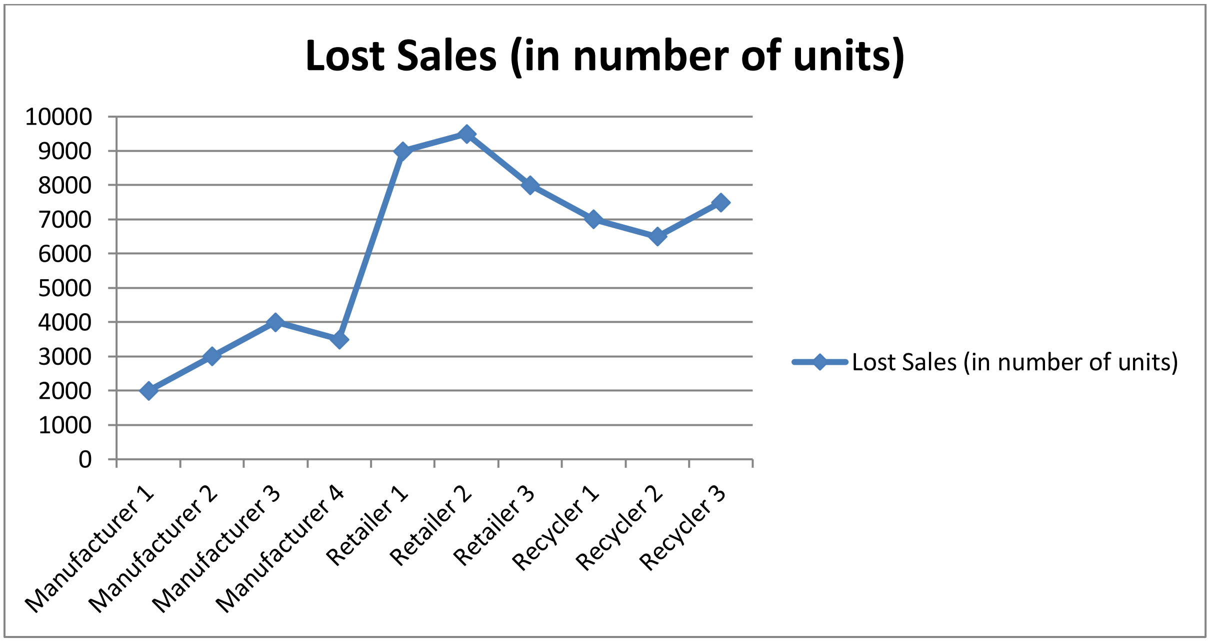

Fig. 7.3(c) Lost sales in CSC

7.2.4.4 Risk Exposure Index

The risk exposure index (REI) is used to identify the particular nodes that need special attention from the SC managers and the risk experts. In the above considered BN model, REI is evaluated based upon the risk impact of individual partners on the CSC revenue. The impact on the revenue is expressed in terms of the average of the disruption probability of each individual risk associated with the CSC partner. The value of REI lies between zero and one, since it is the mean of the probabilities. The CSC partner, having the highest value of REI, has the maximum impact on the revenue of the CSC. REI, here, implies the partner's exposure to the extent of the risk encountered during the implementation of the concept of circularity in the supply chain. Fig. 7.4 shows the risk exposure index of each individual partner that is associated with the company's SC.

It is observed, from graphical results (Fig. 7.4), that the risk exposure index of the three recyclers Re1, Re2 and Re3 are comparatively more than the rest of the partners involved in the CSC. This implies that the recyclers are more vulnerable to the disruptions caused by these CSC risks, or in other words it can be stated that the reverse side of the supply chain is more susceptible to these risks as compared to the forward side.

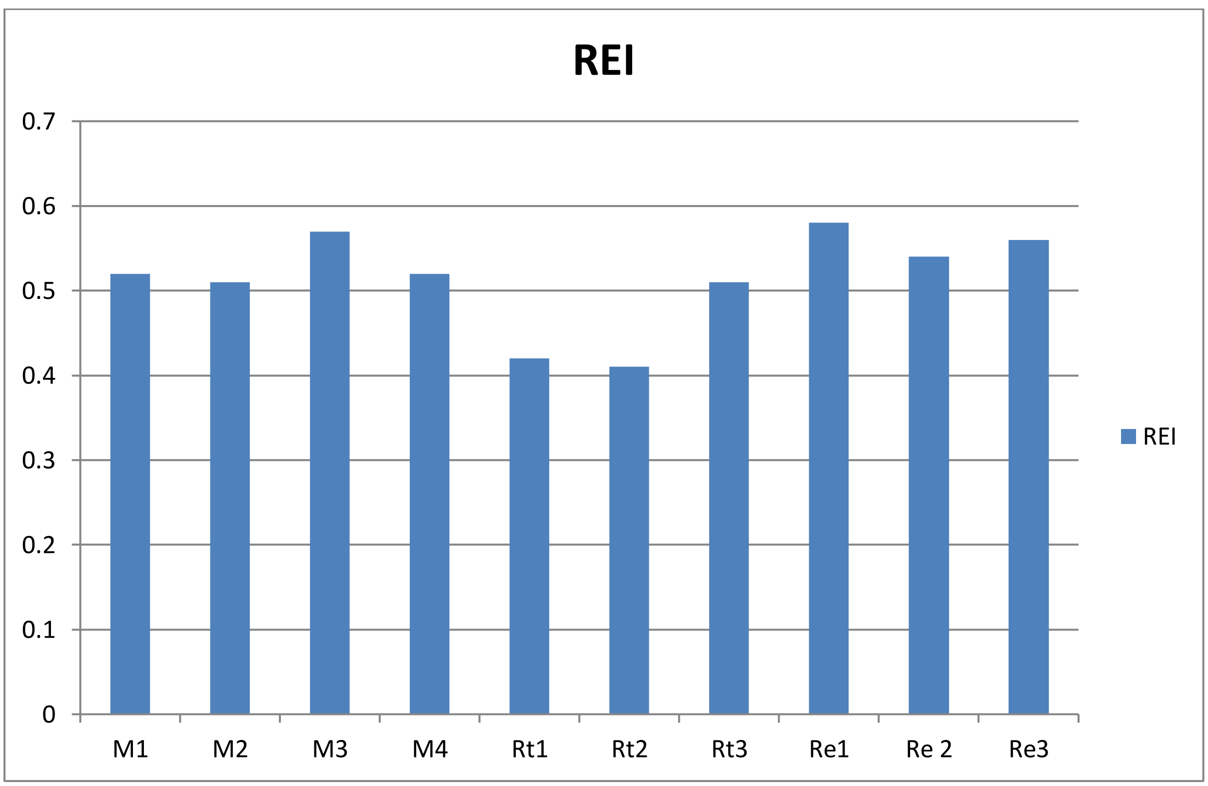

Fig. 7.4 Risk Exposure Index of CSC partners

Fig. 7.5 shows a bar graph representing the probability of disruption of each of the categories of risk faced by the partners of the CSC. It is observed, from graphical results (Fig. 7.5), that the average height of the bars of risk associated with recyclers involved in the CSC of the Indian automobile company is greater as compared to the average height of the manufacturers and retailers. This is attributed to the fact that recyclers are more vulnerable to the risk encountered during the implementation of the concept of circularity in the SC. The disruption probability of economic risk is almost equal for all the CSC partners, which means that any economic downturn will be equally shared by all the partners. The disruptions caused to the activities of the CSC are high in magnitude for the recyclers, because they are bound to operate under strict environmental norms. The pillars of the disruption of social risk are high for the retailers because they have to manage and bridge the gap that exists between the customers and the rest of the partners of the CSC. Manufacturers are the ones who are mainly exposed to the effect of the occurrence of technological risk. Any technological breakdown during the manufacturing operation can seriously affect the production, which, in turn, disrupts the smooth flow of products through the chain. Also, with the incorporation of a novel concept, there is always a threat, whether the implementation of new technology will be compatible with the existing system. The risk that is associated with the management of the proper disposal of waste also plays a major role in the implementation of the CSC concept. Not only should manufacturers efficiently utilize the input resources, but the recyclers should also carry out the operations carefully, because any leakage of hazardous substance into the environment can cause serious health hazards. Any agile change in the design of a product directly affects the manufacturers and recyclers. These risks arise because of the frequent changes in customer demand from the calling population that requires the incorporation of a new complex technology. With the introduction of a novel business technique, the new long-lasting products that are more technology driven, may decrease the sale of the products produced conventionally. Manufacturers are mostly susceptible to the risk of cannibalization, because technology needs to be continuously updated along with the change in market demand.

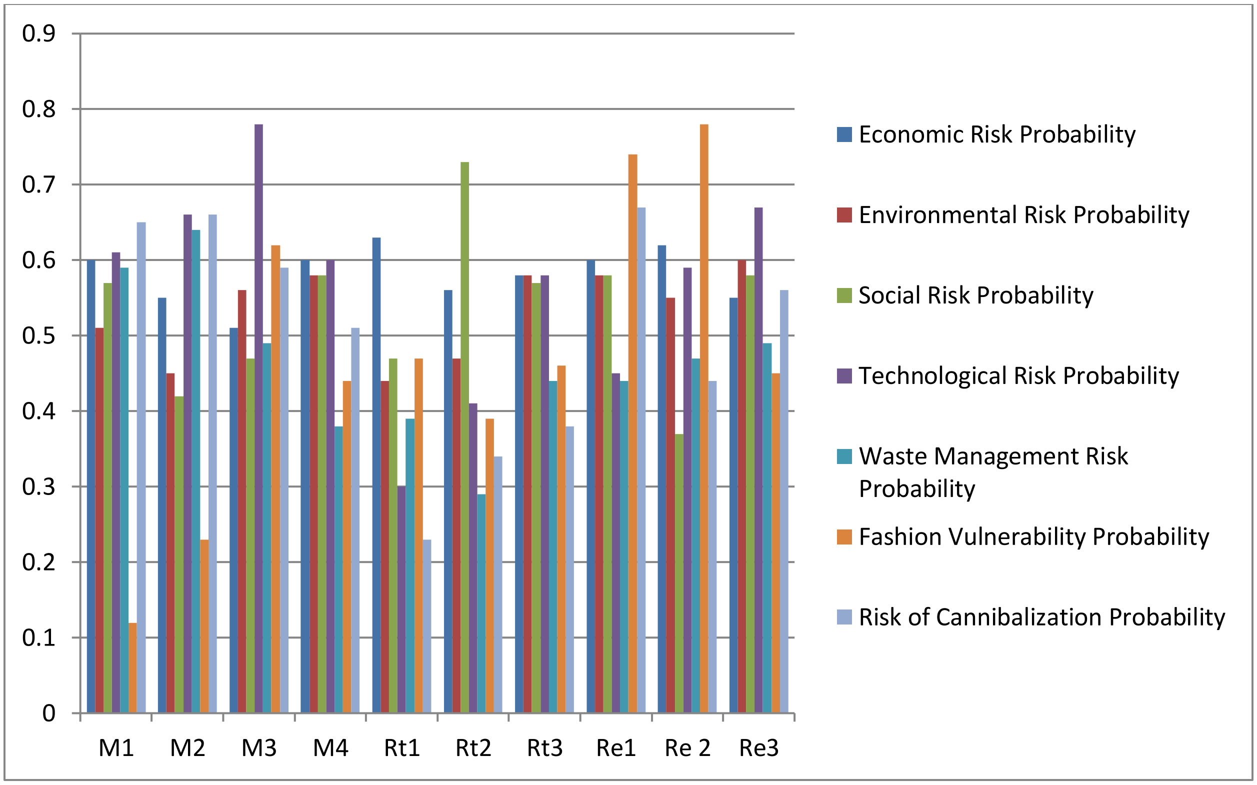

Fig. 7.5 Disruption Probability of CSC Risk for each partner

7.3 Decision framework 2: Coordination decision

The issue of coordination within circular supply chains is one that has received limited attention (Agrawal et al., 2022). Coordination plays a pivotal role in enhancing the efficacy of supply chain operations (Ryu et al., 2009). In a Circular Supply Chain (CSC), coordination becomes a matter of great concern for achieving a high degree of circularity owing to the involvement of a larger number of partners as compared to the traditional linear supply chain (Roy et al., 2022). The integration of various actors within a circular supply chain is of utmost importance as it pertains to the coordination necessary to continuously enhance the overall circularity of supply chain (Alonso-Muñoz et al., 2021; Chhimwal et al., 2023). Management of any organization plays an important role in establishing coordination among the different stakeholders involved in the business (R. K. Singh, 2011). The main responsibility of management is the selection of suitable actors of SC that could lead to improved business performance and fulfillment of the targets (Garg and Sharma, 2020).

