Analysis of Environmental Sustainability Aspects for Steel Supply Chain in India

THESIS

Submitted in the partial fulfillment of the requirement for the degree of

DOCTOR OF PHILOSOPHY

by

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CERTIFICATE

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ABSTRACT

The steel industry is well known for its contribution to economic growth and social development. However, at the same time it is also known for its adverse impact on environment. The continuous increase in steel production in India poses serious threat to environment and also throws direct challenge to environmentalist to negate and minimize its effect on environment amidst the complex supply chain. There are several factors that can help to minimize the environment impact of steel industry. However, all the factors may not be suitable for implementation and have to be rationally selected based on the merit of their significance. It will be extremely beneficial to determine few important parameters or factors which can be focused upon and can have significant effect on environmental sustainability performance of steel industry.

In this research, we aim to identify the important environmental sustainability enablers (ESE's) that have significant effect on the environmental sustainability of the steel supply chain. Using different methodologies and technique the identified ESE's were further categorized to identify the most important enablers. These enablers can be concluded to be the most important factors that can significantly enhance the environmental sustainability performance of Indian steel industry. The research also compares the environmental sustainability performance of integrated steel companies on the selected ESE's. The research provides focused area to the Indian steel industry and also to the Government of India for their holistic and effective approach to counter the environmental threat from steel manufacturing. Also it allows steel companies and environment agencies to compare the environment sustainability performance with the peers. The research will be helpful to the

Government departments to draw the road map for the focused areas for steel companies.

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List of Acronyms

Acronyms	Word
ANP	Analytical Network Process
ACS	Air Pollution Control System
ADRM	Average Direct Relationship Matrix
AHP	Analytical Hierarchy Process
AIM	Asian-Pacific Integrated Model
BF	Blast Furnaces
BOF	Basic Oxygen Furnace
CDQ	Coke Dry Quenching
CES	Competitors Environmental Sustainability
CFCS	Fuzzy Data into Crisp Scores
CII	Confederation of Indian Industry
CMD	Coal Mine Drainage
CSG	Coal Seam Gas
DDRM	Defuzzified Direct Relationship Matrix
DEMATEL	Decision Making Trial and Evaluation Laboratory
DOEs	Design of Experiments
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
ECC	Environmental Compliance Certification
EIF	Electric Induction Furnace
ENS	Environmental Sustainability Culture
EPIs	Environment Performance Indicators
ESC	Environmental Sustainability Culture

Acronyms	Word
ESIPI	Environmental Sustainability Implementation Performance Index
ESM	Environmental Sustainability Measures
ESP	Environmental Sustainability Practices
FDRM	Fuzzy Direct Relationship Matrices
FHP	Flat Heat Pipe Heat Exchanger
GGBFS	Ground Granulated Blast Furnace Slag
GHG	Greenhouse Gas
GRI	Government Regulation and Incentives
GSCM	Green Supply Chain Management
GTA	Graph Theoretic Approach
IAS	Internal Auditing System for Environmental Sustainability
IEA	International Energy Agency
IEF	Influence of External Environment
IRM	Impact Relationship Map
ISM	Interpretative Structural Modelling
KIDA	Katedan Industrial Development Area
KPIs	Key Performance Indicators
PAHs	polycyclic aromatic hydrocarbons
PC	Pulverized Coal
PV	Permanent Value
RES	R&D Program for Environmental Sustainability
GRI	Government Regulation and Incentive
SCE	Supply Chain Environmental
SCM	Supply Chain Management
SCS	Soil Pollution Controlling System

Acronyms	Word
SCs	Significant Categories
SD	System Dynamics
SSCM	Sustainable Supply Chain Management
SSIM	Structural Self-Interaction Matrix
TAS	Technology Adoption for Environmental Sustainability
TEG	Thermoelectric Generation
TISM	Total Interpretive Structural Modelling
TLF	Taguchi Loss Function
TMC	Top Management Commitment
TMI	Top Management Involvement
TRM	Total Relation Matrix
VAP	Value Added Products From Waste
VPM	Variable Permanent Matrix
WCS	Water Pollution Control System
WWTP	Wastewater Treatment Plant

CHAPTER - 1

Thesis Overview

1.1 Backdrop of Environmental Sustainability Aspects of Steel Supply Chain

Historically, steel has been linked with industrial development and has been present in almost all aspects of modern daily life. It plays a significant role in improved living standards of a country. The functions of a typical steel supply chain are from the mining of the iron ore to the finished product in India (Sandhu *et al.*, 2013). It consists of many independent members operating at different locations for various operations whereas the key member is the steel manufacturer as it controls the steel supply chain. The different operations of steel supply chain in general and steel manufacturer in specific consumes huge quantity of energy and in the process, it pollutes the environment significantly with large quantity of environmental emissions (Liu *et al.*, 2012). Sustainability in steel production is a global challenge due to its negative environmental impacts and various sustainability indicators associated with steel production are carbon dioxide emission reduction, recycling of steel scraps, energy reduction, waste heat recovery, reuse of waste generated etc. (Nidheesh and Kumar, 2019). The management of the environmental impacts associated in steel supply chain, is gaining importance worldwide and is a policy issue both in developed and developing countries. Now various stake holders including steel companies, Government and society as a whole have understood the importance of extending environmental focus not only to the steel companies' operations but also the operations along the supply chain contributing to the negative environmental impact. It is evident from the literature. For example, Iranian companies changed their focus from single plant improvements to the whole supply chain (Shekari *et al.*, 2011). The implementation of environmental focus in the steel industries in India has started, however, the appropriate implementation strategy(s) needs to be developed for the industries to compete on a global level (Kumar and Shekhar, 2015). Shen *et al* (2019) investigated the trends of environmental sustainability of Chinese iron and steel sector during the 2005-2015 and concluded that the environmental sustainability level of this sector is declining and it is unsustainable in the long run due to the low and decreasing renewability rate, small and declining ratio of steel scrap utilization, rising environmental costs and descending production efficiency. In order to achieve the enhanced environmental sustainability in steel supply chain, there is a need for a sustainable structure, sustainable conduct, sustainable performance and sustainable performance oriented practices with supply and demand side management having inclined towards environmental focus (Bali *et al.*, 2019). All stakeholders of the steel supply chain in India should understand these aspects. More importantly, the need is for a structured focus of the efforts towards environmental sustainability. The measurement of its implementation of environmental sustainability efforts and its performance measurement are the need of the hour.

In this regard, although the Environmental Sustainability Enablers (ESEs) can potentially offer fruitful results in controlling, managing and enhancing environmental sustainability performance in steel supply chain, but in research and practice, there are some gross to subtle aspects that are overlooked in steel supply chain with respect to environmental sustainability. However, the issues of environmental sustainability in the Indian steel supply chain perspectives are although studied and initiated in isolated manner by various researchers but not analyzed in broad supply chain perspective. Hence, the current work analysed the ESEs, developed structural framework of ESEs for environmental sustainability implementation. Also the methodologies are proposed for environmental performance evaluation of environmental sustainability implementation efforts and assessment of environmental impact. The current work will definitely show the direction for environmental sustainability performance enhancement of steel supply chain in general and Indian perspectives in specific. The implementation of the strategy(s) developed will also definitely incorporate environmental focus in various operations of steel supply chain such as purchasing, manufacturing, recycling and other activities along different stakeholders which will in turn maximize resource utilization, reduce resource consumption and environmental emissions. These identified research gaps are addressed in the current study. The details are mentioned in the following sections.

1.1.1 Research Gaps Focused in The Current Thesis

In this section, the identified research gaps, their significance and the proposed solutions are briefly discussed. The literature support for the derived research gaps is contextually presented along with the different chapters (see Figure 1.1) in the current thesis to comprehensively develop the discussion.

1.1.1.1 Literature review of environmental aspects of steel supply chain

The steel supply chain generates huge amount of waste in the forms of slag, char, fly ash, dusts etc. If the avenues of reuses are not explored, the unorganized dumping will continue and will severely impact the environment (i.e. air, water and soil) in the long run. It is evident that the issues of pollution with steel industry are manifold and complex. Due to its complex nature and volume of operations, it poses extremely serious threats to the environment across its supply chain. While the Indian steel industry is vying for the 200% growth in capacity in next 10 years, it poses series of challenges to the nature and society. For literature review, the research articles were searched on Google Scholar which led to databases of academic journals such as Emerald Insight, IEEE, Science Direct, Springer, Wiley and Taylor & Francis. The keywords such as "green supply chain", "By-products in steel industry", "waste management in steel industry", "green logistics", "impact of mining on environment", "GHG (Greenhouse Effect) in steel industry" and "process efficiency in steel" used to collect finally 158 relevant scholarly articles published by various researchers in the area of environmental aspects of steel supply chain during the years 2005-2020. These articles were studied in detail with a focus to capture various aspects such as year-wise distribution of research articles, research methodology, critical analysis of the objectives and research area categorization based on environmental impact and critically analyzed to report the findings. The literature reviews schematically analyze the current difficulties that the steel industry is facing in terms of environmental sustainability and also the importance of government in regulating and controlling the environmental impact. The followings are the findings drawn from the study:

- It was observed that the research papers were evenly distributed in last 15 years related to environmental impact of steel supply chain and are largely focused on the various aspects such as steel production supply chain, the mining techniques, production efficiencies, advanced waste management techniques and usage of by-products.
- Research work on environmental sustainability in steel supply chain has been

predominantly studied in China and India in comparison to rest of the world. This is conclusive with the fact that the two countries are the top two largest steel producers and generates high amount of by-products and waste across its supply chain. The efficient use of by-products and safe disposal of wastes are the essential focus of the research articles.

- The papers related to advanced technology and production efficiency are available from various countries especially in the developed world. The developing country such as India has to work in this front for achieving the environmental sustainability.
- The research papers discussing the waste management or by-product usage are mostly empirical nature. The by-product usage or waste management requires experiments to establish the facts for its usage or safe disposal. Much of the research papers were found to discuss the usage of slag in concrete for road construction. However, a coordinated effort of supply chain members in this regard is a missing link.
- The researchers had suggested the various methodologies for safe waste water treatment and discharge. Also both air pollution and soil contamination are researched and reported. There are several papers discussing the environmental impact of mining on human health in nearby habitat. However, a coordinated effort in terms of mitigation plan development and its implementation, performance assessment and monitoring and defining the roles and responsibilities of supply chain members in this regard is a missing link.

1.1.1.2 Analysis of environmental sustainability enablers for Indian steel manufacturing supply chain

With the growing production capacity, the Indian steel industry is under enormous pressure to curb detrimental effect on the environment. The steel manufacturing companies are taking various measures to establish a system in place that can facilitate and promote environmental sustainability in the supply chain. From our extensive literature review, it is observed that researches have been carried to identify ESEs for various industries, however limited research has been reported to identify the ESEs along the steel supply chain. Also hardly any literature is available on the cause and effect analysis among the ESEs for achieving the environmental sustainability. Therefore, a methodology using fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) is proposed to establish relationship among ESEs (i.e. cause and effect), evaluate the strength and draw impact-relationship map. The proposed methodology captured the relationship of ESEs between them and divides them into two groups (i.e. cause group and effect group). The relevant eighteen ESEs were classified into cause and effect group and also interactions (i.e. influencing and influenced) of each ESE with other ESEs were evaluated. It was concluded that Competitors Environmental Sustainability Strategy (CES), Environmental Compliance Certification (ECC), Government Regulation & Incentives (GRI), Influence of External Environment (IEF) and Controlling Measures for Air Pollution (ACS) were most important ESEs as they were found to be as the prominent ESEs in the cause group. The three ESEs (CES, GRI and IEF) (from identified five ESEs) are beyond the control of the company and are exclusively controlled and determined by the external agencies. Therefore, steel supply chain in India should keep a close eye on them and implement appropriate strategy(s).

However, the steel supply chain in India must focus on Environmental Compliance Certification (ECC) and Controlling Measures for Air Pollution (ACS) on priority basis. It should adopt right strategy and technology to excel in this direction to push the green initiatives.

1.1.1.3 Development of structural framework for environmental sustainability enablers of Indian steel manufacturing supply chain

The steel companies are always under pressure from society and government to minimize losses and improve their environment sustainability. Minimizing the losses and achieving the desired level of environmental sustainability comes at a cost. The steel industry is capital intensive and any set of activities towards environmental sustainability adds economic burden. In order to bridge the gap, it is desirable to identify and select the appropriate set of ESEs of steel supply chain in India so that maximum return of environmental sustainability can be achieved with minimum effort. The twelve ESEs were identified through extensive literature review, cause group of ESEs obtained from the previous section and discussion held with experts from Indian steel industry. The Interpretative Structural Modelling (ISM) approach was applied to arrange these twelve ESEs in different hierarchies of the structural framework on the basis of their driver dependence power and also diagraph was developed to classify them. The Water Pollution Control System (WCS), Air Pollution Control System (ACS) and Soil Pollution Control System (SCS) were found to be in the bottom hierarchy of ISM framework and these ESEs were also observed in the driving quadrant of the diagraph. These driving ESEs should be given priority for its full scale development, management and monitoring to sustain and enhance the environmental sustainability in Indian steel supply chain whereas Top Management Commitment (TMC), Environment Compliance Certification (ECC) and

Government Regulation and Incentives (GRI) are the antecedents for carrying out the sustainability program. The MICMAC analysis was carried out to develop the driver and dependence power diagram. No identified ESEs are appearing in autonomous driver. These twelve ESEs are not weak enablers towards implementation of environmental sustainability in steel supply chain in India. Three ESEs (i.e. Water Pollution Controlling System (WCS), Air Pollution Controlling System (ACS) and Soil Pollution Controlling System (SCS)) were found to be in dependent cluster and they were also appearing at top of the hierarchy structural model which represents that these ESEs have high dependency power. These three ESEs can be thought as output variables of environmental sustainability program and the performance of the program is directly evaluated through the performance of these three ESEs. The six ESEs (i.e. Value Added Products from waste (VAP), Technology Adoption for Environmental Sustainability (TAS) and R&D Program for Environmental Sustainability (RES), Environmental Sustainability Measures (ESM), Environmental Sustainability Practices (ESP) and Environmental Sustainability Culture (ESC)) were found to the in the linkage cluster and they are also appearing at the middle of structural framework. The three ESEs i.e. Government Regulations and Incentives (GRI), Environmental Compliance Certification (ECC) and Top Management Involvement (TMI) were found to the in the driving cluster and they are also appearing at the bottom of structural framework. These three ESEs will facilitate the other ESEs. They will also ignite and show the direction to environmental sustainability program as these three ESEs have strong driving power and hardly influenced by any other ESEs.

1.1.1.4 Measuring the environmental sustainability of Indian steel supply chain using graph theory approach

Environmental sustainability is an important consideration for steel industry which is not only one of the largest consumer of natural resources but also one of the biggest sources of pollution. The enhancement of environmental sustainability will provide competitive advantage to steel industry. Environmental Sustainability Program (ESP) is important for the manufacturing companies irrespective of their size, region of operation and nature of the business. The ESMs were identified and their post implementation performance should be judiciously monitored. Efforts were made for continuous improvement and in the process, the manufacturing companies can reach to a benchmark level. An extensive literature review was carried out to identify the measures, critical success factors, drivers etc. necessary for the success of ESP in general. Broadly twelve Environmental Sustainability Measures (ESMs) were identified and they were classified into four Significant Categories (SCs) for measuring the Environmental Sustainability Program. Featuring these SCs and ESMs under each significant category, a methodology was proposed using Graph Theoretic Approach (GTA) for evaluating the environmental sustainability implementation performance of Indian steel companies. The analysis was further extended to compare the results with performance in different situations and accordingly set the future targets. The proposed methodology was applied in an Indian steel industry for measuring environmental sustainability along different timeline. It is essential to rightly direct their efforts and resources for enhancing environmental sustainability performance.

1.1.1.5 Comparative analysis of environmental losses in steel manufacturing supply chain using Taguchi loss function and design of experiments

A comparative study of environmental losses among various steel companies will help the industry to establish the benchmark level and put effort to reduce the existing environmental performance gaps. In the process, the environmental losses can be reduced. Therefore, environment loss analysis across steel supply chain is important in order to achieve desired level of sustainability (i.e. derived from the benchmarked level). However, no comparative study towards environmental losses in steel supply chain in developing nations such as India is available. To address the above mentioned issue, a methodology was proposed using Taguchi Loss Function and Design of Experiments to evaluate and compare the environment loss in steel supply chains. The different environment loss factors in steel manufacturing supply chain were studied and the significant factors were identified. The significant environmental loss factors identified for steel supply chain in India are energy loss, electricity loss, by-product gases, by-product ash, by-product slag, water contamination, water recycle and reuse, soil contamination, by-product waste in form of metals and minerals and air contamination. For each loss factor, loss attributes were identified. Their combined contributions along the significant factors were estimated using Taguchi Loss Function and Design of Experiments comparing environment losses at different scenarios. This study is helpful for top management to access their supply chain performance and identify the areas of improvement to remain competitive against their peers.

1.1.2 Thesis Outline

In the Chapter 1, the backdrop of environmental sustainability aspects of steel supply chain with the significance of the current research focus is introduced. As shown in Figure 1.1, the literature review of environmental aspects of steel supply chain has been provided in the Chapter 2 of the thesis. The analysis of environmental aspects of steel supply chain was carried out critically and research gaps were identified. In Chapter 3, a model using fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) was developed to strategically select the relevant ESEs for Indian steel manufacturing supply chain. Further in Chapter 4, the focus is ISM - MICMAC for selecting appropriate set of environmental sustainability enablers for Indian steel for managing and enhancing environmental sustainability. Further in Chapter 5, the focus is on the impact of significant categories and their corresponding environmental sustainability measures. A methodology was proposed using Graph Theory Approach (GTA) to identify, quantify, and evaluate the impact of significant categories on Environmental Sustainability of Indian steel supply chain in different performance situations. Chapter 6 presents the comparative analysis of environmental losses in steel manufacturing supply chain using Taguchi Loss Function and Design of Experiments. Chapter 7 concludes Thesis with suggestions for future research scope of the current work.

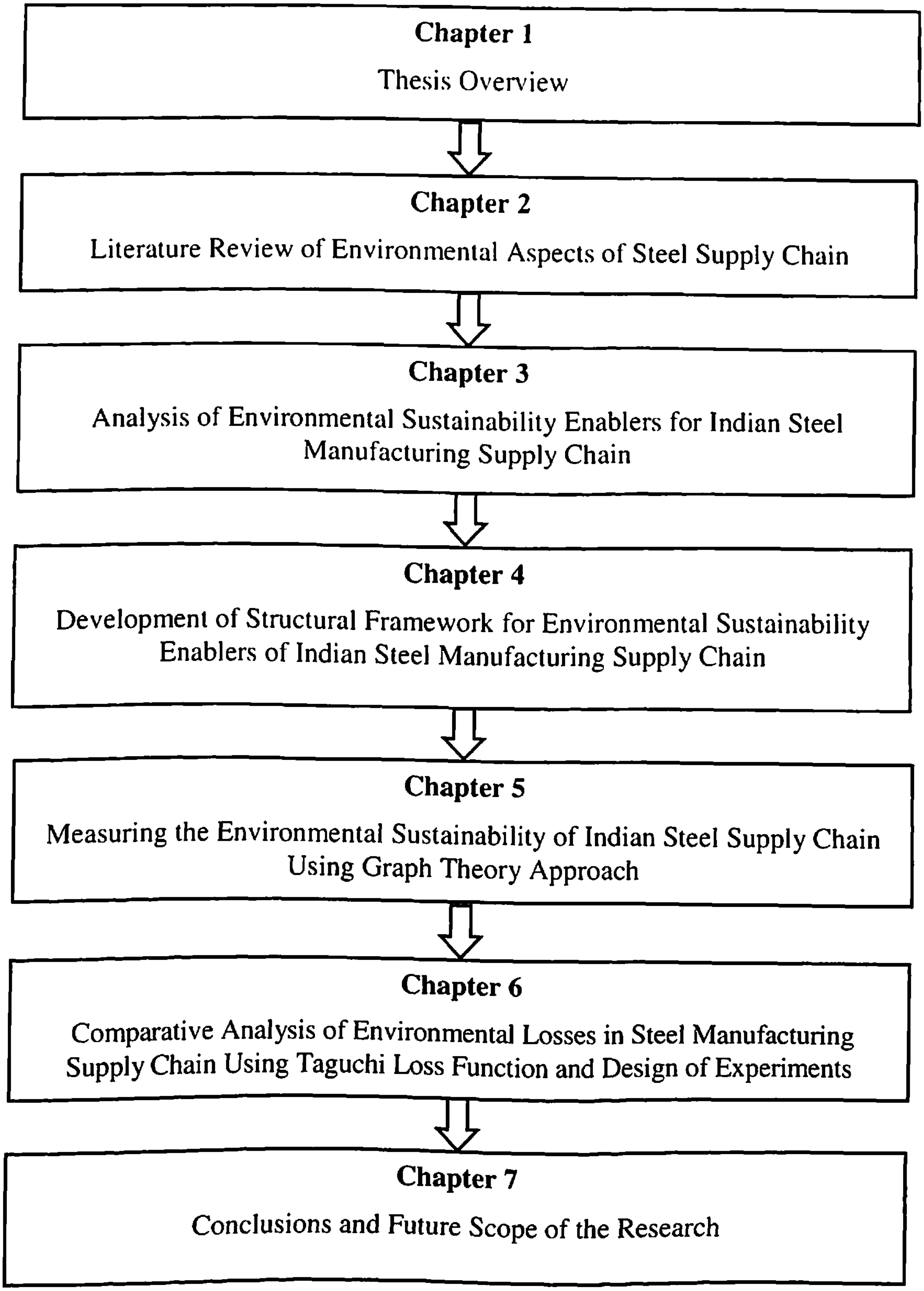

Figure 1.1: Thesis outline showing the flow of research work

CHAPTER - 2

Literature Review of Environmental Aspects of Steel Supply Chain

2 Sectional Abstract

The purpose of the literature on environmental aspects of steel supply chain is to critically analyze the different aspects of it in order to draw future research directions in general and India in specific. A total of 158 relevant scholarly articles published by various researchers were studied in detail in the area of environmental aspects of steel supply chain during the years 2005-2020. These publications were critically analyzed along different environmental aspects of steel supply chain. The future research prospects for the environmental aspects of steel supply chain were discussed. The number of research publications along environmental aspects of steel supply chain has gradually increased in the last 15 years. This increased number indicates that the focus on environmental implications both in research and practice is a step towards developing environmental sustainability in long run. Most of the publications have been found to be from regions and countries specializing in steel production highlighting their contribution to this field of study. It was observed that certain processes and stages have been given much more attention compared to others owing to respective process criticality. However, the holistic approach for controlling environmental aspects along the steel supply chain is hardly focused. Analysis was limited to only the peer-reviewed journals and conference papers whereas reports, manuals and white papers were excluded. This systematic review revealed the current research gaps and future research work to be carried out to make steel supply chain more environmental sustainable.

2.1 Introduction

The iron and steel industry is one of the important industries in the world due to its versatility of usage. Considering the production sequence, iron is produced and converted to steel with the inclusion of other elements. The steel is far more versatile than iron and therefore the industry is often referred to as steel industry instead of iron and steel industry. In subsequent discussion, the steel industry or steel supply chain are used for the iron and steel industry and iron and steel supply chain respectively. It can be conveniently assumed that every industry, directly or indirectly is dependent on the steel. Steel is present in as small an object as a needle to as large an object as space rockets or submarine. Iron and steel are widely used as raw material for the manufacturing of engineering goods, scientific, medical and defense equipment's, infrastructure construction works and many others. For walking in the path of growth, a country such as India should focus and expand the capacity of steel industry. The steel production capacity of a country, to certain extent, displays its economic outlook. The steel industry is perhaps an important pillar of a nation's industrial economic infrastructure and the consumption of steel per capita of population is an indicative index of its industrialization and progress. Today, the steel industry plays such a major role that its production is used as an index of national prosperity. Since prehistoric times, human beings have been involved in the extraction of iron ore and steel making. However, the major steel production enhancement was visible in 20th century which is also the period of rapid industrialization. In the year 2019, the total crude steel production in the world was approximately 1869 million tonnes (World Steel Association, 2020). Table 2.1 provides the details of top 10 steel producing countries along with their production data.

China alone accounts for nearly 50% of world's total crude steel production. Much of the capacity has been added in last three decades which has also witnessed the rapid economic growth of China. The second highest crude steel production is in India. The important thing to note from Table 2.1 is that the steel production capacity has grown in the developing nation while some of the developed nations such as Japan and Germany have witnessed decline in the production. The last two decades have seen considerable growth in crude steel production in developing nations especially China and India. Table 2.2 shows the average annual growth rate in crude steel production since 1980 and the growth rate in different periods were mostly in the positive side. The per capita consumption of steel in world, India and China for the last 4 years is mentioned in Table 2.3. From the Table 2.3., it can also be observed that the per capita consumption in the last four years has increased by approximately 31% in China, 18% in India and 13% in world. Thus the growth of steel consumption is being driven by the developing nations such as China and India. It can be seen that India lags considerably behind the world's average, while for China it can be assumed that they have reached their saturated level of production capacity. The next decade could witness the significant growth in steel production capacity in India. India has targeted to increase its production capacity to 300 million tonnes by year 2030.

The steel industry is a determining factor of country's economic performance, but poses serious threat to the environment. The steel industry is energy intensive and makes considerable use of natural resource, thereby continuously depleting the resources and polluting the environment. Table 2.4 shows the environment performance data of global steel industry for the recent twelve years. Over 70% of global steel produced today from iron ore is largely dependent on coal. The most notable changes that occurred in the iron and steel industry of many industrialized countries since World War II are the transition from open hearth to basic oxygen and electric arc furnaces and the use of continuous casting methods instead of ingots.

Table 2.1: Top 10 steel producing countries (World Steel Association, 2019)

Rank	Country	2019 (Mt)	2018 (Mt)	% Growth
1	China	996.3	920	8.3
2	India	111.2	109.3	1.8
3	Japan	99.3	104.3	-4.8
4	United States	87.9	86.6	1.5
5	Russia	71.6	72	-0.7
6	South Korea	71.4	72.5	-1.4
7	Germany	39.7	42.4	-6.5
8	Turkey	33.7	37.3	-9.6
9	Brazil	32.2	35.4	-9
10	Iran	31.9	24.5	30.1

Table 2.2: Average growth rate for crude steel production per annum (World Steel Association, World Steel Figures, 2020)

Years	Average growth rate	Years	Average growth rate
1980-85	0.10%	2000-05	6.20%
1985-90	1.40%	2005-10	4.50%
1990-95	-0.50%	2010-15	2.50%
1995-00	2.50%	2015-19	3.60%

Table 2.3: Per capita consumption of steel of World, India and China (World Steel Association, World Steel Figures, 2020)

	2016	2017	2018	2019
World	203.8 kg	216.5 kg	224 kg	229.3 kg
India	63.1 kg	66.2 kg	71.5 kg	74.3 kg
China	481.6 kg	544.6 kg	585.6 kg	632.9 kg

Table 2.4: Environment performance measure of world steel industry (World Steel Association, sustainability indicators 2020 report)

Indicators	UNIT	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
CO2 emissions	Tonnes CO_2/tonne crude steel cast	1.8	1.79	1.81	1.8	1.76	1.75	1.82	1.8	1.87	1.87	1.84	1.81	1.83
Energy Intensity	GJ/tonne crude steel cast	20.1	20.1	20.5	20.1	19.8	19.6	20.1	19.8	20.3	20.3	19.9	19.5	19.8
Material efficiency	% of materials converted to products & co-products	97.9	98	97.9	97.5	96.1	96.5	98	97.5	97.4	96.9	96.5	96.3	97.5

At the time of independence of India, the total hot metal production was only 1.5 million tons per annum. The industry has come a long way to reach 110 MT today. The sector saw phenomenal growth after economic liberalization in 1991 and is projected to reach 300 MT by 2030. Most of the steel production in India is through two routes: Blast Furnace-Basic Oxygen (BF-BOF) and Direct Reduced Iron - Electric Arc Furnace or Induction Furnace (DRI-EAF/EIF). The BF-BOF is a relatively more efficient process compared to DRI-EAF. However, at the same time BF-BOF is highly capital intensive compared to the other. About 65% of crude steel is produced through BF route while the remaining is produced through DRI root. Due to less capital investment, the small DRI units are mushrooming in India. Presently, India is the largest DRI producer in the world. Natural gas based DRI are relatively cleaner and a few companies have incorporated the technology. The extent to which iron and steel firms adopt new technology depends in part on previous successful experience with the technology, which makes innovation less of a gamble, and on the speed at which technologies change. Firms are likely to delay adoption of technologies that are improving rapidly and tend to adopt a technology after a slowdown in technical progress. Improvements in technology in steel industry are cost driven, however long-lived. Once the advanced technology is implemented, it determines the firm's long-term material, energy, and emissions profiles. The sustainability performance of Tata Steel, Jamshedpur unit, India is presented in Table 2.5.

Table 2.5: Indian steel environment performance measure of Tata steel, Jamshedpur unit (Tata Steel, sustainability performance, 2020)

Indicators	**Unit of measurement**	**Values**
Greenhouse gas emissions	Tonnes CO2/tonne crude steel cast	2.27
Energy Intensity	GJ/tonne crude steel cast	23.55
Material efficiency	% of materials converted to products & co-products	98.9

The advanced technology can substantially lower air emissions, water usage and other by product wastage. Reducing the environmental impact of coke production can also be achieved through recycling coke by-products and reducing waste water volume. Table 2.5 represents the environmental performance data of Tata Steel. Tata Steel is the largest and the oldest steel plant in India. It has been considered as sustainable champion by World Steel Association. Considering the data from Table 2.5, as a representation of Indian steel performance, it can be observed that an integrated steel plant emits out at an average of 2.27 tonne of CO_2 per tonne of steel. Thus an Indian steel industry generates approximately 250 million tonnes of CO_2 each year which is likely to increase to 700-750 million tonnes by 2030. On an average, the steel industry consumes 11 m^3 of water per tonne of crude steel (Kanchan, 2013). The Indian steel industry is estimated to be consuming 1.2-billion-meter cube of water each year which is likely to grow to over 3-billion-meter cube by 2030. An integrated steel plant handles millions of tonnes of raw material. The process may include digging, crushing, loading, unloading, movement, blending, storage and processing. Thus without proper process and practices in place, material loss and pollution are unavoidable. Slag generation is relatively high. Approximately 100-180 kg is slag is generated in blast furnace, while 140-280 kg of slag is generated in electric steel making per tonne of crude steel (Kanchan, 2013). The industry generates huge amount of waste in the forms of slag, char, fly ash and dusts if the avenues of reuses are not explored, the unorganized dumping will continue which in turn will impact environment severely in the long run. It is evident that the issues of pollution with steel industry are manifold and complex. Due to its complex nature, it will pose extremely serious threats to the environment across its supply chain. While the Indian steel industry is vying for a 200% growth in capacity in next 10 years, it poses series of challenges to nature and the society.