Selection of SC partners based on CE perspectives is one of the crucial problems of circular supply chain management (CSCM) that is yet to be addressed. During the selection of suitable partners the sustainability aspect need to be integrated due to stringent environment norms, strict government policies and economic interest (Mao et al., 2020). The proposed study's ultimate aim is to create a framework for selecting appropriate actors for CSC. Therefore this study develops an approach that best describes the role of individual partners in achieving the desired objective. In this study, Graph Theory and Matrix approach (GTMA) has been utilized as a selection methodology as this approach comprehensively evaluates all the criteria's and the interdependencies among them. The criteria were established by means of an exhaustive review of the literature and in consultation with experts in the field of supply chain management. The coordination index was subsequently determined for the various alternatives of the SC. The coordination index is a numerical value that is derived from a permanent function that employs the GTMA methodology. A higher coordination index value corresponds to a better alternative selection. The coordination index values were evaluated and the optimal SC alternative was chosen through comparison.

7.3.1 Selection of Coordination attributes and alternatives

Identify the selection attributes/criteria's in order to determine the value of selection index for different alternatives. Based on comprehensive review of literature and discussion with experts, eight attributes were finalized. The attributes are reviewed in Table 2.9 and are listed as Information Exchange (IE), Revenue Sharing (RES), Risk Sharing (RIS), Resource Sharing (RESS), Joint Decision Making (JDM), Joint Product Development and Promotional Activities (JPDPA), Environmental Collaboration (EC), Stakeholder Pressure (SP). The different alternative chosen for the study are:

Coordination Alternative 1 (ALTR 1): Forward direction

Coordination Alternative 2 (ALTR 2): Reverse direction

Coordination Alternative 3 (ALTR 3): Circular direction

7.3.2 Graph Theory and Matrix Approach

Selection of CSC partner depends upon the number of attributes used in the selection process and the interdependency among them. GTMA is a simplified logical decision making approach. It is a matrix approach which consists of directional graphs depicting relationships among attributes. GTMA is used when there is larger number of nodes and it is difficult to analyze and compute the solution through other graphical techniques. In GTMA, digraph comprises of nodes and edges. These nodes serve as representations of attributes, while the edges depict the interaction between these selected attributes. The representation of the interrelationship among the attributes can take the form of a directional graph (digraph) or a matrix. Attribute refers to the criteria that determine the selection index for a specific problem. After the selection of attributes, a digraph representing the attributes and their interaction is framed. The quantity of nodes within the directed graph is equal to the quantity of attributes that have been selected for examination. Additionally, an edge or directed arrow showcases their respective significance. Based on the previous study of (Rao and Padmanabhan, 2006), a schematic framework is developed for the proposed study.

7.3.2.1 Development of digraph and matrix

The digraph's nodes and edges are denoted by $M=\{m_i\}$ and $E=\{e_{ij}\}$, respectively, with i=1, 2, 3...n. Each node M_i represents the i^{th} attribute/criteria for selecting an alternative, while e_{ij} represents the relative importance value of the i^{th} attribute over the j^{th} attribute. For example, if an arrow is directed from node 'i' to node 'j', this indicates that the i^{th} attribute is relatively more important than the jth attribute. On the other hand, if attribute 'j' is relatively more important than attribute 'i', the arrow or edge will be directed from node 'j' to node 'i', and the relative importance value will be denoted by 'e_{ji}'. The digraph's graphical representation facilitates the analysis of the attributes' relative importance. However, as the number of nodes increases, it becomes challenging to visualize the digraph, and it is therefore represented in matrix form.

The conversion of a directed graph into a square matrix results in a relative importance matrix, where the non-diagonal elements signify the significance of one attribute over the other. The importance of an attribute for a specific alternative is indicated by the diagonal elements of the relative importance matrix. As the matrix or directed graph can alter depending on the number of attributes considered for the analysis, a generalized permanent function is established instead of computing determinant of the matrix. One of the major drawbacks of computing determinant of a matrix is the loss of information owing to the presence of negative signs. Therefore, researchers usually prefer to utilize the permanent function value while selecting the best alternative for a suggested problem.

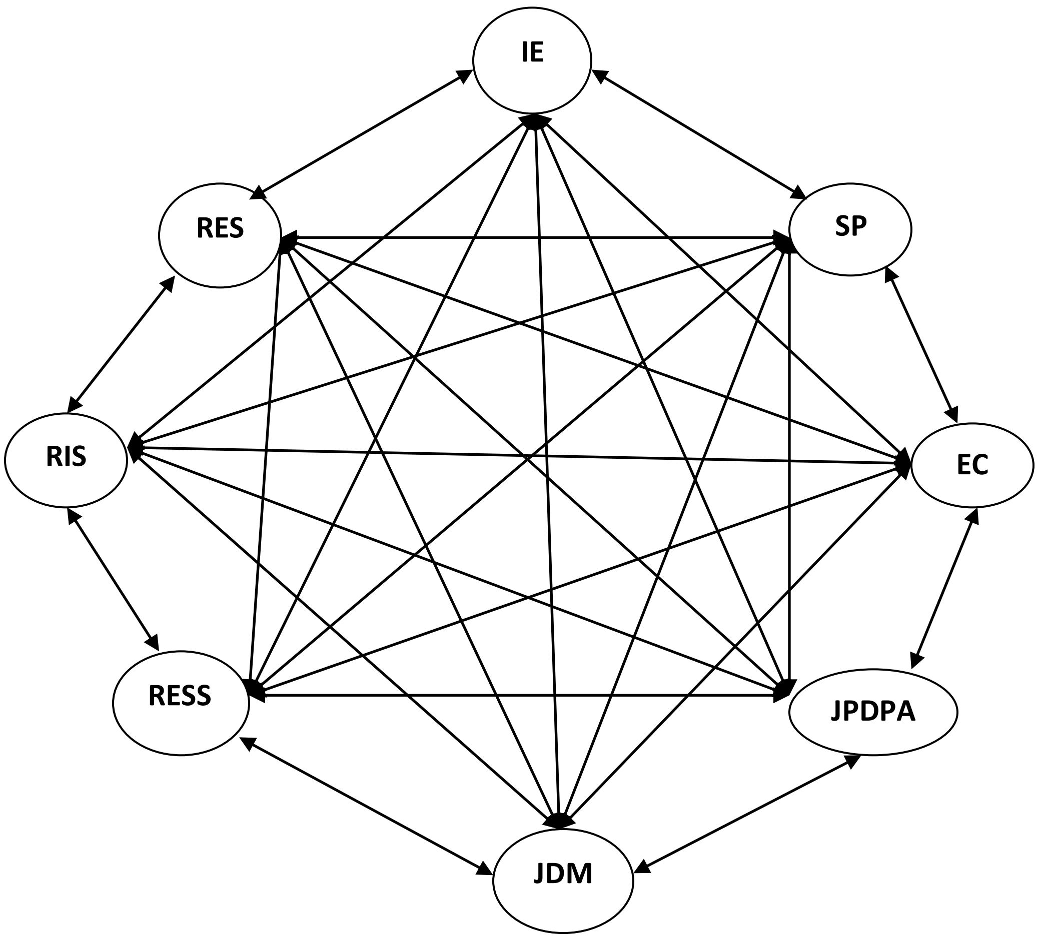

Fig. 7.6 Coordination attributes digraph

$$[C] = \begin{bmatrix} d_1 & c_{12} & c_{13} & c_{14} & c_{15} & c_{16} & c_{17} & c_{18} \\ c_{21} & d_2 & c_{23} & c_{24} & c_{25} & c_{26} & c_{27} & c_{28} \\ c_{31} & c_{32} & d_3 & c_{34} & c_{35} & c_{36} & c_{37} & c_{38} \\ c_{41} & c_{42} & c_{43} & d_4 & c_{45} & c_{46} & c_{47} & c_{48} \\ c_{51} & c_{52} & c_{53} & c_{54} & d_5 & c_{56} & c_{57} & c_{58} \\ c_{61} & c_{62} & c_{63} & c_{64} & c_{65} & d_6 & c_{67} & c_{68} \\ c_{71} & c_{72} & c_{73} & c_{74} & c_{75} & c_{76} & d_7 & c_{78} \\ c_{81} & c_{82} & c_{83} & c_{84} & c_{85} & c_{86} & c_{87} & d_8 \end{bmatrix}$$

In this study eight attributes have been selected to analyze the coordination outcome on the sustainability of supply chain. The selection of attributes is the result of an exhaustive literature survey, as well as fruitful discussions with industry and academia experts who possess extensive experience in the realm of sustainability. The attributes have already been discussed in Chapter 2 and are listed as Information Exchange (IE), Revenue Sharing (RES), Risk Sharing (RIS), Resource Sharing (RESS), Joint Decision Making (JDM), Joint Product Development and Promotional Activities (JPDPA), Environmental Collaboration (EC), Stakeholder Pressure (SP). Fig. 7.6 portrays the digraph for the eight attributes selected. It is difficult to visualize all the eight attributes on the digraph, therefore it is transformed into a 8X8 matrix [C] which represents the relative importance of each of the attributes. The diagonal elements of the matrix [C] are represented as d_{ij}, where i = j and non diagonal elements are represented c_{ij}, where i ≠ j. The values of the non diagonal elements remain same for all the alternatives whereas the values of the diagonal element of the matrix may change according to the alternatives considered for the study.

7.3.2.2 Permanent function

The permanent function of the matrix $[C]_{m\times m}$ can be computed using Eqn. 7.4:

$$\text{per(C)} = \prod_{i=1}^{m} d_i + \sum_i \sum_j \sum_k \ldots \sum_m (c_{ij}\, c_{ji}) d_k d_l \ldots d_m + \sum_i \sum_j \sum_k \ldots \sum_m (c_{ij}\, c_{ji} c_{ki} + c_{ik} c_{kj} c_{ji}) d_l d_m \ldots d_m + \Big(\sum_i \sum_j \sum_k \ldots \sum_m (c_{ij} c_{ji})(c_{kl} c_{lk}) d_m d_n \ldots d_m + \sum_i \sum_j \sum_k \ldots \sum_m (c_{ij}\, c_{jk} c_{kl} c_{li} + c_{il} c_{lk} c_{kj} c_{ji}) d_m d_n \ldots d_m\Big) + \Big(\sum_i \sum_j \sum_k \ldots \sum_m (c_{ij} c_{ji})(c_{kl} c_{lm} c_{mk} + c_{km} c_{ml} c_{lk}) d_n d_o \ldots d_m + \sum_i \sum_j \sum_k \ldots \sum_m (c_{ij}\, c_{jk} c_{kl} c_{lm} c_{mi} + c_{im} c_{ml} c_{lk} c_{kj} c_{ji})\, d_n d_o \ldots d_m + \cdots\Big) \tag{7.4}$$

The generalized equation of permanent function for a m×m matrix [C] as defined by (Forbert and Marx, 2003) can be written as:

$$\text{Per(C)} = \sum_p \prod_{i=1}^{n} c_i\,, P_i \tag{7.5}$$

where P_i represents permutation of i^{th} attribute.

To calculate the value of permanent function, Python was utilized as a programming language to write a generalized program for a m×m matrix [C]. Once the program is compiled the value of the matrix elements is entered according to the syntax. The software takes time to compute the permanent function value. The permanent function value is indicative of the coordination index for various alternatives. In order to ascertain the coordination index's value for selecting the best alternative, the subsequent step-by-step approach is elucidated below:

7.3.3 Case illustration and problem description

XYZ limited is one of the leading enterprises in the Indian electric vehicle (e-vehicle) manufacturing sector having its manufacturing plant in the National Capital Region (NCR), Gurugram, Delhi. The firm continuously strives to provide green and sustainable mobility solutions in India for over a decade. The organization endeavours to transform the mobility system of the country into a 'Zero emission' transportation system by launching a wide variety of e-vehicles in the country. XYZ limited is an ISO (International Organization for Standardization) 14000 certified organization that has well established environmental management system and is socially responsible to provide sustainable day to day business operations. The company has approximately 1200 employees and its net revenue was 3.2 million USD in the previous financial year. The firm has a huge market share of over 4 lakh customers with its presence in more than 25 states having 700 plus retail outlets all over the country. Recently, the company started partnering with other firms to provide best business solutions and increase their sustainability output in this sector.

Poor infrastructure in the e-mobility system is one of the major drawbacks that inhibit customers thinking to opt for e-vehicles. The company is not only focusing on producing e-vehicles but to build an infrastructure where the customers feel comfortable while moving through the e-mobility system. Therefore the company is working hard to partner with those organizations with whom they can provide the best possible e-mobility solutions and increase their market share. The major challenge the company is facing is to establish coordination with these partners. In order to overcome sustainability based challenges the company wants to identify whether the coordination needs to be established in the forward, reverse or circular direction. Therefore the proposed study uses these three directions as three alternatives in GTMA approach applied for the above mentioned problem. The selection attributes were finalized through exhaustive literature survey and through discussion with various experts from industry and academia. For assigning values to the relative importance matrix opinions from six different experts were gathered. Out of six experts, five were from industry and one from academia. All the experts fall under sustainability domain, whether it is sustainable business operations or sustainable supply chain management and all of them are having more than 20 years of experience. The experts are holding key positions in their respective organization and their valuable suggestion can definitely provide useful results.

7.3.4 Development of decision framework

Step 1: Identify the selection attributes/criteria's in order to determine the value of selection index for different alternatives. Based on comprehensive review of literature and discussion with experts, eight attributes were finalized. The attributes are reviewed in Table 2.9 and are listed as Information Exchange (IE), Revenue Sharing (RES), Risk Sharing (RIS), Resource Sharing (RESS), Joint Decision Making (JDM), Joint Product Development and Promotional Activities (JPDPA), Environmental Collaboration (EC), Stakeholder Pressure (SP). The different alternative chosen for the study are:

Coordination Alternative 1 (ALTR 1): Forward direction

Coordination Alternative 2 (ALTR 2): Reverse direction

Coordination Alternative 3 (ALTR 3): Circular direction

Step 2: Find out the relative importance of coordination attributes. The value of relative importance of coordination attributes is assigned according to the scale shown in Table 7.4. The scale shown in Table 7.4 is utilized to assign values to the non-diagonal elements of matrix [C]. Here, the expert opinions were taken to assign values to the non diagonal elements according to the various scales mentioned in Table 7.4. The responses were analyzed and similar values from experts were recorded. The values are displayed in matrix [A]. It is noteworthy that the non-diagonal elements possess identical values across all alternatives. The next step discusses the values of diagonal elements for different alternatives.

Table 7.4 Relative importance scale for attribute

Rationalization	c_{ij}	1- c_{ij}
Both the attributes are having same importance	0.5	0.5
One attribute (i) is having marginally more importance than the other attribute (j)	0.6	0.4
One attribute (i) is having high importance than the other attribute (j)	0.7	0.3
One attribute (i) is having very high importance than the other attribute (j)	0.8	0.2
One attribute (i) is having extremely high importance than the other attribute (j)	0.9	0.1
One attribute (i) is having exceptionally high importance than the other attribute (j)	1	0

Step 3: The third step involves allocation of value to the attributes of each coordination alternative. The values are allocated according to the scale shown in Table 7.5. For this purpose the experts were asked to select the suitable values which are represented by the diagonal elements of each coordination alternative. The assignment of values to the diagonal elements of all three coordination alternative was done by experts and these values are shown in Table 7.6.

$$[A] = \begin{bmatrix} d_1 & 0.7 & 0.5 & 0.5 & 0.7 & 0.5 & 0.2 & 0.1 \\ 0.3 & d_2 & 0.3 & 0.3 & 0.2 & 0.3 & 0.1 & 0.2 \\ 0.5 & 0.7 & d_3 & 0.5 & 0.4 & 0.5 & 0.4 & 0.5 \\ 0.5 & 0.7 & 0.5 & d_4 & 0.5 & 0.5 & 0.5 & 0.3 \\ 0.3 & 0.8 & 0.6 & 0.5 & d_5 & 0.5 & 0.4 & 0.3 \\ 0.5 & 0.7 & 0.5 & 0.5 & 0.5 & d_6 & 0.3 & 0.3 \\ 0.8 & 0.9 & 0.6 & 0.5 & 0.6 & 0.7 & d_7 & 0.5 \\ 0.9 & 0.8 & 0.5 & 0.7 & 0.7 & 0.7 & 0.5 & d_8 \end{bmatrix}$$

Table 7.5 Significance of attribute for each coordination alternative

Scale of significance	Value of d_i
Severely low	0.0
Extremely low	0.1
Very low	0.2

Low	0.3
Below average	0.4
Average	0.5
Above average	0.6
High	0.7
Very high	0.8
Extremely high	0.9
Exceptionally high	1.0

Table 7.6 Values of diagonal elements for each coordination alternative

Attribute	ALTR 1	ALTR 2	ALTR 3
Information Exchange (IE)	0.3	0.5	0.9
Revenue Sharing (RES)	0.2	0.3	0.7
Risk Sharing (RIS)	0.1	0.4	0.8
Resource Sharing (RESS)	0.4	0.3	0.7
Joint Decision Making (JDM)	0.3.	0.5	0.8
Joint Product Development and Promotional Activities (JPDPA)	0.5	0.2	0.6
Environmental Collaboration (EC)	0.4	0.6	0.8
Stakeholder Pressure (SP)	0.5	0.7	0.7

Step 4: The matrix [A] was utilized to record the values of the diagonal elements pertaining to every coordination alternative. This results in the formulation of three matrices for all three coordination alternative chosen for the study. These matrices are represented as follows:

$$[\text{ALTR 1}] = \begin{bmatrix} 0.3 & 0.7 & 0.5 & 0.5 & 0.7 & 0.5 & 0.2 & 0.1 \\ 0.3 & 0.2 & 0.3 & 0.3 & 0.2 & 0.3 & 0.1 & 0.2 \\ 0.5 & 0.7 & 0.1 & 0.5 & 0.4 & 0.5 & 0.4 & 0.5 \\ 0.5 & 0.7 & 0.5 & 0.4 & 0.5 & 0.5 & 0.5 & 0.3 \\ 0.3 & 0.8 & 0.6 & 0.5 & 0.3 & 0.5 & 0.4 & 0.3 \\ 0.5 & 0.7 & 0.5 & 0.5 & 0.5 & 0.5 & 0.3 & 0.3 \\ 0.8 & 0.9 & 0.6 & 0.5 & 0.6 & 0.7 & 0.4 & 0.5 \\ 0.9 & 0.8 & 0.5 & 0.7 & 0.7 & 0.7 & 0.5 & 0.5 \end{bmatrix}$$

$$[ALTR\ 2] = \begin{bmatrix} 0.5 & 0.7 & 0.5 & 0.5 & 0.7 & 0.5 & 0.2 & 0.1 \\ 0.3 & 0.3 & 0.3 & 0.3 & 0.2 & 0.3 & 0.1 & 0.2 \\ 0.5 & 0.7 & 0.4 & 0.5 & 0.4 & 0.5 & 0.4 & 0.5 \\ 0.5 & 0.7 & 0.5 & 0.3 & 0.5 & 0.5 & 0.5 & 0.3 \\ 0.3 & 0.8 & 0.6 & 0.5 & 0.5 & 0.5 & 0.4 & 0.3 \\ 0.5 & 0.7 & 0.5 & 0.5 & 0.5 & 0.2 & 0.3 & 0.3 \\ 0.8 & 0.9 & 0.6 & 0.5 & 0.6 & 0.7 & 0.6 & 0.5 \\ 0.9 & 0.8 & 0.5 & 0.7 & 0.7 & 0.7 & 0.5 & 0.7 \end{bmatrix}$$

$$[ALTR\ 3] = \begin{bmatrix} 0.9 & 0.7 & 0.5 & 0.5 & 0.7 & 0.5 & 0.2 & 0.1 \\ 0.3 & 0.7 & 0.3 & 0.3 & 0.2 & 0.3 & 0.1 & 0.2 \\ 0.5 & 0.7 & 0.8 & 0.5 & 0.4 & 0.5 & 0.4 & 0.5 \\ 0.5 & 0.7 & 0.5 & 0.7 & 0.5 & 0.5 & 0.5 & 0.3 \\ 0.3 & 0.8 & 0.6 & 0.5 & 0.8 & 0.5 & 0.4 & 0.3 \\ 0.5 & 0.7 & 0.5 & 0.5 & 0.5 & 0.6 & 0.3 & 0.3 \\ 0.8 & 0.9 & 0.6 & 0.5 & 0.6 & 0.7 & 0.8 & 0.5 \\ 0.9 & 0.8 & 0.5 & 0.7 & 0.7 & 0.7 & 0.5 & 0.7 \end{bmatrix}$$

Step 5: The determination of the permanent function value for each coordination alternative is computed through the input of matrix element values into a program that has been formulated on the Python programming language.

Step 6: The permanent function values/coordination index values for each of the coordination alternative is generated through Python programming language. The coordination alternatives are arranged according to the values of permanent function. These values are used for the selection of best coordination alternative and are arranged in ascending order. The values of coordination index for each coordination alternative are as follows:

Coordination index for coordination alternative-1 (ALTR-1) = 71.9433

Coordination index for coordination alternative-2 (ALTR-2) = 89.2606

Coordination index for coordination alternative-3 (ALTR-3) = 173.6

7.3.5 Result and discussion based on framework

The coordination index for alternative-1 that reflects the coordination achieved in the forward direction is having the least value, which means the coordination among the partners as we move downstream in the supply chain does not lead to the achievement of sustainability goals. Similarly if we move in the reverse direction, the coordination among the upstream partners will be slightly more significant in achieving the objectives of sustainability. However the coordination achieved among the members of circular supply chain (including forward as well as reverse supply chain) will significantly effect in achieving sustainability goals.

Past research on issues of coordination in supply chain have yielded similar results. De Giovanni (2017) found that environmental consciousness among the stakeholders and revenue sharing contracts could significantly align the motivation of supply chain (SC) members in closing the loop. He (2017) studied different supply risk sharing contracts for a closed loop supply chain (CLSC). The study incorporated game theory models to derive and analyze equilibrium equations for recycling price and quantity of remanufacturing for a CLSC model. The authors observed that supply risk reduction approaches may lead to the alignment of environmental and financial objectives while demand risk reduction approaches cannot lead to such alignments. Alamdar et al. (2018) examined both centralized and decentralized CLSC models. The authors found that joint decision making and collaboration among the members of SC could effectively establish coordination in decentralized CLSC and is favorable for both the customers and the supply chain as a whole. Zheng et al. (2019) investigated a three-echelon CLSC model consisting of manufacturer, distributer and retailer. The authors applied cooperative game approach to characterize interaction among different partners. The finding of the study revealed that equitable allocation of surplus profit satisfy collective rationality and fall in the core of cooperative game thereby making the entire coalition stable. Agrawal et al. (2022) explored the coordination gap in the circular business model of a two-echelon circular supply chain comprising of e-commerce and re-commerce companies. The authors applied game theory approach to investigate the coordination problem in centralized and decentralized model of circular supply chain. The findings reveal potentials for improvement in decentralized model and the results of the study show coordination contracts may affect channel decision and profits of SC members. Momeni et al. (2022) focused on coordination issue of a circular supply chain consisting of one manufacturer and one retailer with a novel buy back contract of regenerating expired products. The findings of the study reveal sharing of incentives and revenue on each unit of reused product leads to better coordination among the SC members and encourage them to adopt circular initiatives.

7.4 Concluding remarks

It can be inferred from the comprehensive analysis of existing literature, surveys, and a case study conducted within the Indian manufacturing sector that specific issues such as Risk Management and coordination decision-making significantly impact the performance of CSC. The study primarily concentrated on proposing decision-making frameworks for addressing these issues, utilizing Bayesian Network and Graph Theory and Matrix Approach methodologies. These research frameworks were meticulously formulated and subsequently exemplified through a case study involving a manufacturing firm operating within the Indian manufacturing domain. The outcomes and deliberations revolving around these frameworks were thoroughly examined. The deductions drawn from each of the frameworks are expounded upon in the subsequent sections.

A framework for risk management based on Bayesian Network theory was developed to generate risk profile of various CSC partners. The study is able to demonstrate how the risk is propagated across the CSC network, and the disruption caused at individual nodes of the network. Risk assessment in the supply chain is a dynamic process, so the objective of the research is to establish an index system that is dynamic in nature, reflecting every possible cause of disruption. The purpose of apprehending the word 'dynamic' with the index system is to show its flexible nature of adapting to the changing needs of business reality. The choice of risk measures should not only reveal the current status of the impact of CSC risk, but also predict the future changes in the trend of performance parameters. By incorporating the BN methodology for the model formulation, we are able to address this gap. An important advantage of using the BN methodology is that it gives an intuitive interpretation of the risk propagation across the network of the supply chain. Also, this methodology is based on the rigorous mathematical computational theory of determining probabilities of risk occurrence. The work of mathematical computation increases exponentially with the increase in the number of nodes.

The results of the study reveal that the reverse supply chain is more vulnerable to risk that is encountered during the implementation of the concept of circularity (Panjehfouladgaran and Lim, 2020). The findings also reveal a lack of preparedness, in terms of the risk identification, analysis and mitigation strategies that are required for the implementation of a novel concept of circularity during the phase of the pandemic. The findings of this study also bridge the gaps identified in the past literature, which directs the application of SCRM to an extended level (Lahane et al., 2020). The finding also supports the future research directions of the literature, mentioning the need of multi-tier SCRM study from the developing country context (Tukamuhabwa et al., 2017; Tummala and Schoenherr, 2011). From the industry viewpoint, the results of the study will help the managers and the practitioners better understand the impact of risk propagation across the network of the supply chain.

In the second framework, GTMA was employed for the selection of best coordination alternative as this approach comprehensively evaluates all the selection criteria and the interdependencies among them. The selection of coordination attributes is based upon comprehensive review of literature and collecting valuable expert opinions. A case of an electric vehicle manufacturing company was discussed where the firm is working hard to partner with those organizations with whom they can provide the best possible e-mobility solutions. The major challenge the company is facing is to establish coordination with these partners. In order to overcome sustainability based challenges the company wants to identify whether the coordination needs to be established in the forward, reverse or circular direction. Therefore the proposed study uses these three directions as three alternatives in GTMA approach applied for the above mentioned problem. The outcomes of the study indicate low value of coordination index for forward supply chain, which means the coordination among the partners as we move downstream in the supply chain does not lead to the achievement of sustainability goals. In case of reverse supply chain, the coordination among the upstream partners will be slightly more significant in achieving the objectives of sustainability. However the coordination among the members of circular supply chain (including forward as well as reverse supply chain) will significantly effect in achieving sustainability goals.