Although the production, trade and exchange of iron ore and steel has been going on for centuries and the steel supply chain has been in existence ever since, it has only gained importance and attention after Keith Oliver, a consultant at Booz Allen Hamilton coined and popularized the term Supply Chain Management in 1980s (Blanchard, 2010). Supply chain management in general can be defined as the process of integrating various processes and entities such as suppliers, manufacturers, inventory and retailers in such a way that is ensures the production and delivery of finished products in the correct required quantity at the correct time while at the same time minimizing the costs and keeping in the mind customer's satisfaction. Globalization has increased the supply chain complexity. The environmental threat of steel manufacturing is visible across its supply chain staring from mining, logistics and production. More the complex the supply chain is, more difficult is to achieve environmental sustainability.

To counter the above complexities and make the steel supply chain more environmentally sustainable, numerous research works have been carried out throughout the years which call for a systematic literature review and study the adopted approach. Hence, an effort has been made to systematically study, understand and review all the major works that have been conducted in the field of steel supply chain in the context of environmental sustainability for the years 2005 to 2020 and have been presented in the subsequent sections.

2.2 Review Methodology

The aim of the literature review is to identify and address the various environmental issues across the iron and steel supply chain and also the initiatives undertaken to mitigate the environmental hazards. The research articles were searched on Google Scholar which led to the other databases such as Academic Journals, Emerald Insight, IEEE, Science Direct, Springer, Wiley and Taylor & Francis. The articles were searched with the keywords such as "green supply chain", "By-products", "waste management", "green logistics", "impact of mining on environment", "greenhouse gas (GHG)", "process efficiency" in iron and steel industry/supply chain. The papers were downloaded and segregated in a year-wise manner for the period 2005-2020. The research articles on the scholarly databases were reviewed and downloaded till there was relevance in the content. The scholarly articles from peer reviewed journals and international conferences kept were for the study (236 out of 406 downloaded). A few articles were excluded from the directory on the basis of scope of the study in the first iteration. A few other articles without proper source portal such as author and peer-journal information were also excluded from the study. In the second iteration, on the basis of reading/going through the abstracts and full text reading, a total number of 158 articles are selected to address the environmental issues out of 236 organized articles and the rest were excluded. Every effort was made to fetch all the relevant articles but yet some articles might have remained out of sight. However, there have also been a few limitations in the review methodology. Due to non-availability of full-access to few articles and journals, the study is concluded from the existing reserve of downloaded articles. Figure 2.1 represents the diagram for literature review methodology followed in the current study.

2.3 Year-wise Distribution of Research Articles

From Table 2.2, it is evident that the growth of crude steel production was moderate from 1980 to 2000 and showed substantial growth since 2000. The environment concerns and political discussions also gathered pace and importance in the 21st century. More researches were sponsored in the area of environmental sustainability and hence, more articles were available highlighting the environmental and sustainable issues. The articles were collected for the period 2005 to 2020. The year wise distribution is shown in Figure 2.2. From the Figure 2.2, it can be observed that the papers are more or less evenly distributed across the years. There has been ever increasing concern on growing environment impact due to continuous growth in steel production. The research in the direction to identify and address the environmental impact across the steel supply chain and the likely solution to minimize and mitigate this impact has gathered more focus in 21st Century. The selection criteria to identify the research papers from 2005 were drawn environmental impact across the steel supply chain. The research papers from 2005 are largely focused on steel production, the mining techniques, production efficiencies, advanced waste management techniques and usage of by-products.

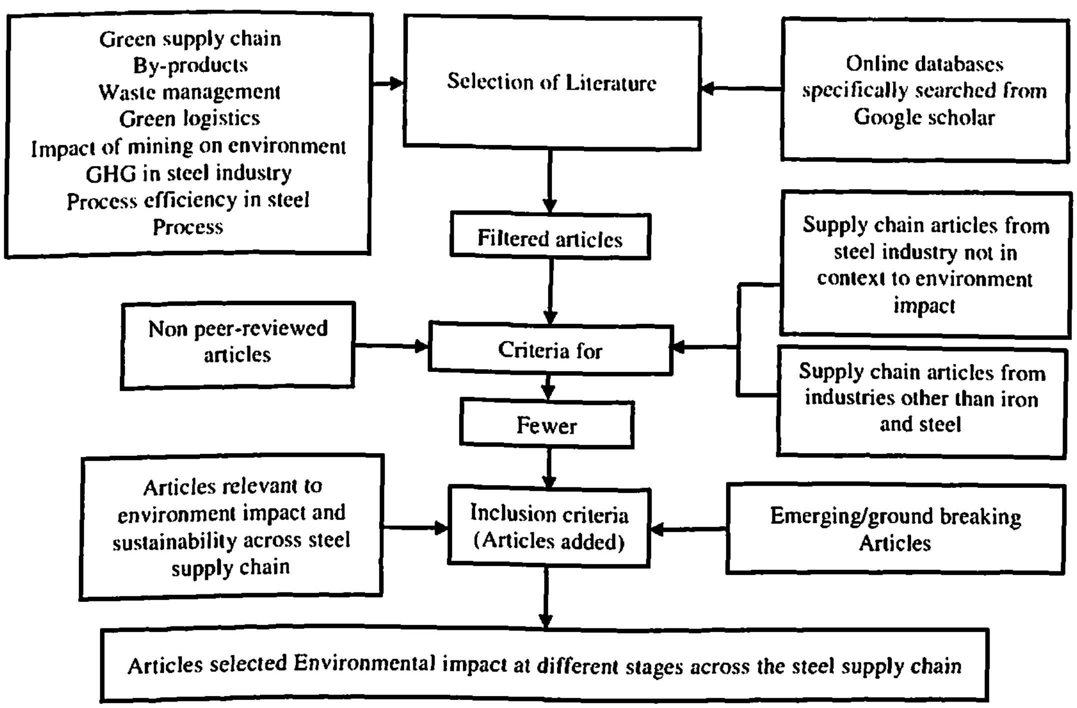

Figure 2.1: Flow chart of review methodology

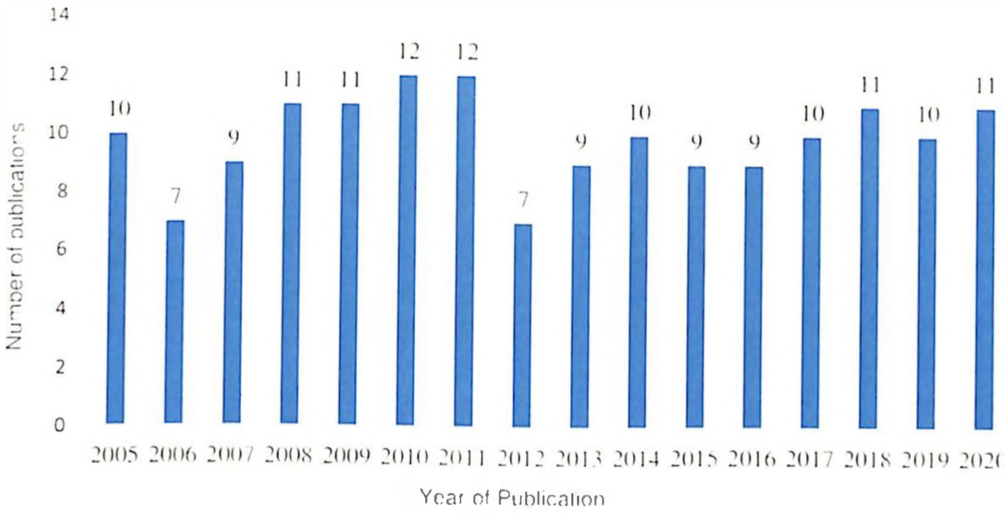

Figure 2.2: Year-wise number of publication

2.4 Research Methodology

All the scholarly articles collected were classified into types of the methodologies used by the authors when carrying out their work. The classifications are listed down as below:

Conceptual: This type of research papers is most likely to be conducted by observing and analyzing information which is already present on a given particular topic and does not involve conducting any practical experiments. This type of research methodology is most likely to be related to abstract concepts or ideas.

Empirical: This type of research is based on collected data and measured phenomena and knowledge is derived from actual experience rather than any theory or belief.

Viewpoint: In this type of research paper, the author presents his/her opinion and interpretation as content.

Case Study: In this type of research paper a single place or phenomenon is treated as the subject of analysis upon which data is collected and analyzed to predict future trends or identify any particular hidden issue or research problem.

Combinational: This type of research paper is a combination of two or more research methodologies.

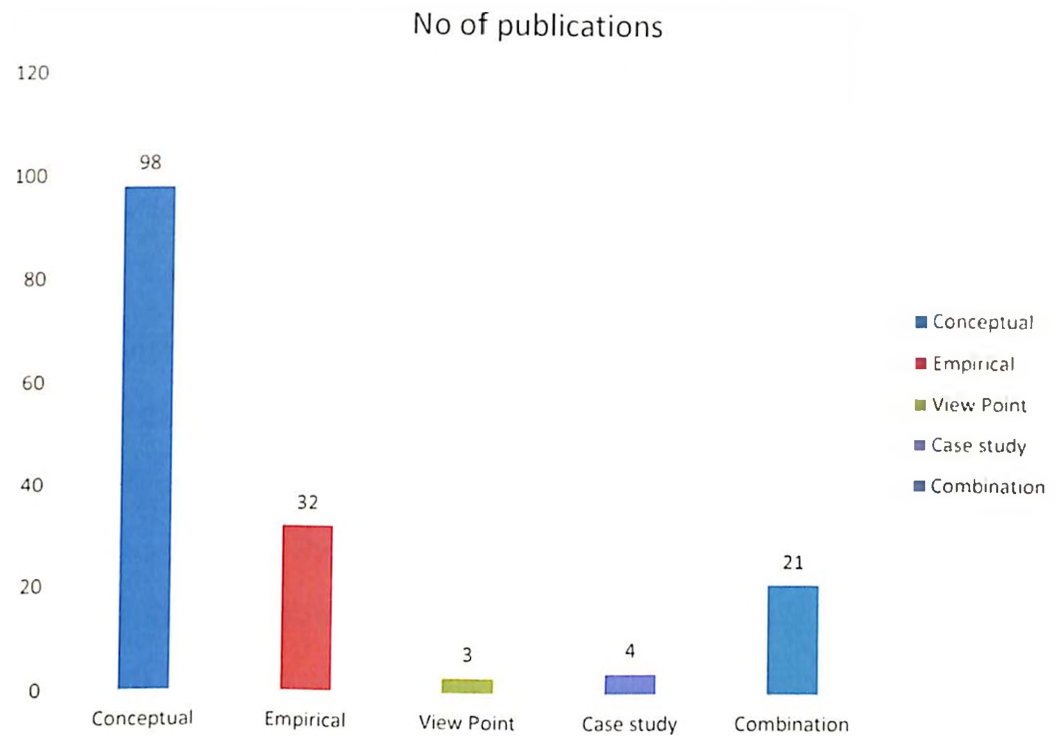

Figure 2.3: Research methodologies used in steel supply chain publications

From Figure 2.3, it is evident that most of the research articles were conceptual in nature. The papers have mostly identified the parameters in the existing activity or set of activities and have suggested the relevant remedies. Few papers were empirical, these were mostly the by-product usage, where the on-hand experiment was demonstrated to establish the fact for its usage. Few case studies were discussed which found to be majorly from the mining. The mining activity is such that it leaves its footprints even after the mining activity is completed. The abandoned mines will continue to threaten the environment and pollute water bodies, soil and air. The few case studies were identified to have discussed the existing mines under use and also the abandoned mines.

2.5 Distribution of Research Papers by Country Basis

The number of research articles published related to environmental aspects of steel supply chain from different countries is presented in Figure 2.4. The number of research papers related to environmental aspects of steel supply chain published from China and India are 45 (28.48 %) and 40 (25.31 %) respectively. Nearly 54 % of research papers were found to be from China and India combined. China and India are the two largest steel manufacturing units. Apart from the manufacturing capacity, the two countries have rich resources of minerals, thereby accounting for substantial mining activity. It is also important to note that the selected research articles collectively cover 36 countries. This is enough to conclude the importance of the industry and its global presence and significance. Most of the steel producing countries have touched the subject on mining and steel making. Also few papers were found from countries such as Australia (10), Brazil (5), Italy (5), Sweden (5), UK (5), South Africa (4), Iran (3), Korea (3) and USA (3). Australia and Brazil are particularly rich mineral belts and account considerable mining activities. Much of the research papers are from Brazil and Australia in context to mining activity. The research articles from European countries, US, Korea, Japan and other developed nations addresses the new technologies for higher supply chain efficiency. The steel-making capacity in the developed nations are mostly scrap based. Mining, coke ovens and blast furnace are resource and energy intensive and have significant impact on the environment. By eliminating these three activities the steel supply chain is comparably much cleaner than that of integrated steel plant where the supply chain starts from mining. Consequent to it the research articles from developed world are mostly concentrated towards advanced technology. Most of the articles from India and China are concentrated towards mining, by-products and waste management.

This is conclusive with the fact that the two countries are the top two largest steel producer's and generates high amount of by-products and waste across its supply chain. The efficient use of by-products and safe disposal of wastes are the essential focus of the research articles. Since the two countries are rich mineral belts and accounts for hefty mining activities, several research articles were found to address the environmental issue and providing the roadmap for environment sustainable mining. Iran is another country which is rapidly enhancing its steel-making capacity to meet the growing demand and is found to get involved in the related research. The research from Japan and Korea is mostly concentrated to process and product efficiency improvement and addresses the technological aspect. The papers from African countries were mostly focused towards mining due to its rich mineral belt. The number of papers published from other twenty-five countries is 30. These countries are Canada (2), Greece (2), Malaysia (2), Poland (2), Spain (2), Bangladesh (2), Algeria (1), Belgium (1), Chile (1), Czech Republic (1), Denmark (1), Egypt (1), Finland (1), Germany (1), Israel (1), Japan (1), Jordan (1), Netherland (1), New Zealand (1), Nigeria (1), Russia (1), Serbia (1), Singapore (1) and UAE (1).

2.6 Critical Analysis of Objectives of Selected Research Papers

The total of 158 papers were studied and the objectives and summary for each of the research papers have been listed in Table 2.6 serially in a year wise order. An effort has been made to review all the selected research articles as concise as possible.

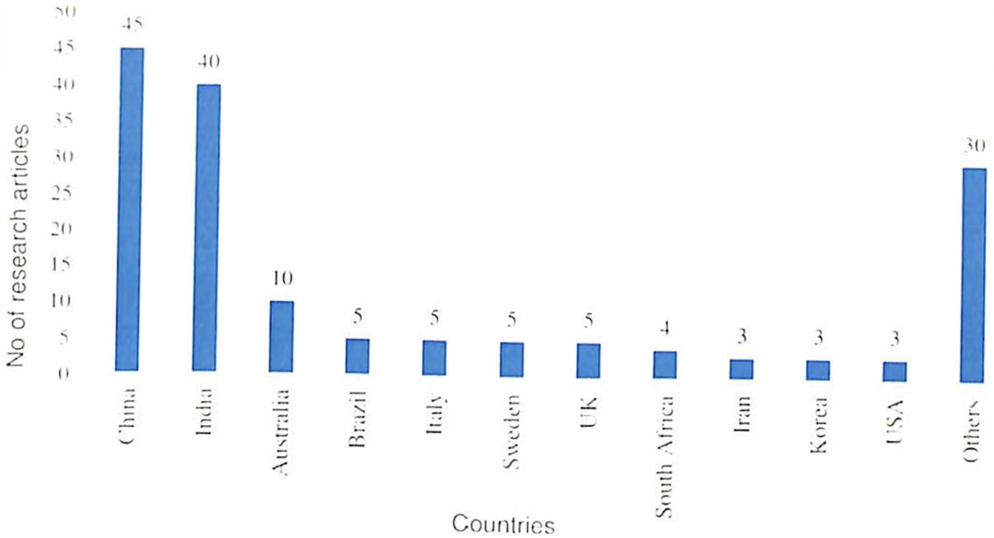

Figure 2.4: Country-wise number of articles

Table 2.6: Objectives and summary of the selected articles related to environmental impact on steel supply chain

Authors	Objective
Deshpande and Shekdar (2005)	Discussed the existing status of waste generation, its characteristics and the disposal methods being adopted in India. Also developed strategies for improvements in the existing waste management practices.
Mudd (2005)	Emphasized the importance and necessity for accounting of mining waste including the overburden and waste rock.
Bradecki and Dubiński (2005)	Discussed transformations in the Polish coal-mining industry and identify the practical implication of implementation of innovative technical, organizational and legal solutions in the mining industry
Feuerborn (2005)	Studied the utilization of coal combustion product's (waste) across the globe.
Glauser *et al.*, (2005)	Studied the sustainability of coal mining at Satna Catarina, Brazil
Brereton *et al.*, (2005)	Development of improved methods for monitoring the effects of coal mining on neighboring communities.
Binbin (2005)	Identified the various strategies adopted for the sustainable manufacturing in steel industry.

Authors	Objective
Wang *et al.*, (2005)	Discussed the reuse of the scraps in steel industries and designs a supply chain networks for the reverse logistics.
Hidalgo *et al.*, (2005)	Discuss the impact on iron and steel industry of CO_2 emission for the period until 2030.
Wang and Wheeler (2005)	Developed an econometric model of endogenous enforcement in which factories' levy rates and emissions are jointly determined by the interaction of local and national enforcement factors, abatement costs and regulator manager negotiations that are sensitive to plant characteristic.
Kim *et al.*, (2006)	Identified and compares the technical efficiency of iron and steel industry.
Luiten *et al.*, (2006)	Analyzed four case studies of innovations in energy-efficient industrial process technologies: two in the paper and pulp industry and two in the iron and steel industry and investigate the influence of government intervention.
Newbold (2006)	Provided the evidence for improving environmental performance and highlights the challenges associated with the mining industry.
Huang *et al.*, (2006)	Introduced the strategies undertaken in China to improve solid waste management.
Singh (2006)	Highlighted the measures that can be adopted to overcome the environmental challenges associated with mining.
Hedström and Rastas (2006)	Evaluated experimental methods to determine the phosphorus sorption capacity of blast furnace slag.
Yadav *et al.*, (2006)	Identified the various waste generated in steel production and discuss their recycling through pellet plant to draw out the mineral value from them.
Dvorak *et al.*, (2007)	Development of a new unit for catalytic destruction of waste gases and achieves maximum utilizing heat losses in the combustion chamber and catalytic reactor.
Das *et al.*, (2007)	Analyzed the characterization, beneficiation and utilization aspects of blast furnace flue dust, blast furnace sludge, ladle sludge and ladle slag generated at modern steel plants.

Authors	Objective
Mortier *et al.*, (2007)	Discussed the case study of the initiatives by Arcelor Gent, Belgium towards water waste management.
Kumar *et al.*, (2007)	Identified the various by waste in steel production and their recycling through Corex to draw out the mineral value from them, a case study of JSW steel plant.
Aigbedion and Iyayi (2007)	Discussed the environmental impacts of an unorganized mining in Nigeria region and the need for government regulations and initiatives from mining industry to minimize environmental damage.
Sinha *et al.* (2007)	Identified the various environmental issues associated with mining and its adverse impact on local habitat and discussed the Government mining sustainability polices and the need for capital and economic instruments for sustainable agriculture livelihood.
Singh *et al.* (2007)	Presented a conceptual decision model, using analytical hierarchy process (AHP) to assist in evaluating the impact of an organization's sustainability performance.
Barnes and Dhanda (2007)	Analyzed the adoption and diffusion of clean technology and reverse logistics in the industry, utilizing a qualitative theoretical framework and drawing from extant case and industry data.
Wang *et al.* (2007)	Studied the potential to mitigate the CO_2 generation in Chinese steel industry and the incremental cost associated with it.
Singh (2008)	Discussed the environmental issues associated with mining and need to bring the balance between mineral extraction and environment restoration.
Ye (2008)	Analyzed the damage cause by Shanxi coal mining to the water resources, by use of the methods of environmental economics and a reference to environmental compensation mechanism is provided.
Hobbs *et al.*, (2008)	Examines and study the environmental impact management, specially the water management at mining area.
LI *et al.*, (2008)	Discussed the decline of soil quality, farmland productivity and land use in subsided area due to coal mining and discuss the need for the master planning of land use, protection of cropland and effective decision-making of government officials.

Authors	Objective
Kopfle and Hunter (2008)	Discussed the growth of Direct Reduced Iron - Electric arc furnace (DRI-EAF) route in the world (excluding China).
Kuang (2008)	Discussed the growth of steel industry in China and need to form an industrial chain of circular-economy with steel plants as its core, which carries out three functions of producing high quality steel products, high-efficient energy transformation, and utilizing wastes of society using advanced technology.
Xingwu (2008)	Discussed the ways to save energy and waste discharge reduction in the steel industry through adoption of advanced technology.
Singh *et al.*, (2008)	Identified the environmental strategies emphasized the need for the industry to develop robust methodology to monitor Environment Performance Indicators (EPIs) and perform benchmarking with competitors, conduct environmental risk assessment, improve their hazardous waste management practices, and make environmental investments on regular intervals.
Jha *et al.*, (2008)	Discussed the preparation of excellent adsorbent materials from slag useful in reducing eutrophication in wastewaters.
El-Mahllawy (2008)	Studied the recycling feasibility of Kaolin Fine Quarry Residue (KFQR) combined with Granulated Blast-Furnace Slag (GBFS) and granite-basalt fine quarry residue (GBFQR) to make a brick resistible to chemical actions, particularly sewage waters, and possesses better properties than the conventional one.
Huang and Liu (2008)	Identified the comprehensive utilization of electric furnace slag.
Qasrawi *et al.*, (2009)	Discussed the usage of steel slag in concrete and identifies the enhancement in strength of concrete, especially tensile strength when correct mix ratio is used.
Li *et al.*, (2009)	Studied the effect of mixture of blast furnace slag and steel making slag in concrete and determine the mechanical properties through experimental results.
Branca *et al.*, (2009)	Studied the ways to reduce the disintegration of ladle furnace slag into powder and minimize its free dispersion into the environment in order to achieve a more sustainable solution.
Ming-yin *et al.*, (2009)	Identified the green incentive mechanism in China and abroad and establishes the green incentive mechanism derived out from three aspects - market incentive, government incentive and technology incentive.

Authors	Objective
Jiangwei (2009)	Identified the environment problem associated coal mining and discusses the importance of sustainable development of the coal mine.
Yu and Niu (2009)	Identified the usefulness the green paste filling system which liberates dull reserves, digest gangue, protect the surface environment and reduce amount of roadway excavation projects.
Chikkatur *et al.*, (2009)	Discussed the need for long term vision, a systematic policy and participation of stake holders for sustainable development of India coal industry.
Ghose (2009)	Provided a technology vision for the year 2050 for sustainability of global mining industry
MacKillop (2009)	Analyzed to what extent 'waste' management is an issue of objective material properties, in contrast to social and organizational perceptions and practices around materials.
Yang *et al.*, (2009)	Demonstrated the coke dry quenching (CDQ) and utilization of its waste heat for electricity thereby achieving improved energy efficiency and subsequent CO_2 emission reductions.
Jiuju (2009)	Highlighted the major technology progress made in production process across the production stages to improve process efficiency.
Chunbao Charles and Cang (2010)	Provided an overview of new CO_2 breakthrough technologies for iron and steel industry.
Zhengfu *et al.*, (2010)	Discussed the environmental issue of mining and the need for sustainable mining practices and restoration of mined area.
Si *et al.*, (2010)	Provided the use of analytic hierarchy process (AHP) to evaluate the environmental sustainability of coal mining in the Qijiang area, Western China.
Singh *et al.*, (2010)	Discussed the case study of Jhansi open cast mine in perspective to the environmental issues and social – economic condition in nearby areas and provides a framework for management strategies to improve the environmental conditions.
Sarma *et al.*, (2010)	Identified and discussed the impact of coal mining on plant diversity and tree population structure in its proximity.

Authors	Objective
Pratt and Shilton (2010)	Studied the full-scale active slag filter operation for removing of phosphorous from effluents and analyses its performance over a period of time.
Baciocchi *et al.*, (2010)	Assessed the CO_2 uptake achievable by each type of slag under mild operating conditions and to investigate the effects of carbonation on the mineralogy and leaching behavior of the residues.
Joulazadeh and Joulazadeh (2010)	Provided the ways to utilize blast furnace and basic oxygen furnace slag from the result obtained from the researches carried out in ESCo of Iran.
Zore and Valunjkar (2010)	Discussed the utilization of slag in the road construction in place of the natural aggregates.
Sarkar *et al.*, (2010)	Explored the possibility of usage of electric arc furnace slag for manufacturing of vitrified tiles and also demonstrates the shortcomings and difficulties in the process.
Sen and Mishra (2010)	Identifies the various wastes that generates out of the iron and steel industry and provides the conceptual input for its utilization in construction of roads and highways.
Koranne and Bansode (2010)	Studied the chemical and engineering properties of slag and finds it suitable for road construction in place of natural aggregates.
Iacobescu *et al.*, (2011)	Studied the valorisation of electric arc furnace steel slag (EAFS) in the production of low energy belite cements and also determines the influence of slag addition on the physicochemical properties of the cement.
Ipshita and Tarar (2011)	Studied the effect of steel slag on agricultural topsoil through laboratory and field tests and estimating out the optimum dosage of steel slag as liming material for agricultural use.
Manjunath *et al.*, (2011)	Experimentally determined the improvement of undrained shear strength Su of black cotton soil after curing for 28 days with 4% lime and 40 % ground granulated blast furnace slag.
Huang *et al.*, (2011)	Studied the feasibility and effectiveness of constructed wetland as pretreatment method, in a constructed wetland/ultrafiltration/ reverse osmosis (CW/UF/RO) process for waste water treatment.

Authors	Objective
Huaming *et al.*, (2011)	Identified the various wastes of steel industry and discussed about the latest technology that can be adopted to make maximum usage out of the waste.
Ahrens *et al.*, (2011)	Discussed the presence of Poly-Fluoroalkyl Compounds (PFCs) in air around a Wastewater Treatment Plant (WWTP) and two landfill sites using sorbent-impregnated polyurethane foam (SIP) disk passive air samplers.
Rootzén *et al.*, (2011)	Assessed the role of CO_2 capture and storage (CCS) technologies in reduction of CO_2 emissions from European industries.
Wiley *et al.*, (2011)	Assessed the cost and feasibility of implementing CO_2 capture at existing steel making facilities in Australia.
Ni *et al.*, (2011)	Studied the potential emission reduction and energy saving for Chinese iron and steel industries with the use of advanced technologies and also assessed the economic and emission reduction potential for each technology.
Muduli and Barve (2011)	Discussed the role of green supply chain management (GSCM) to achieve sustainable development, and identified various challenges faced during greening the mining supply chains.
Laurence (2011)	Defined the concept of sustainable mining and identifies the role of the mining operator/worker to be a part of standard practices.
Silva *et al.*, (2011)	Studies the presence and concentration of trace elements in coal mine drainage (CMD) from 49 abandoned mines located in the coal fields of the Brazilian state of Santa Catarina.
Weng *et al.*, (2012)	Analyzed the pollutant loads and intensities from coal mining in conjunction with production data.
Bian *et al.*, (2012)	Discussed the need to evaluate mining waste and identified the routes to utilize these waste into useful products which can be used as fuel, construction material, mineral extraction etc.
Nzimande and Chauke (2012)	Investigated the challenges faced by the coal sector as far as mine rehabilitation and closure is concerned and highlights the importance of government regulation in mining.
Abu-Eishah *et al.*, (2012)	Investigated the effect of using electric arc furnace (EAF) steel slag as coarse aggregate in concrete.

Authors	Objective
Maghchiche *et al.*, (2012)	Presented the basic characteristics of slag, analyzed its modification when incorporated with some essential plant nutrients and explores the possibility of its application as fertilizer.
Zhang *et al.*, (2012)	Presented a regression analysis to verify the relationship among CO_2 reduction practices, determinants and performance of the companies.
Oda *et al.*, (2012)	Compared specific energy consumption among countries in fossil power generation, steel, and cement sectors.
Milford *et al.*, (2013)	Analyzed a global mass flow, combined with process emissions intensities to allow forecasts of future steel sector emissions under all abatement options.
Zhang *et al.*, (2013)	Reviewed the proposed granulation and technologies to recover heat from molten slag.
Yang *et al.*, (2013)	Discussed problems in China's steel metallurgy slag comprehensive utilization, and emphasized the need for development of the new method for the comprehensive utilization
Chinnaraju *et al.*, (2013)	Studied the effect on strength of concrete on replacement of coarse aggregates with steel slag and fine aggregates with eco sand.
Saki *et al.*, (2013)	Assessed the use of the steel slag as a low-cost absorbent to remove cadmium pollutant from industrial wastewater.
Ramesh *et al.*, (2013)	Discussed the furnace and welding slags use in different proportions in plain concrete as a replacement to the aggregates and studied the strength of concrete.
Howladar (2013)	Determined the impact of underground coal mining on water environment around the Barapukuria coal mining area, Dinajpur by direct field investigation, questionnaire survey and laboratory analysis.
Adibee *et al.*, (2013)	Determined the impacts of waste dumps on the environment and identified the characteristics of the wastes, their acid generation potential, the availability of hazardous contaminants, and a prediction of their environmental impacts on the site.
Finnveden *et al.*, (2013)	Suggested and discussed policy instruments that could lead towards a more sustainable waste management.