From the findings of the study, it can be concluded that sustainability cannot be attained individually rather it requires involvement of each individual partner to collectively work towards making supply chain sustainable. Coordination in supply chain plays a significant role in integrating different actors of SC to achieve sustainability goals. Implementing circular models in the supply chain can be a potential pathway to ecological sustainability. Circular business models require a high level of coordination among the SC partners. The interdependency among Circular supply chain partners is high as compared to those involved in forward or reverse supply chain. Lean and green practices should be adopted individually as well as in collective form to move towards the net-zero emission economy. The supply chain as a whole should coordinate together in efficiently utilizing the resources, adopting green technologies, eliminating non-value-added activities and minimizing wastage to reach net-zero targets.

CHAPTER 8

DEVELOPMENT OF CIRCULARITY FRAMEWORK FOR THE MANUFACTURING INDUSTRY

8.1 Introduction

The development of a Circularity Framework is essential to the attainment of sustainable development goals. The adoption of circular strategies is either at system level or product level. However, the exploration of circularity of material flow in case of developing economies is still limited in the existing literature. Therefore, this chapter aims to identify the circularity potential of non-ferrous materials like Aluminium extracted from the products. A case of the Indian Aluminium industry is considered in this chapter. In proposed study, the Markov Chain method is used as a stochastic modeling technique to explore the degree of circularity in the material flow analysis of aluminium through its various lifecycle stages. The novelty of this study is two-fold: (1) it gives an insight about the material movement in the circular supply chain depending upon its current state and the time during which it remains in the respective state, and (2) it also gives a brief idea about the circularity of metal flow at different stages such as recycling of Aluminium Circular Supply Chain.

The present academic research on CE covers a wide range of issues namely: drivers, barriers and practices (Agyemang et al., 2019; Govindan and Hasanagic, 2018), circular business models (Boons and Lüdeke-Freund, 2013; Hopkinson et al., 2018), circular strategies (Alamerew et al., 2020; Blomsma et al., 2019; Geissdoerfer et al., 2017), circular design (Desing et al., 2021; Moreno et al., 2016; Wastling et al., 2018); circular supply chain (CSC) (De Angelis et al., 2018; Genovese et al., 2017) and circular supply chain risk (Chhimwal et al., 2021; Ethirajan et al., 2020; Lahane and Kant, 2021). The current literature on CE shows increasing interest among researchers towards interdisciplinary aspects in achievement of circularity (Sauvé et al., 2016) and more stress is laid on the challenges in the implementation of CE principles (Buchert et al., 2013; Chhimwal et al., 2021a; Nasr et al., 2018). However, the exploration of circularity potential both at the product and system (micro, meso and macro) level is still lacking in the past literature related to CE (Afrinaldi, 2020). Therefore this study aims to explore the circularity potential of a product based on CE strategies.

8.2 Markov Chain Approach

To analyze the flow of Aluminium in a supply chain network, Markov Chain approach is used because the material flow across various states has a random probability distribution or pattern that could be analyzed statistically with the help of reliable data sources. Past literature shows that only few studies have applied the Markov method in the area of material lifecycle assessment and material flow analysis of products (Afrinaldi, 2020). Hu and Bidanda (2009) developed a decision support system for sustainable product lifecycle management based on stochastic modeling and dynamic programming. By applying this concept on a product line the author concluded that logic based decision making can be developed at every stage of the product life cycle. Liao et al. (2021) formulated a data-driven decision process framework based on a Discrete-Time Markov Chain (DTMC) model for optimized decision making of repair and replacement of medical equipment. Eckelman et al. (2012) presented a comprehensive modeling of the lifecycle analysis of a non-renewable resource, namely Nickel. The author incorporated Markov Chain (MC) modeling to keep a track of the amount of metal entering each cycle during its use phase. Yamada et al. (2006) developed a model based on MC methodology that can measure the mean number of times a material is said to enter the supply chain after completing each lifecycle. The author outlined that the value derived through MC method could be used to keep a check on environmental burden caused by the extraction of virgin material.

Based on the previous studies, it is inferred that the past literature only focused on the use phase of the material while applying MC method to life cycle assessment and material flow analysis. Past literature reflects that most of the time the MC model has been applied to keep a track of the material circulated during use phase of the product. While this study tries to capture the holistic viewpoint of the application of MC model so that other relevant circularity measures are predicted and explored. This model also gives an idea about how long the material stays in a particular state depending upon its current condition. As the material flow cycle consists of an absorbing state, therefore this study utilized absorbing MC method as an appropriate technique to analyze the flow of material through different stages.

8.2.1 Case illustration and problem description

In last decade manufacturing sector in India has seen a tremendous growth owing to the key government reforms like Make in India, Smart city initiative, focusing on urbanization and initiatives like Foreign Direct Investment (FDI). The expansion of manufacturing sector has resulted in further exploitation of natural resources and waste generation. The use of non-ferrous metals in the process of manufacturing has also increased due to high demand in automobile, construction and consumable products. The inherent characteristics of non-ferrous metals such as high recyclability, high tensile strength to weight ratio and high durability map with the circular economy attributes required in sustainable production and consumption model (Wang, 2016). There are a wide range of critical challenges such as under developed downstream industry, global competition and quality availability which are hampering the usage of non-ferrous metals in the Indian manufacturing sector (KPMG, 2016). One of the key challenge faced by the non-ferrous metals industry in India is its huge dependence on the import of metal scrap as cost becomes a major factor during the extraction of raw materials. Secondly, in India, recycling of scrap metal is mostly informal and under developed.

The Indian Aluminium industry is witnessing a rapid growth with its expansion both in the primary metal production and downstream aluminium-using industrial sectors. The demand and consumption of Aluminium in almost every sector is expected to rise, in continuation of the trend observed in the past (see Fig. 8.1). Aluminium consumption in India is estimated to increase from 3.3 million metric tonnes in 2020 to 5.3 million metric tonnes by 2025, an Compound Annual Growth Rate (CAGR) of 10.8%, well above the 2.2% world primary aluminium production CAGR observed from 2016 to 2020 (Reichl and Schatz, 2022). Looking at the huge consumption potential of Aluminium across various sectors, it’s contribution towards economic growth is significant. One of the special characteristics is that the quality of Aluminium does not deteriorate on being repeatedly recycled. The data provided by International Aluminium Institute (IAI) suggests that 75 percent of all Aluminium ever produced is still in productive use by virtue of its high durability and recycling properties. Globally, on an average three-fourth of the Aluminium used in cars, airplanes, building and consumable products is recycled (Payne, 2021). As Government of India (GOI) targets to achieve an annual GDP of 5 trillion dollars by 2025, there has to be a significant shift in the paradigm of metal usage. Over the next few years, as

India advances to meet its economic growth targets, the focus lies on adopting circular economy practices in Indian Aluminium industry as Aluminium demand is expected to rise significantly across various sectors (IBEF, 2023).

The total demand of Aluminium across different sectors in India has gone up from 1.9 million tonnes in 2015 to 3.7 million tonnes in 2020 and is expected to be somewhere up to 6 million tonnes by 2025 (Indian Bureau of Mines, 2022). Fig. 8.1 consists of bar graph depicting the consumption, primary production, secondary production and scrap import of Aluminium in India in million tonnes taken year-wise from 2012 to 2021. From the graph it is observed that over the last decade the primary production of Aluminum in India has sharply increased as compared to secondary production and thus has resulted in the exploitation of natural resources. Therefore, the gap between primary and secondary production can be reduced by the implementation of CE principles. There are two different methods to produce Aluminium. The first method is primary production wherein Aluminium is extracted from ores (bauxite) with the help of different refining processes and the other one is secondary production in which Aluminium is obtained through recycling of aluminium scrap obtained from end-of-life products. This study constitutes a simplified case illustration wherein due to insufficient data, the logistics operations are not considered during the formulation of the model.

According to the reports published by Indian Bureau of Mines (2022) and (CRISIL, 2021), at the national level, from 2012 to 2021, the total primary production of Aluminium is 27 million tonnes while the total secondary production is approximately 9.8 million tonnes. The total domestic consumption of Aluminium from 2012 to 2021 is approximately 32 million tonnes while the Aluminium scrap imported during this period accounted for 9 million tonnes. Assuming an average recycling rate of Aluminium in India to be 25 percent and 75 percent of Aluminium ever produced remains in usage, the problem is to forecast the probability percentage of material going to the landfill and those coming back into the value chain. Therefore, MC method is used in the study to analyze the flow of Aluminium through different material flow states. Aluminium is specifically chosen in this study as it is an ideal material for the circular economy due to its high recycling potential.

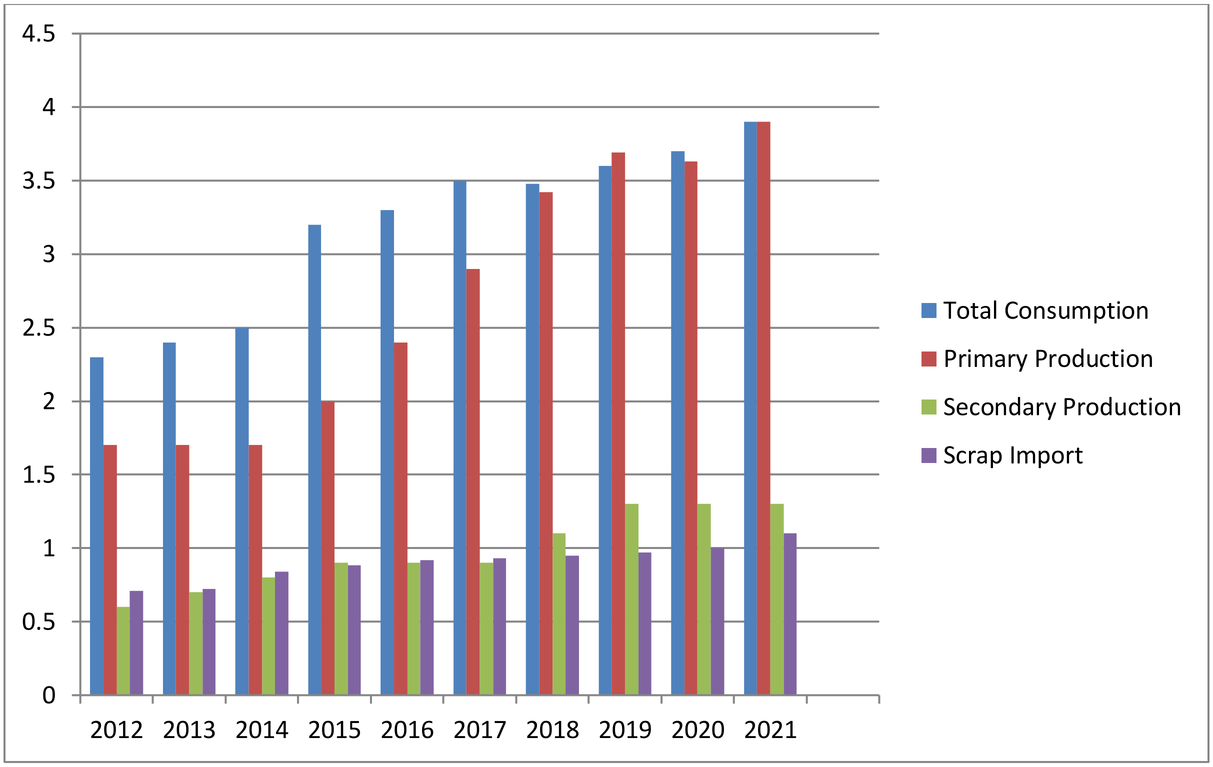

Fig. 8.1 India's Aluminium Consumption, Primary Production, Secondary Production & Scrap Import in million tonnes year-wise (Indian Bureau of Mines, 2022)

8.2.2 Model assumption

- Markov chain is used for modeling the material flow in a circular network of supply chain as the material movement to the next state solely depends on the immediate preceding state. Let us assume, the EoL stage (disposal or recycling) is solely based on its consumption stage and the material movement towards the customer primarily relies on the recycling or production stage. Accurate prediction can be made using MC model if the movement of the material is steady. Therefore, while using MC modeling technique to analyze the circularity of Aluminium, this study assumes that the amount of Aluminium circulated in the Indian economy is constant over a long time span.
- Let Hs represent the material history upto time 's'. This parameter contains information about the states the material has gone through from it's initial state ($t = 0$) upto time ($t = s$). A Markov process can be considered as a Stochastic process, if for all s, $t \geq 0$, for all possible history Hs and all non-negative integers i, j

$$Pr(Y(t + s) = j \mid Y(s) = i \cap H_s) = Pr(Y(s + t) = j \mid Y(s) = i) \tag{8.1}$$

If, the probability $Pr(Y(s + t) = j \mid Y(s) = i)$ does not depend on time s, that means the transition probabilities of the process are stationary and the equation can be rewritten as

$$P_{ij} = Pr(Y(s + t) = j \mid Y(s) = i) \tag{8.2}$$

From Eqn. 8.2 it can be inferred that if a system is in state i at time s, then probability of the system being in state j at time 's+t' is independent of the time 's'. Markov chain can be considered as a stationary transition process if the transition probability occurring in one step does not change with respect to time. The transition probability of one step must fulfill the following conditions:

$$P_{ij} \geq 0$$

$$\sum_j Pij = 1$$

The one step transition probability matrix (TPM), P contains the one step transition probabilities and is shown as:

$$P = \begin{bmatrix} P_{11} & P_{12} \dots & P_{1n} \\ P_{21} & P_{22} \dots & P_{2n} \\ \vdots & & \vdots \\ P_{n1} & P_{n2} \dots & P_{nn} \end{bmatrix} \tag{8.3}$$

- There are two types of processes which can generally be related to the flow of a material. One that is cyclic in nature and the other which is absorbed after certain time period. The processes in a MC, which comes to an end after a particular time are represented as absorbing states. If material flow is seen as a stochastic process, then some of the stages are classified as absorbing states, such as landfill. Because once the material enters the absorbing states, its movement to other states is restricted. Stages like production, consumption and recycling are considered as transient states, because material movement is possible through these states.