Authors	Objective
Chand and Paul (2014)	Reviewed the current state of utilization and recycling of ladle slag produced from different steel plants in India.
Dhande (2014)	Discussed the heat wastage in ladle and simulates a heat energy solidification process for a continuous casting machine and the constructive shape of the liquid pool is predicted considering at different conditions in an effort to mitigate heat wastage.
Alcamisi *et al.*, (2014)	Presented the main simulation results related to one case study of wastewater treatment, namely the stripping of ammonia from coke ovens wash water.
Wen *et al.*, (2014)	Evaluated the potential for energy conservation and CO_2 emissions mitigation in China's iron and steel industry during 2010 and 2020, a detailed model was developed and applied based on Asian-Pacific Integrated Model (AIM).
Wübbeke and Heroth (2014)	Examined the reasons for weak steel recycling in China and discusses measures the government can take to improve recycling.
Stojiljkovic *et al.*, (2014)	Identified the factors and discuss the environmental impact of underground coal mining.
Merem *et al.*, (2014)	Analyzed the impacts of coal mining activities on West Virginia's environment.
De Araújo and Schalch (2014)	Discussed recycling of the electric arc furnace dust by sintering of a composite, pre-cast agglomerate (PCA) consisting of electric arc furnace dust agglomerate to coke particles, mill scale and ceramic fluorite into pellets.
Wang *et al.*, (2014)	Defined the thermodynamic relations between dephosphorisation and temperature of liquid steel and uses regression analysis to predict end point phosphorous content in BF steel making process.
Kuroki *et al.*, (2014)	Described the thermoelectric generation (TEG) system using the waste heat in the steelmaking process.
Jahanshahi *et al.*, (2015)	Provided a summary of the progress made over the 8 years of an R&D program that focused on the development of know-how and processes that could result in substantial reduction in net CO_2 emission by the steel industry.
Lobato *et al.*, (2015)	Presented an updated review of the management of slag, sludge, dusts, and mill scales generated by the steel industry, including precipitating sludge generated by galvanizing processes.

Authors	Objective
Ghanbari *et al.*, (2015)	Presented the numerical study of economics and environmental impact of an integrated steelmaking plant, using surrogate, empirical and shortcut models based on mass and energy balance equations for the unit operations.
Sarkar and Mazumder (2015)	Discussed the various solid wastes that generates in steel industry, and identifies the challenges associated with them and highlights the need for sustainable management practices for improved solid waste management.
Fan and Zhang (2015)	Reported three cases that illustrate key factors and mechanisms to protect water supply during underground mining and protecting aquifers and surface waters
Goswami (2015)	Discussed the various environmental hazards associated with mining.
Hota and Behera (2015)	Provided an assessment of the cost of coal mining on agriculture and human health in one of the prominent mining regions in the Indian state of Odisha.
Bouzon *et al.*, (2015)	Identified the drivers that enable reverse logistics practice in an emerging economy.
Wang *et al.*, (2015)	Discussed the model and investigates the injection of biomass into blast furnaces (BF), in place of pulverized coal (PC) from fossil sources and also identifies the reduction of total emission.
Colla *et al.*, (2016)	Discussed water reuse and facility management concepts for the main circuits in different steel plants through the salt elimination techniques via reverse osmosis.
Zhao and Liu (2016)	Provided a comprehensive picture of state of the art of biological processes for treating coal gasification wastewater.
Saini *et al.*, (2016)	Presented a study that includes a review of the environmental impact studies done on various specific aspects in India, which involve methodologies of field-site investigation, laboratory analysis and satellite data processing.
Gupta and Nikhil (2016)	Discussed the ground water contamination near coal mines and elaborates on general aspects of ground water, and share some results of research done in India.
Golofastova *et al.*, (2016)	Analyzed of the environmental safety performance at the local level (a coal mining enterprise) and proposals for improvement of the management decision support mechanism aimed at improving the environmental safety.

Authors	Objective
Xu *et al.*, (2016)	Provided the computation method of coal oxidation factors and used it to estimate the CO2 emissions of China in 2011 based on the production data of twenty typical iron and steel enterprises.
Karayannis (2016)	Discussed the utilization of waste/by products of steel industry as input raw material for other products.
Huang *et al.*, (2016)	Developed artificial green reef through granulated blast furnace slag and steel slag.
Coppola *et al.*, (2016)	Studied the usage of steel slag in concrete in pace of natural aggregates.
Ali *et al.*, (2017)	Discussed the impact of water from coal mine activities located within or discharging into high conservation environments, such as National Parks, in the outer region of Sydney, Australia.
Sun *et al.*, (2017)	Addressed the problems of major geo-environmental hazards caused by high-intensive coal mining in China's western eco-environment frangible area.
Mishra and Das (2017)	Investigated the environmental effect of coal mining in the nearby village areas.
Kumar *et al.*, (2017)	Assessed the impact of coal mining on soil nutrients and their efficient restoration through different combination of soil amendments.
Rosales *et al.*, (2017)	Analyzed the cementation and pozzolanic reaction characteristics of stainless steel slag waste to evaluate its strength activity index and its environmental impact.
Gao *et al.*, (2017)	Studied the feasibility of steel slag utilization in asphalt mixtures for microwave deicing and also takes the environmental hazards into account.
He and Wang (2017)	Presented a list of energy-efficient technologies and practices applicable to the steel industry, includes case studies around the world and provides information of energy and cost savings.
Maghool *et al.*, (2017)	Demonstrated the research, an extensive suite of engineering and environmental tests on steel slag aggregates to evaluate their potential usage as road construction material.
Zhang *et al.*, (2017)	Discussed a techno-economic model that links theoretical, technical, and economic potential with the characteristics of waste energy resources and waste recycling technologies.

Authors	Objective
Jouhara *et al.*, (2017)	Presented the design, manufacture and testing of an innovative heat recovery system based on a Flat Heat Pipe heat exchanger (FHP).
Khunte (2018)	Discussed the various waste generated in the steel making process and the ways to mitigate and utilize these waste.
Guo *et al.*, (2018)	Analyzed and discuss the steel slag treatment, recycling, and management in China.
Sista and Dwarapudi (2018)	Emphasized on a novel and promising product for the future, the Iron powder, its prospects, applications and synthesis from various steel industry by-products.
Sun *et al.*, (2018)	Evaluated the carbon footprint of the waste management sector to identify direct and indirect carbon emissions, waste recycling carbon emission using a hybrid life cycle assessment and input-output analysis of Japan and China.
Forrest and Loate (2018)	Identified the reasons for failure of South Africa's coal mining water regulatory systems.
Choi *et al.*, (2018)	Studied the sustainability performance from the data obtained from different firms in the steel industry.
Sun *et al.*, (2018)	Discussed the intelligent manufacturing to achieve production efficiency, quality and flexibility
Ma *et al.*, (2018)	Identified the ways the China's steel industry can improved the environmental sustainability w.r.t. to water management.
Karakaya *et al.*, (2018).	Explored the potential pathways for sustainability transitions in the iron and steel industry.
Yang *et al.*, (2018)	Identified the policy preferences that have substantial effect on CO_2 emissions reductions.
Swain *et al.*, (2018)	Discussed the issues pertaining to the solid waste generation in Rourkela Steel Plant, Odisha in terms of volumes toxicity, challenges and efforts towards recycling and utilization in eco-friendly manner.
Mukherjee and Pahari (2019)	Compared the two mining methods with respect to advantages, disadvantages, environmental impact and feasibility.
Bhar (2019)	Develop a framework for sustainable improvement in performance of coal mining operations using an integrated approach of interpretative structural modelling and fuzzy MICMAC analysis.

Authors	Objective
Qi *et al.*, (2019)	Uses system dynamics (SD) and the Malmquist-Luenberger (ML) Index to model and demonstrate the sustainable effect of the policy (Tax and subsidies) on green mining construction.
Sun *et al.*, (2019)	Provided an approach that can fairly and comprehensively assess the environmental impact of industrial multi-air emissions.
Emerson and Stephanopoulos (2019)	Discussed various available technologies for Co2 mitigation and emphasized that technologies that valorize CO2 waste streams are likely to achieve widespread adoption.
Lee *et al.*, (2019)	Identified the potential use of steel slag in concrete and studies and compare the mechanical properties of concrete with blast furnace slag, steel slag and granulated blast furnace slag.
Sun *et al.*, (2019)	Studied the impact of waste water discharge from steel industry on environment via total environmental impact score.
Nidheesh and Kumar (2019)	Studied and reviews the sustainability aspects for steel and cement industries.
Chen *et al.*, (2019)	Evaluated engineering properties, cost, and energy and environmental impacts of three previous concrete mixtures: pervious concrete with regular Portland cement (PC-Regular); with fly ash (PC-FA); and with blast furnace slag (PC-BFS).
Arens (2019)	Reviewed policy activities, R&D projects and activities in the field of digitalising the European steel industry.
Wang *et al.*, (2020)	Developed the concept of mass-thermal network optimization in iron and steel industry, which unrolls a comprehensive map to consider current energy conservation technologies and low grade heat recovery technologies from an overall situation.
Sinha *et al.*, (2020)	Explored the potential of utilizing the solid waste generated from steel industry for the fabrication of porous ceramic membrane from Linz Donawitz (LD) slag.
Roslan *et al.*, (2020)	Presented an experimental study on the properties of concrete prepared from electric arc furnace steel slag and steel sludge.
Roychand et al., (2020)	Demonstrated the use of steel slag to remove phosphorus content from the municipal wastewater and subsequently use it as an aggregate replacement in concrete.
Wang *et al.*, (2020)	Studied the use of fly ash and flue gas desulphurization gypsum as basic components to develop green binder materials and the effects of mineral additions, including ground-granulated blast-furnace slag, steel slag, cement and hydrated lime, and chemical additives on the mechanical strengths of the systems were studied.

Authors	Objective
Naidu *et al.*, (2020)	Discussed the properties of blast furnace slag and explores its potential application and uses.
Aziz *et al.*, (2020)	Studied the performance of steel slag as replacement of aggregate in concrete (w.r.t. to physical, chemical and mechanical properties) in construction activity.
Post *et al.*, (2020)	Presented an assessment of the hydrological impacts of proposed coal mines and coal seam gas (CSG) developments in the Gloucester, Hunter, Namoi and Galilee sub regions of eastern Australia.
Jiang *et al.*, (2020)	Reviewed the distribution, characteristics and formation of coal mine goaf water in karst areas in China.
Nowacki (2020)	Discussed the environment sustainable waste management policies.
Das *et al.*, (2020)	Presented the sustainable innovative technology that uses the coke breeze to treat the waste effluent from coke plant.

The research articles were found to cover all the stages of supply chain starting from mining to production and logistics. The articles were found covering the broad range of discussion across the steel supply chain. The environment issues associated with the mining, adverse effect on the nearby habitat, on the agriculture activity in nearby areas, long term effect on soil and water bodies, effect on mining workers and operators etc. The papers also discuss about government regulations and management policies for improving of mining activities. Few case studies were discussed to demonstrate the long term environment impact of unplanned and unregulated mining. Articles in context to the abandoned mines were also found to have discussed the depth of long term environmental consequences of unregulated mine abandoning. Many articles were found to address the by-product usage in steel industry. Slag was one of the most discussed by-products. The slag is generated in abundance both in blast furnace and steel making. The papers provide the detailed description of the properties of slag and its potential usage. The waste water treatment is one of the subjects which was suitably addressed and available in various research articles. Similarly, the flue gases and their disposal management were addressed it the research articles. Few articles were found to have addressed the green logistics and also the reverse logistics.

2.7 Research Area Categorization Based on Environmental Impact

The activities involved in steel supply chain can be broadly divided into three stages namely mining, logistics and production. The mining activity involves the extraction of raw material, while the logistics involves the transportation of the raw material from supply sources and mines to production unit and the production unit is the location where the raw material is processed through set of activities and converted to steel. However, when the various activities of the steel supply chain are assessed for the environmental impact it is observed the environmental impact and the related issues varies considerably due to substantial difference in processes involved in the three stages. The articles were selected with the objective to understand the research being available to the environmental sustainability of steel supply chain. In consideration to the process similarity and in context to the impact on the environment, the steel supply chain is categorized into five stages. The five stages are mining, logistics, production efficiency, by-products, waste management. The mining is an industry in itself and have enormous amount of researches available on it for the mitigation of an environment impact. The production efficiency is one separate identified stage which involves the technology advancement and innovation that can maximize the utilization of input supply elements. It is evident that 100% utilization of input is impossible as the process inefficiency will generate the undesired output apart from steel. These undesired products can either be utilized and consumed or disposed of. The utilization of these undesired products to further use is categorized under by-product. The by-product usage is directly helpful in achieving the environmental sustainability. The undesired products those cannot be utilized as by-products has to be disposed in the regulated manner without affecting the environment and are categorized under waste management. The research articles that provides waste disposal methodologies and discusses the environment impact of their direct disposal to nature are considered under waste management category. The last identified category is logistics, where the environment impact due to material transportation is considered. It was observed that most of the available research literature, industrial experiments could be classified in these five stages in context to environment sustainability in steel supply chain. Figure 2.5 shows the number of publications in each identified stage.

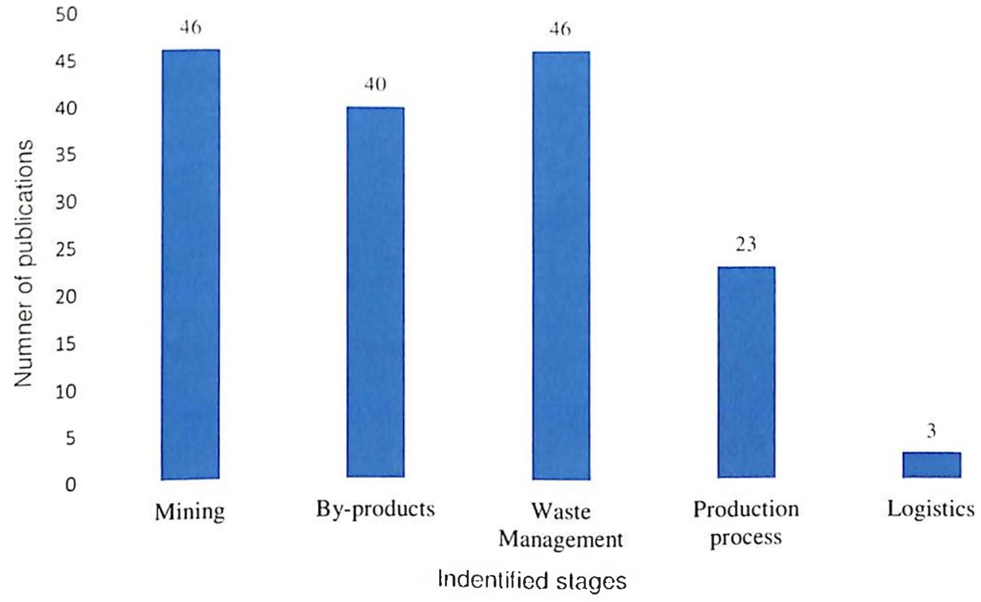

Figure 2.5: Number of publications across different stages

2.8 Conclusions

The steel supply chain is vast and complex as it involves considerable number of processes and consumes enormous energy. The environmental impacts are evident across its vast supply chain starting from mining to production and logistics. All the three important natural elements air, water and soil are found to be affected across the supply chain. The selected research articles have addressed the environmental issues. It was observed that most of the literature reported is in the area of mining, by-products and waste management. Enormous amount of undesired products is generated in steel production. The research endeavors to maximize the use of these products as a by-product i.e. it is used as input raw material in other production, while the remaining undesired products that cannot be used as by-products are categorized under waste and their disposal has to be carefully managed such that it does not affects the environment. Most of the research articles are conceptual or empirical in nature. The research papers discussing the waste management or by-product usage are mostly empirical nature. The by-product usage or waste management requires experiments to establish the facts for its usage in different applications with a special focus on Indian environment or its safe disposal. Many research papers were found to discuss the usage of slag in concrete for road construction while others have distinctly compared the properties of blast furnace slag and steel slag. It was also noticed that researchers had suggested the various methodologies for safe waste water treatment and discharge. There were several papers discussing the environmental impact of mining on human health in nearby habitat. One major problem identified was the improper abandoning of mines. Several research works are available from India, China, Australia, Brazil, South Africa etc. in context to mining due to abundant availability of mines. Similarly, lot of work in field of by-product usage and waste management was focused on China and India, due to their large product capacity which is still growing. The papers related to advanced technology and production efficiency were available from various countries especially in the developed world. The research allowed us to schematically analyze the present difficulties the steel industry is facing in terms of environmental sustainability and also the importance of the role of government in regulating and controlling the environmental impact.

It is evident that much work has been carried out and also in progress to mitigate the environmental impact and achieve maximum environmental sustainability in iron and steel manufacturing. The papers pertaining to mining takes into account the environmental issue of mining and suggest the remedial measures. Similarly, the papers pertaining to by-product usage address the best possible usage of undesired products. The similar approach was observed in waste management. While these research papers are identifying the measures for minimizing the environmental impact in their focused area, the broad consideration of entire supply chain was missing. There were limited articles available that discusses the environmental sustainability of the entire supply chain and evaluate its performance.

CHAPTER - 3

Analysis of Environment Sustainability Enablers for Indian Steel Manufacturing Company

3 Sectional Abstract

The purpose of this chapter is to analyze the Environmental Sustainability Enablers (ESEs) for an Indian steel manufacturing company in order to select the appropriate set of ESEs for implementing and enhancing environmental sustainability. A methodology using fuzzy Decision-Making Trail and Evaluation Laboratory (DEMATEL) is proposed to analyze ESEs capturing multiple experts' qualitative judgments on their mutual impacts. It is applied to an Indian steel manufacturing company in order to understand the salient features of the concept. The relevant eighteen ESEs were classified into cause and effect group and also interactions (i.e. influencing and influenced) of each ESE with other ESEs were evaluated. It was observed that the five ESEs (i.e. competitors' environmental sustainability strategy, environmental compliance certification, government regulations and incentives, influence of external factors and air pollution controlling system) are the most prominent in the cause group. The prominent effect factors are. The results obtained are specific to an Indian steel manufacturing company and it cannot be generalized for steel manufacturing sector. However, the current study can show direction to carry out such work in other manufacturing companies. The proposed methodology will be helpful for allocating efforts and resources to enhance the impact of ESEs for successful achievement of environmental sustainability. No such study has been reported in the literature with an objective to develop structural framework for Indian steel manufacturing company in order to improve environmental sustainability.

3.1 Introduction

Rapid industrialization has resulted in inordinate exploitation of natural resources due to increased population and urbanization. The world witnessed the development around it with increased pace of environmental deterioration. It was at the end of the last century that the world community decided to step up the measures to protect environment amid growing industrialization. The beginning of 21st century saw the growing awareness towards environment and an increased pressure from society for industries to go green. The various industries have started assessing their supply chain in order to introduce and enhance environmental sustainability with the aim to achieve the comprehensive competitive advantage. The basic objectives of strategic competitive advantage in manufacturing supply chain includes cost, quality, delivery, flexibility and innovation (Krause et al., 2001), however, the environmental sustainability performance should also be considered (de Burgos et al., 2001). In today's manufacturing environment, it was observed that most of current environmental activity is in pollution prevention rather than fully coordinated supply chains, and despite its recognized importance in addressing environmental sustainability in the closed supply chain is still far from being an industry norm (Ashby, 2018). Therefore, the decision makers in manufacturing industries in general and steel industries in specific lies in attaining levels of comfort with respect to social responsibility, economic viability, and environmental sustainability, while protecting the heritage of future generations (Renukappa *et al.*, 2012).

Although the production of steel is vital for the economic growth, it contributes significantly to the pollution level amplification in every country as it causes water, air and soil pollution and generates solid and hazardous waste (Amin and Banerjee, 2010). Also steel finishing operations such as pickling, galvanizing, plating etc.

involves a surface cleaning process to eliminate scale, rust and dust. This process is carried by immersion of steel in hot acidic solution. There are severe problems in its disposal of solid waste to lined sites (landfills). If the sludge is disposed on land, it may pose serious consequences. During the rains, all the toxic compounds (leachate) will go into the ground and may pollute soil and ground water. The steel industries in India are adopting various measures to curb pollution and achieve desired level of environmental sustainability along its supply chain. Indian steel industry too has taken several steps towards environmental sustainability. With the growing production capacity, the Indian steel industry is under enormous pressure to curb detrimental effect on the environment. The companies are taking various measures to establish system in place that can facilitate and promote environment sustainability in the supply chain. From our extensive literature review, it is observed that few researches have been carried on identifying ESEs for various industries, however very limited research has been reported to identify the ESEs along the steel supply chain. Also no literatures are available on cause and effect analysis among the enablers for achieving the environmental sustainability. Therefore, a methodology using fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) is proposed to establish relationship among ESEs (i.e. cause and effect), evaluate the strength and draw impact-relationship map. It is applied to an Indian steel manufacturing company to explain the concept. The remainder of the paper is as follows. The Section 2 presents the literature review on ESEs; Section 3 deals with the proposed methodology for analyzing the ESEs; Section 4 features the analysis of ESEs using the proposed methodology for an Indian steel manufacturing company; Section 5 includes the results and discussions; and Section 6 highlights the conclusions drawn from the interpretation of the results.

3.2 Literature Review on Environment Sustainability Enablers

The ESEs facilitate the successful implementation and enhancement of environment sustainability. On the basis of extensive literature review, twenty ESEs were identified, (see Table 3.1). A brief discussion on all twenty significant categories is mentioned below.

Table 3.1: ESEs identified from literature review

ESE	Abbreviation	Citation
Supply Chain Environmental Sustainability Initiatives	SCE	Lee, 2008; Eltayeb and Zailani, 2009; Eltayeb *et al.*, 2011; Leigh and Li 2015; Quader *et al.*, 2015; Hsu *et al.*, 2016 and Goyal *et al.*, 2018
Environmental Sustainability Performance Measurement System	ESC	Rao, 2002, Singh *et al.*, 2007; Chin *et al.*, 2015; Rehman *et al.*, 2016; Long *et al.*, 2016; Shamaii *et al.*, 2017; Wu *et al.*, 2017; Goyal *et al.*, 2018; Sangwan and Choudhary 2018; and Chuang and Huang, 2018
Top Management Involvement and Support	TMI	Zhu *et al.*, 2008; Diabat and Govindan, 2011; Giunipero et al, 2012; Muduli *et al.*, 2013; Paillé *et al.*, 2014; Govindan et al, 2014; Chin *et al.*, 2015; Anthony *et al.* 2016; Luthra *et al.*, 2016; Dubey *et al.*, 2017; Walls and Berrone 2017 Goyal *et al.*, 2018, Soepardi and Thollander, 2018; Sangwan and Choudhary, 2018; and Latan *et al.*, 2018
Value Added Product from waste	VAP	Qasrawi, 2014; Kumar *et al.*, 2015; Quader *et al.*, 2015; Huang *et al.*, 2016; and Pan *et al.*, 2016
Environmental Sustainability Practices Adoption	ESP	Muduli *et al.*, 2013; Govindan et al., 2015; Sangwan and Mittal, 2015, Rehman *et al.*, 2016; Sangwan and Choudhary, 2018, Miska et al, 2018; Vejvar *et al.*, 2018
Environmental Sustainability Culture	ENS	Gunasekaran and Spalanzani, 2012; Kurdve *et al.*, 2014; and Dubey *et al.*, 2017

ESE	Abbreviation	Citation
Information Systems for Environmental Sustainability	ISE	Melville, 2010; Dao *et al.*, 2010; Malhotra *et al.*, 2013; Goyal *et al.*, 2018
Environmental Corporate Social Responsibility	CSR	Fabian and Hill, 2005; Spence, 2006; Faisal *et al.*, 2006; Wright *et al.*, 2007; Helfaya and Moussa, 2017; Chuang and Huang, 2018; and Acharya and Patnaik, 2018
Internal Auditing System for Environmental Sustainability	IAS	Watson and Emery, 2004; Soh and Martinov-Bennie, 2015; and Acharya and Patnaik, 2018
R&D Program for Environmental Sustainability	RES	Quayle, 2003; Hall, 2006; Bose and Pal, 2012; Yang *et al.*, 2012; Hsu *et al.*, 2013; Guoyou *et al.*, 2013; Quader *et al.*, 2015; and Schmitz, 2017
Water Pollution Controlling System	WCS	Clift and Wright, 2000; Klassen, 2000; Rao and Holt, 2005; Van Caneghem *et al.*, 2010; Kumar *et al.*, 2012; Malik et al., 2014; Banerjee *et al.*, 2015; Brraich, and Jangu, 2015; Quader *et al.*, 2015; Wu *et al.*, 2017; and Govil and Krishna, (2018)
Air Pollution Controlling System	ACS	Hendrickson *et al.*, 1998; Guggemos and Horvath, 2004; Ho *et al.*, 2009; Miller *et al.*, 2010; Van Caneghem *et al.*, 2010; Zhang *et al.*, 2014; Quader *et al.*, 2015; Wang *et al.*, 2016; Francová *et al.*, 2017
Soil Pollution Controlling System	SCS	Wang *et al.*, 2003; Razo *et al.*, 2004; Favas *et al.*, 2011; Rachwał et al., 2015; Qing *et al.*, 2015; Yin *et al.*, 2016 and Govil and Krishna, 2018
Environmental Compliance Certification	ECC	Kwon *et al.*, 2002; Vachon, 2007; Zhu *et al.*, 2007; and Nawrocka *et al.*, 2009; Prasad and Mishra, 2017 and Rino and Salvador, 2017

ESE	Abbreviation	Citation
Influence of External Factors	IEF	Vachon and Klassen, 2006; Chien and Shin, 2007; Ramudhin *et al.*, 2008; Min and Kim, 2012; Kumar and Shekhar, 2015
Government regulations and Incentives	GRI	Zang *et al.*, 2008; Giunipero et al, 2012; Mittal and Sangwan, 2015; Sangwan and Choudhary, 2018 and Wang *et al.*, 2018
Technology Adoption for Environmental Sustainability	TAS	Cao and Zhang, 2011; and Kusi *et al.*, 2014; Quader *et al.*, 2015; Mittal and Sangwan, 2015; Rachwal *et al.*, 2015; and Karakaya *et al.*, 2018
Competitors' Environmental Sustainability strategy	CES	Ginsberg and Bloom, 2004; Orsato, 2006; Zhu, and Sarkis, 2007; and Leonidau *et al.*, 2015
Inbound Logistics	INL	Min and Galle, 2001; Rao, 2002; and Zhu *et al.*, 2008
Outbound Logistics	OUL	Murphy and Poist, 2002; Kleindorfer *et al.*, 2005; Zhu *et al.*, 2008 and Bhetja *et al.*, 2011

Supply chain environmental sustainability initiatives: Deploying supply chain environmental sustainability initiatives can influence sustainable supply chain initiative programs eco-reputation and eco-innovation strategic orientations of any manufacturing organizations (Hsu *et al.*, 2016). The implementation of environmental supply chain sustainability could push organizations to focus on alleviating environmental issues, providing economic and social benefits (Eltayeb *et al.*, 2011). Quader *et al.* (2015) discussed about the selection of the appropriate technology and their barriers and stages of development and deployment for sustainable green iron and steel manufacturing. Leigh and Li (2015) suggested that Industrial Ecology and Industrial Symbiosis can help in achieving environmental sustainability development.

Environmental sustainability performance measurement system: Long *et al* (2016) mentioned that Environmental Sustainability Performance Measurement System is an important tool for steel manufacturing organizations to implement, measure, monitor and enhance environmental sustainability performance in a systematic manner. It prepares the future perspective and forms the road map considering the available resources. It documents the performances along different dimensions of environmental sustainability and also pins out the seriousness of the environmental sustainability policy to the desired departments in the organization. It will be highly effective if well designed and adopted.

Top management involvement and support: It is the driving engine for any strategic policy adoption in general and environmental sustainability policy in specific. Sustainability programs require top management involvement and support (Giunipero *et al.*, 2012). Until the top management is willing to achieve something, it is unlikely for an organization to achieve it. This is probably the most effective enabler to achieve desired level of environmental sustainability. Resource allocation is directly determined by Top Management Involvement and Support and hence the results. High Top Management Involvement and Support is visible through strategic decisions, resource allocations, and quick problem solving attitude.

Value added product from waste: Literature suggests that steel manufacturing organizations are putting efforts to use waste for value added products as much as possible and feasible and it is a significant step towards waste management. Kumar *et al.* (2015) studied the use of the major by-products such as heat energy, blast furnace gas, coke oven gas in iron and steel industries. Pan *et al.* (2016) proposed an accelerated carbonation process for utilization of four different types of slag (i.e. blast furnace slag, basic oxygen furnace slag, electric arc furnace slag and ladle refining furnace slag) from steel manufacturing companies. Similar studies also reported in the literature such as development of green artificial reef concrete through the reuse of granulated blast furnace slag and steel slag (Huang *et al.*, 2016); and use of steel slag aggregate to enhance the mechanical properties of recycled aggregate concrete (Qasrawi, 2014).

Environmental sustainability practices adoption: Manufacturing organizations have been implemented environmental sustainability practices because of coercive factors like government regulations in beginning and later on to gain competitive advantages whereas large scale enterprises are performing better than medium-sized enterprises which are doing better than small and micro enterprises in GM (Sangwan and Choudhary, 2018). The various factors motivating organizations to adopt environmental sustainability practices are government regulations, organizational policies, availability of greener technologies, incentives in the form of tax exemptions, competitive advantage, etc. (Mittal and Sangwan, 2015).

Environmental sustainability culture: Environmental sustainability culture with alignment of different factors such as top management can offer benefits to those organizations that are pursuing environmental performance (Dubey *et al.*, 2017). It is mostly referred as the soul of an organization aiming to achieve cleaner production or green production goals. The better the environmental sustainability culture, the better are its operations.

Information system for environmental sustainability: Information System for environmental sustainability allows companies to proactively transform all the activities along the supply chain to benefit society both economically and environmentally (Melville, 2010). It has the ability to create beliefs and confidence in enabling and transforming sustainable processes and practices along the supply chain for environmental and economic performance enhancement (Malhotra *et al.*, 2013). Adequate information handling and visibility on real time basis helps in quick decision and timely action. With recent innovations and improvement in information management system have helped organizations to avert various routine problems in operations and improve their operation ease and productivity.

Environmental corporate social responsibility: It covers the area beyond the business boundaries but effective enough to make positive impact on designated business objective. With the emergence of environmental sustainability and green business management, increasing demands have been made on businesses in the areas of environmental corporate social responsibility (Chuang and Huang, 2018). Helfaya and Moussa (2017) found that the effective board CSR strategy and CSR-oriented directors have a positive and significant impact on the quality of environmental sustainability disclosure, but not on the quantity in UK listed firms.