8.2.3 Model formulation

To construct a Markov model for analyzing the circular flow of material, we consider certain stages through which the material flows. Let us denote these stages as a set of variables representing state space model as S = {1, 2,…,x, x + 1,…,x + y}, where x and y represent the number of transient and absorbing states respectively. The length of S represents the depth of information gathered from the Markov Model.

Absorbing Markov Chain

If it is impossible to leave a particular state i of a Markov Chain then this state will be regarded as an absorbing state, .i.e.

$$P_{ii} = P(X_{n+1} = X_i \mid X_n = X_i) = 1 \tag{8.4}$$

A Markov Chain is said to be an absorbing chain if

- There is atleast one absorbing state (there can be more than one absorbing state also).
- Movement from any state to atleast one absorbing state is possible in a finite number of steps.

A Markov chain containing an absorbing state is not the only and sufficient condition for the chain to be called as Absorbing Markov Chain (AMC). It must also comprise of states that eventually reach an absorbing state with probability equal to 1. The states which are not absorbing are called transient states. Hence, in an AMC, there are absorbing states or transient states. Now there are certain questions that need to be answered while we study an AMC. Some common questions that should be addressed about such a chain are

1. What will be the probability of the material reaching an absorbing state?
2. The average number of times the material will remain in each transient state?
3. On an average, what is the time taken by the material to get absorbed?

To answer all the above questions, we need to first represent the TPM of the given absorbing DTMC (or the generator matrix of the absorbing DTMC) in a particular form, called as canonical form. An arbitrary absorbing DTMC is considered. The states are renumbered so that transient states come first. If there are 'x' transient states and 'y' absorbing states, then the TPM will have the following canonical form.

$$P = \begin{bmatrix} Q_{x\times x} & | & R_{x\times y} \\ - & | & - \\ 0_{y\times x} & | & \mathrm{I}_{y\times y} \end{bmatrix}$$

First 'x' states are transient and last 'y' states are absorbing. Here '0' is an y×x zero matrix. Now, the transition matrix, P is constructed in the next step (see Eqn. 8.5). Matrix, P comprises of all the transient and absorbing states. All the absorbing states are located at the south and east corner of matrix, P. P_{ij} represents the probability of transition from state 'i' to state 'j'. If state '1' represents Fabrication phase and state '2' represents Assembly phase, then P_{12} represents the probability of the material moving from the 'Fabrication' phase to 'Assembly' phase. Based on previous studies, (Duchin & Levine, 2010; Pillai & Chandrasekharan, 2008), by modifying the matrix elements of Q and R several useful predictions can be made. The first prediction is the expected time the material remains in state 'j' given that the immediate preceding state is 'i' which is represented by E_{ij} and computed using Eqn. 8.6. T_j is the average time spent by the material in state 'j' and I is the identity matrix.

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & | & p_{1x+1} & \cdots & & p_{1x+y} \\ p_{21} & p_{22} & \cdots & | & p_{2x+1} & \cdots & & p_{2x+y} \\ \cdots & \cdots & \cdots & | & \cdots & \cdots & & \cdots \\ p_{x1} & \cdots & p_{xx} & | & p_{xx+1} & \cdots & & p_{xx+y} \\ - & - & - & | & - & - & & - \\ 0 & \cdots & 0 & | & 1 & 0 & \cdots & 0 \\ 0 & \cdots & 0 & | & 0 & 1 & 0 & 0 \\ \vdots & \cdots & \vdots & | & \vdots & 0 & \ddots & 0 \\ 0 & \cdots & 0 & | & 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} Q & | & R \\ - & | & - \\ 0 & | & \mathrm{I} \end{bmatrix} \tag{8.5}$$

$$E_{ij} = \text{element } (i,j) \text{ of } (I - Q)^{-1} \times T_j \tag{8.6}$$

Let us now focus on the n-step TPM of the given absorbing DTMC, P^n. A standard matrix algebra argument shows that

$$P^n = \begin{bmatrix} Q^n & | & * \\ - & | & - \\ 0 & | & \mathrm{I} \end{bmatrix}$$

where '*' is some complicated expression not required. Here the entries of the sub-matrix Q^n, say Q^n_{ij}, the probability of being in transient state j after n steps given that the initial state was transient state i. Now since the chain is an absorbing chain, in long run, as n→∞, the chain will be eventually absorbed in one of the absorbing states, and hence the probability of being in any of the transient states after n steps approaches zero as $n \to \infty$. That is, as $n \to \infty$, $Q^n \to 0$. Thus every entry of Q^n must approach zero as n approach infinity.

Fundamental Matrix:

'Starting from a transient state i the expected number of visits made to a transient state j before being absorbed' is one of the basic properties that characterize an absorbing DTMC. The (i,j) entry of Q^k denotes the probability of transitioning from i to j in exactly 'k' steps. The fundamental matrix, N can be computed by taking the summation for all 'k' from 0 to ∞. Further it is stated that

$$N = \sum_{k=0}^{\infty} Q^k = [I_x - Q]^{-1} \quad (8.7)$$

where I_x is $x \times x$ Identity matrix. With the fundamental matrix N in hand, we can now obtain other properties of an absorbing DTMC as discussed below:

Absorption probabilities: Matrix 'A' denotes the Absorption Probability Matrix. The $(i,j)^{th}$ entry of the matrix 'A' correspond to the probability of being absorbed in the absorbing state j, when starting from transient state i. From the CE perspective, the probabilities of absorption can be referred as the likelihood of material moving to those states that do not constitute a cycle such as land-filling. Elements of Matrix 'A' represents the probabilities of absorption which is computed using Eqn. 8.8.

$$A = (I - Q)^{-1}R \quad (8.8)$$

The material going to the absorbing state (land-filled) and the average amount of material flowing through a particular state can easily be calculated if the initial conditions are known, such as the average amount of material produced or consumed. These estimates can be computed using Eqn. 8.9 and 8.10. In the equations, U, W and P_o are the row vectors representing average amount of material being absorbed, the expected amount of material visiting a particular state and the average quantity of material being produced respectively.

$$W = P_o(I - Q)^{-1} \quad (8.9)$$

$$U = P_o * A \quad (8.10)$$

Time to absorption: As we are dealing with discrete time chains, 'time' here is equivalent to number of steps. Now we address this question: On an average, what is the time taken by the material to get absorbed given that the chain starts in state i ? The answer is stated as below.

The time taken by the material when starting from state 'i' before being absorbed is the i^{th} entry of the vector $\vec{t}$ =N.$\vec{1}$, here $\vec{1}$ is a column vector of length 't' whose entries are all 1.The material in any of the transient state for a given starting state i can easily be estimated by adding all the entries in the i^{th} row of N. Therefore, the time to absorption 't_i' can easily be approximated by adding all the entries of the i^{th} row of N.

8.3 Results and Discussion

According to the reports of Indian Bureau of Mines (2022) and CRISIL (2021), the total Aluminium production of India (primary as well as secondary) from the year 2012 to 2021 was approximately 36.8 million tonnes. Aluminium is produced either by raw extraction through ores or through recycling of production waste ("primary recycling") and discarded end-of-life products ("secondary recycling"). The aluminium production from bauxite ores resulted in the production of 27 million tonnes of Aluminium from the year 2012 to 2021, while the Aluminium generated through recycling accounts for 9.8 million tonnes. The Aluminium consumed during the process of fabrication accounted for 32 million tonnes from 2012 to 2021 and rest of the aluminium is treated as production waste which can be recycled. Now, the Aluminium bearing products can either be kept in the value chain, by extending their use phase thanks to one or several of the 4R processes, or secondary Aluminium can be recovered from end-of-life products via recycling. The total waste includes production waste (primary waste) and that generated from end-of-life products (secondary waste). Fig. 8.2 shows the sequence of states for Aluminium flow constituting the entire material flow analysis.

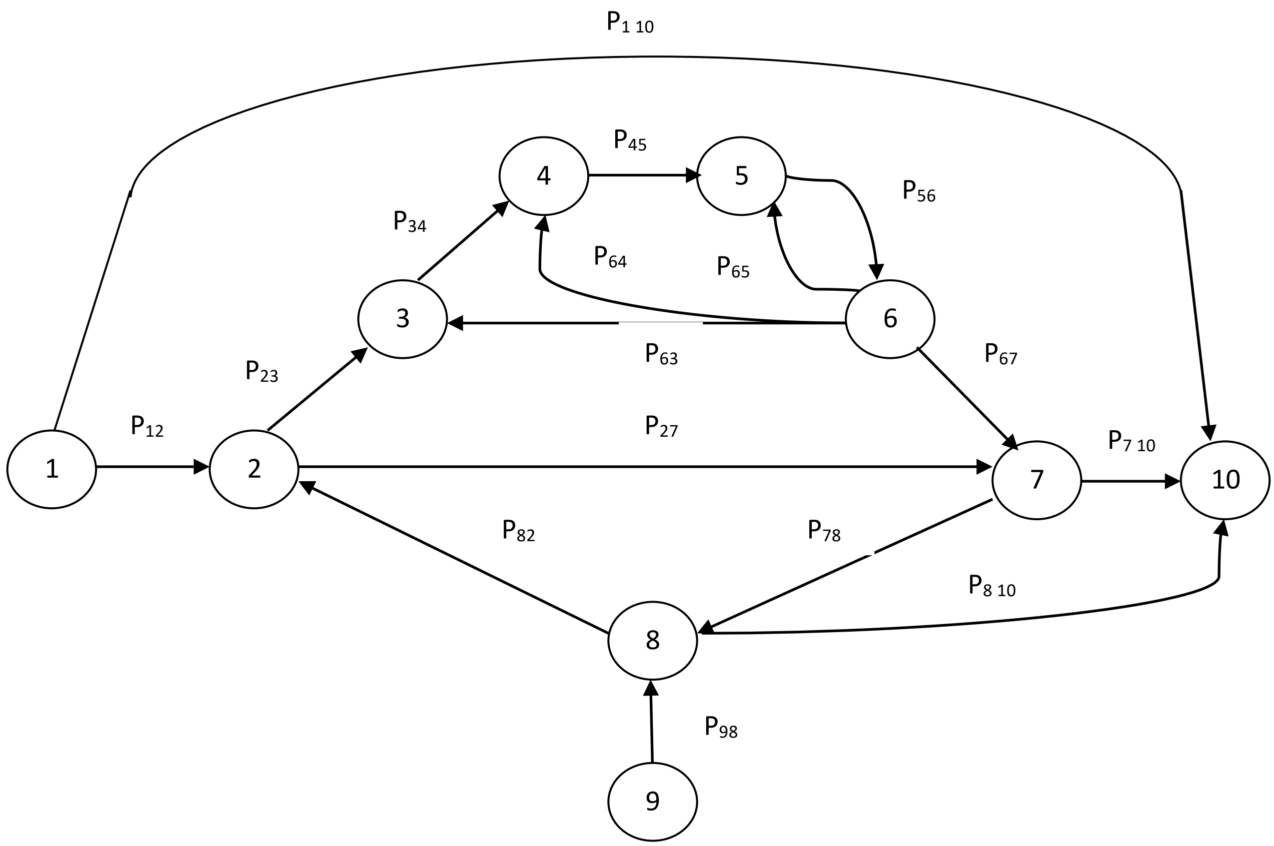

Fig. 8.2. Material Flow Analysis (MFA) of Aluminium

Now let's define state '1' as 'raw extraction', '2' as 'Production', '3' as 'Development or Fabrication', '4' as 'Assembly', '5' as 'Usage', '6' as 'Discard', '7' as 'Waste','8' as 'Recycling','9' as 'Scrap Import' and '10' as 'Landfill'. Therefore, the set of states constituting S= {1,2,3,4,5,6,7,8,9,10}. Here there are nine transient states {1,2,3,4,5,6,7,8,9} and one absorbing state {10}. The transition matrix, P is represented as