Internal auditing systems: For successful implementation and achievement of environment sustainability in steel supply chain, there should be strong internal auditing across the supply chain with defined guidelines like any other audits such as financial audits. Internal auditing systems need to address the current perceived skills gap along various dimensions of environmental sustainability to build transparency and accountability for it internal improvements (Soh and Martinov-Bennie, 2015).

R&D program for environmental sustainability: R&D department is predominantly responsible for innovation and improvement in business. The sustainable innovation capability of enterprises is comprised of knowledge innovation capability, production innovation capability, and market innovation capability (Chen, 2016). The department gives inputs to other departments for their functional improvement in general and environmental sustainability in specific. The implementation of carbon capture and storage technology in coal-based integrated steel plant would be an efficient means for sustainable green iron and steel manufacturing (Quader *et al.*, 2015). R&D in environmental sustainability not only prepares the future business prospect but also off-sets the threats of stringent steps by government and agencies for environment conservation.

Air Pollution Control System: Air pollution in recent past has gained enough attention in the world so that steel manufacturing company has started analyzing and implementing various steps for minimizing air pollution along the supply chain in general and manufacturing plant in specific. Regulatory norms and pro-environment initiatives from companies through usage of improved technology can be highly effective in controlling air pollution. Zhang et al (2014) analyzed the co-benefits of implementing energy efficiency measures that jointly reduce greenhouse gas emissions and air pollutants, in comparison to only air pollution control (end-of-pipe technology) in steel manufacturing.

Soil Pollution Controlling System: Soil pollution is mainly caused due to irregular manufacturing activities and unplanned infrastructure activities. Qing *et al.* (2015) found that steel industrial district in China showed much higher concentrations of heavy metals compared to the rest of sampling sites, indicating significant contamination introduced by steel industry on soils. Soil pollution in mining activity is the most common in manufacturing industry including steel (Yin et al., 2016). Usage of improved mining technology and incentives for green mining can be highly effective in controlling soil pollution. Many a time, the soil gets polluted due to improper disposal system of contaminated water and sludge.

Water Pollution Controlling System: Water pollution is mainly caused due to illegitimate leakage or flow of waste from industry to water bodies. Govil and Krishna, (2018) revealed that the water in the Katedan Industrial Development Area (KIDA), Hyderabad, Telangana State, India have high concentrations of arsenic (As), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), lead (Pb), and zinc (Zn) relative to WHO guideline values due to industrial activities, that includes steel processing. The adequate measures should be in place to control water pollution for successful environment sustainability.

Environmental compliance and certification: Environmental norms are generally set by the law of land and vary for industries based on the nature of work. It is the first line of step for the industry to comply towards environment sustainability and induces the sense of responsibility in the companies towards environment. Industry associations like Confederation of Indian Industry (CII) may include ISO 14001 compliance as one of the criteria when awarding environmental (GreenCo) rating to plants and it benefits to the companies (Rino and Salvador, 2017 and Prasad and Mishra, 2017).

Influence of external environment: The hazards of industrialization on the environment are visible to external environment (i.e. society and nature). The pressures from external environment had positive on environmental sustainability (Dubey *et al*., 2017). With the recent changes in climate, there has been increased voice from the external environment for increased measures in enhancing environmental sustainability. The enabler at times can be most effective driver for the industries to go environment sustainable.

Government regulations and incentives: Government regulations are the parameters/policies that become mandatory for the companies to follow. Government influences and improves the performance on corporate environmental practices by regulations (Wang *et al.*, 2018). The most important are the government incentives that are capable of generating the self-motivation for the companies to achieve the desired level of environment sustainability. The incentives also help companies to achieve cutting edge through environment sustainability programs and induces healthy competition with the industry.

Technology adoption for environmental sustainability: Adopting modern and cleaner technology is the need of hour for manufacturing industries in general and steel manufacturing industries in specific for enhancing environmental sustainability. Literatures are available related to this in steel manufacturing along varies processes and practices throughout the globe. For example, Karakaya et al (2018) concluded that steel manufacturing companies, governmental agencies and knowledge institutions in Sweden strongly collaborated to drive the transition towards hydrogen-based direct reduction technology for enhancing environmental sustainability.

Competitor's environmental sustainability strategy: Every business house keeps a close look at its competitors, so that it does not miss on any business parameter that may affect its business prospect. Any initiative towards green (environmental sustainable) activities from the competitor can be the driving force for the other companies to emulate it. Chinese manufacturing industries have experienced increasing ecological pressures from a variety of institutional players including market, governmental, and competitive sources (Zhu, and Sarkis, 2007).

Inbound logistics: Inbound logistics refers to the pool of activities associated with the inward movement of goods, raw material etc. to the company's premises. Zhu et al (2008) found that inbound logistics activities are potential polluters to the environment in Chinese manufacturing firms. In the most of the heavy engineering industries, the inbound logistics is dependent on the country's infrastructure which is turn is determined by government.

Outbound logistics: Outbound logistics refers to the pool of activities associated with the outward movement of goods, finished goods and by products, from the company premises to the desired destination. Similar to inbound logistics, the outbound logistics is heavily dependent on the country's infrastructure which is turn is determined by government and one of the potential polluters to the environment (Zhu *et al.*, 2008).

3.3 Application of the Proposed Methodology for Environmental Sustainability

A methodology using fuzzy DEMATEL as mentioned in Figure 3.1 is proposed to analyze the ESEs for successful adoption of environmental sustainability. The proposed methodology has the ability to capture the relationship of ESEs between them and divides them into two groups (i.e. cause group and effect group). It also evaluates the influence of the cause group on the effect group where such influence is used to estimate the ESEs weights (Dalalah *et al.*, 2011). One can find a few recent applications of fuzzy DEMATEL such as analyzing critical success factors of sustainable project management in construction (Mavi and Standing, 2018); performance assessment of green supply chain management (Kazancoglu *et al.*, 2018); analyzing the agile manufacturing barriers (Potdar *et al.*, 2017); evaluating TQM adoption success factors to improve Indian MSMEs performance (Gupta *et al.*, 2017) and analyzing supplier development program enablers (Routroy and Kumar, 2014) in general and in steel manufacturing in specific such as analyzing critical success factors for the iron and steel industry in Turkey (Kabak *et al.*, 2016); and critical factors and CO_2 capture technology for sustainable iron and steel manufacturing (Quader and Ahmed, 2016).

The notations used in the fuzzy DEMATEL are mentioned below:

F:	Fuzzified Direct Relationship Matrix (FDRM)
$F_{ij} = (l_{ij}, m_{ij}, r_{ij})$:	Elemental value of FDRM, where it indicates the degree that a criterion i influences criterion j
$(xl_{ij}, xm_{ij}, xr_{ij})$:	Normalized value of (l_{ij}, m_{ij}, r_{ij})
$min\ l_{ij}$:	Column wise minimum l_{ij}
$max\ r_{ij}$:	Column wise maximum r_{ij}
xls_{ij}:	Left spread measure of normalized fuzzy number
xrs_{ij} :	Right spread measure of normalized fuzzy number
x_{ij}:	Total normalized crisp value calculated from left and right spread measures of normalized fuzzy numbers
z_{ij} :	Crisp value defuzzified from triangular fuzzy number
z^k:	Defuzzified matrix obtained from the k^{th} expert
h:	Number of experts
n:	Number of criteria
$T=t_{ij}$:	Total Relation Matrix (TRM)
$A=a_{ij}$:	Average Direct Relationship Matrix (ADRM)
$\max_{1\le i\le n} \sum_{j=1}^{n} a_{ij}$:	Total direct influence of the criteria on other criteria
$\max_{1\le j\le n} \sum_{i=1}^{n} a_{ij}$:	Total direct influence received from other criteria
R:	Vector of length $n$representing rows sum of the TRM
C:	Vector of length $n$representing columns sum of the TRM

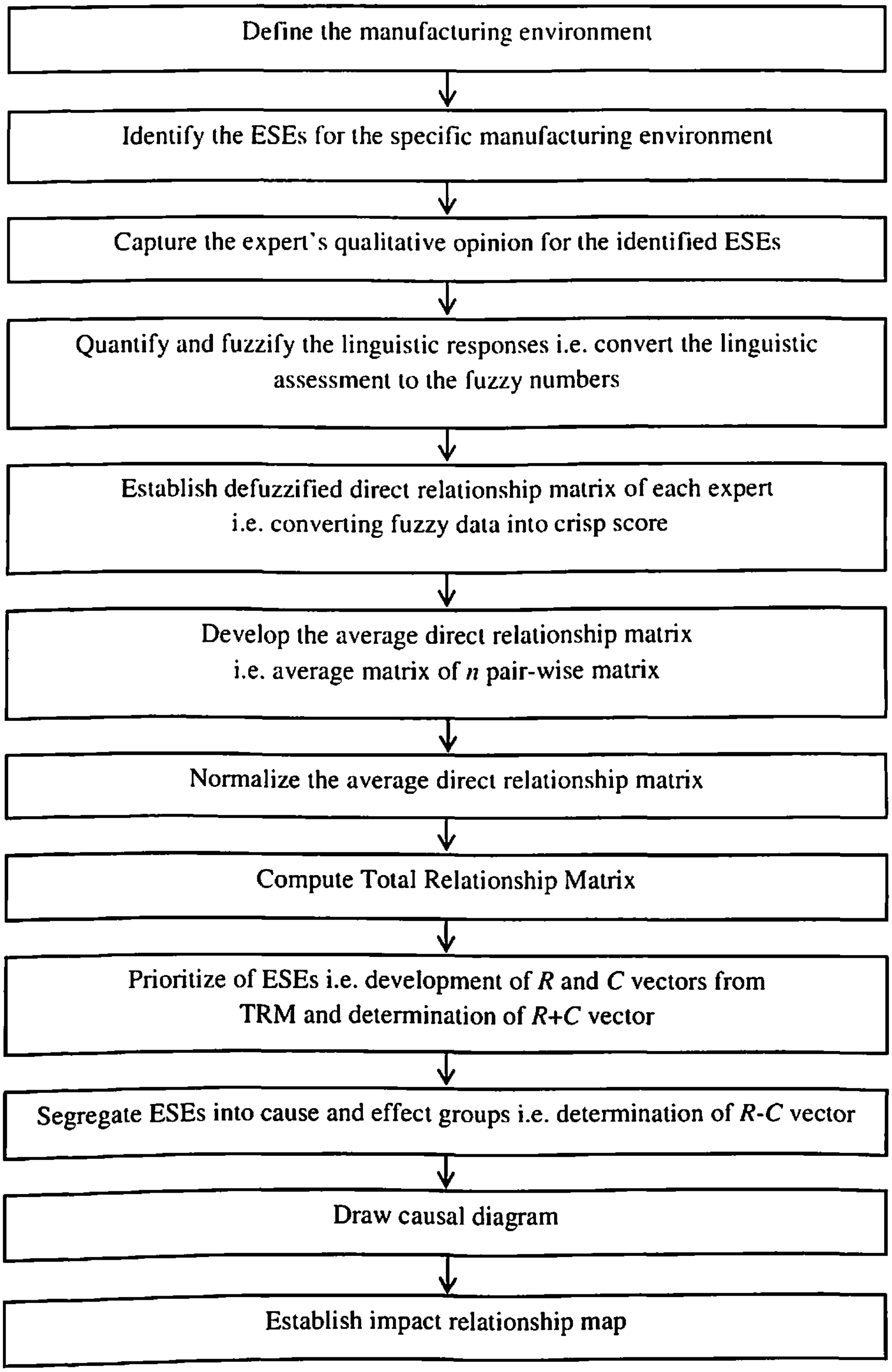

Figure 3.1: Proposed methodology for analyzing ESEs

For the detail step by step algorithm, one can see in the Figure 3.1. Each step used is discussed below:

3.3.1 Define the Manufacturing Environment

Manufacturing environment is the series of activity that transforms initial product (raw material) into the desired product (finished goods). The series of activity involves usage of natural resources directly and indirectly. As the manufacturing environment involves the usage of natural resources, the environment deterioration is always there; directly or indirectly. The manufacturing environment therefore always strive to attain environment sustainability.

3.3.2 Identification of Specific Set of ESE's

Here, enablers of Environment Sustainability are considered as to be the evaluation criteria for this proposed methodology. The ESE's are to be identified through literature review, brain storming sessions and discussions with industrial experts, researchers and academicians. Again, the relevant ESEs particular to the case company is to be sorted out from the generic set of enablers.

3.3.3 Capture the Expert's Qualitative Opinion for the Identified ESEs

The expert's qualitative opinions regarding mutual influence of the relevant ESEs identified from previous steps should be captured using pair wise comparison matrix. These pair wise comparisons should be carried out using linguistic variables i.e. low, medium, high and very high influence.

3.3.4 Quantification and Fuzzification of Linguistic Responses

Pair-wise comparison matrices were to be developed for the ESEs by taking the expert's qualitative opinions in terms of linguistic responses. These linguistic responses were to be transformed in to a scale of 0-4 to get the quantified direct relationship matrices. Subsequently, fuzzify the matrices to capture the uncertainty in the experts' opinions such that the results obtained are much more accurate. To develop fuzzified direct relationship matrices, convert the influence scores assigned to the linguistic variables into triangular fuzzy numbers as mentioned in Table 3.2.

3.3.5 Development of Defuzzified Direct Relationship Matrix of Each Expert

Develop the Defuzzified Direct Relationship Matrix (DDRM) for each expert using Converting the Fuzzy data into Crisp Scores (CFCS) method (Opricovic and Tzeng, 2003). The details of CFCS are mentioned below:

(i) Normalization:

$$xr_{ij} = (r_{ij} - minl_{ij})/\Delta_{min}^{max}$$

$$xm_{ij} = (m_{ij} - minl_{ij})/\Delta_{min}^{max}$$

$$xl_{ij} = (l_{ij} - minl_{ij})/\Delta_{min}^{max}$$

(where, $\Delta_{min}^{max} = max\, r_{ij} - min\, l_{ij}$)

(ii) Left and right spread measures of normalized fuzzy numbers,

$$xrs_{ij} = xr_{ij}/(1 + xr_{ij} - xm_{ij})$$

$$xls_{ij} = xm_{ij}/(1 + xm_{ij} - xl_{ij})$$

(iii) Compute total normalized crisp score

$$x_{ij} = [xls_{ij}(1 - xls_{ij}) + xrs_{ij} \times xrs_{ij}] / (1 - xls_{ij} + xrs_{ij})$$

(iv) Compute crisp value

$$z_{ij} = \min l_{ij} + xr_{ij} \times \Delta_{min}^{max}$$

3.3.6 Development of Average Direct Relationship Matrix (ADRM)

Calculate the ADRM by taking the average of all "h" DDRMs (where, h is the number of experts).

If $z^1, z^2, z^3, \dots, z^h$ are the DDRMs obtained then ADRM (A) is obtained as shown below:

$$A = (\sum_{k=1}^{h} z^k)/h$$

The ADRM elemental values can be represented as $A = [a_{ij}]_{n\times n}$

3.3.7 Normalization of Average Direct Relationship Matrix

The normalized ADRM is denoted as D. It is calculated as follows

$$D = \frac{A}{S}$$

where, $S = \max\left(\max_{1\le i\le n} \sum_{j=1}^{n} a_{ij}, \max_{1\le j\le n} \sum_{i=1}^{n} a_{ij}\right)$

3.3.8 Computation of Total Relation Matrix

$$T = D(I - D)^{-1}$$

where, I is the identity matrix

$$T = [t_{ij}]_{n\times n}$$

3.3.9 Prioritization (i.e. degree of importance) of AMBs

From the total relation matrix (T) obtained in the previous step, R and C vectors are formed. R represents the row sum of matrix T:

$$R = \left[\sum_{i=1}^{n} t_{i1} \sum_{i=1}^{n} t_{i2} \cdots \sum_{i=1}^{n} t_{ij} \cdots \sum_{i=1}^{n} t_{in}\right]$$

(where, j represents the row number, i represents column number and n represents number of rows or columns of matrix T, since T is a square matrix). Similarly, C represents column sum of matrix T:

$$C = \left[\sum_{j=1}^{n} t_{1j} \sum_{j=1}^{n} t_{2j} \cdots \sum_{j=1}^{n} t_{ij} \cdots \sum_{j=1}^{n} t_{in}\right]$$

From R and C vectors, determine the $R + C$ vector (where each element of the vector indicates the degree of importance of the corresponding enabler) and prioritize the enablers.

3.3.10 Segregation of ESEs into Cause and Effect Groups

Determine the $R - C$ vector from R and C vectors obtained in the previous step. The positive signed elements indicate that the corresponding ESEs are causes and negative ESEs indicate effects.

3.3.11 Development of Causal Diagram

Develop a causal diagram for the ESEs taking their R + C and R – C values along X-axis and Y-axis respectively.

3.3.12 Development of Impact Relationship Map

On the basis of experts' opinion, set the threshold value for developing impact relationship map. This threshold value filters out insignificant interdependent relationships between ESEs. It is deducted from all the elements of TRM and then the relationships between ESEs having negative values are ignored to determine the reduced TRM. This reduced TRM forms the basis for developing the impact relationship map.

3.4 Application of the Proposed Methodology for an Indian Steel Manufacturing Company

The methodology proposed in Section 3 for enhancing environmental sustainability was applied to an Indian steel manufacturing company through the analysis of its ESEs. The name of case company was not disclosed to protect confidentiality. The case company is a captive steel plant with manufacturing capacity of more than 6 million tonnes of steel per annum and doing business for more than 25 years. The top management is committed to enhance the environmental sustainability and has been taking various steps towards protecting environment and adopted green practices along its supply chain. The top management commitment was visible through the various steps the company has undertaken and the necessary resource allocations along its supply chain. They agreed to extend full cooperation for the study. Each ESE was discussed with the team of experts. They were from environment control department team, maintenance team, quality department, operation team and R&D

department. It was appeared that though the management was eager to adopt green practices and enhance environmental sustainability but there is concern on resource allocation for such activities like other companies. It was observed that company had planted one million trees around the company premises as part of their endeavor to protect the environment. This milestone was highly admired by the entire city and also developed awareness in society towards environment. In the effort to minimize wastage, the waste gases from coke oven and blast furnace which have high calorific values were collected, filtered and used in reheating furnace in the rolling mills. The environment department monitors the composition of the gases emitting out of various chimneys at regular intervals. In case of the deviation from the permissible limits in the emitting gasses; the environment department informs the concerned operation team to take necessary steps. It was observed that only on the feedback from the environment department the corrective actions are taken by the respective department. There is lack of real time information visibility available with the operation team. The company has attained all the necessary environment clearances and certificates for their manufacturing activities and operates strictly under the environmental norms set by the regulatory authority. It was also observed that though the company promotes green activities but the communication in the form of training and seminars are limited to the junior level or more precisely at the entry level only. Thus there is lack of awareness and knowledge among employees towards green activities. During the discussion with experts across various departments, it was concluded that the company has taken several steps recently towards environment sustainability and are willing to take more necessary steps in future also. The case company had already implemented environmental sustainability practices across its supply chain and taking extra measure to achieve its desired level. It has environment department that takes care of the environmental sustainability activities across the departments and also system is in place for regular checks on critical units. The records are maintained and used in decision making for improvement and innovation. The quarterly audits are carried out to maintain authenticity of the records. Water recycling and waste gases management are few successful initiatives taken by the company. In order to motivate the workforce, top management always praises the good work and need based training is being provided to the workforce from time to time. Presence of strong support from ERP and the records are maintained which are visible for references, study and further analysis.

The relevant information for the application of the proposed methodology was collected from a team consisting of five experts and each expert has minimum seven years of experience in Indian steel industries and three years in the case company. They are working as a senior engineer or manger and professionally qualified to handle environmental sustainable activities and programs. ESEs mentioned in Table 3.1 were discussed with the team and it was concluded that 18 ESEs (i.e. Supply Chain Environmental Sustainability Initiatives; Environmental Sustainability System; Top Management Involvement and Support; Value Added Product from waste; Environmental Sustainability Practices Adoption; Environmental Sustainability Culture; Information Systems for Environmental Sustainability; Environmental Corporate Social Responsibility; Internal Auditing System for Environmental Sustainability; R&D Program for Environmental Sustainability; Water Pollution Controlling System; Air Pollution Controlling System; Soil Pollution

Controlling System; Environmental Compliance Certification; Influence of External Factors; Government regulations and Incentives; Technology Adoption for Environmental Sustainability and Competitors' Environmental Sustainability strategy) out of 20 were found to be relevant for implementing and enhancing environmental sustainability. Two ESEs (i.e. Inbound Logistics and Outbound Logistics) were found to be irrelevant for the case company as they have hardly any impact considering the nature of operation and existing country's infrastructure. In order to apply the proposed methodology, each expert's qualitative judgment regarding mutual influence of ESEs was captured through pair wise comparison matrix using linguistic variables i.e. low, medium, high and very high influence and then transformed to a scale of 0-4 to obtain the quantified direct relationship matrices (see fourth expert's judgments in Table 3.3). Subsequently, it was converted to triangular fuzzy numbers as mentioned as given in Table 3.2 to capture the uncertainty that exists in experts' judgments. All the five Fuzzy Direct Relationship Matrices (FDRM) were defuzzified to develop Defuzzified Direct Relationship Matrix (DDRM) through Fuzzy Data into Crisp Scores (CFCS) method (Opricovic and Tzeng, 2003). All the obtained five DDRMs were averaged to form ADRM. The normalized ADRM and TRM had been calculated and are mentioned in Table 3. 5 and Table 3.6 respectively. The $R + C$ vector (see Table 3.7) is calculated to rank the importance of ESEs. The $R - C$ vector (see Table 3.8) was calculated to divide ESEs into cause (ESEs with positive sign) and effect group (ESEs with negative sign). Also the causal diagram (see Figure 3.2) was developed with $R + C$ and $R - C$ in X-axis and Y-axis respectively. The threshold value was decided on the basis of experts' judgment for developing Impact Relationship Map (IRM) to segregate insignificant interdependent relationships. The threshold value was considered as the average value (0.0184) of TRM and it was deducted from Total Relation Matrix (TRM) elements to find reduced TRM. The reduced TRM (see Table 3.9) was determined ignoring elements having negative values for only TMI, the strength of influencing on and influenced by other ESEs is shown in Table 3.10 and similar analysis is also carried out for other ESEs. The prominent influencing on and influenced by other ESEs for each ESE was determined by Pareto analysis (see Figure 3.3, Figure 3.4 and Figure 3.5) and is presented in Table 3.11 and Table 3.12 respectively. Finally, IRM was developed for each ESE and IRM of Internal Auditing System for Environmental Sustainability is shown in Figure 3.6.

Table 3.2: Quantification and fuzzification scale for linguistic responses

Linguistic terms	**Influence score**	**Triangular fuzzy numbers**
No Influence (No)	0	(0, 0, 0.25)
Very low influence (VL)	1	(0, 0.25, 0.50)
Low influence (L)	2	(0.25, 0.50, 0.75)
High influence (H)	3	(0.50, 0.75, 1.00)
Very high influence (VH)	4	(0.75, 1.00, 1.00)

Table 3.3: Response matrix of the fourth expert

	SCE	ESC	TMI	VAP	ESP	ENS	ISE	CSR	IAS	RES	WCS	ACS	SCS	ECC	IEF	RRI	TAS	CES
SCE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
ESC	4	0	2	4	4	2	3	3	2	4	4	4	4	4	0	0	3	4
TMI	3	4	0	2	3	3	4	4	3	4	3	3	3	2	0	0	4	4
VAP	4	2	0	0	2	2	1	0	2	3	2	2	2	4	0	0	3	3
ESP	3	2	1	3	0	4	3	2	0	0	0	0	0	0	1	0	1	2
ENS	2	0	0	0	3	0	1	2	0	0	0	0	0	0	0	0	0	3
ISE	4	0	0	3	3	3	0	1	2	0	0	0	0	0	2	0	2	2
CSR	3	2	0	0	3	2	2	0	0	0	0	0	0	0	2	0	0	2
IAS	2	0	0	3	2	0	2	0	0	0	3	3	3	0	0	0	2	1
RES	4	2	0	4	2	0	2	0	0	0	4	4	4	3	0	0	4	3
WCS	3	0	0	4	2	0	3	0	2	3	0	0	0	0	2	0	2	2
ACS	3	0	0	4	2	0	3	0	2	3	0	0	0	0	2	0	2	2
SCS	3	0	0	4	2	0	3	0	2	3	0	0	0	0	2	0	2	2
ECC	4	0	0	3	0	0	0	0	1	2	4	4	4	0	2	0	3	1
IEF	4	4	3	0	3	2	4	3	3	3	4	4	4	4	0	4	4	4
GRI	3	3	4	3	2	2	1	3	3	4	4	4	4	4	3	0	4	3
TAS	4	3	0	3	3	2	2	2	2	4	3	3	3	0	0	0	0	0
CES	4	3	0	4	3	3	3	2	3	4	4	4	4	0	0	0	4	0

Table 3.4: Average direct relationship matrix

	SCE	ESC	TMI	VAP	ESP	ENS	ISE	CSR	IAS	RES	WCS	ACS	SCS	ECC	IEF	GRI	TAS	CES
SCE	0.033	0	0	0.5	0	0.733	0	0	0	0	0	0	0	0	0	0	0.033	0
ESC	0.92	0.5	0	0.733	0	0	0.733	0.733	0	0	0.92	0	0	0	0	0.033	0	0
TMI	0.78	0.033	0.033	0	0.733	0	0	0	0	0.967	0	0	0	0	0.033	0	0	0
VAP	0.967	0.033	0.873	0	0	0	0.22	0.733	0	0	0	0	0	0.033	0.033	0	0	0
ESP	0.733	0	0	0	0.733	0	0	0	0	0	0	0	0.733	0	0	0	0	0
ENS	0.5	0.033	0.033	0.033	0.033	0.5	0	0.033	0.733	0.92	0	0.733	0	0.733	0	0	0	0
ISE	0.967	0.033	0	0	0	0	0	0	0	0.033	0.733	0	0	0	0	0	0	0
CSR	0.733	0.033	0.967	0	0.5	0.033	0	0	0	0.967	0	0	0.967	0	0	0	0	0
IAS	0.547	0.033	0.92	0.5	0.033	0.5	0.5	0.733	0.5	0	0	0	0.033	0	0	0	0	0
RES	0.92	0.033	0	0.78	0	0.033	0	0.547	0.92	0	0	0.967	0	0	0	0	0	0
WCS	0.733	0	0	0.5	0	0	0.5	0	0	0	0	0	0	0	0	0	0	0
ACS	0.733	0.967	0.967	0.033	0.033	0.687	0.733	0	0.033	0	0.967	0.967	0	0	0	0	0	0
SCS	0.733	0	0.033	0	0.687	0	0.033	0	0	0	0	0	0	0	0	0	0	0
ECC	0.967	0.733	0.453	0.733	0	0.033	0	0.5	0	0.967	0	0	0	0	0	0	0	0
IEF	0.967	0.033	0.033	0	0	0.967	0	0	0	0	0.967	0	0	0	0	0	0	0
GRI	0.733	0.687	0.967	0.033	0.033	0	0	0	0.967	0	0.033	0	0	0	0	0	0	0
TAS	0.967	0.78	0	0	0	0	0	0.033	0	0	0	0	0	0	0	0	0	0
CES	0.967	0.733	0.033	0.967	0.78	0.733	0.733	0.5	0.733	0.967	0.92	0.92	0.92	0.033	0.033	0.033	0.967	0.0333

Table 3.5: Total relationship matrix

	SCE	ESC	TMI	VAP	ESP	ENS	ISE	CSR	IAS	RES	WCS	ACS	SCS	ECC	IEF	GRI	TAS	CES
SCE	0.01	8E-04	0	0.04	0	0.056	9E-04	0.0026	0.003	0.004	0.0004	0.004	2E-04	0.003	1E-04	0	0.002	0
ESC	0.09	0.038	0.01	0.06	0	0.005	0.058	0.0582	8E-04	0.005	0.0718	7E-04	0.004	4E-04	2E-04	0.0025	2E-04	0
TMI	0.07	0.003	0	0.01	0.06	0.004	8E-04	0.0036	0.005	0.07	0.0008	0.006	0.003	3E-04	0.002	0	2E-04	0
VAP	0.08	0.003	0.07	0	0.01	0.005	0.016	0.0536	9E-04	0.009	0.0013	9E-04	0.004	0.003	0.003	0	2E-04	0
ESP	0.06	0	0	0	0.06	0.003	2E-04	0.0002	2E-04	3E-04	0	2E-04	0.056	2E-04	0	0	1E-04	0
ENS	0.06	0.011	0.01	0.01	0	0.046	0.007	0.0121	0.063	0.075	0.0056	0.065	0.001	0.055	1E-04	0	1E-04	0
ISE	0.07	0.003	0	0	0	0.004	0.002	0.0005	4E-04	0.003	0.0531	4E-04	0	2E-04	0	0	2E-04	0
CSR	0.07	0.003	0.07	0.01	0.05	0.007	0.001	0.0038	0.006	0.075	0.0007	0.006	0.072	4E-04	2E-04	0	2E-04	0
IAS	0.06	0.004	0.08	0.04	0.01	0.042	0.039	0.0579	0.041	0.012	0.0025	0.003	0.007	0.002	3E-04	0	1E-04	0
RES	0.08	0.009	0.02	0.06	0	0.014	0.008	0.0471	0.07	0.006	0.0063	0.076	0.004	9E-04	2E-04	0	2E-04	0
WCS	0.06	2E-04	0	0.04	0	0.003	0.037	0.0021	2E-04	6E-04	0.002	2E-04	2E-04	3E-04	1E-04	0	1E-04	0
ACS	0.08	0.079	0.08	0.01	0.01	0.06	0.065	0.0059	0.007	0.01	0.0837	0.079	8E-04	0.003	2E-04	0.0002	2E-04	0
SCS	0.06	1E-04	0	0	0.05	0.003	0.003	0.0002	2E-04	4E-04	0.0001	2E-04	0.003	2E-04	0	0	1E-04	0
ECC	0.09	0.056	0.04	0.06	0	0.008	0.005	0.0456	0.006	0.076	0.0044	0.006	0.003	6E-04	3E-04	0.0001	2E-04	0
IEF	0.08	0.003	0	0.01	0	0.077	0.003	0.0013	0.005	0.006	0.0703	0.005	1E-04	0.004	0	0	2E-04	0
GRI	0.07	0.052	0.08	0.01	0.01	0.007	0.006	0.0074	0.073	0.006	0.0062	8E-04	0.001	4E-04	2E-04	0.0001	2E-04	0
TAS	0.08	0.058	0	0.01	0	0.004	0.003	0.0059	3E-04	8E-04	0.0041	3E-04	4E-04	2E-04	0	0.0001	2E-04	0
CES	0.12	0.066	0.02	0.09	0.07	0.069	0.067	0.0513	0.065	0.08	0.0801	0.081	0.074	0.006	0.003	0.0026	0.07	0

Table 3.6: Prioritization of ESEs

Enablers	SCE	ESC	TMI	VAP	ESP	ENS	ISE	CSR	IAS
R	0.1262	0.4030	0.2327	0.2560	0.1810	0.4315	0.1455	0.3704	0.3951
C	1.2678	0.3887	0.4886	0.4699	0.3269	0.4173	0.3212	0.3593	0.3445
R+C	1.3940	0.7917	0.7213	0.7258	0.5079	0.8488	0.4667	0.7297	0.7396
R-C	-1.1416	0.0143	-0.2559	-0.2139	-0.1459	0.0142	-0.1757	0.0112	0.0507
Enablers	**RES**	**WCS**	**ACS**	**SCS**	**ECC**	**IEF**	**GRI**	**TAS**	**CES**
R	0.4074	0.1458	0.5721	0.1235	0.4094	0.2639	0.3201	0.1603	1.0150
C	0.4399	0.3934	0.3340	0.2341	0.0807	0.0095	0.0057	0.0751	0.0024
R+C	0.8473	0.5392	0.9061	0.3576	0.4901	0.2734	0.3258	0.2355	1.0174
R-C	-0.0325	-0.2476	0.2380	-0.1106	0.3287	0.2544	0.3143	0.0852	1.0126

Table 3.7: Importance of ESEs

Enablers	SCE	CES	ACS	ENS	RES	ESC	IAS	CSR	VAP
R+C	1.39	1.017	0.906	0.8488	0.847	0.792	0.740	0.730	0.726
Ranking	1	2	3	4	5	6	7	8	9
Enablers	**TMI**	**WCS**	**ESP**	**ECC**	**ISE**	**SCS**	**GRI**	**IEF**	**TAS**
R+C	0.721	0.540	0.508	0.490	0.467	0.358	0.326	0.273	0.236
Ranking	10	11	12	13	14	15	16	17	18

Table 3.8: Cause and effect groups of ESEs

Enablers	CES	ECC	GRI	IEF	ACS	TAS	IAS	ESC	ENS	CSR
R-C	1.013	0.329	0.314	0.254	0.238	0.085	0.050	0.014	0.014	0.011
Grouping	**Cause group of environment sustainability enablers**									

Enablers	RES	SCS	ESP	ISE	VAP	WCS	TMI	SCE
R-C	-0.0325	-0.1106	-0.1459	-0.1757	-0.2139	-0.2476	-0.256	-1.1416
Grouping	**Effect group of environment sustainability enablers**							

Table 3.9: Reduced total relationship matrix

	SCE	ESC	TMI	VAP	ESP	ENS	ISE	CSR	IAS	RES	WCS	ACS	SCS	ECC	IEF	GRI	TAS	CES
SCE	0	0	0	0.02	0	0.037	0	0	0	0	0	0	0	0	0	0	0	0
ESC	0.07	0.02	0	0.04	0	0	0.04	0.04	0	0	0.05	0	0	0	0	0	0	0
TMI	0.05	0	0	0	0.038	0	0	0	0	0.052	0	0	0	0	0	0	0	0
VAP	0.06	0	0.049	0	0	0	0	0.04	0	0	0	0	0	0	0	0	0	0
ESP	0.04	0	0	0	0.04	0	0	0	0	0	0	0	0.04	0	0	0	0	0
ENS	0.04	0	0	0	0	0.028	0	0	0.04	0.057	0	0.047	0	0.04	0	0	0	0
ISE	0.06	0	0	0	0	0	0	0	0	0	0.03	0	0	0	0	0	0	0
CSR	0.05	0	0.053	0	0.028	0	0	0	0	0.057	0	0	0.05	0	0	0	0	0
IAS	0.04	0	0.058	0.02	0	0.024	0.02	0.04	0.02	0	0	0	0	0	0	0	0	0
RES	0.07	0	0	0.04	0	0	0	0.03	0.05	0	0	0.058	0	0	0	0	0	0
WCS	0.04	0	0	0.02	0	0	0.02	0	0	0	0	0	0	0	0	0	0	0
ACS	0.06	0.06	0.059	0	0	0.042	0.05	0	0	0	0.07	0.061	0	0	0	0	0	0
SCS	0.04	0	0	0	0.034	0	0	0	0	0	0	0	0	0	0	0	0	0
ECC	0.07	0.04	0.022	0.05	0	0	0	0.03	0	0.058	0	0	0	0	0	0	0	0
IEF	0.06	0	0	0	0	0.059	0	0	0	0	0.05	0	0	0	0	0	0	0
GRI	0.05	0.03	0.058	0	0	0	0	0	0.05	0	0	0	0	0	0	0	0	0
TAS	0.06	0.04	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CES	0.1	0.05	0.004	0.07	0.049	0.05	0.05	0.03	0.05	0.062	0.06	0.063	0.06	0	0	0	0.1	0

Table 3.10: TMI's strength of influencing on and influenced by other ESEs

ESE	Strength of influencing	ESE	Strength of influenced
RES	0.0520	ACS	0.0588
SCE	0.0477	IAS	0.0577
ESP	0.0379	GRI	0.0575
		CSR	0.0530
		VAP	0.0488
		ECC	0.0224
		CES	0.0038

Table 3.11: List of ESEs influencing each enabler

ESE	ESEs influencing others ESEs	Prominent ESEs influencing others ESEs
SCE	ENS, VAP	ENS, VAP
ESC	SCE, WCS, VAP, ISE, CSR, ESC	SCE, WCS, VAP, ISE,
TMI	RES, SCE, ESP	RES, SCE, ESP
VAP	SCE, TMI, CSR	SCE, TMI, CSR
ESP	SCE, ESP, SCS	SCE, ESP, SCS
ENS	RES, ACS, IAS, SCE, ECC, ENS	RES, ACS, IAS, SCE, ECC
ISE	SCE, WCS	SCE, WCS
CSR	RES, SCS, TMI, SCE, ESP	RES, SCS, TMI, SCE
IAS	TMI, SCE, CSR, ENS, VAP, IAS, ISE	TMI, SCE, CSR
RES	SCE, ACS, IAS, VAP, CSR	SCE, ACS, IAS, VAP
WCS	SCE, VAP, ISE	SCE
ACS	WCS, SCE, ACS, ESC, TMI, ISE, ENS	WCS, SCE, ACS, ESC, TMI
SCS	SCE, ESP	SCE, ESP
ECC	SCE, RES, VAP, ESC, CSR, TMI	SCE, RES, VAP, ESC
IEF	SCE, ENS, WCS	SCE, ENS, WCS
GRI	TMI, IAS, SCE, ESC	TMI, IAS, SCE, ESC
TAS	SCE, ESC	SCE, ESC
CES	SCE, VAP, ACS, WCS, RES, SCS, TAS, ENS, ISE, ESP, ESC, IAS, CSR, TMI	SCE, VAP, ACS, WCS, RES SCS, TAS, ENS, ISE, ESP, ESC, IAS

Table 3.12: List of ESEs influenced by each enablers

ESE	Influenced ESEs	Prominent Influenced ESEs
SCE	CES, ECC, ESC, RES, ACS, VAP, IEF, TAS, ISE, CSR, GRI, TMI, ESP, WCS, IAS, ENS, SCS,	CES, ECC, ESC, RES, ACS, VAP, IEF, TAS, ISE, CSR, GRI, TMI
ESC	ACS, CES, TAS, ECC, GRI, ESC	ACS, CES, TAS, ECC, GRI
TMI	ACS, IAS, CSR, VAP, ECC	ACS, IAS, CSR, VAP
VAP	CES, ECC, RES, ESC, IAS, WCS, SCE,	CES, ECC, RES, ESC
ESP	CES, ESP, TMI, SCS, CSR,	CES, ESP, TMI, SCS
ENS	IEF, CES, ACS, SCE, ENS, IAS,	IEF, CES, ACS, SCE
ISE	CES, ACS, ESC, IAS, WCS	CES, ACS, ESC
CSR	ESC, IAS, VAP, CES, RES, ECC	ESC, IAS, VAP, CES
IAS	GRI, RES, CES, ENS, IAS	GRI, RES, CES, ENS
RES	CES, ECC, CSR, ENS, TMI	CES, ECC, CSR, ENS, TMI
WCS	ACS, CES, ESC, IEF, ISE	ACS, CES, ESC, IEF
ACS	CES, ACS, RES, ENS	CES, ACS, RES, ENS
SCS	CES, CSR, ESP	CES, CSR
ECC	ENS	ENS
TAS	CES	CES

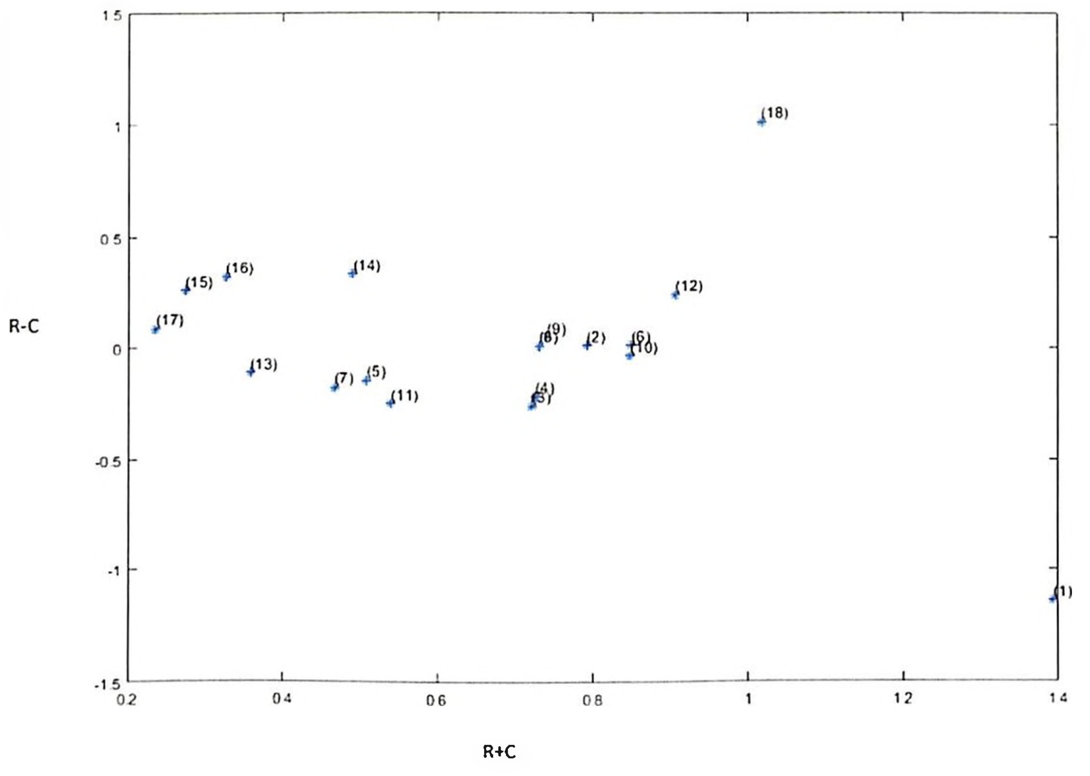

Figure 3.2: Causal diagram of ESEs

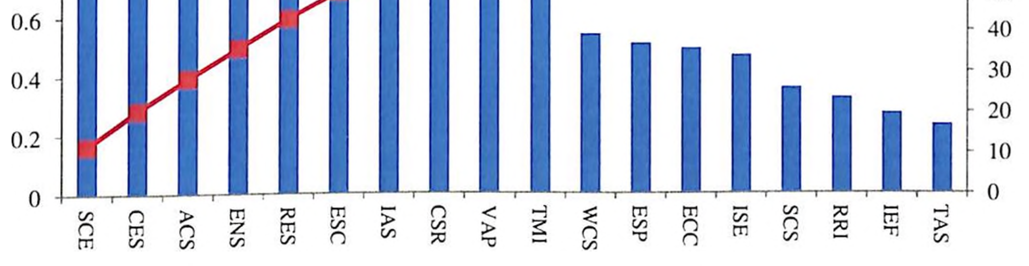

Figure 3.3: PARETO Chart to identify group of important ESEs

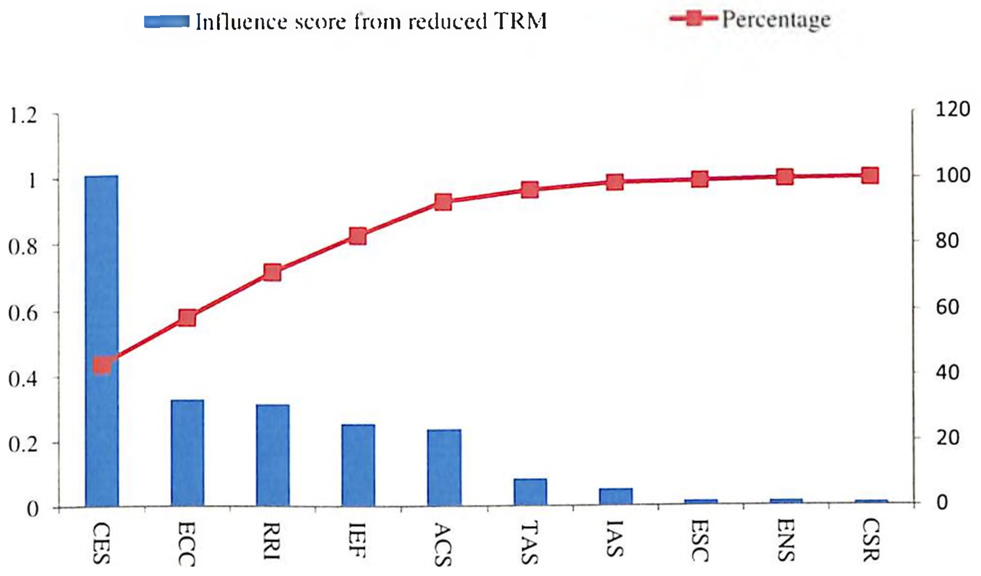

Figure 3.4: PARETO Chart to identify group of important ESES influencing

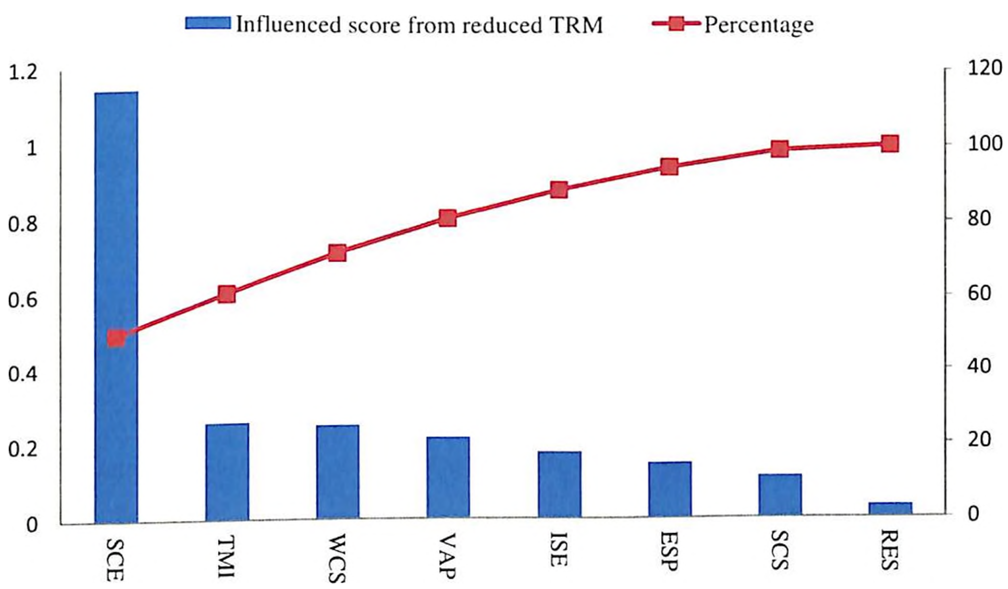

Figure 3.5: PARETO Chart to identify group of important ESEs influenced

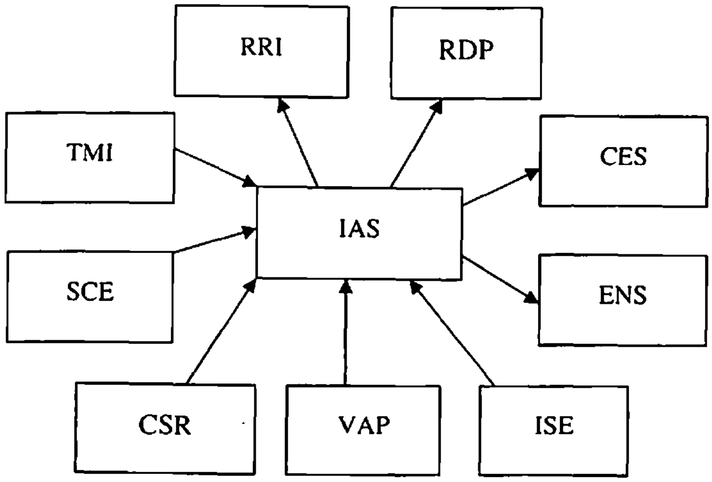

Figure 3.6: Impact relationship map of internal auditing system for environmental sustainability

3.5 Results and Discussion

The proposed model was applied to an Indian steel manufacturing company as mentioned in Section 4 in order to improve environmental sustainability. However, no such study has been reported in the literature with an objective to develop structural framework for Indian steel manufacturing company. The results obtained from the current study are discussed under three sections i.e. ranking of ESEs; classification of ESEs into cause and effect group; and establishment of interactions for each ESE using IRM.

3.5.1 Ranking of ESEs

In order to know the importance of the ESEs, the identified eighteen ESEs were ranked taking the values of $R + C$ vector (Table 3.7). For the case Indian steel manufacturing company, Supply Chain Environmental Sustainability Initiatives (SCE) was the most important ESE with the highest R + C value of 1.394, while Technology Adoption for Environmental Sustainability (TAS) was the least important with the lowest of R + C value of

0.2355 (Table 3.7). The degree of importance of all ESEs was determined and is mentioned in Table 8. A Pareto Chart (as shown in Figure 3) was made taking the degrees of importance for identifying the critical ESEs. From the Pareto Chart, seven ESEs (i.e. Supply Chain Environmental Sustainability Initiatives (SCE), Competitors Environmental Sustainability strategy (CES), Air Pollution Control System (ACS), Environmental Sustainability Culture (ENS), Research & Development Program (RES), Environmental Sustainability System (ESC) and Internal Auditing System for Environmental Sustainability (IAS) were identified as important ESEs. These ESEs have significant negative impact on the environmental sustainability performance. Therefore, the case company should give attention on the performance along these seven ESEs.

3.5.2 Classification of ESEs into Cause and Effect Group

The ESEs were divided into cause and effect group on the basis of R – C vector (Table 3.8). Ten ESEs (i.e. CES, ECC, GRI, IEF, ACS, TAS, IAS, ESC, ENS, and CSR) were identified under cause group and rest eight ESEs (i.e. RES, SCS, ESP, ISE, VAP, WCS, TMI and SCE) were identified under effect group. The most influencing ESE is found out to be competitor green strategy (CES) with highest R – C value of 1.0126 whereas the most influenced ESE is found out to be Supply Chain Environmental Sustainability Initiatives (SCE) with the lowest R – C value of minus 1.1416. The Pareto Charts (Figure 3.4 and Figure 3.5) were also developed for degree of influencing and degree of influenced for both cause and effect groups respectively to identify the prominent group of ESEs in each group. The prominent ESEs of cause group are Competitors Environmental Sustainability strategy (CES), Environment Compliance Certification (ECC), Government Regulation and Incentive (GRI) and Influence of External Environment (IEF) whereas the prominent ESEs of effect group are Supply Chain Environmental Sustainability

Initiatives (SCE), Total Management Commitment (TMI), Water Pollution Controlling System (WCS) and Value Added Product from waste (VAP). Causal diagram (see Figure 3.2) was also prepared by plotting $R + C$ vector values as abscissas and $R - C$ values as ordinates on a Cartesian plane to show the distribution of ESEs visually. The case company should put efforts on prominent cause group members (i.e. CES, ECC, GRI and IEF) and was advised to monitor its implementation level on continuous basis. Similarly, it was suggested for measuring the performance improvement of prominent effect group members (SCE, TMI, WCS and VAP). So, the Key Performance Indicators (KPIs) for evaluating the implementation level of cause group members should be identified and documented whereas KPIs should be identified to access the performance of prominent effect group members.

3.5.3 Establishment of Interactions for each ESE using IRM

The interactions of all eighteen ESEs cannot be represented in one Impact Relationship Map (IRM). Therefore, the IRM was prepared for each ESE considering reduced TRM matrix. One can see the interactions (i.e. influencing and influenced) from other ESEs. Although IRM for each ESE was made, but the IRM prepared for "IAS" ESE is given in the paper (see Figure 3.6). Pareto chart for each ESE was drawn to determine the prominent influencing and influenced ESEs for a specific ESE (see Table 3.12).

3.6 Conclusions

The proposed methodology using fuzzy DEMATEL was applied to Indian steel manufacturing company to analyze the identified ESEs those have significant impact on the environmental sustainability performance. It will be helpful for allocating efforts and resources to enhance the impact of ESEs for successful implementation of environmental sustainability program in the Indian steel manufacturing company. The following relevant observations related to ESEs in the case company were made:

- Identifying the important ESEs using R+C value, one cannot conclude that on which ESEs it has to focus as many enablers may not influence other enablers and therefore may not be overall effective in terms of the final outcome. So, there is a great necessity of categorizing the ESEs into cause and effect group from the R – C value.
- Classification of ESEs into cause and effect group gives the relative understanding of each enabler among the ESEs. It was concluded that Competitors Environmental Sustainability strategy (CES), Environmental Compliance Certification (ECC), Government Regulation & Incentives (GRI), Influence of External Environment (IEF) and Air Pollution Control System (ACS) were most important ESEs as they were found to be as the prominent ESEs in cause group. The three enablers (CES, GRI and IEF) (from identified five ESEs) are beyond the control of the company and are exclusively controlled and determined by the external agencies. The case company should keep a close eye on them and implement appropriate strategy(s) to satisfy the requirements of these three ESEs. However, the case company must focus on Environmental Compliance Certification (ECC) and Air Pollution Control System (ACS) on priority basis. It should adopt right strategy and technology to excel in this direction in pushing the green initiatives.

The results obtained including numerical values and various implications observed are specific to an Indian steel manufacturing company and it cannot be generalized for steel manufacturing sector. However, the current study can show direction to carry out such work in other manufacturing companies.

CHAPTER - 4

Structural Framework of Environmental Sustainability Enablers for Enhancing Environmental Sustainability of Indian Steel Supply Chain

4 Sectional Abstract

The objective of this Chapter is to establish structural framework of Environmental Sustainability Enablers (ESEs) and also to classify them on the basis of driving and dependence power with an objective of environmental sustainability enhancement of Indian steel supply chain. The ESEs were identified through extensive literature review and discussion held with experts from Indian steel industry. The Interpretative Structural Modelling (ISM) approach was applied to an Indian steel supply chain to arrange these twelve ESEs in different hierarchies of the structural framework on the basis of their driver dependence power and also diagraph was developed to classify them. The Water Pollution Control System (WCS), Air Pollution Control System (ACS) and Soil Pollution Control System (SCS) were found to be in the bottom hierarchy of ISM framework and these enablers were also observed in the driving quadrant of the diagraph. These driving enablers should be given priority for its full scale development, management and monitoring to sustain and enhance the environmental sustainability in Indian steel supply chain whereas Top Management Commitment (TMC), Environment Compliance Certification (ECC) and Government Regulation and Incentives (GRI) are the antecedents for carrying out the sustainability program. The outcomes from the methodology provide the basis for an Indian steel manufacturing industry to develop the right strategy in their quest for environmental

sustainability. Although the study on environmental sustainability enablers of various industries were reported in the literature, but the comprehensive study to identify the significant ESEs related to Indian steel supply chain for environmental sustainability in specific have been hardly carried out. The current study will definitely be a valuable addition to environmental sustainability literature in general and steel supply chain environmental sustainability in specific.

4.1 Introduction

The steelmakers have increased their production to meet the increased demand of steel due to increasing urbanization and industrialization demands in different parts of the globe such as China, Russia, Brazil and India (Pinto and Diemer, 2020). The developing nations are continuously enhancing their industrial activities including steel production for improving their economic positions and sometimes, without proper planning of even environmental aspects. The continuous additions of the industrial activities are increasing burden on environment. Environment protection has geared extensive pace in last two decades. The call to protect the nature and minimize the effect of industrial activities is no longer confined to developed nations but constantly grappling the developing nations such as India. Some industries are energy intensive and the environment losses are more compared to other industries. Steel industry is one of such industry which is energy intensive and consumes large amount of metals and natural minerals. Steel industry has considerable impact on environment but at the same time, it contributes enormously to the countries progress and growth including employment. The steel sector is under constant watch of the environmentalist. The steel companies are always under pressure from society and government to minimize losses and improve their environment sustainability. Minimizing the losses and achieving the desired level of environmental sustainability comes at a cost. The steel industry is capital intensive and any set of activities towards environmental sustainability adds economic burden. In order to bridge the gap, it is desirable to identify and select the appropriate set of Environmental Sustainability Enablers (ESEs) of steel supply chain in India so that maximum return of environmental sustainability can be achieved with minimum effort. These ESEs are mostly industry specific and cannot be generalized.

From our extensive literature review, it was observed that hardly any research has been carried out to identify the ESEs along the steel supply chain in India. Also no literatures are available which establishes the structural relationship between the ESEs so that managers can have appropriate set of ESEs to put efforts to enhance environmental sustainability. Using Interpretative Structural Modelling (ISM) approach, we establish the relationship between the ESEs and classify them on the basis of driving and dependence power. These classifications can help in selecting appropriate set of ESEs and to develop strategy for enhancing the environmental sustainability. The proposed methodology is applied to steel supply chain in India to study and establish the salient features of the concept. The reminder of the current work is arranged as follows: Section 4.2 presents the literature review on environmental sustainability in steel supply chain and ESEs in steel supply chain. The ESEs in Indian Steel Supply Chain are discussed in Section 4.3. The proposed methodology (Interpretative Structural Modeling approach) is discussed in Section 4.4. Section 4.5 elaborates the application of the proposed methodology whereas Section 4.6 analyzes critically the results obtained. Section 4.7 concludes the present work with future direction.

4.2 Literature Review

Sustainability is defined as meeting the needs of the present without compromising on the ability of the future generation to meet their own needs (The World Commission on Environment and Development, 1987). The social, economic and environmental dimensions are captured in the sustainability term. It is widely applied to the business environment and particularly in manufacturing environment both in literature and practice. Presently, the sustainability plays a significant role for any supply chain and its management (i.e. sustainable supply chain management) has got importance in manufacturing environment. Sustainable Supply Chain Management (SSCM) is defined as "the management of supply chain operation, resources, information and funds in order to maximize the supply chain profitability while at the same time, minimizing the environmental impacts and maximizing social well-being (Hassini *et al.*, 2012)".

Sustainability in steel production is a global challenge and some of the sustainability indicators associated with steel production are carbon dioxide emission reduction, recycling of steel scraps, energy reduction, waste heat recovery and reuse of waste generated (Nidheesh and Kumar, 2019). The large-scale manufacturing of steel plays a crucial role and directly link to the development in a country. The mass production leads to serious environmental deterioration. So, the sustainable production policy should be promoted in these fields (Nidheesh and Kumar, 2019). Prasad *et al* (2020) studied empirically the critical success factors for SSCM in the context of Indian steel sector and concluded that organizational factors have higher order of significance compared to external factors. Also they observed that among the organizational factors, top leadership commitment and support has a significant contribution in creating favorable organizational environment whereas the compliances to environmental standards (ISO 14001) and safety standards (OHSAS 18001) create a condition to facilitate SSCM practices in the organization. Organizational sustainability performance is highly dependent on its culture and work practices. The impact of organizational practices on sustainability performance in Indian steel sector was studied and the findings suggest that the implementation of organizational practices can significantly expand its environmental performances (Prasad *et al.*, 2018). The steel industry in China, which contributes almost 50% of the total world crude steel production, on average consumes 7-8 m^3 of water per ton of steel in comparison to developed countries which only consume 3-4 m^3 per ton of steel, with some steel mills performing much better (Gao *et al.*, 2011). The other reason is that most of the Chinese large and medium-size steel mills were established in the 1980s and therefore the efficiency of their use of water is comparatively low due to outdated technologies (Tong *et al.*, 2020). Almost 82% of the water is used for just once-through cooling (Suvio *et al.*, 2012). Wang (2016) emphasized that China steel enterprises should focus on green supply chain management to remain internationally competitive through constant usage of innovative and improved technology and forming strategic cooperation across the supply chain. Debnath and Sebastian (2014) studied the effigies of Indian steel companies. According to them continued efforts to update technology and equipment are critical in order to improve the efficiency and retain the competitive edge in the iron and steel industry. Shekhari *et al.* (2011) studied the factors influencing the green supply chain and emphasized on waste management, minimizing soil, air and water pollution and strict compliance to government regulation. It is being increasingly rewarding for steel mills to follow the 3Rs - Reuse, Reduce and Recycle, when it comes to water usage (Tong *et al.*, 2019). Nezamoleslami *et al.* (2020) discussed broad application of water footprint concept in steel plants. Water shortage is seen as a significant challenge due to growing water and electricity demands of industries, global water abstractions are expected to be raised by 55 percent, between 2000 and 2050. McBrien *et al.* (2016) emphasized on heat recovery in the high energy consumption of steel industry. Soil contamination is one of the serious concerns of a steel plant. Yang *et al* (2020) studied the soil heavy metal contamination, via magnetic susceptibility and X-ray fluorescence spectrometry on an abandoned steel and iron plant and found that the soil magnetic susceptibility and heavy metal contents decreased with increasing distance from the plant's industrial area. English *et al* (2006) identified the manner and quantity of waste generation studied during production and to take necessary rectification steps to minimize it. Dahlström and Ekins (2006) studied supply chain of UK steel sector to identify the scrap arising at various stage of the supply chain and identify the environmental burden of it. Technology advancement over the period has a positive result. In the research conducted at the Thailand steel mill, it was concluded that the importance of the Governmental policies and support to promote the use of clean energy and to stimulate sustainability of the steel industry (Somboonwiwat *et al.*, 2018). Goyal *et al* (2018) discussed in detail the environment sustainability enablers and approached graph theory to compare the environmental sustainability performance of steel companies in India. Ozcan *et al* (2018) studied the strategic entry and operational integration of emerging market multinational enterprises in mature markets. The research points out the much needed advantage to access high quality product and technology for better management and control of operations. However, such decisions are highly strategic; underlining the important role of top management. The steel manufacturing companies should optimize their packaging processes, should develop a policy on green supply chain management practices to guide the company on green supply chain management. The policy should clearly state when and how the environmental audit should be conducted and ensures the chain members to comply with specific environmental standard (Barasa *et al.*, 2015). Kumar and Shekhar (2015) highlighted about green supply chain management through adoption of green procurement and green transportation. By-products generated in steel production can also be used as raw materials for various other processes such as cement production, steel production, electrode preparation, road construction, manufacturing of ceramics, glass, fertilizer, cosmetics etc. as well as for soil improvement (Nidheesh and Kumar, 2019).