$$P = \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} & P_{15} & P_{16} & P_{17} & P_{18} & P_{19} & P_{1\,10} \\ P_{21} & P_{22} & P_{23} & P_{24} & P_{25} & P_{26} & P_{27} & P_{28} & P_{29} & P_{2\,10} \\ P_{31} & P_{32} & P_{33} & P_{34} & P_{35} & P_{36} & P_{37} & P_{38} & P_{39} & P_{3\,10} \\ P_{41} & P_{42} & P_{43} & P_{44} & P_{45} & P_{46} & P_{47} & P_{48} & P_{49} & P_{4\,10} \\ P_{51} & P_{52} & P_{53} & P_{54} & P_{55} & P_{56} & P_{57} & P_{58} & P_{59} & P_{5\,10} \\ P_{61} & P_{62} & P_{63} & P_{64} & P_{65} & P_{66} & P_{67} & P_{68} & P_{69} & P_{6\,10} \\ P_{71} & P_{72} & P_{73} & P_{74} & P_{75} & P_{76} & P_{77} & P_{78} & P_{79} & P_{7\,10} \\ P_{81} & P_{82} & P_{83} & P_{84} & P_{85} & P_{86} & P_{87} & P_{88} & P_{89} & P_{8\,10} \\ P_{91} & P_{92} & P_{93} & P_{94} & P_{95} & P_{96} & P_{97} & P_{98} & P_{99} & P_{9\,10} \\ P_{10\,1} & P_{10\,2} & P_{10\,3} & P_{10\,4} & P_{10\,5} & P_{10\,6} & P_{10\,7} & P_{10\,8} & P_{10\,9} & P_{10\,10} \end{bmatrix} = \begin{bmatrix} Q & | & R \\ - & | & - \\ 0 & | & \mathrm{I} \end{bmatrix}$$

$$
P = \left[\begin{array}{ccccccccc|c}
0 & 0.7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.3 \\
0 & 0 & 0.87 & 0 & 0 & 0 & 0.13 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0.25 & 0.25 & 0.25 & 0 & 0.25 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.33 & 0 & 0.67 \\
0 & 0.25 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.75 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
\hline
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1
\end{array}\right]
= \left[\begin{array}{c|c}
Q & R \\
\hline
0 & I
\end{array}\right]
$$

To compute the value of $(I - Q)^{-1}$, we first need to calculate the value of $(I - Q)$. $(I - Q)^{-1}$ is the fundamental matrix of size 9×9, represented by 'N'.

$$
I - Q = \begin{bmatrix}
1 & -0.7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & -0.87 & 0 & 0 & 0 & -0.13 & 0 & 0 \\
0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 & 0 \\
0 & 0 & -0.25 & -0.25 & -0.25 & 1 & -0.25 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & -0.33 & 0 \\
0 & -0.25 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -1 & 1
\end{bmatrix}
$$

$$
N = (I - Q)^{-1} = \begin{bmatrix}
1 & 0.76 & 1.33 & 1.99 & 2.66 & 2.66 & 0.76 & 0.25 & 0 \\
0 & 1.09 & 1.90 & 2.84 & 3.79 & 3.79 & 1.09 & 0.36 & 0 \\
0 & 0.09 & 2.16 & 3.23 & 4.31 & 4.31 & 1.09 & 0.36 & 0 \\
0 & 0.09 & 1.16 & 3.23 & 4.31 & 4.31 & 1.09 & 0.36 & 0 \\
0 & 0.09 & 1.16 & 2.23 & 4.31 & 4.31 & 1.09 & 0.36 & 0 \\
0 & 0.09 & 1.16 & 2.23 & 3.31 & 4.31 & 1.09 & 0.36 & 0 \\
0 & 0.09 & 1.16 & 0.23 & 0.31 & 0.31 & 1.09 & 0.36 & 0 \\
0 & 0.27 & 0.47 & 0.71 & 0.95 & 0.95 & 0.27 & 1.09 & 0 \\
0 & 0.27 & 0.47 & 0.71 & 0.95 & 0.95 & 0.27 & 1.09 & 1
\end{bmatrix}
$$

The first row of 'N' indicates the expected number of visits made by the material (Aluminium) at various stages given that the chain started at the raw extraction stage. From the matrix it can be noted that, the extraction stage is visited once, production and waste state is visited 0.76 times, fabrication and assembly is visited 1.33 and 1.99 times respectively, use phase and discard stage is visited 2.66 times and recycling is visited only 0.25 times. The material (Aluminium) visits the production and waste state less than one because there are inevitable losses during extraction and recycling of material. Very low percentage of raw material goes to the recycling stage which shows lack of infrastructure for recycling and unorganized scrap collection methods. Secondly, it can be observed that if the material starts at the recycling stage, very less percentage of the material reaches the production state which shows lack of recycling facilities within the country. The secondary aluminium is recycled again as can be seen from the expected number of visits made to the recycling stage.

Now the next step is to find the elements of matrix A also called absorption probability matrix. To find the elements of matrix A, refer to equation 6 given in the previous section. From the canonical form R can be represented as a matrix of size 9×1 where there are 9 transient states and 1 absorbing state.

$$A = (I - Q)^{-1}R = \begin{bmatrix} 1 & 0.76 & 1.33 & 1.99 & 2.66 & 2.66 & 0.76 & 0.25 & 0 \\ 0 & 1.09 & 1.90 & 2.84 & 3.79 & 3.79 & 1.09 & 0.36 & 0 \\ 0 & 0.09 & 2.16 & 3.23 & 4.31 & 4.31 & 1.09 & 0.36 & 0 \\ 0 & 0.09 & 1.16 & 3.23 & 4.31 & 4.31 & 1.09 & 0.36 & 0 \\ 0 & 0.09 & 1.16 & 2.23 & 4.31 & 4.31 & 1.09 & 0.36 & 0 \\ 0 & 0.09 & 1.16 & 2.23 & 3.31 & 4.31 & 1.09 & 0.36 & 0 \\ 0 & 0.09 & 1.16 & 0.23 & 0.31 & 0.31 & 1.09 & 0.36 & 0 \\ 0 & 0.27 & 0.47 & 0.71 & 0.95 & 0.95 & 0.27 & 1.09 & 0 \\ 0 & 0.27 & 0.47 & 0.71 & 0.95 & 0.95 & 0.27 & 1.09 & 1 \end{bmatrix} \begin{bmatrix} 0.3 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0.67 \\ 0.75 \\ 0 \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}$$

From the elements of matrix A, it can be inferred that irrespective of the material being in any of the state, it is most likely that the material goes to the landfill after completing its average useful life. This shows lack of circular initiative being adopted after the product has been discarded. Also due to lack of recycling facilities and insufficient reverse logistics activities being adopted, there are material losses occurring at each of the transient states.

Another measure that can be computed using the Fundamental Matrix N, is the time to absorption. Since we have considered a discrete time chain here 'Time to absorption' is the expected number of steps (number of cycles) taken by the material before being absorbed. We now answer the question: Given that the material starts at state 'i', what is the expected number of steps before being absorbed. For that we need to compute the vector $\vec{t}$ =N.$\overrightarrow{1}$, where $\overrightarrow{1}$ is a column vector of length't' whose entries are all 1.

$$\vec{t} = \text{N}.\vec{1} = \begin{bmatrix} 1 & 0.76 & 1.33 & 1.99 & 2.66 & 2.66 & 0.76 & 0.25 & 0 \\ 0 & 1.09 & 1.90 & 2.84 & 3.79 & 3.79 & 1.09 & 0.36 & 0 \\ 0 & 0.09 & 2.16 & 3.23 & 4.31 & 4.31 & 1.09 & 0.36 & 0 \\ 0 & 0.09 & 1.16 & 3.23 & 4.31 & 4.31 & 1.09 & 0.36 & 0 \\ 0 & 0.09 & 1.16 & 2.23 & 4.31 & 4.31 & 1.09 & 0.36 & 0 \\ 0 & 0.09 & 1.16 & 2.23 & 3.31 & 4.31 & 1.09 & 0.36 & 0 \\ 0 & 0.09 & 1.16 & 0.23 & 0.31 & 0.31 & 1.09 & 0.36 & 0 \\ 0 & 0.27 & 0.47 & 0.71 & 0.95 & 0.95 & 0.27 & 1.09 & 0 \\ 0 & 0.27 & 0.47 & 0.71 & 0.95 & 0.95 & 0.27 & 1.09 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} = \begin{bmatrix} 11.41 \\ 14.87 \\ 15.56 \\ 14.56 \\ 13.56 \\ 12.56 \\ 2.56 \\ 4.72 \\ 5.72 \end{bmatrix}$$

Considering the product material is initially present in state 'i', each individual value of column vector $\vec{t}$ corresponds to the estimated number of cycles of material flow before being absorbed in the absorbing state. Here in this study, we have considered 'landfill' as the absorbing state. The computed values of column vector $\vec{t}$ provide some interesting facts. It is observed that Aluminium embedded during the fabrication and development of product remains for the longest duration in the material flow cycle before going to the landfill. Aluminium that is produced either through primary or secondary production methods remains for the second longest duration in the material circulating cycle. While the Aluminium which is considered as 'waste' (having low recycling potential) remains for the shortest duration in the material flow cycle. The reducing trend in the circularity as we move downstream in the supply chain from production to consumption reflects lack of circular initiatives adopted at each of the stage of material flow.

In order to forecast the average amount of Aluminium visiting each of the material flow states, the average of the total Aluminium production of last ten years from 2012 to 2021 is considered as the initial condition. Out of 3.78 million tonnes of the average amount of Aluminium produced (primary as well as secondary production) in India from the year 2012 to 2021, the average amount of Aluminium that visits the product development, usage and recycling stage can be estimated using equation 7. By utilizing equation 8, the quantity of Aluminium that will be considered as wastage (having low recycling potential) can be estimated. Both these results are presented in Table 8.1.

Table 8.1 Average amount of Aluminium visiting each of the material flow stage

Material flow Stage	Average Quantity (million tonnes)
Product development or fabrication	7.18
Usage	14.32

Recycling	1.36
Wastage	3.78

Based upon the information provided in Table 8.2, the expected time the material remains in usage state from each of the market sector can be estimated using equation 5 given as

$$E_{ij} = \text{element } (i,j) \text{ of } (I - Q)^{-1} \times T_j$$

The expected time Aluminium remains in 'usage' state in the automotive sector given that 'assembly' is the immediate preceding state is computed as element (4,5) of $(I\text{-}Q)^{-1} \times T_5 = 4.31 \times 15 = 65$ years, where T_5 is the average time spent in the usage state, which is the fifth state in the material flow cycle. The complete results are shown in Table 8.2.

Table 8.2 Average and Expected time Aluminium remains in usage state of various sectors.

Market sector	**Average time spent (years)**	**Probability factor**	**Expected Usage Time (years)**
Automotive	15	4.31	65
Packaging	1	4.31	4.3
Building & Construction	30	4.31	130
Engineering	20	4.31	86
Others	10	4.31	43

Average and expected useful lifespan of aluminium in various sectors is shown in the form of bar graph in Fig. 8.3. The colossal difference between the average and expected usage period of Aluminium across various sectors is due to the consideration of circular movement of material in the Markov model which resulted in a larger value of probability multiplication factor. The expected usage time across various market sectors could only be achieved if circular initiatives are adopted at each of the intermediate material flow states.

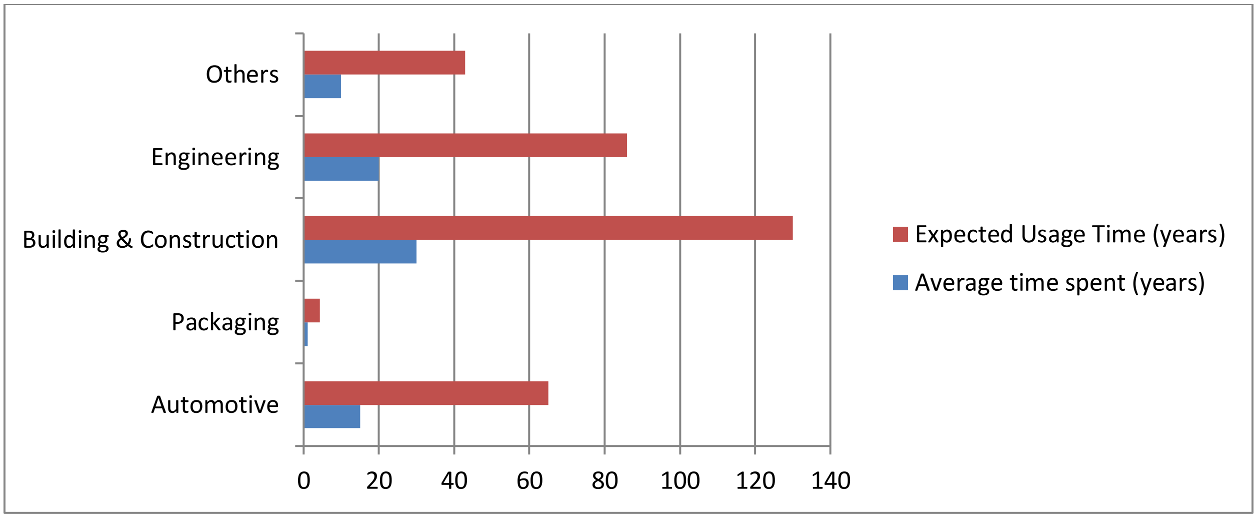

Fig. 8.3 Average and Estimated usage span of Aluminium across various sectors

8.4 Concluding remarks

This study is able to demonstrate the circularity potential of Aluminium for the non ferrous metal industry in the context of developing economy. Globally, the second most used metal after iron is Aluminium. India stands at third position in the world in terms of Aluminium consumption with an average annual usage of 3.3 million tonnes per year. In order to meet such a huge demand of this crucial metal in the near future, there is need to adopt such initiatives which create balance between the supply and demand. Implementing Circular Economy approach may lead to the reduction in the wastage of the metal and could enhance the value chain operations over the entire product lifecycle. The study constitutes a scientific methodology to assess supply chains on the basis of process know-how, providing science-based, policy relevant findings in support of the collection, processing and value addition. In order to make India self reliant in terms of production of Aluminium certain circular initiative need to be adopted at all levels and across all sectors. Higher consumption of Aluminium leads to large amount of scrap generation. Reuse and recycling of metal scrap is important in order to address the issue of limited availability of raw material, elevated prices of metal and growing environmental concerns. Since Aluminium is a crucial metal its economic contribution in the creation of wealth and Gross Domestic Product (GDP) of the nation is significant. Adopting circular initiatives can bring major sociological transformation and creation of jobs at all levels of supply chain.

From the strategic perspective, this study is able to demonstrate how a critical metal, Aluminium, can be made available in secondary form when primary resource is scarcely available. Implementing circular initiatives in the supply chain can reduce the import of metals and alloys and promote export of value added products through recycling and reuse. Policies on recycling of metal scrap are framed and refined by the Government but its implementation at the ground level is still missing due to lack of coordination among the key stakeholders. Therefore, the government, industry and the consumers need to collectively work to improve the recycling potential of non ferrous metal industry.

CHAPTER 9

CONCLUSION AND FUTURE RESEARCH DIRECTIONS

9.1 Introduction

In recent years, there has been a growing interest in circular supply chains (CSC) as a solution to the challenges of sustainable production and consumption in developing countries. This study focuses on the Indian manufacturing sector, exploring current practices, challenges, and risks associated with the adoption of circular economy (CE) principles. Through a survey, hypotheses were tested using the Likelihood Ratio Test, revealing a positive association between CE practices and performance. Key challenges were identified and analyzed using fuzzy-DEMATEL, and risk propagation was examined in a CSC network using Bayesian Network methodology. The study highlights the importance of coordination among stakeholders and the role of management in achieving circularity. It also assesses the circularity potential of non-ferrous materials like aluminum using the Markov Chain methodology. The findings aim to assist industrialists, academicians, and researchers in effectively implementing CSC, contributing to sustainable development goals.

9.2 Synthesis of the work done

The study has concentrated on the theoretical advancement of CSC, with the objective of pinpointing the factors that impact the execution and effectiveness of CSC in the Indian manufacturing sector. The investigation has delved into specific CSC concerns through a combination of qualitative and quantitative research methods, utilizing surveys, case studies, as well as development models and decision frameworks. The culmination of the research is depicted in Fig. 9.1 and outlined in the subsequent sections.

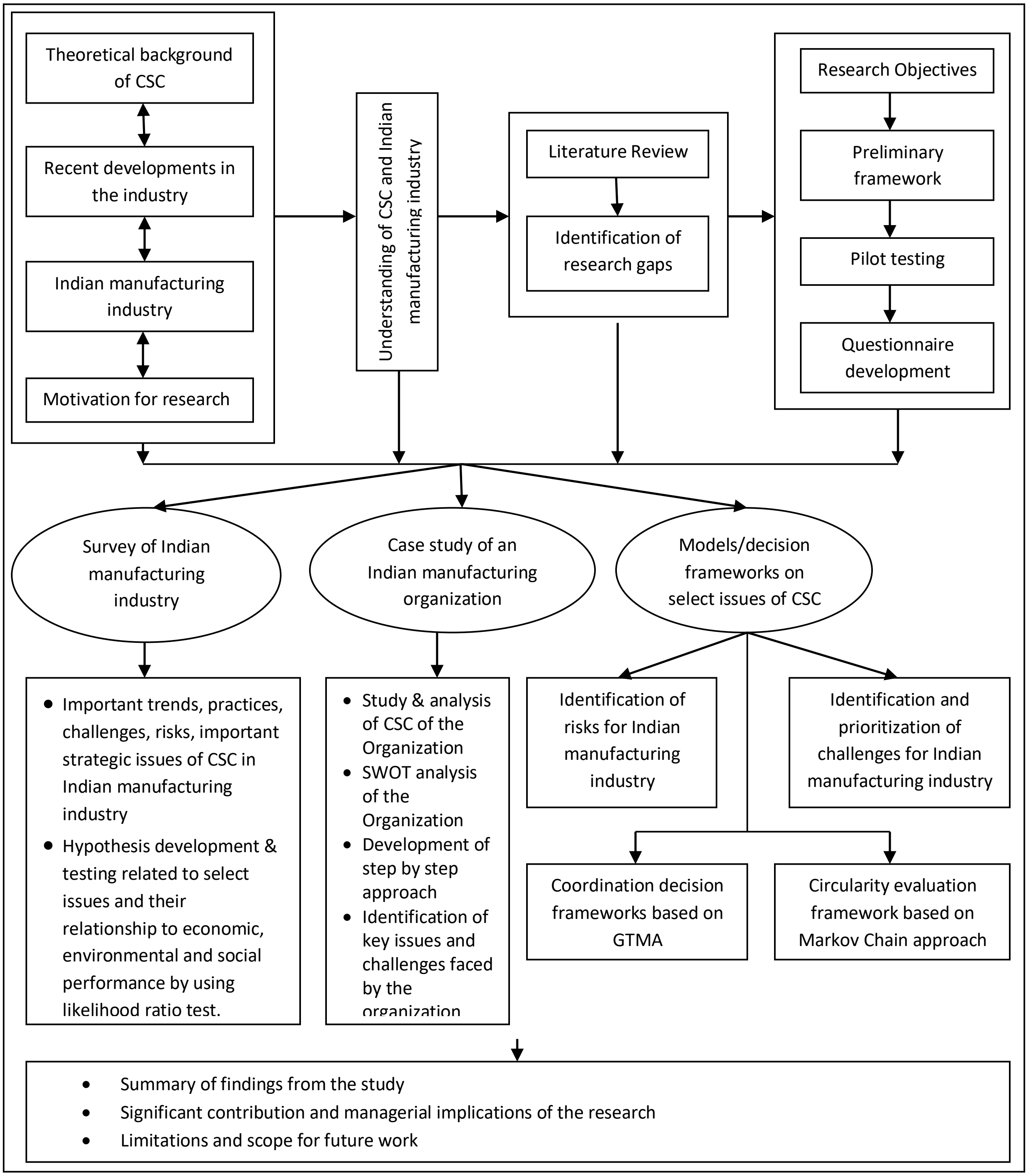

Fig. 9.1 Synthesis of the work done

This study comprehensively reviews the literature on circular economy (CE), identifying research gaps and establishing a transition framework for the Indian manufacturing sector. Utilizing surveys and case studies, it explores crucial issues and performance indicators, ensuring reliability and validity through extensive data collection and pilot studies. Key challenges were prioritized using the Fuzzy-DEMATEL technique, and hypotheses were tested to assess their impact on the economic, social, and environmental performance of circular supply chains (CSC) using the Likelihood Ratio Test method. The study also analyzed a leading Indian automobile manufacturer to identify CSC issues and challenges through a systematic case study approach.

Furthermore, Pareto analysis and fuzzy logic were employed to rank challenges and establish causal relationships, while Bayesian Network methodology was used to develop a risk assessment framework, illustrating risk propagation across the CSC network. The study examined the circularity potential of non-ferrous metals in the Indian aluminum industry using the Markov Chain model, and the coordination among supply chain stakeholders was evaluated using the Graph Theory and Matrix approach (GTMA). The findings indicate that CE practices significantly impact CSC performance, providing decision frameworks to support sustainable development goals and the transition to a net-zero economy.

9.3 Summary of the findings from the study

Upon reflecting on the synthesis of the work completed, the primary findings of the research are listed below.

9.3.1 Findings from the survey

The survey reveals a gap in studies on the adoption and implementation of Circular Supply Chains (CSC) in the Indian context, highlighting a potential area for future research. This study addresses key issues in CSC, including practices, challenges, and risks, within the Indian manufacturing sector, developing models and frameworks to evaluate CSC performance. Utilizing the Likelihood Ratio Test and Minitab software, the study finds significant associations between CSC practices and performance outcomes, with p-values below 0.05 indicating substantial differences in outcome percentage profiles. Cleaner production practices significantly impact environmental performance, while green consumption affects social performance. Similarly, challenges and risks identified in the study are shown to significantly influence CSC performance, particularly affecting economic outcomes. The findings suggest that addressing these challenges and risks is crucial for the successful adoption and implementation of CSC, emphasizing the need for strategies that consider environmental, economic, and social aspects.

9.3.2 Findings from the case study

The nascent stage of the circular economy (CE) concept requires significant attention from researchers and practitioners for successful application in the manufacturing industry, offering solutions to issues like waste generation, resource scarcity, and sustainable economic benefits. CE implementation in manufacturing faces serious challenges, necessitating research for effective application, particularly in developing economies like India, where the manufacturing sector contributes significantly to GDP. This study, focusing on India's large customer base and substantial manufacturing sector, provides empirical insights into circular supply chain risk management, revealing higher vulnerability in reverse supply chains and a lack of readiness for risk management strategies, especially during pandemics. The findings address literature gaps, suggest extending supply chain risk management (SCRM) applications, and emphasize multi-tier SCRM studies in developing countries, aiding industry managers in understanding risk propagation in supply chains.

9.3.3 Findings from the models/decision frameworks

The application of CE in Indian manufacturing industry is in nascent stage. India’s manufacturing sector significantly contributes to the economic development of the nation; therefore, this study identified and analyzed sustainability related challenges faced during the implementation of the circularity concept. Comprehensive survey of literature and the use of Pareto analysis yielded ten significant challenges which were further analyzed using fuzzy-Decision-Making Trial and Evaluation Laboratory approach. Findings revealed that noncompliance of environmental laws, revenue generation, design issues owing to technological limitations and less preference to refurbished and reused product are some of the major challenges to the CE practices in the manufacturing industry. The research work developed some of the decision framework for select issues of CSC which are enumerated as follows.

9.3.3.1 Findings from GTMA model

This study employs the Graph Theory and Matrix Approach (GTMA) to select the best coordination alternative by evaluating criteria and interdependencies identified through literature review and expert opinions. GTMA calculates a coordination index using the permanent function value for each alternative, which can be helpful to firms in benchmarking and improving coordination. A case study of an electric vehicle manufacturer reveals that forward supply chain coordination has a low impact on sustainability goals, reverse supply chain coordination is slightly more effective, and circular supply chain coordination, encompassing both forward and reverse flows, significantly enhances sustainability outcomes.

9.3.3.2 Findings from Markov Chain model

This study explores the circularity potential of products in circular supply chains, focusing on the material flow of non-ferrous metals like aluminum using a Markovian approach. The findings reveal that a very low percentage of raw materials reach the recycling stage, indicating inadequate recycling infrastructure and unorganized scrap collection methods. The Absorbing Markov Chain model shows that materials are most likely to end up in landfills after their useful life, and circularity decreases downstream in the supply chain due to insufficient circular initiatives. These results align with previous studies, such as Soo et al. (2021), which highlighted the limited impact of focusing solely on recycling rates, and Wang et al. (2018), which emphasized the importance of addressing leakages in metal cycles. The study concludes that effective CE strategies, including increased scrap utilization, extended product use phases, and design for reuse and remanufacture, are essential, along with adequate government measures, to ensure sustainable growth in the manufacturing industry.

9.4 Significant contribution of the research

The research work has attempted to address the select issues of Circular Supply Chain (CSC), identified based on the comprehensive literature review and exploration of Circular Economy (CE), especially in the context of Indian manufacturing industry. The work reported has explored the various issues of CSC and proposed the solution methodologies by developing models, frameworks, case studies such as identifying and prioritizing key factors, decision frameworks for circularity and implementation decisions, and framework for evaluating performance of CSC.

The research work will help the industrialists, academicians, and researchers in implementing, developing, and operating CE systems effectively and efficiently. Some of the significant contributions of the research work are enumerated as follows.

- A thorough examination of the literature pertaining to CE has been conducted, laying a solid foundation for current researchers and constructing the transitional framework. The study has adeptly pinpointed the gaps in research and linked them to the areas necessitating further investigation.
- A framework for the identification and prioritization of key challenges for the implementation of CE in Indian manufacturing industry was developed by using Fuzzy-DEMATEL methodology.
- This research is able to develop a circular supply chain risk framework, in order to generate risk profiles of various CSC partners and studied the disruption caused due to the occurrence of various risk on the performance of CSC.
- This research work is able to demonstrate the circularity potential for the non ferrous metal industry in the context of developing economy. Markov Chain is used as a stochastic modeling technique to develop a probabilistic model for the material flow.
- Graph Theory and Matrix Approach (GTMA) has been incorporated in the research work to analyze the role of coordination among multiple stakeholders in achieving sustainable development goals.
- Survey method was used to analyze the recent developments in the CE of Indian manufacturing industry through descriptive analysis and hypothesis testing.