Several studies have been reported in the literature for analysing factors/attributes/critical success factors related to supply chain with environmental sustainability focus and these studies are from different industrial setups. Although the literature contains a good number of research papers studying the structural analysis of environmental sustainability enablers of different manufacturing supply chain, but not much attention has been paid to explore and analyze them in the steel industry or steel supply chain perspectives. Hence, the present work attempts to contribute to the following research gaps:

- To develop an understanding of environmental sustainability enablers (ESEs) for steel supply chain in Indian perspectives.
- To identify and develop a structural framework of ESEs using driving and dependence power for the implementation of environmental sustainability for an Indian steel supply chain.
- To classify the ESEs using driving and dependence power to select the appropriate set of ESEs for successful adoption environmental sustainability.

4.3 Environmental Sustainability Enablers in Indian Steel Supply Chain

The available literatures on Environmental Sustainability on steel supply chain were reviewed to prepare the list of Environmental Sustainability Enablers (ESEs) in Indian steel supply chain. The cause and effect analysis made on ESEs in Indian steel supply chain using fuzzy Decision-Making Trail and Evaluation Laboratory (DEMATEL) by Goyal *et al.*, 2019 was also taken into account in specific for deciding the list of ESEs in Indian steel supply chain. On the basis of these analysis and experts' opinion in Indian steel sector, twelve ESEs as mentioned in Table 4.1 were considered as the relevant ESEs for achieving environmental sustainability. These twelve ESEs are discussed in this Section.

Table 4.1: Significant environmental sustainability enablers from literature

ESE	Abbreviation	Citation
Environmental Sustainability Measures	ESM	Chin *et al.*, 2015; Rehman *et al.*, 2016; Shamaii *et al.*, 2017; Goyal *et al.*, 2018; Sangwan and Choudhary 2018; Chuang and Huang, 2018 and discussion held with experts during industrial visits and focused group members.
Top Management Involvement	TMI	Diabat and Govindan, 2011; Giunipero *et al*, 2012; Muduli *et al.*, 2013; Paillé *et al.*, 2014; Luthra *et al.*, 2016; Walls and Berrone 2017; Goyal *et al.*, 2018, Soepardi and Thollander, 2018; Sangwan and Choudhary, 2018; Latan *et al.*, 2018; Obal *et al.*, 2020 and discussion held with experts during industrial visits and focused group members.
Value Added Products from waste	VAP	Guo *et al.*, 2018; Li and Dai, 2018; Tong *et al.*, 2019; Branca *et al.*, 2020; Gao *et al.*, 2020b; Obal *et al.*, 2020; Teo *et al.*, 2020 and discussion held with experts during industrial visits and focused group members.
Environmental Sustainability Practices	ESP	Muduli *et al.*, 2013; Govindan *et al.*, 2015; Mittal and Sangwan, 2015, Miska *et al* , 2018; Vejvar *et al.*, 2018; Chege and Wang, 2020; Chen *et al.*, 2020 and discussion held with experts during industrial visits and

ESE	Abbreviation	Citation
		focused group members.
Environmental Sustainability Culture	ESC	Gunasekaran and Spalanzani, 2012; Kurdve *et al*.. 2014; Gracia *et al*., 2020; Obal *et al*., 2020; Piwowar, 2020; Wiktor, 2020 and discussion held with experts during industrial visits and focused group members.
R&D Program for Environmental Sustainability	RES	Bose and Pal, 2012; Yang *et al*., 2012; Hsu *et al*., 2013; Guoyou *et al*., 2013; Quader *et al*., 2015; Chege and Wang, 2020; Chen *et al*., 2020 and discussion held with experts during industrial visits and focused group members.
Water Pollution Controlling System	WCS	Van Caneghem *et al*., 2010; Gao *et al*., 2011; Brraich, and Jangu, 2015; Govil and Krishna, 2018, Bali *et al*., 2019 and discussion held with experts during industrial visits and focused group members.
Air Pollution Controlling System	ACS	Zhang *et al*., 2014; Francová *et al*., 2017; Mele and Magazzino, 2020; Tang *et al*., 2020 and discussion held with experts during industrial visits and focused group members.
Soil Pollution Controlling System	SCS	Favas *et al*., 2011; Rachwał *et al*., 2015; Qing *et al*., 2015; Yin *et al*., 2016 and Govil and Krishna, 2018; Yang *et al*., 2020 and discussion held with experts during industrial visits and focused group members.
Environmental Compliance Certification	ECC	Nawrocka *et al*., 2009; Barasa *et al*., 2015; Prasad and Mishra, 2017 and Rino and Salvador, 2017; Chen *et al*., 2020 and discussion held with experts during industrial visits and focused group members.
Government Regulations and Incentives	GRI	Giunipero *et al*., 2012; Mittal and Sangwan, 2015; Sangwan and Choudhary, 2018; Somboonwiwat *et al*., 2018; Wang *et al*., 2018; Chen *et al*., 2020 and discussion held with experts during industrial visits and focused group members.
Technology Adoption for Environmental Sustainability	TAS	Quader *et al* ., 2015; Mittal and Sangwan, 2015; Rachwał *et al*., 2015; and Karakaya *et al*., 2018; Ozcan *et al*., 2018, Bali *et al*., 2019, Gao *et al*., 2020a and discussion held with experts during industrial visits and focused group members.

Environment sustainability measures **(ESM):** It implies to the policy measures those have been established in the company or industry to achieve the desired level of environmental sustainability. It involves the identification of parameters and control measures those are constantly monitored across the supply chain of steel company to ensure the desired results. These are generally the internal policy driven measures mostly controlled and reported by individual departments and are governed by the central environment department of the organizations.

Top management involvement **(TMI):** It refers to the determination and seriousness of the decision making body of an organization towards environment sustainability. The top management is the source that defines the vision and mission of an organization. It is the ultimate governing body that decides and formulates the strategy for an organization and allocates the resources to achieve the same. Steel industry is capital intensive and therefore any technology advancement or implementation of any process may require substantial resources and, the decision in which case can only be initiated by top management.

Value added products from waste **(VAP):** Value added products refer to the useful finished goods predominantly obtained from the residual by-products or the waste. The best example of the value added product developed in the steel industry is fly ash brick. At the same time, the slag is widely used in the manufacturing of cements. Most of the primary steel plants in India have fly ash brick manufacturing units and cement manufacturing units in or near the steel manufacturing premises. The value added conversion and use of by products and waste is of great benefit as it considerably minimizes the environmental hazard and also becomes the source of additional revenue. The supply chain involved for value added products needs to be studied and focus should be made for its successful implementation with business sustainability so that the waste generated from different operations along the supply chain can be better handled and leads to environmental sustainability.

Environment sustainability practices **(ESP):** It implies to the implementation of the green practices across the supply chain. The well-defined procedures must be adopted across the supply chain to ensure that the desired environment results are achieved across at every stage of the supply chain. It can only be possible through adoption of the standard procedures and reaching out to all the stakeholders including employees to ensure the necessary awareness towards the environment and green supply chain. The necessary steps should be adopted to impart required knowledge and awareness among the departments and employees towards environment and green practices. The efforts should be made to develop the common consensus within cross functional departments towards green initiatives and practices.

Environment sustainability culture **(ESC):** Culture forms the most important element of any organization. It is soul and the true representation of any organization. The culture of any organization is mostly driven by the organizations vision and its strategic priorities. A healthy culture is the most desirable for any stable organization. It is comparably easy to implement the changes and policies in a productive and healthy culture. Organizational culture becomes extremely important in the organizations that employees large work force. The steel industry is work force intensive in India which makes it more desirable to have a healthy work culture so that the policies, practices and work processes can be implemented more efficiently with a focus on environmental sustainability.

***Research towards environment sustainability* (RES):** It refers to the R&D department that is focused on improving technology, product, process and inventing new practices that will support the overall objective of achieving the desired level of environmental sustainability. R&D in every industry is most important department as it is the source of technology up gradation and process improvement. The continuous improvement in any process can only be achieved through constant research. The steel industry involves enormous activities across the supply chain from mining to shipment of finished goods including value added products from wastes. Considering the nature of supply chain, there is always a scope of improvement through R&D. The process improvement, better product development and technology up gradation together will contribute to environment sustainability.

***Water pollution control system* (WCS):** Steel industry is energy intensive and generates enormous amount of heat energy. The water is mostly used in the form of absorbent and coolant at every stage of the supply chain. The water utilization in steel industry is enormous. The requirement of this enormous amount of water is fulfilled through the water bodies like lake, river etc. Though the most of the water under use is recycled but still in the process, the contamination of water bodies is quite high. The steel companies must adopt the methodology and define the measurable parameters to check the water usage and water contamination.

***Air pollution control system* (ACS):** It is well known that the steel industry emits outs huge volume of gases that are generated upon fuel burning. These gases are emitted out to the atmosphere through the chimneys. As the steel industry is the continuous manufacturing process, the gaseous emission into the atmosphere is also constant. There is enormous emphasis on the cleanliness of the emitting the gases to minimize its impact on environment. The control parameters are frequently monitored to check the emitting gases. It is always desirable to have the advanced control system in operation to monitor the emitting gases.

Soil pollution control system **(SCS):** Soil pollution control is another challenge for steel industry. Soils pollution occurs across the supply chain starting from the mining to production. The steel supply chain usually encompasses various check points where the control parameters are constantly monitored to ensure minimum soil contamination. Such rigorous control system is most desirable notably at mining and production.

Environment compliance certification **(ECC):** It refers to the strict compliance to the government policies and statutory norms. The compliances towards guidelines are defined by the standards and specification for production, process and environment protection. It is one of the most effective manner in which the steel company can be pushed for reforms to achieve environment sustainability. The government regulations are broadly designed on long term perspective which in turn enables the companies to design and formulate their organizational strategy. The government policies in each country are mostly individual country driven. But in recent years, due to growing environmental concerns, the world is coming together to identify the common policies that the can be adopted as a common roadmap by all countries. These policy compliances sometimes require strict usage of advanced technology which puts extra pressure on the organizations mostly in developing countries or underdeveloped countries. However, at the same time global policy compliances help the organizations to establish the parity with the developed world and makes them future ready. Therefore, the compliance to regulations is one of the most effective manner in which the organizations can achieve the environment sustainability.

Government regulations and incentives **(GRI):** The steel industry encompasses various activities throughout its supply chain, starting from mining to production and logistics. Every stage has its own impact on environment. The mining has huge impact on soil and water pollution while the production activity impacts hugely on air and soil apart from huge waste and by product generation. Considering the nature of operations, it becomes excessively important to determine the control measures and establish the achievable set of guidelines that can be followed by companies. The government regulations provide the clarity to the organizations and help them to draw out the roadmap to satisfy the regulatory requirements. It also helps in creating the future course of action. Along with the regulations, the incentive schemes play an important role in the environment sustainability. The incentive schemes are generally the additional benefits that an organization gets when it achieves the extra milestones. The incentives schemes act as an attractive element that allows organization to target the benefits associated with it. Many a times the policies which are incentive driven today become the regulatory policy in future. Thus, the incentive schemes also act as the indicator of the likely modification and revision of the regulatory policies in future.

Technology adoption for environment sustainability **(TAS):** Technology plays an important part in the process improvement and product development including by-product development. Better the technology better will be the usage of resources. The step improvement in technology in any organization is mostly obtained either through R&D or technology adoption through outsourcing. In developing countries like India the investment in the R&D field is limited. Much of the advanced technology is outsourced through the developed world. It helps the organization to remain competitive. The advanced technology helps to improve the process and also the product. Most of the times the technology makes the process so efficient that the usage of resources is reduced considerably and the waste generation are equally minimized. The technology adoption can be substantially helpful in achieving the environment sustainability across different activities of steel supply chain.

4.4 Proposed Methodology for Analyzing ESEs

The current study aims to establish a set of appropriate ESEs for steel supply chain in India so that the environmental sustainability effort can be more focused. This is possible only when driving ESEs can be identified. The literature suggests that Interpretive Structural Modeling (ISM) methodology proposed by Warfield (1974) has the ability to analyze the intricate relationship between the elements/attributes/factors/drivers/barriers in a complex system. It has the ability to draw the order and direction of the complexity of relationships. ISM methodology has been used as a qualitative tool by various researchers to draw the order and direct the relationships among the elements in the form of graphical presentation (Sage, 1977; Kumar and Routroy, 2014). The driver and dependency relationships between them are the basic inputs of the model. These relationships are expressed qualitatively and should be assessed qualitatively by a group of experts. The application of ISM methodology is reported in the literature in various areas including environmental sustainability for different industries such as manufacturing industry (Bux *et al.*, 2020; and Singh *et al.*, 2020) and mining industry (Ramaganesh and Bathrinath, 2020) but such study is not reported in literature for steel supply chain in India. Most of the researchers have expressed that the results obtained from this type study are context specific and they cannot be generalized. Therefore, a comprehensive study of relevant ESEs of steel supply chain is carried out taking inputs from literature and experts in steel supply chain in India.

The various steps of the proposed methodology for analyzing ESEs are discussed below:

Step 1: Identify the list of ESEs through literature review, brainstorming sessions and discussions with the industry experts and academic researchers related to Indian steel supply chain.

Step 2: Establish the relevant set of ESEs with the help of industry experts and consultants/academicians working in the field environment sustainability and green supply chain in steel industry.

Step 3: Form a focused group of industry experts for analyzing the ESEs and develop the structural relationship digraphs of ESEs. The following procedural steps are executed for establishing the structural relationships in between the ESEs.

Step 3.1: Capture the opinions of focused group for contextual relationships between ESEs to develop Structural Self-Interaction Matrix (SSIM). Four symbols (A: ESE "j" leads to ESE "i"; V: ESE "i" leads to ESE "j"; X: ESE "i" leads to ESE "j" and ESE "j" leads to ESE "i" and O: no relationship between ESE "i" and ESE "j") are used for obtaining the type of the relation that exists between the ESEs ("i" and "j").

Step 3.2: Substitute V, A, X and O of SSIM with 1 and 0 to develop Initial Reachability Matrix (IRM) as mentioned in Table 4.2.

Table 4.2: Developing IRM from SSIM

Contextual relationships in SSIM	**Binary Value in (IRM)**	
Cell (i, j)	Cell (i, j)	Cell (j, i)
V	1	0
A	0	1
X	1	1
O	0	0

Step 3.3: Develop the Final Reachability Matrix (FRM) from IRM accounting the transitivity among the contextual relations of ESEs. Transitivity in the relationship is determined as follows: if ESE "i" is related to ESE "j" and ESE "j" is related to ESE "k", then ESE "i" is related to ESE "k". Then the (i, k) entry in the FRM becomes 1.

Step 3.4: Carry out the level partitioning of ESEs by developing the reachability and antecedent sets for each ESE on the basis of FRM. The reachability set of an ESE contains the ESE itself and the other ESEs which it may reach. Whereas, the antecedent set of an ESE contains the ESE itself and other ESEs which may reach it. Obtain the intersection set of an ESE by taking out the common relations in between the reachability and antecedent sets. The ESEs for which the reachability and intersection sets are same will occupy the top-level in the structural hierarchy of the digraphs. The top-level ESEs are separated out from the initial set of ESEs and then the process is repeated until all the ESEs are assigned to a level.

Step 3.5: Develop a lower triangular matrix (LTM) or a canonical matrix from the level partitions obtained in the previous step. It is just another form of FRM in which ESEs are positioned and clustered according to the level of partition.

Step 4: Develop a structural directed graph (called as digraph) on the basis of entries in the LTM obtained in the step 3.5. If a relationship (directly or indirectly) exists between ESE "i" and ESE "j" then it is shown by an arrow (i.e. link) pointing from ESE "i" to ESE "j". The development of digraph should be made on the basis of critical direct links which can utmost simultaneously define the associated relationships between the other ESEs.

Step 5: Plot the driver dependence diagram (with dependence power along the X-axis and driving power along the Y-axis) to classify the ESEs into four groups by dividing the XY plane into four quadrants depending upon their intensity of powers. These four quadrants are Autonomous (weak driving and dependency power), Dependence (weak driving and high dependency power), Linkages (strong driving and dependency power) and Drivers (strong driving and weak dependency power).

4.5 Application of Proposed Methodology for Analyzing of ESEs

ESEs were identified through literature review, brainstorming sessions and discussions held with the industry experts and consultants working alongside steel industry. The industry experts from three leading integrated Indian steel plants were contacted for their assessment of the identified ESE's. The industry experts have an average experience of 27 years in steel industry and were holding the department head position in their respective companies. Further it was observed that all the three companies have full time on roll consultants who guide the companies on day to operational activities to improve the environment sustainability and also help them to formulate the policy. These consultants were also contacted and their views and suggestions on the selected ESE's were considered. The three leading steel companies (A, B and C) are integrated steel plants with the total consolidated capacity of 37 million tons. Steel company A is pioneer in environment protection and has distinction to planting 10 million trees around their steel manufacturing plant. The company has a reputation of working extensively in the field of environment conservation. The same was reflected in their process where they were monitoring the processes with utmost precision and any deviation from the set standards were addressed and rectified instantly. They had developed the in-house technology to utilise the blast furnace exits gases (having considerable calorific value) as fuel in the reheating furnace in rolling mill. The data's and inputs were sought from Head, Environment department, having the experience of 28 years in the field of environment. Company B has special distinction of technology tie up with peers from developing nation and has installed the most modern iron and steel making unit in India. They are using Corex technology for iron making against the conventional blast furnace. The data's and inputs were sought from Vice President, Supply Chain, having the experience of 21 years in the field of environment. Company C is one of the highly reputed steel companies in the world and has comprehensive and progressive approach to all the necessary requirements for environment sustainability. The data's and inputs were sought from Unit Head, Environment department having the experience of 32 years in the field of environment.

The field experts were mostly from the industry experts and research scholars. Four consultants were contacted. Three of the consultants were working as independent advisors to the steel companies, while the fourth consultant is working as the employer in one of the leading consultant firm and is presently associated and providing consultation to two steel companies in the field of environment. The average working experience of the four consultants is 33 years. The consultants were very useful as they provided the vital data's in the context to steel industry and in few instances they were also critical on policy formation and implementation which provided the unbiased opinion. Their opinion on government policy was vital as it they were able to compare and relate to the policies of other countries. The inputs from the experts (See Table 4.3) were driven out of the industry context which inarguably covered the broader prospect. The names of companies, officials and the consultants are kept confidential as a matter of privacy and also in line with the agreement. The ESEs obtained in step 1, were subjected to thematic content analysis and the experts' opinions were sought to arrive the consensus about the relevancy of the selected ESEs. There upon based on the expert's opinion, the consensuses were reached for the final 12 ESE's (see Table 3.3).

Table 4.3: Details of experts in the focus group

Expert	Company name/ Consultant	Qualification	Experience	Position held
First Expert	Company A	M Tech	28 years	Head, Environment Department
Second Expert	Company B	M Tech	21 years	Vice President, Supply Chain and CSR
Third Expert	Company C	M Tech	32 years	Unit head, Environment Department
Fourth Expert	Consultant AA	PhD	40 years	Independent advisor to steel companies
Fifth Expert	Consultant BB	PhD	36 years	Independent advisor to steel companies
Sixth Expert	Consultant CC	M Tech	27 years	Working with a consulting firm advising on environmental aspect across the steel supply chain.
Seventh Expert	Consultant DD	M Tech	29 years	Previously employed with Bureau of Indian Standards (BIS) and currently advising the steel companies

Following the step 3.1, SSIMs of the 12 ESEs were constructed and the experts' opinions regarding the influence of one ESE over the other were collected. The opinions from industry experts and consultants directly associated with the three steel companies were considered. In ascertaining the type of relationship in between the ESEs, a threshold value of 70 percent was fixed. All the types relationships imparted in between the ECEs of SSIMs were supported by more than 70 percent of experts' opinions. The SSIM's were developed based on expert opinion (see Table 4.4). Then, on the basis of SSIMs, the IRMs (see Table 4.5) and FRMs (see Table 4.6) of ESEs were subsequently obtained by following the steps 3.2 and 3.3. There upon the level partitioning of ESEs was carried. Subsequently on the basis of these levels, the respective LTMs were developed according to the steps 3.4 (see Table 4.7). Below table shows the distribution of ESEs along different levels

Table 4.4: Structural self-interaction matrix of ESEs

	ESM	TMI	VAP	ESP	ESC	RES	WCS	ACS	SCS	ECC	GRI	TAS
ESM	0	A	A	X	X	A	V	V	V	A	A	A
TMI		0	V	V	V	V	V	V	V	A	A	V
VAP			0	V	V	O	V	V	V	A	A	X
ESP				0	X	A	V	V	V	A	A	A
ESC					0	A	V	V	V	A	A	A
RES						0	V	V	V	A	A	X
WCS							0	O	O	A	A	A
ACS								0	O	A	A	A
SCS									0	A	A	A
ECC										0	X	V
GRI											0	V
TAS												0

Table 4.5: Initial reachability matrix of ESEs

ESM	TMI	VAP	ESP	ESC	RES	WCS	ACS	SCS	ECC	GRI	TAS
0	0	0	1	1	0	1	1	1	0	0	0
1	0	1	1	1	1	1	1	1	0	0	1
1	0	0	1	1	0	1	1	1	0	0	1
1	0	0	0	1	0	1	1	1	0	0	0
1	0	0	1	0	0	1	1	1	0	0	0
1	0	0	1	1	0	1	1	1	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
1	1	1	1	1	1	1	1	1	0	1	1
1	1	1	1	1	1	1	1	1	1	0	1
1	0	1	1	1	1	1	1	1	0	0	0

Table 4.6: Final reachability matrix of ESEs

	ESM	TMI	VAP	ESP	ESC	RES	WCS	ACS	SCS	ECC	GRI	TAS	DrP	Rank
ESM	1	0	0	1	1	0	1	1	1	0	0	0	6	IV
TMI	1	1	1	1	1	1	1	1	1	0	0	1	10	II
VAP	1	0	1	1	1	1	1	1	1	0	0	1	9	III
ESP	1	0	0	1	1	0	1	1	1	0	0	0	6	IV
ESC	1	0	0	1	1	0	1	1	1	0	0	0	6	IV
RES	1	0	1	1	1	1	1	1	1	0	0	1	9	III
WCS	0	0	0	0	0	0	1	0	0	0	0	0	1	V
ACS	0	0	0	0	0	0	0	1	0	0	0	0	1	V
SCS	0	0	0	0	0	0	0	0	1	0	0	0	1	V
ECC	1	1	1	1	1	1	1	1	1	1	1	1	12	I
GRI	1	1	1	1	1	1	1	1	1	1	1	1	12	I
TAS	1	0	1	1	1	1	1	1	1	0	0	1	9	III
DeP	9	3	6	9	9	6	10	10	10	2	2	6		
Rank	II	IV	III	II	II	III	I	I	I	V	V	III		

DeP: Dependence Power, Drp: Driving Power

Table 6.7: Level partitioning of ESEs

Level	Environmental sustainability enablers
I	ACS, WCS, SCS
II	ESM, ESP, ESC
III	TAS, RES, VAP
IV	TMI
V	ECC, GRI

Based on these LTMs, the diagraphs of PCEs under respective domain were constructed. These digraphs were constructed by positioning the ESEs as per the partitioned levels and the order in which they were partitioned. Links between the ESEs in the diagraphs were laid out on the basis of direct links (noted as 1 in the respective LTM of ESEs) as well as the associated transitive links based on the laid direct link. It must be noted that the direct links laid here becomes the critical ones and the basis for establishing all the relationships between the ESEs. According to step 5, using the driving and dependence powers of ESEs the driver dependence diagrams of ESEs were plotted (see Figure 4.1 and Figure 4.2).

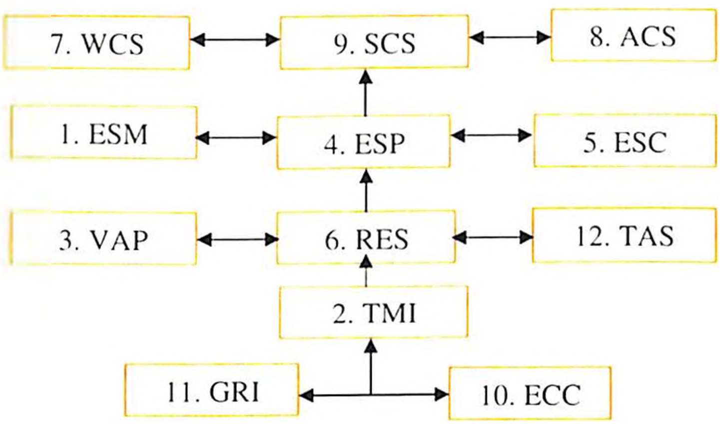

Figure 4.1: Structural diagram of environmental sustainability enablers

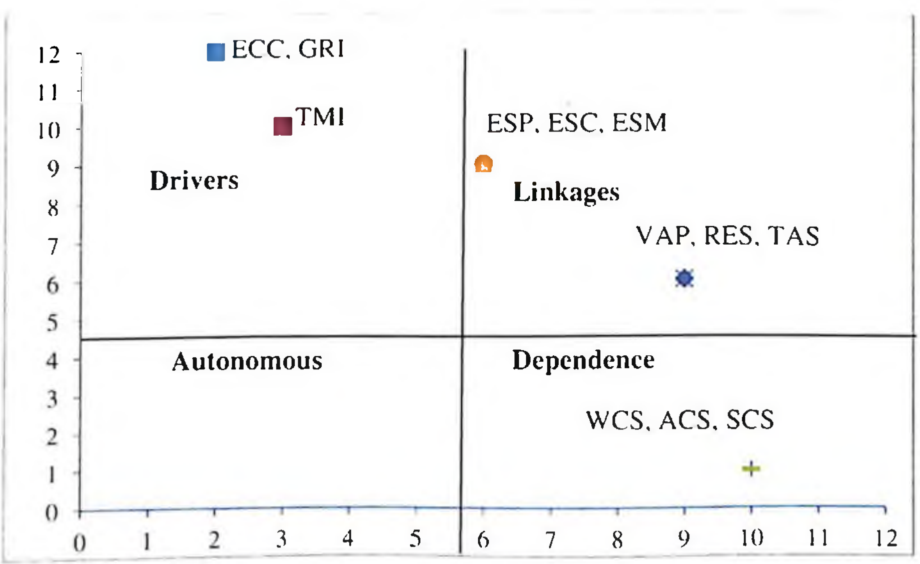

Figure 4.2: Driver dependence diagram of environmental sustainability enablers

4.6 Results and Discussion

The hierarchical structural model of twelve ESEs (see Figure 4.1) was drawn on the basis of the focused group experts' judgement (i.e. contextual realtionships and tranisitivity relationships between ESEs) and application of ISM methodology as discussed in Section 4. The obtained ISM model for ESEs of steel supply chain in India consists of five levels (see Figure 4.1). The first two drivers are policy driven and government controlled. Government Regulations and Incentives (GRI) and Environmental Compliance Certification (ECC) are appearing at Level 5 whereas Top Management Involvement (TMI) is at level 4. These three ESEs are at the bottom of the ISM model and are considered to be the most significant and controlling ESEs for the implementation of environmental sustainability in the steel supply chain. All the drivers are heavy weight and require considerable deliberation as they have potential to leave long term impact, both fruitful and severe, on the industry and company. For example, any changes in Government policy may result in few companies able to comply while the others may fail. It may impact the overall steel industry in the country. The top management involvement will be more in terms of financial and human resources when GRI and ECC are strictly followed. Both GRI and ECC are found to impact each other. Government regulations and policies have the prominent impact on the overall level of environment sustainability of any steel company in the country. The steel industry is capital intensive and requires additional funds or involves capital burden in its aim to stepping towards improving environment sustainability. Thus the government incentive policy is much likely to add a relief and a much required push to the steel companies in their endeavor to the environment protection. The desire for environment sustainability in steel industry may require process enhancement, latest technology implementation, employee training etc. These factors also involve considerable expenditure and require management decision. Thus the top management commitment plays an important role and is the one of important drivers. The ESEs such as Value Added Products from waste (VAP), Technology Adoption for Environmental Sustainability (TAS) and R&D Program for Environmental Sustainability (RES) are in level 3 whereas Environmental Sustainability Measures (ESM), Environmental Sustainability Practices (ESP) and Environmental Sustainability Culture (ESC) are found at level 2. These six ESEs form the heart of the model. The technology adoption and R&D Program are strategic decisions and require huge investment for its successful implementation in different operations along the steel supply chain. The efforts such as entrepreneur development preferably proximity to production facilities and support for technology development for waste use both internally and externally for value added products should be made for reduction of waste generation and its complete use for value added products. The technology tie-up with peers is certainly going to add the much required push in the quest for improved environmental sustainability and based on the level of technology transfer, the various parameters would be affected. The decision regarding these three ESEs are generally discussed and planned at top management with proper budget allotment. Therefore, the top management involvement can create a platform for their successful implementation. It was observed that these three ESEs have mutually impact on each other. They also have impact on all the ESEs in the level 2 such as ESM, ESP and ESC which are mostly internal to the organizational culture, practices and measures related to environmental sustainability. The three ESEs (i.e. Water Pollution Controlling System (WCS), Air Pollution Controlling System (ACS) and Soil Pollution Controlling System (SCS)) are the top-level enablers of the framework and hence, these three ESEs have more dependency on other ESEs in particularly on ESM, ESP and ESC. The performances of these three ESEs (i.e. WCS, ACS and SCS) have direct impact on environmental sustainability of steel supply in India. Their successful implementation, monitoring and enhancement have to be assessed on continuous basis through right set of performance indicators for these three ESEs and their performances should be benchmarked periodically.

The MICMAC analysis was carried out to develop the driver and dependence power diagram (see Figure 4.2) was developed considering driving and dependence power of ESEs. The diagraph of ESEs will assist the steel manufacturing company in India to understand the mutual relationship and linkage of various ESEs which will play a significant role for successful adoption of environmental sustainability program. It has the capability to develop four clusters of the ESEs considering the relative importance and interdependencies between them.

***Autonomous cluster*:** The autonomous ESEs have weak driving and dependence power. In the present study, no identified ESEs are appearing in autonomous driver (see Figure 4.2). These twelve ESEs are not weak enablers towards implementation of environmental sustainability in steel supply chain in India. This was also got confirmed by the focused group team.

***Dependent cluster*:** The dependent ESEs have high dependence power and low driving power (see Figure 4.2). Three ESEs (i.e. Water Pollution Controlling System (WCS), Air Pollution Controlling System (ACS) and Soil Pollution Controlling System (SCS)) were found to be in dependent cluster and they were also appearing at top of the hierarchy structural model which represents that these ESEs have high dependency power. These three ESEs can be thought as output variables of environmental sustainability program and the performance of the program is directly evaluated through the performance of these three ESEs. This was also got confirmed by the focused group team.

Linkage cluster: The linkage ESEs has high dependence power and high driving power. The six ESEs (i.e. Value Added Products from waste (VAP), Technology Adoption for Environmental Sustainability (TAS) and R&D Program for Environmental Sustainability (RES), Environmental Sustainability Measures (ESM), Environmental Sustainability Practices (ESP) and Environmental Sustainability Culture (ESC)) were found to the in the linkage cluster (Figure 4.2) and they are also appearing at the middle of structural framework (see Figure 4.1). The ESEs such as ESM, ESP and ESC have high driving power and less dependence in comparison to VAP, TAS and RES. These six ESES are unstable in nature and small change in them can affect the environmental sustainability program as these six ESEs connect the ESEs in dependent and driving cluster. This was also got confirmed by the focused group team.

Driving cluster: The driving ESEs have high driving power and low dependence. The three ESEs i.e. Government Regulations and Incentives (GRI), Environmental Compliance Certification (ECC) and Top Management Involvement (TMI) were found to the in the driving cluster (Figure 4.2) and they are also appearing at the bottom of structural framework (see Figure 4.1). The ESEs such as ECC and GRI have high driving power and less dependence in comparison to TMI. These three ESEs will facilitate the other ESEs and will ignite and show the direction to environmental sustainability program as these three ESEs have strong driving power and hardly influenced by any other ESEs. This was also got confirmed by the focused group team.

4.7 Conclusions

In the current work, the Environmental Sustainability Enablers (ESEs) of steel supply chain in India were studied by ISM-MICMAC analysis method and have come up with recommendations for the steel manufacturer in selectively exercising the ESEs for controlling, managing and enhancing environmental sustainability. From the obtained results, it was observed that Government Regulations and Incentives (GRI) and Environmental Compliance Certification (ECC) are the most important ESEs for achieving environmental sustainability in Indian steel industries. Government should take appropriate steps and provide platform for its successful implementation at the ground. Top Management Involvement (TMI) also plays critical role for its adoption and make the steel business sustainable both business and environment front. These three ESEs are just act as fuel to run the environmental sustainability vehicle on track and also have the potential to bring substantial changes in the environment sustainability of India steel companies. Thus, the role of the Government and Top Management are the most important in achieving the desired level of sustainability in Indian steel industry. In context to environment sustainability, it is also observed that the steel industry in comparison to other industries is more driven and governed by government policies. Thus a periodic modification in government policy in terms of incentives and reward & recognition on the basis of environmental sustainable performance, possibly in consensus with industry experts, can play a progressive role in ensuring the continuous improvement in environment sustainability. GRI, ECC and TMI are the input factors whereas the factors in dependent cluster such as WCS, ACS and SCS are the output factors to the environmental sustainability program for steel supply chain in India. The performance of these output factors should be evaluated on periodic basis by both internal committee and external agency(s) along the different relevant operations of the steel supply chain. The relay factors who are in linkage cluster such as Value Added Products from waste (VAP), Technology Adoption for Environmental Sustainability (TAS) and R&D Program for Environmental Sustainability (RES), Environmental Sustainability Measures (ESM), Environmental Sustainability Practices (ESP) and Environmental Sustainability Culture (ESC)) should be closely looked into for their implementation as it controls the output factors and get influenced by input factors. The outcomes of the work will definitely show the direction for academicians, researchers, and supply chain managers of the iron and steel industry for environmental sustainability attainment and enhancement in Indian steel supply chain. The current study will also definitely a valuable addition to environmental sustainability literature in general and steel supply chain in specific.

4.7.1 Limitations and Future Scope

The outcomes of the current study are limited to the Indian steel manufacturing company in specific but the results will not change significantly for the steel sectors in India. However, an empirical analysis can be used to explore and validate the structural framework for its acceptability. The contextual and transitivity relationship between ESEs were developed on the basis of focused group's opinion and needs empirically analysis to strengthen the current work. The same is also true for proposed structural framework for the successful implementation of environmental sustainability biasness in experts' opinion. In the current study, the opinion of focused group which consists of seven experts forms the inputs for analyzing ESEs in the different stages of ISM methodology. However, the robustness of this analysis can be improved by increasing the number of experts from different functional areas of steel manufacturing company and consultant (Devi et al., 2020). The ESEs can be analyzed through structural equation modeling (SEM) to get more details such as strength of relationship between ESEs (Kannan *et al.*, 2008). The use of mixed approach such as DEMATEL, Analytical Network Process (ANP), Total Interpretive Structural Modelling (TISM) and SEM for the analysis of ESEs can also give better insight (Devi et al., 2020).

CHAPTER - 5

Measuring the Environmental Sustainability in Indian Steel Supply Chain

5 Sectional Abstract

Increasing social awareness together with the new regulations for environmental sustainability are forcing supply chain of Indian steel companies to quantify, evaluate and compare their environmental sustainability performance. Broadly twelve Environmental Sustainability Measures (ESMs) were identified and they were classified into four Significant Categories (SCs). Featuring these SCs and ESMs under each significant category, a methodology was proposed using Graph Theoretic Approach (GTA) for evaluating the environmental sustainability performance of Indian steel companies. The analysis was further extended to compare the results with performance in different situations and accordingly set the future targets. In order to demonstrate the utility of the proposed methodology, it was applied to an Indian steel company. The results obtained indicated that there have been significant growths achieved in the environmental sustainability performance over a period of five years. It was also found that a performance gap exists and it will reach the target value after two years. The proposed approach is aimed at providing a procedure for evaluating the environmental sustainability performance. This study is an attempt to assist a Steel Industry to assess its sustainability program and accordingly define its course of actions. Although many issues related to environmental sustainability have been widely recognized and studied, there are no specific studies available in the literature to assess the environmental

sustainability performance along the timeline. The proposed model has the ability to capture the performance and interdependencies of SCs. ESMs under each SC and also to quantify the environmental sustainability performance along the timeline.

5.1 Introduction

Ever since the beginning of the industrialization, the manufacturing sector has been expanding rapidly across the globe. Last four decades have seen exponential growth in manufacturing sector, particularly in the developing countries as they are expanding their manufacturing capacity to match their domestic requirements. This is also true for steel sector. The steel sector is not only energy and resource consumption enterprise but also one of the worst polluter. There is a tremendous pressure on steel industry in India from various stake holders particularly from Government and Society to make their processes more sustainable in order to decrease pollution and the greenhouse effect. As per the analysis, 1.8 tons of CO_2 is produced and emitted to environment per unit ton production of steel (Ministry of Environment and Forest (India), 2006), it is therefore important to make steel industry environmentally sustainable by inducing green practices. One can find many research articles focusing on various dimensions of sustainability in different sectors in general and manufacturing sector in specific in the literature. Many researchers (Petroni, 2000; Tse, 2001; Ruud, 2002; and Corbett and Kirsch, 2004) viewed ISO 14001 certification as path towards the green image of the company. Green Supply Chain (GSC) (i.e. environment conscious) is important philosophy to achieve corporate profit with reduction of environment risk (Van Hoek, 1999). It is considered a managerial approach that seeks to minimize environmental and social impacts of firm's products or services (Rettab and Brik, 2008). One must incorporate environmental criteria into organizational decisions of purchasing and supplier relation to achieve GSC (Gilbert, 2001). Green Supply Chain Management (GSCM) is the integration of environmental aspects in conventional supply chain for a holistic improvement of environmental performance (Davies and Hochman, 2007; and Srivastava, 2007). It can be defined as the integration from purchasing to life cycle management flowing from supplier to manufacturers, customer and closing the loop with reverse logistics (Zhu *et al.*, 2008a). Many authors have studied about the various issues such as a model of integrated steel supply chain (Kusi *et al.*, 2014); a steel supply chain model with simulation related to the steel supply chain (Sandhu *et al.*, 2013); integrated steel supply chain in UK (Potter *et al.* 2002); and the analysis of the performance outcomes of Korean steel supply chain (Youn *et al.*, 2014). But in all the above studies, environmental sustainability consideration is ignored. Considering an impact, the steel industry has on environment, the environment sustainability aspects cannot be ignored. In steel production, the main emissions are CO_2, SOx, NOx and dust. Mining of Iron ore and coal are responsible for land, water and air pollution.

Many authors have also studied about the sustainability issues in Indian steel supply chain such as benefits of recycling of steel to society from technical, economic and environmental perspective (Yellishetty *et al.*, 2011), factors affecting the GSCM in steel industries (Shekari *et al.*, 2011), behavioral factors in GSCM of mining industries of India (Muduli *et al.*, 2013), barriers in GSCM (Govindan *et al.*, 2013), a path to achieve GSCM in Indian steel industries (Kumar and Shekhar, 2015),) different green issues in Indian mining practices (Muduli and Barve, 2011) and green vendor selection for Indian steel industries (Sivakumar *et al.*, 2014). Although there is a need for measuring and comparing the environmental sustainability performance of steel supply in Indian, but hardly any work has been carried in these aspects. Therefore, a methodology was proposed using Graph Theoretic Approach (GTA) for evaluating the environmental sustainability performance of Indian steel companies.

5.2 Literature Review

Sustainability is broadly defined in Brundtland report as "to meet today's requirement without affecting the ability of future generations to meet their requirement" (WCED, 1987). Environmental sustainability means transforming our wants of living to maximize the chances that environmental condition will indefinitely support human security, well-being and health (McMichael *et al.*, 2003). To be more generic, it creates the possibility that all forms of life will flourish forever (Ehrenfeld, 2005). It has three dimensions: environment, economy and society also known as triple-bottom line. Many authors defined environment sustainability in various ways with central focus on triple bottom line. For example, Moreli (2011) defined environmental sustainability as "a condition of balance, resilience and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the service necessary to meet those needs nor by our actions diminishing biological diversity" whereas Elliat (2010) had defined environmental sustainability as "activities to minimize the negative impacts and maximize the positive impacts of human behaviour on environment through design, production, application, operation, and disposal of products and services throughout their life cycle". Researchers had studied and analyzed the various aspects of environmental sustainability in different industry sectors such as transportation and logistics (Evangelista, 2014), manufacturing industry (Guoyou *et al.*, 2013), petrochemical (Samuel *et al.*, 2013), wind power (Yang *et al.*, 2013), sewage treatment plant (Schanbroeck, 2015), wine industry (Santini *et al.*, 2013), sea ports (Acciaro, 2014) and electronic industry (Kannan *et al.*, 2014). Different authors have also identified various factors i.e. continuous assessment of environmental inputs (Sutherland *et al.*, 2008); green product development (UN Environment programme, 2009); use of renewable energy resources (O'Brien,1999); eco-friendly communication technology (Hilty *et al.*, 2006); and pressure from stakeholders and personal quest for better environment (Bey *et al.*, 2013) to obtain environmental sustainability. It is important to measure environmental sustainability on continuous basis and also some authors have specified certain performance indicators for measuring environmental sustainability i.e. consumption of ozone depleting substances and use of natural resources (Moldan *et al.*, 2012); recycling of waste and green practices in organization (Pozo *et al.*, 2013); emission control of toxic gases (Jeon *et al.*, 2013), green infrastructure (Hoggart and Hendrerson, 2005); waste management and tree felling (Ugwu and Haupt, 2005); sustainable packaging and product life cycle assessment (Caniato *et al.*, 2012); environmental marketing and reverse logistics (Faisal, 2010).

5.3 Environmental Sustainability Measures in Supply Chain for Indian Steel Industry

Environmental sustainability is an important consideration for steel industry which is not only one of the largest consumer of natural resources but also one of the biggest sources of pollution. The enhancement of environmental sustainability will provide competitive advantage to steel industry. Many researchers have identified various Environmental Sustainability Measures (ESM) (also known as Green Supply Chain Measures) and some of them are green technology innovation (Tianhai, 2013); optimum transportation practices (Ray and Kaul, 2013); green information and technology (Kusi *et al.*, 2014); internal environment management (Shekari *et al.*, 2011); green innovation and motivation (Muduli *et al.*, 2013); re-use and recycling (Graczyk *et al.*, 2012); and green production and warehousing (Bhetja *et al.*, 2011) for improving environmental sustainability in steel industry. Environmental Sustainability Program (ESP) is important for the manufacturing companies irrespective of their size, region of operation and nature of the business. The ESMs should be identified and their performance post implementation should be judiciously monitored. Efforts should be made for continuous improvement and in the process, the manufacturing companies can reach to a benchmark level. An extensive literature review was carried out to identify the measures, critical success factors, drivers etc. necessary for the success of ESP in general. These measures, critical success factors, drivers etc. were discussed and their relevance in Indian context was examined. Finally, twelve ESMs (see Table 5.1) were found as necessary for ESP in the Indian context.

Table 5.1: Environmental sustainability measures for steel industry

Measure	**References**
Green Image Building (GIB)	Simpson *et al.*, 2007; Chen, 2008; Skulstad, 2008; Chang and Fong, 2010; Lee *et al.*, 2010; Azevedo *et al.*, 2012; Bell *et al.*, 2013; Quader *et al.*, 2015; and Kumar and Shekhar, 2015.
Self-Imposed Environmental Policy (SEP)	Green *et al.*,1998; Beamon,1999; Berger *et al.*, 2001; Rao, 2002; Hervani *et al.*, 2005; Tsoulfas and Pappis, 2006; and Castke and Balzarova, 2008.
Top Management Commitment (TMC)	Zhu and Sarkis, 2004; Barrat, 2004; Hsu and Hu, 2008; Zhu *et al.*, 2008a; Pagell and Wu, 2009; Diabat and Govindan, 2011; and Muduli *et al.*, 2013.
Reduction of usage of Natural Resources (RNR)	Boudreau *et al.*, 2008; Shekari*et al.*, 2011; Jenkin *et al.*, 2011; Green *et al.*, 2012; Graczyk *et al.*, 2012; Chou and Chou, 2012 and Nishat *et al.*, 2013.
Green Training and Awareness (GTA)	Cook and Seith,1992; Wong,1998; Daily and Huang, 2001; Jabbour and Santos, 2008; Olugu *et al.*, 2011; Massoud *et al.*, 2011; and Muduli *et al.*, 2013.
Organizational Culture (ORC)	Toni *et al.*,1994; Maloni and Benton,1997; Mason-jones and Towill,1998; and Govindarajulu and Daily, 2004
Information Infrastructure and Information Visibility (IIV)	Boudreau *et al.*, 2008; Wagner *et al.*, 2009; Setterstrom, 2008; Jenkin *et al.*, 2011; and Muduli *et al.*, 2013.
Green practice adoption through R&D (GRD)	Hall, 2006; Quayle, 2003; Bose and Pal, 2012; Hsu *et al.*, 2013; and Shen *et al.*, 2013.
Controlling Measures for Water and Air Pollution (CWA)	Supply and Council,1997;Hendrickson *et al.*,1998;Klassen,2000; Clift and Wright, 2000; Guggemos and Horvath,2004;Rao and Holt,2005; Ho *et al.*,2009; Miller *et al.*,2010; and Kumar *et al.*, 2012.

Measure	References
Soil Pollution Controlling System (SCS)	Huamain *et al.*,1999; Hilson, 2000;Wang *et al.*,2003; Razo *et al.*,2004; and Favas *et al.*, 2011.
Government regulations and Incentives (GRI)	Vachon and Klassen, 2006; Chien and Shin,2007; Ramudhin *et al.*, 2008; Min and Kim,2012; and Kumar and Shekhar, 2015.
Collaboration with peers for technology and strategy exchange (CTE)	Simpson *et al.*,2007; Gaffen and Rothenberg,2008; Lovelady and El-Halwagi, 2009; and Kusi *et al.*, 2014.

The chosen twelve ESMs were discussed below:

Green image building (GIB): Green image building indicates to develop an environmental friendly business image among the business community and public. Due to recent surge in awareness towards the environmental sustainability, the society as a whole is expecting from the manufacturing industries in general and steel industries in specific to take steps for reducing environment deterioration due to their various operations along the supply chain. The contribution by industries to environment also adds to their brand image. It is also viewed by most experts as a long term survival strategy. Many experts pointed out during our industrial visits in India that this enabler will act as driving force to environmental sustainability activities of the company with earning benefits from competitive advantage.

Self-imposed environmental policy (SEP): Self-imposed Environmental Policy indicates the in-house developed environmental policies based on current practices and future plans for measuring, monitoring and enhancing environmental sustainability. This shows the commitment of the organization towards environmental sustainability and it compels various stakeholders to focus on it. Internal policy of such kind are most important as it clearly defines the management commitment and also guides the teaching and training programs in the organisation.

Top management Commitment (TMC): Top management Commitment refers to the determination and seriousness of the decision making body of an organization towards environment sustainability. The top management is the source that defines the vision and mission of an organization. An organizational activities and priorities are determined by top management, which forms the guidelines underlining the direction for the set vision. It is the ultimate governing body that decides and formulates the strategy for an organization and allocates the resources to achieve the same. Steel industry is capital intensive and therefore, any technology advancement or implementation of any process may require substantial resources and, the decision in which case can only be initiated by top management. Decisions pertaining to environmental sustainability may involve organizational structural changes and key resource allocations which is possible only on the concurrence and direction of top management. Most large steel companies are public or private limited and have managing board in place that decides and clears the strategic moves. The capital and resource infusion required for environmental sustainability may therefore require clearance from managing board.

Reduction of usage of Natural Resources (RNR): *Reduction of usage of natural resources* refers to minimal usage of natural resources for steel production. It can be achieved through adoption of practices that minimize wastage through efficient process, optimal utilization, recycling, reuse, and improved product design. Many experts during our industrial visits in India pointed out that RNR is very important for steel industry as it consumes considerable amount of natural resources and is significant contributor to pollution. Use of high grade coal can significantly reduce its per capita consumption in steel production. The re-use of water, fuel, oil etc. can be significantly improved through the use of effective treatment technology.

Green training/awareness (GTA): Green Training/Awareness implies to the implementation of the teaching and training programs for successful implementation of necessary awareness and green practices across the supply chain. The well-defined procedures must be adopted across the supply chain to ensure that the desired awareness is achieved across at every stage of the supply chain. The steel supply chain is complex and involves several processes. Each process has its own complex operations. It therefore can only be possible through adoption of the standard procedures and reaching out to all the stakeholders including employees to ensure the necessary awareness towards the environment across the green supply chain. Each stage across the supply chain may require different approach and hence the set of environmental sustainable practices may vary accordingly. It is therefore important to identify the required training programs suitable at each stage and efforts should be towards the standardization of the green practices for ease of adoption and effective implementation. The necessary steps should be adopted to impart required knowledge, awareness and training among the departments and employees towards environment and green practices. Efforts should be made to develop the common consensus within cross functional departments towards green initiatives and practices.

Organizational culture (ORC): Organizational Culture forms the most important element of any organization. It is soul and the true representation of any organization. The culture of any organization is mostly driven by the organizations vision and its strategic priorities. A healthy culture is the most desirable for any stable organization. It is comparably easy to implement the changes and the policies in a productive and healthy culture. A healthy wok culture not only helps in effective implementation of strategic policies but also ensures the true feedback which is very important for an effective outcome. Organizational culture becomes extremely important in the organizations that employees large work force and complex supply chain. The steel industry is work force intensive which makes it more desirable to have a healthy work culture so that the policies, practices and work processes can be implemented more efficiently with a focus on environmental sustainability. The work force in steel supply chain involves labors, technicians, engineers, researchers, business graduates etc. The range of human resource in steel industry is extremely diversified and it is very important to have a work culture that accommodates, nurtures and complement each other. Without the healthy work culture, a productive steel supply chain cannot be imagined. Any policy implementation across the supply chain for an environmental sustainability can be successful only with a healthy work culture.

***Information infrastructure and information visibility (IIV)*:** Information infrastructure and information visibility implies the development of proper communication channel that enables easy access of real time information related to environmental sustainability in general. The information visibility on real time basis will help in monitoring and rectifying any issues related to environmental sustainability. Steel manufacturing is a continuous production process and hence, its complex supply chain continuously witness numerous activities. Therefore, it makes its vital to have the real time information of every desired activity or parameter. Without the efficient information infrastructure, it would be nearly impossible to have an efficient supply chain and work on its continuous improvement.

***Green practice adoption through R&D (RDP)*:** Focus on R&D refers to the R&D department that is focused on improving technology, product, process and inventing new practices that will support the overall objective of achieving the desired level of environmental sustainability. R&D in every industry is most important department as it is the source of technology up gradation and process improvement. The continuous improvement in any process can only be achieved through constant research. The steel industry involves enormous activities across the supply chain from mining, production to shipment of finished goods including production of value added products from the generated wastes. Over the period, the continuous research has resulted in production of value products. The fly ash is widely used in brick making, blast furnace slag is a key ingredient in cement production, blast furnace slag and steel slag are now days widely used as coarse aggregate in construction industry. Several products generated cross the steel supply chain were earlier treated as waste have now turned into the valuable products due to continuous research and development. Apart from it, the process efficiency has been considerably improved over the last several decades with the help of R&D. Considering the nature of supply chain, there is always a scope of improvement through R&D. The process improvement, better product development and technology up gradation together will contribute to environment sustainability.

Controlling measures for water and air pollution (CWP): Steel industry is energy intensive and generates enormous amount of heat energy. The water is mostly used in the form of absorbent and coolant at every stage of the supply chain. The water utilization in steel industry is enormous. The requirement of this enormous amount of water is fulfilled through the water bodies like lake, river etc. Though the most of the water under use is recycled but still in the process, the net usage of water and the contamination of water bodies is quite high. It is well known that the steel industry emits outs huge volume of gases that are generated upon fuel burning. These gases are emitted out to the atmosphere through the chimneys. As the steel industry is the continuous manufacturing process, the gaseous emission to the atmosphere is also constant. There is enormous emphasis on the cleanliness of the emitting the gases to minimize its impact on environment. Steel industry has always been under scanner and international watch for its emissions and carbon footprints. Steel industry has considerable share in carbon emissions It is always desirable to have the advanced control system in operation to monitor the emitting gases and the water usage.

Controlling measures for soil pollution (CSP): Soil pollution control is another challenge for steel industry. Soils pollution occurs across the supply chain starting from the mining to production. Enormous amount of soil pollution occurs at mining site due to improper handling of top soil and unregulated mine abandoning. Several research papers were found in the literature discussing the environment impact of mining, where most of them were heavily focused on soil contamination in nearby areas. In few cases, the impact is so enormous that the agriculture land near the mines have turned non cultivable due to soil pollution. Apart from it the areas adjoining the steel production units also witness severe impact on soil quality. The large number of wastes are generated across the steel supply chain and if not safely disposed majorly results in soil pollution. It is therefore desirable to monitor and check the soil pollution near the operational sites. The steel supply chain usually encompasses various check points where the control parameters are constantly monitored to ensure minimum soil contamination. Such rigorous control system is most desirable notably at mining and production.

Government Regulations and Incentives (GRI): The steel industry encompasses various activities throughout its supply chain, starting from mining to production and logistics. Every stage has its own impact on environment. The mining has huge impact on soil and water pollution while the production activity impacts hugely on air and soil apart from huge waste and by product generation. Considering the nature of operations, it becomes excessively important to determine the control measures and establish the achievable set of guidelines that can be followed by companies. The government regulations provide the clarity to the organizations and help them to draw out the roadmap to satisfy the regulatory requirements. It also helps in creating the future course of action. Along with the regulations, the incentive schemes play an important role in the environment sustainability. The incentive schemes are generally the additional benefits that an organization gets when it achieves the extra milestones. The incentives schemes act as an attractive element that allows organization to target the benefits associated with it. Many a times the policies which are incentive driven today become the regulatory policy in future. Thus, the incentive schemes also act as the indicator of the likely modification and revision of the regulatory policies in future.

Collaboration with peers for technology and strategy exchange (CTE): Technology plays an important part in the process improvement and product development including by-product development. Better the technology, better will be the usage of resources. The step improvement in technology in any organization is mostly obtained either through R&D or technology adoption through outsourcing. In developing countries like India the investment in the R&D field is limited. Much of the advanced technology is outsourced through the developed world. It helps the organization to remain competitive. The advanced technology helps to improve the process and also the product. Most of the times the technology makes the process so efficient that the usage of resources is reduced considerably and the waste generation are equally minimized. The technology adoption can be substantially helpful in achieving the environment sustainability across different activities of steel supply chain.

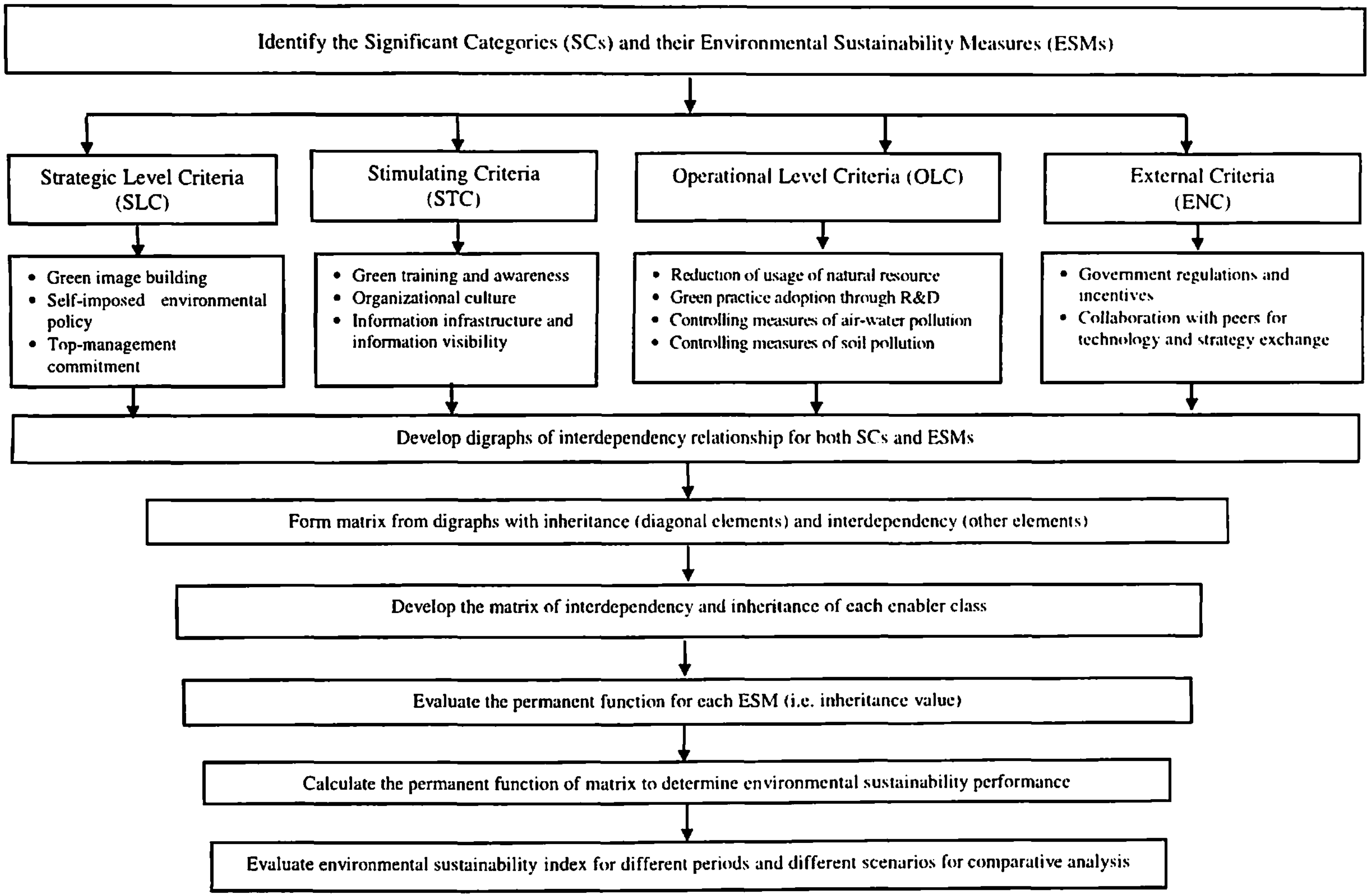

Figure 5.1: Flow chart for comparative green performance analysis along the timeline

5.4 Graph Theoretic Approach for Measuring the Environmental Sustainability in Supply Chain for Indian Steel Industry

Graph Theoretic Approach (GTA) has the ability to capture both the performances of the Measures/critical success factors (i.e. inheritance) and their interdependencies (i.e. interactions) among themselves in a multi-level problem to determine the system performance (put references). Many researchers have applied GTA in addressing various research problems such as supplier development program (Routroy *et al.*, 2016) supply chain network design problems (Pishvaee and Rabbani, 2011); collaboration in between manufacturers and retailers of Indian apparel retail industry (Anand and Bahinipati, 2012); quantify the effects of barriers on the green supply chain management practices (Muduli *et al.*, 2013); measuring the coordination index (Kaur *et al.*, 2006); selection of suitable supply chain strategy (Faisal *et al.*, 2006); quantification of information risks in supply chain (Faisal *et al.*, 2007a); quantification of risk mitigation environment of supply chains (Faisal *et al.*, 2007b); determination of the supply chain relationship index (Thakkar *et al.*, 2008); selection of contractor (Darvish *et al.*, 2009); modelling and measurement of supply chain vulnerability (Wagner and Neshat, 2010); quantification of the performance index as well as understanding of the complex relationships among relevant cold chain attributes (Joshi *et al.*, 2012). Apart from the applications, the GTA has been used in total quality management (Franceschini *et al.*, 2006), total productive maintenance (Attri *et al.*, 2014), machining (Jangra *et al.*, 2011), remanufacturing (Sabharwal and Garg, 2013), process routing (Kato, 1995) and robotics (Rao and Padmanabhan, 2006).