9.5 Managerial implications of the study

This study identifies significant challenges in implementing Circular Economy (CE) in developing economies, prioritizing ten key challenges based on their criticality. The findings offer theoretical implications for future research on sustainable development practices and aid in building a conceptual framework for CE transition in emerging economies like India, which faces resource scarcity and rapid population growth. Effective implementation of CE requires participation from all stakeholders, with government policies facilitating smoother transitions, as seen in Germany and Japan. The study's insights help organizations understand the severity of challenges and develop strategies to address them, enhancing the adoption of sustainable business models.

Additionally, the study contributes to risk analysis theory by exploring risks in circular supply chains (CSC) using Bayesian Network (BN) methodology to model risk events and their impact on performance parameters such as revenue, sales, and inventory costs. The findings provide a holistic understanding of risk propagation and suggest using the Risk Exposure Index (REI) to quantify disruption risks. The study also demonstrates the circularity potential of aluminum in the non-ferrous metal industry, emphasizing the importance of recycling to balance supply and demand. Implementing CE initiatives can reduce metal wastage, enhance value chain operations, and promote economic growth by making aluminum available in secondary forms. The framework developed aids decision-making for selecting CSC partners, helping practitioners and policymakers achieve sustainability and net-zero targets.

9.6 Limitations and future scope of work

Every research endeavor possesses inherent strengths and limitations. Similarly, this particular research work is not exempt from encountering certain limitations. The constraints of the research work, as well as proposed avenues for future investigations, can be outlined as follows:

- This research focuses on the adoption and implementation of CE in the Indian manufacturing industry. Findings and conclusions are specific to this industry, limiting generalization to other sectors like textiles, automobiles, and pharmaceuticals.
- Data was collected from a few experts. Future studies could involve more experts to provide comprehensive data across different domains.
- Only ten challenges to CE application were identified and prioritized. Future research could consider more challenges and explore other techniques beyond Fuzzy-DEMATEL to predict interrelationships.
- The study analyzed risk propagation in the automobile industry's supply chain. Results are industry-specific and may not apply to other industries with different supply chain networks.

- The Bayesian Network technique used in this study accommodates only a limited number of risks. This limitation might affect the model's ability to represent a partner's true risk profile accurately.
- Risk event data were gathered from a small group of experts. The Conditional Probability Table (CPT) may vary depending on expert perceptions and different risk scenarios.
- The study addresses coordination issues in circular supply chains. Results are based on a specific company's case, which may differ from others. Future studies could apply the approach to different products and sectors for better conclusions.
- The likelihood ratio test was used to investigate the association between variables and performance outcomes. While widely accepted, it has assumptions and limitations. Future studies could also consider t-tests and F-tests for hypothesis testing.
- The Markov Chain approach assumes stationary transition probabilities, which might limit real-world applications. This model is suitable for monolithic products and primarily considers recycling. Future studies could include other circular lifecycle stages like repair, reuse, refurbish, and remanufacture.

9.7 Concluding remarks

The principal discoveries of this study are poised to make a significant contribution towards tackling various challenges and issues pertaining to the adoption and execution of Circular Economy (CE) from an Indian perspective. The investigation took place within an Indian manufacturing entity during a period marked by the emergence of initiatives like "Make in India", "Digital India", "Foreign Direct Investment (FDI)", waste management regulations, among others, which revolutionized the landscape of the Indian manufacturing sector. Due to the enforcement of regulations such as those by the Waste Management Society of India and the National Manufacturing Policy, manufacturing firms in India are compelled to reassess their strategies for managing end-of-life product returns. Many organizations are gearing up for the implementation of CE by restructuring their supply chains. The study pinpointed and ranked critical challenges hindering the adoption of CE within the Indian manufacturing sphere. These factors yielded valuable insights into CE within the Indian manufacturing sector, offering guidance to industry professionals and scholars seeking to implement CE. The primary focus of the study centered on specific challenges, examining them through surveys, case studies, and proposing solutions through the establishment of frameworks and models. The research noted a positive correlation between circularity decisions and the triple bottom line performance of Circular Supply Chains (CSC). Frameworks for CSC have been devised to evaluate the ecological, financial, and societal performance of the manufacturing sector. This study concentrated on the triple bottom line performance to assess the role of CE in enhancing the sustainability endeavors of an organization. The research introduced transitional and conceptual frameworks, along with statistical models, that could enhance the triple bottom line performance of CSC. The outcomes of this thesis can aid scholars, researchers, and professionals in their forthcoming endeavors. Additionally, the findings could prove advantageous for industrialists and managers in the efficient development, implementation, and operation of CSC systems.

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Appendix-I

SURVEY QUESTIONNAIRE

SECTION A: General Information

We are carrying out a survey of the Indian Manufacturing Industry with the intention of performing an empirical analysis on the circular supply chain. Each individual response will be kept confidential and shall not be divulged to any third party.

* Indicates required question

Firm/Organization/Company Profile

1. Name of the organization * ____

2. Year of establishment * ____

3. Annual Turnover (in million dollars) of the organization. *

Mark only one oval.

- <100
- 100 to 300
- 300 to 500
- >500

4. Number of employees in the organization *

Mark only one oval.

- <200
- 200 to 500
- 500 to 1000
- >1000

5. Product/services offered by the organization * ________________________________

SECTION B: Rating of Factors for the adoption and implementation of CSC

Please provide rating to the subsequent factors related to your organization utilizing the likert scale (1 indicating a very low level, 2 indicating a low level, 3 indicating a medium level, 4 indicating a high level, and 5 indicating a very high level). (Please select only ONE option in each category)

6.

S.No.	**Importance of Circular Economy strategies for the adoption and implementation of CSC concept by the organization**	**Rating**				
		1	2	3	4	5
1	Reuse					
2	Repair					
3	Refurbish					
4	Redesign					
5	Remanufacture					
6	Recycle					

7.

S.No.	**Effect of Circular Economy Practices on the adoption and implementation of Circular Supply Chain concept**	**Rating**				
		1	2	3	4	5
1	Collaborative business models					
2	Policies on product recycling and reuse					
3	Creating a recycling oriented society					
4	Waste trade markets					
5	Regional level collaboration of eco-industrial parks					
6	Policies for eco-industrial parks					
7	Industrial symbiosis					
8	Green consumption					
9	Cleaner production					

8.

S.No.	**Significance of Challenges faced by the organization during Circular Supply Chain implementation**	**Rating**				
		1	2	3	4	5
1	Lack of standardization					
2	Non-compliance of environmental laws					
3	Lack of economic inducement					
4	High capital investment cost					
5	Design issues owing to technological limitations					
6	Lack of infrastructure and unavailability of advance tool					
7	Less preference to reused or refurbished products					
8	Coordination with supply chain partners					
9	Managing product quality through recovered parts					
10	Revenue generation					
11	Resource allocation					
12	Monitoring of carbon emissions					
13	Strengthening of regional markets					

14	Social integrity					
15	Customer connect					
16	Regulation compliance					
17	Financial constraints					
18	Joint decision making					

9.

S.No.	Importance of Risks encountered by the organization during CE implementation	Rating				
		1	2	3	4	5
1	Economic Risk					
2	Environmental Risk					
3	Social Risk					
4	Technological Risk					
5	Waste management Risk					
6	Agile Vulnerability					
7	Risk of Cannibalization					

SECTION: C Current trends in Indian manufacturing industry

Kindly provide rating on the subsequent aspects pertaining to your organization, using a rating scale of 1 to 5. Please assign 1 for very low, 2 for low, 3 for medium, 4 for high, and 5 for very high.

10.

S.No.	Factors depicting the current trends of CSC implementation in your organization	Rating				
		1	2	3	4	5
1	Annual Growth rate of the organization					
2	Use of secondary material					
3	Use of an e-commerce platform					
4	Use of Industry 4.0 technologies with regard to CE implementation					
5	Use of 6R strategies					
6	Use of renewable sources of energy					
7	Use of AI tools and techniques for minimizing wastage					
8	Importance of consumer awareness					
9	Adoption of product lifecycle management					
10	Incorporation of Extended Producer's Responsibility					

11.

S.No.	Important trends in Circular Supply Chain in Indian manufacturing industry	Rating				
		1	2	3	4	5
1	Significance of circular economy in the organization					
2	Investment in circular supply chain as percentage of total investment					
3	Revenue from circular supply chain activities					
4	Significance of circular supply chain as a part of corporate strategy					

5	Stakeholder pressure in Circular Economy implementation					
6	Involving customers/clients in circular activities					
7	Availability of suitable outsourcing partners for circular operations					
8	Availability of experts in this domain					
9	Contribution of Circular Supply Chain in improving the overall sustainability of organization					

SECTION: D Performance evaluation of Circular Supply Chain

Kindly provide rating on the subsequent aspects pertaining to your organization, using a rating scale of 1 to 5. Please assign 1 for very low, 2 for low, 3 for medium, 4 for high, and 5 for very high.

12.

S.No.	Economic Performance of Circular Supply Chain	Rating				
		1	2	3	4	5
1	Revenue generation					
2	Value extraction					
3	Market capture					
4	Growth rate of Gross Domestic Product (GDP)					
5	Effect on sales					
6	Effect on total supply chain cost					

13.

S.No.	Environmental Performance of Circular Supply Chain	Rating				
		1	2	3	4	5
1	Reduction in total energy consumption					
2	Reduction in use of raw material					
3	Logistics optimization					
4	Minimizing packaging material					
5	Use of secondary material					
6	Waste minimization					

14.

S.No.	Social Performance of Circular Supply Chain	Rating				
		1	2	3	4	5
1	Number of jobs created					
2	Social Security					
3	Occupational health and safety					
4	Effective utilization of local resources					
5	Supplier Assessment					
6	Socio-economic compliance					

Respondent Profile

Please enter the following details. Your personal information will be kept strictly confidential and will not be shared with anybody.

Name (Optional)

____

Designation

____

Profile

Mark only one oval.

◯ Industrialist

◯ Academician

Total Industry/Academic experience

____

Your expertise

____

Do you want to get the findings of the study?

Mark only one oval.

◯ Yes

◯ No

Official e-mail (Optional)

____

Contact No. (Optional)

____

Thank you very much for taking the time to complete this questionnaire.

List of Publications from the Research work

(i) List of Papers Published in International Journals

1. Chhimwal M, Agrawal S and Kumar G (2023) "Markovian approach to evaluate circularity in supply chain of non ferrous metal industry", Resources Policy, Elsevier, Vol. 80, 2023; https://doi.org/10.1016/j.resourpol.2022.103260. **(SSCI, IF: 10.2, Pub: Elsevier)**
2. Chhimwal M, Agrawal S and Kumar G (2021) "Challenges in the implementation of Circular Economy in manufacturing industry", Journal of Modeling in Management, Vol. 17, No. 4, 2022. https://doi.org/10.1108/JM2-07-2020-0194. **(ESCI, Pub: Emerald)**
3. Chhimwal M, Agrawal S and Kumar G (2021) "Measuring Circular Supply Chain Risk: A Bayesian Network Methodology", Sustainability, 13(15), 8448, ISSN 2071-1050; https://doi.org/10.3390/su1315. **(SCIE, IF: 3.9, Pub: MDPI)**
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(ii) List of Papers presented/published in conference proceedings

1. Chhimwal M, Agrawal S and Kumar G (2021) "Issues of Outsourcing and Benchmarking in Circular Supply Chain" Young Researchers International Conference on Global Dynamics and Emerging Trends: India and Europe held on March 4-5, 2021 jointly organized by Directorate, International Affairs, GGSIPU, Delhi & Jean Monnet Module and Centre for European Studies, JNU, Delhi.
2. Chhimwal M, Agrawal S and Kumar G (2019) "Identification of Circular Economy Risk from Indian manufacturing perspective" Global Conference on Flexible Systems Management (GLOGIFT-19) organized by DoMS, IIT Roorkee from 6^{th}-8^{th} December, 2019.

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Madhukar Chhimwal is currently a research scholar in the Department of Mechanical Engineering at Delhi Technological University, Delhi, India. He obtained Master's in Manufacturing Systems Engineering (MSE) from Sant Longowal Institute of Engineering and Technology (Deemed University, Estd. Govt. of India), Sangrur, Punjab, India and Bachelor's in Mechanical Engineering from Guru Gobind Singh Indraprastha University, Delhi, India. He is a recipient of Swachhta Saarthi Fellowship (SSF) 2021-22 under "Waste to Wealth Mission" spearheaded by The Office of the Principal Scientific Adviser to the Government of India (GOI), housed at Invest India. He has published various research papers in journals of international repute viz. Resources Policy (Elsevier), Sustainability (MDPI), Journal of Modeling in Management (Emerald), International Journal of Intelligent Enterprise (Inderscience). His focused areas of research are circular economy, circular supply chain, sustainability and risk management.