The procedural steps to be followed are detailed below:

Step 1 Identify the Environmental Sustainability Measures (ESMs) and classify them in to Significant Categories (SCs).

Step 2 Develop a two-level graphical structure with SCs and their corresponding ESMs as nodes. Position the SCs at the top level and their corresponding ESMs at the bottom level and conceptually join the nodes with the ESMs.

Step 4 The edges joining two nodes of the graph (unidirectional/ bidirectional) represent the interdependency between the SCs at the top level and between the ESMs of each SC at the bottom level.

Step 5 Assign a weight b_{ij} (see Table 5.2) for the all directed ESMs between the graph nodes to quantify the level of interdependency between members at the same level.

Table 5.2: Scale to quantify the interdependency level

Qualitative measure of interdependency	Quantified value
Very strong	5
Strong	4
Medium	3
Weak	2
Very Weak	1

Step 6 Collect the performances of ESMs qualitatively and accordingly quantify them on a scale 1-9 (see Table 5.3). A high value of 9 indicates extremely high performance along the performance index, while 1 indicates extremely poor performance.

Step 7 Develop a Variable Permanent Matrix (VPM) of each SC in which all diagonal terms represent the performances of corresponding ESMs under the SC and non-diagonal terms represent the extent to which each ESE positively influences other ESE.

Step 8 Develop a VPM in which all the diagonal terms are filled with the permanent values of VPMs of SCs. The non-diagonal elements of VPM are filled by the interdependencies between the SCs. Then, calculate the permanent value of

VPM. The aforesaid permanent value is nothing but a function of a matrix similar to that of a determinant. The permanent equation says Per(B) for any 4*4 matrix is defined mathematically as mentioned below:

$$\begin{aligned} Per(B) = {} & B^1B^2B^3B^4 + b_{12}b_{21}B^3B^4 + b_{13}b_{31}B^2B^4 + b_{14}b_{41}B^2B^3 + b_{23}b_{32}B^1B^4 \\ & + b_{24}b_{42}B^1B^3 + b_{23}b_{32}B^1B^4 + b_{34}b_{43}B^1B^2 + b_{12}b_{23}b_{31}B^4 \\ & + b_{21}b_{32}b_{13}B^4 + b_{12}b_{24}b_{41}B^3 + b_{21}b_{42}b_{14}B^3 + b_{13}b_{34}b_{14}B^2 \\ & + b_{41}b_{43}b_{31}B^2 + b_{23}b_{34}b_{42}B^1 + b_{32}b_{43}b_{24}B^1 + b_{12}b_{21}b_{34}b_{43} \\ & + b_{13}b_{31}b_{24}b_{42} + b_{14}b_{41}b_{23}b_{32} + b_{12}b_{23}b_{34}b_{41} + b_{14}b_{43}b_{32}b_{21} \\ & + b_{13}b_{34}b_{42}b_{21} + b_{12}b_{24}b_{31} + b_{14}b_{42}b_{23}b_{31} + b_{13}b_{32}b_{24}b_{41} \end{aligned}$$

The matrix is defined as $B = \begin{pmatrix} B^1 & b_{12} & b_{13} & b_{14} \\ b_{21} & B^2 & b_{23} & b_{24} \\ b_{31} & b_{32} & B^3 & b_{34} \\ b_{41} & b_{42} & b_{43} & B^4 \end{pmatrix}$

Step 9 The permanent value of VPM for environmental sustainability calculated in the previous step is expressed as environmental sustainability implementation performance index (ESIPI). Generally this value would be quite high therefore, $\log_{10}$(ESIPI) is used to reduce the ESIPI into a smaller number called the crisp value of the ESIPI.

Step 10 Calculate the crisp values of ESIPI for different case situations.

Step 11 Compare the crisp values of ESIPI across different periods to establish a relationship between company's performances along the timeline.

Step 12 Plot a graph with timeline on X-axis and crisp values of ESIPI on Y-axis to visualize the implementation performance of environmental sustainability program.

5.4.1 Application of the Proposed Methodology

A case study conducted in an Indian steel manufacturing company 'I' is discussed to demonstrate the utility of the proposed approach (the name 'I' is used to preserve the confidentiality of the said company) for measuring the environmental sustainability. It is an integrated steel plant having capacity of over 5 million tones and produces wide range of steel products primarily used in construction and heavy engineering industries. It is a multi-national company having world's largest coal based sponge iron plant, operating with in-house technology and two blast furnaces. The company is equally concerned about environment and has taken considerable steps along many dimensions to limit environment deterioration. The company makes an optimal use of the high calorific gases emitting out of the blast furnaces and coke oven. These gases are burnt down in reheating chambers for heating the raw material during rolling activity. Water recycling and minimal wastage of electricity are few of the production laws strictly followed in the production activity. One million trees planted around plant premise is one of the few notable steps that company has taken towards conserving the nature. The environmental department works as an autonomous body and maintains regular check on the carbon emission from the chimneys and takes corrective measures. The company has established itself as an environmental conscious organization continuously involved in improving the greenness of its supply chain and has received many environmental certificates and approvals from the government.

A detail discussion was carried out with the senior engineers and managers in order to find the relevant environmental sustainability Measures for the environmental sustainability program in the company 'I'. It was decided that the twelve Measures shown in Table 5.1 are relevant and were further classified into four significant categories as mentioned in Table 5.1. In order to assess the degree of improvement in environmental sustainability program, it was decided to take the judgments from team consisting of six experts to evaluate the environmental sustainability program. A two-level graph structure (see Figure 5.1) was developed keeping four SCs at the top level and taking their corresponding environmental sustainability Measures at the bottom level. The degree of interdependency was taken on a scale of 1 to 5 (between the SCs at top level and between the environmental sustainability Measures of each SC at bottom level) through collective judgments of six experts. Higher the value indicates higher the degree of interdependency (see Table 5.2). Figure 5.2 shows the interdependency that exists between SCs whereas Figure 5.3 shows the interdependency that exists between environmental sustainability Measures for the significant category 'SLM'. Similarly, the interdependency level of environmental sustainability Measures for other SCs was obtained. A scale of 1 to 9 as shown in Table 5.3 was used to evaluate the performance of environmental sustainability Measures along the timeline (i.e. two years before, present period and two years down the line). The diagonal elements of Table 5.4 show the performances of environmental sustainability Measures for the year 2015 and non-diagonal elements indicate the interdependency level of environmental sustainability Measures for significant category 'SLM'. Then the problem was further solved through a highly user-friendly software (i.e. executing the graph theory approach) developed in C# language with the help of Microsoft Visual Studio Integrated Development Environment on the basis of algorithm mentioned in previous section (i.e. section 3). The Permanent Value (PV) of Variable Permanent Matrix (VPM) of each SC was calculated, Table 5.5 shows the PVs of the SCs for the second quarter in the year 2015. Then the PV for environmental sustainability program (i.e. ESIPI: Environmental Sustainability Implementation Performance Index) was calculated. This process was adopted along the timeline and

Table 5.6 shows the PVs and their corresponding ESIPI. As the ESIPI values were quite high, they were converted into logarithmic scale (see Table 5.6). The ESIPIs along different case situations for the case company 'I' were calculated and shown in Table 5.7.

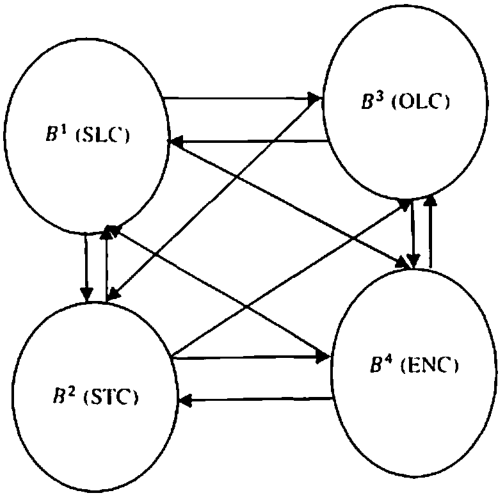

Figure 5.2: The interdependency levels between significant categories of ESMs

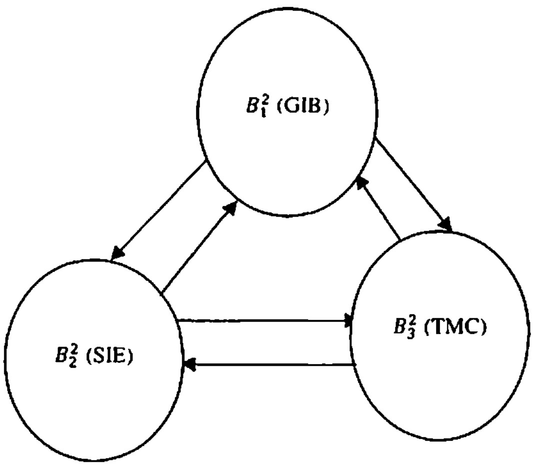

Figure 5.3: The interdependency levels of ESMs under the significant category 'SLC'

Table 5.3: Scale for obtaining degree of performance (Saaty, 1980 and Satty, 2000)

Intensity of importance	Definition and explanation
1	Extremely poor performance
2	Very poor performance
3	Poor performance
4	Marginally poor performance
5	Average performance
6	Marginally high performance
7	High performance
8	Very high performance
9	Extremely high performance

Table 5.4: Performance and interdependency levels of SC- 'SLC' in 2015

	GIB	SEP	TMC
GIB	5	4	5
SEP	5	7	2
TMC	4	5	7

Table 5.5: Permanent value of VPM of SCs and ESIPI in 2015

	SLC	STC	OLC	ENC	ESIPI	Log_{10}(ESIPI)
Permanent value	732	336	6774	66	110023073792.00	25.42

Table 5.6: PVs of SCs and ESIPIs along timeline

Year	PV of SLC	PV of STC	PV of OLC	PV of ENC	PV of ESIPI	Log_{10}(ESIPI)
2015	732	296	6326	50	68584869888.00	24.95
2016	732	336	6774	66	110023073792.00	25.42
2017	921	543	10431	73	380953493504.00	26.67

PV: Permanent Value; ESIPI: Environmental Sustainability Implementation Performance Index

Table 5.7: PVs of VPMs of SCs and ESIPIs along different case situations

Case situation	PV of SLC	PV of STC	PV of OLC	PV of ENC	PV of ESIPI	Log_{10}(ESIPI)
Practically Achievable (PA)	921	745	9444	73	473205932032	26.88
Theoretical Best (TB)	1336	910	13320	91	1473944354816	28.02
Practically Best (PB)	1036	821	10431	82	746683957248	27.34
Theoretical Worst (TW)	208	46	840	11	89730080	18.31
Ideal Worst (IW)	6	24	6	2	9835	9.19

PV: Permanent Value; ESIPI: Environmental Sustainability Implementation Performance Index

5.4.2 Different Situation Analysis

The degree of implementation and importance of various ESMs will result in different ESIPI. In order to calculate the range within which these values of ESIPI can vary, it is imperative to estimate the ESIPI for different situations (i.e. theoretically best, practically best, practically achievable, worst and ideal worst-case situation). One can find the similar approach used by researchers (i.e. Grover *et al.*, 2005 and Anand and Bahinipati, 2012).

5.4.3 Practically Achievable Case Situation

In this case, a brain storming session was carried to determine the performance that is feasible and achievable along different ESMs. The interdependencies along ESMs and Segment (i.e. feasible) in the context of present and in the near future were considered. The VPM for significant category and ESP are shown in Table 5.5 and Table 5.6 respectively. Finally, ESIPI for this case was calculated and converted into logarithmic scale (see Table 5.7).

5.4.4 Theoretically Best Case Situation

The hypothetical best-case or theoretical best-case situation was derived by having the maximum values for both performances and interdependencies in the ESP. Therefore, the diagonal elements of VPM of ESMs for the four significant categories would be 9 and other elements of VPM would be 5,4,2,1 for different combinations. The performance value of each significant category as calculated above was taken as diagonal elements of VPM and non-diagonal elements as 5, 4, 2, and 1 for different cases. Finally, ESIPI for this case was calculated and converted into logarithmic scale (see Table 5.7).

5.4.5 Practically Best Case Situation

In this case, it was assumed that the performance of all ESMs have reached to the highest level. Therefore, the diagonal elements of VPM of ESMs for the four significant categories would be 9. The other elements of VPM would be as previously found out by the experts' opinions. The performance value of each significant category as calculated from above will become the diagonal element of VPM and non-diagonal elements will be as previously found out by the experts' opinions. Finally, ESIPI for this case was calculated and converted into logarithmic scale (see Table 5.7).

5.4.6 Worst Case Situation

In this case, it was assumed that the performance and dependency level of all ESMs is at minimum. Therefore, the diagonal elements of VPM of ESMs for the four SCs would be 1 and the other elements of VPM will be as previously found out by the expert's opinions. The performance value of each significant category as calculated from above will become the diagonal element of VPM and non-diagonal elements will be as previously found out by the expert's opinion. The finally ESIPI for this case is calculated and converted into logarithmic scale (see Table 5.7).

5.4.7 Ideal Worst Case Situation

The hypothetical worst-case or theoretical worst-case situation can be derived by having the minimum values for both performances and interdependencies in the ESP. Therefore, the diagonal elements of VPM of ESMs for the four significant categories would be 1 and other elements of VPM would be 1. The performance value of each significant category as calculated from above will become the diagonal element of VPM and non-diagonal element will be 1. Finally, ESIPI for this case is calculated and converted into logarithmic scale (see Table 5.7).

In demonstrating the above mentioned process along different case situations, the obtained sets of intermediary data are tabulated for a better comprehension. Table 5.4 shows the performance levels and the interdependency levels of ESMs under 'SLM' in the present situation. Table 5.5 shows the VPM for the current situation. The permanent of this VPM for ESP gives ESIPI for the Current case situation (which can also be confirmed from Table 5.7). The obtained permanent values across the SCs and the ESIPIs along various case situations are summarized in the Table 5.7. Finally, for better visualization a graphical plot was generated (see Figure 5.4) on the basis of obtained data along various case situations. It shows the green supply chain implementation performance of the case company 'I' with its supplier 'A' along the timeline. This plot helps the company to understand its implementation performance dynamics over a period of time, perceive the target it has to achieve and take necessary actions if there is any decrement in the ESIPI.

5.5 Results and Discussion

The following are the key findings obtained by applying the proposed methodology to the case company '*I*' (i.e. Indian steel Industry). The results indicate that the environmental sustainability performance of the case company 'I' has increased during last two years due to the implementation of environmental sustainability program. It was also observed that there was a steady increase in the performance along all the four significant categories. This concludes that the performance of all the significant categories have increased in the implementation of environmental sustainability program (see Table 5.6). The Log10 (ESIPI) value is 25.42 in 2015 and it can be achieved to 26.67 by 2017. The performance for practically achievable, practically best and theoretical best case situation for case company 'I' are calculated as 26.88, 27.34 and 28.02 respectively. This indicates that the scope of improvement still exists even after 2017 and the environmental sustainability performance of the case company 'I' can be further enhanced.

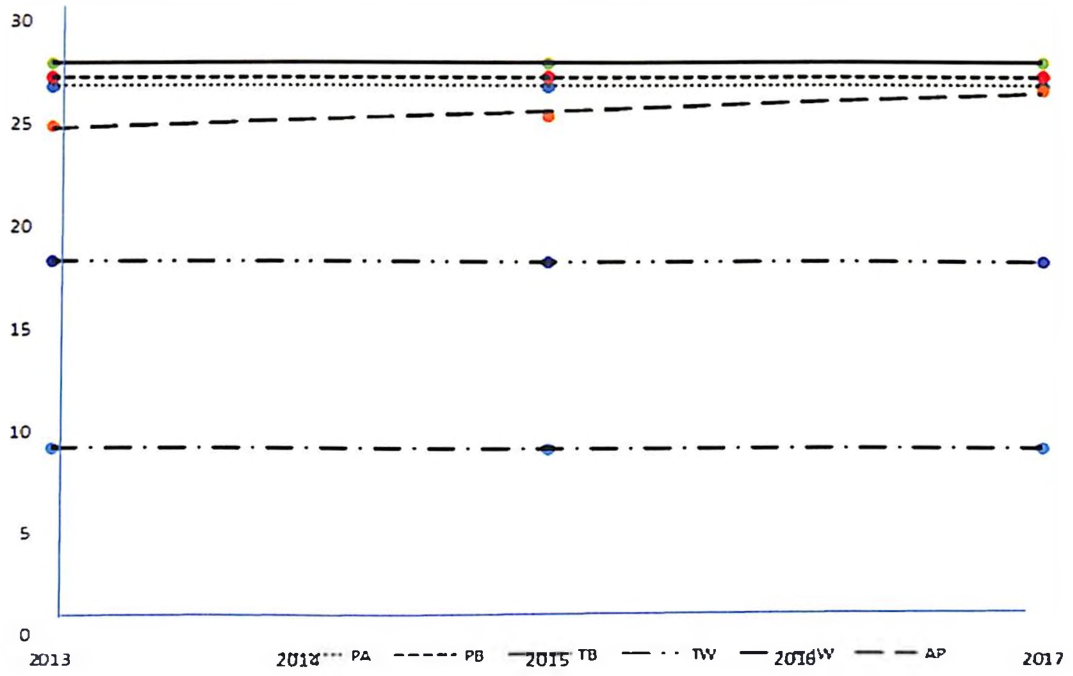

Figure 5.4: Environmental sustainability performance of case company along different case situations

The environmental sustainability program should be continued till it attains the performance level of practically achievable case situation. Thus, with these case situations, the case company 'I' was able to access the present and achievable environmental sustainability performance. Also it had got a direction to develop strategy(s) to mitigate the performance gap. The case company 'I' should put effort and resource to achieve the performance of practically best case situation. While achieving this value, the company should estimate and analyze the level of efforts and resource requirement. The case company may consider environmental sustainability performance of practically best case situation as a benchmarked value. The case company 'I' should put effort and resource to achieve this target once performance of practically achievable t case situation is achieved. The case company 'I' should evaluate the performance and fix or revise the target (if needed) along the timeline. The measurement of environmental sustainability performance at time interval will help managers to track and monitor its performance which in turn will trigger for corrective actions on real time basis.

5.6 Conclusions and Future Research

A simple and structured methodology using GTA is proposed to measure the environmental sustainability in supply chain for steel industry in general and Indian steel industry in specific. It is essential to rightly direct their efforts and resources for enhancing environmental sustainability performance. The proposed methodology was applied in an Indian steel industry for measuring environmental sustainability along different timeline in order to explain the salient features of the proposed approach. This work will fill the gap that exists in the area of environmental sustainability evaluation in steel supply chain. It was concluded from the obtained results that the environmental sustainability performance of the case company 'I' is improving along the timeline but there is scope for improvement. The various managerial implications that a company can achieve through the proposed approach was explained in specific to the case company and as well as in general. However, the numerical results obtained are completely in specific to the case company and so they obtained cannot be generalized for other companies. On the basis of ESIPIs across various situations and by developing a typical graphical layout as shown in the Figure 5.4, the manufacturing companies can make effective discretion in managing its environmental sustainability program.

CHAPTER - 6

Comparative Analysis of Environment Losses in Steel Manufacturing Supply Chain using Taguchi Loss Function and Design of Experiments

6 Sectional Abstract

In India, the performance of steel manufacturing supply chain in terms of environment losses need to be assessed in comparison to their peers. This helps the decision makers such as Government to provide significant incentives to motivate the efforts for their enhanced environmental sustainability performance along environmental loss factors. This objective of this chapter is to compare and evaluate the environmental performance of steel supply chains considering relevant environmental loss factors using Taguchi Loss Function and Design of Experiments. The different environment loss factors in steel manufacturing supply chain were studied and the significant factors were identified. Their combined contributions along the significant factors were estimated using Taguchi Loss Function and Design of Experiments comparing environment losses at different scenarios. The proposed methodology using Taguchi Loss Function and Design of Experiments was applied to three Indian steel manufacturing companies (Company A, Company B and Company C). The Company A with minimal average environmental loss score is found to be operating its supply chain with higher efficiency and has better environmental performance compared to the other two companies (B and C). The results obtained are based on the study carried out in three Indian steel manufacturing companies. Therefore, the results cannot be generalized. The work carried out will definitely show the direction for

comparative environmental performance assessment of manufacturing industries in general and steel industries in specific considering environmental loss factors and environmental conditions. It determines individual performance across each environmental loss factor and their combined impact. Although there is a need to have comparative performance analysis with respect to environmental losses among steel companies in developing countries such as India, but hardly any study has been reported in this direction. This work will definitely add the value to supply chain literature in general and environment losses in steel manufacturing supply chain in specific.

6.1 Introduction

The world's steel production capacity was found to be around 1.69 billion tons in 2017 (World Steel Association, 2018) and is also projected to increase to 2.8 billion tons by 2050 (Boston Consulting Group, 2015). In last two decades, China witnessed the rapid growth in industrialization driven by rapid growth in steel manufacturing which now accounts to 49% of world capacity (World Steel Association, 2018). Similarly, the growth in India is expected to follow the same demand pattern and the increase in per capita steel consumption is inevitable. Although steel is undoubtedly a significant driver of the economy, however at the same time, it carries with it the most undesired output 'the environmental hazards'. As per International Energy Agency (IEA), the world steel industry accounts for approximately 5% of total man-made greenhouse gases. For steel industry, the average CO_2 intensity is 1.8 tons of CO_2 per ton of steel whereas the average energy intensity is approximately 20 GJ per ton of crude steel (World Steel Association, 2014). Over the past decades, with increasing steel manufacturing, the huge amount of by-products (slags) generated need to be reused in an efficient way not only to reduce landfill slag sites but also for sustainable and eco-friendly agriculture (Gwon et al., 2018). China has taken measures to improve its steel industries' environmental sustainability performances in recent years as they are energy-intensive and high pollution industries in the country (Shen *et al.*, 2019).

Yet, one cannot imagine a life without steel due to its versatility of usability. Goyal *et al* (2019) analyzed the Environmental Sustainability Enablers (ESEs) for an Indian steel manufacturing company using fuzzy Decision-Making Trail and Evaluation Laboratory and found ESEs (i.e. competitors' environmental sustainability strategy, environmental compliance certification, government regulations and incentives, influence of external factors and air pollution controlling system) are the most prominent in the cause group for implementing and enhancing environmental sustainability. So, every attempt should be made to make the industry more and more sustainable and environmental friendly. In India, steel is primarily produced through Blast Furnace route in integrated steel plant system. Different companies operate their processes with different approach and also the technology implemented varies. Consequent to this variation, the environmental impact across the supply chain of different companies varies. A comparative study of environmental losses among various steel companies will help the industry to establish the benchmark level and put effort to reduce the existing gap. In the process, the environmental losses can be reduced. Therefore, environment loss analysis across steel supply chain is important in order to achieve desired level of sustainability (i.e. derived from the benchmarked level). However, no comparative study towards environmental losses in steel supply chain in developing nations such as India is available. To address the above mentioned issue, a methodology was proposed using Taguchi Loss Function and Design of Experiments to evaluate and compare the environment loss in steel supply chains. This will provide a platform to know the standings of each one steel manufacturing supply chain in comparison to its competitor. The remainder of the

Chapter is as follows. Section 6.2 presents the literature review on environmental loss factors related to steel manufacturing supply chain in general. Section 6.3 deals with the proposed methodology for analysing environmental loss factors and the application of it in Indian steel supply chains was discussed in Section 6.4. Section 6.5 includes the results and discussions whereas Section 6.6 highlights the conclusions drawn from the interpretation of the results.

6.2 Literature Review on Environmental Loss Factors

Steel making is energy intensity industry. Involves multiple processes and consumes enormous energy at every stage of the manufacturing process. Among the different methodology of steel making, the specific energy consumption of making of crude steel from blast furnace route is approximately 2.6 times higher than the electric arc furnace route (Sakamoto *et al.*, 1999). However, most of the steel manufacturing plant in India is from blast furnace route. The steel making using blast furnace process generates various greenhouse gases in addition to slag, sludge, ash etc. that have negative impacts on environment as it contaminates directly or indirectly water, air and soil. At the same time, various losses occurred from different processes which can be minimized or avoided to have better business sustainability. The significant environmental loss factors were captured (see Table 6.1) and discussed below:

Energy losses: Paramount concern is to reduce the energy loss in steel making and its management will make industry more competitive and environmental efficiency (Worrell *et al.*, 1997). The heat losses in steel making are considerable high (i.e. 36% of the total energy input) and some heat losses are recoverable like in the furnace and the crucible and mould (Mohsen and Akash, 1998). Overall exergy losses for steel plants with smelting reduction depend heavily on the hot metal charge in the steelmaking step (Costa *et al.*, 2001). Using Direct Reduced Iron (DRI) in the blast furnace route not only lowers the energy use in the system, but also the most efficient way of reducing the CO_2 emission from the system (Larsson and Dahl, 2003). Results from Blast Furnace-Basic Oxygen Furnace (BF–BOF) route of steel making indicate that the corrections for hot metal ratios and quality of raw materials have large effects on the apparent specific energy consumption (Oda *et al.*, 2012). It is required to derive the statistical information of energy use in the industry which includes the need for more detailed energy consumption information for the different processes (Worrell *et al.*, 2001). Energy conservation technologies like coke dry quenching, exhaust gas heat recovery equipment considerably reduces the energy intensity and CO_2 intensity. In the near future, the energy efficiency improvements depend upon the reduction of CO_2 and energy intensity (Chen *et al.*, 2014).

Electricity losses: Most of the integrated steel plants in India have captive power plant to suffice its non-interrupt electric supply. Similarly, these plants have more than one rolling mill to cater their product mix. During rolling, at the time of raw material breakdown into finish good heavy load is felt than the non-breakdown period. If the rolling pattern in different mills is not synced properly, then there will be extreme grid load at times and low grid load at times. During the low grid load, the excess load has to be shed to open grid thereby electric wastage is evident. This can be considerable reduced with proper loading through calculated rolling pattern at different mills such that the load is shared uniformly. Not much research is available on effect of variation of grid loading due to rolling.

Table 6.1: Various environmental losses in steel supply chain

Environment Loss Factors	**Citation**
Energy Loss	Worrell *et al.*, 1997; Mohsen and Akash 1998; Costa *et al.*, 2001; Worrell *et al.*, 2001; Larsson and Dahl 2003; Oda *et al.*, 2012 and Chen *et al.*, 2014.
Electricity loss	Discussion held with experts during industrial visits.
By-product gases	Anderson and Fisher 2002; Kim *et al.*, 2002; Chunbao and Cang 2010; Kong *et al.*, 2010; Zhang *et al.*, 2011; and Zhao *et al.*, 2015.
By-product ash	Cheng 2003; Dermatas and Meng 2003; Ilic *et al.*, 2003; Cho *et al.*, 2005 and Yao *et al.*, 2015.
By-product slag	Escalante *et al.*, 2001; Motz and Geiseler 2001; Shi 2002; Feng *et al.*, 2004; Shi 2004; Chen *et al.*, 2007; Kourounis *et al.*, 2007; Tsakiridis *et al.*, 2008; Jiang *et al.*, 2018; Guo *et al.*, 2018; Gwon *et al.*, 2018 and Reddy *et al.*, 2019.
Water contamination	Sengupta *et al.*, 2005; Mortier *et al.*, 2008; Gao *et al.*, 2011; Gu *et al.*, 2015 and Sun *et al.*, 2019.
Water recycle and reuse	Anderson 2003; Das *et al.*, 2007; Yellishetty *et al.*, 2011; Gu *et al.*, 2015 and Sun *et al.*, 2019.
Soil contamination	Nriagu and Pacyna 1988; Khan *et al.*, 2000; Pandey *et al.*, 2004; Dash *et al.*, 2009; Laghlimi *et al.*, 2015; Pandey *et al.*, 2016 and Chakraborty *et al.*, 2017.
By-product waste in form of metals and minerals	Szekely, 1996; Zunkel, 1997; Yadav *et al.*, 2001; Colombo *et al.*, 2003; Das *et al.*, 2007; Freitas, 2008 and Zhu *et al.*, 2019.
Air contamination	Somers *et al.*, 2002; Yang *et al.*, 2002; Jerrett *et al.*, 2004; Liberti *et al.*, 2006; Tsai *et al.*, 2007; *Zhang et al.*, 2014; Azimifard *et al.*, 2018; and Chisalita *et al.*, 2019.

Electricity losses: Most of the integrated steel plants in India have captive power plant to suffice its non-interrupt electric supply. Similarly, these plants have more than one rolling mill to cater their product mix. During rolling, at the time of raw material breakdown into finish good heavy load is felt than the non-breakdown period. If the rolling pattern in different mills is not synced properly, then there will be extreme grid load at times and low grid load at times. During the low grid load, the excess load has to be shed to open grid thereby electric wastage is evident. This can be considerable reduced with proper loading through calculated rolling pattern at different mills such that the load is shared uniformly. Not much research is available on effect of variation of grid loading due to rolling

By-product gases: In the process of steel making various gases are emitted from each process which acts as a by-product for other industry. In an integrated steel, the by-product gases are generated which carry approximately 30% of the total energy involved in steel making. The efficient utilization of these gases can save a good amount of energy and considerably reduce CO_2 (Zhao *et al.*, 2015). Steel industries are big source of dioxins and their controlled emission should be monitored correctly (Anderson and Fisher 2002). Multi-period optimization approach is used for an optimal distribution of by-product gases and to prevent unfavourable by-product gas emission (Kim *et al.*, 2002). Short term approach (like top pressure recovery turbine and coke dry quenching) and long-term approach (like developing CO_2 breakthrough technology and increasing the percentage utilization of renewable energy) have the ability to achieve a significant reduction in CO_2 emissions from the steel producing industry (Chunbao and Cang 2010). To achieve significant reduction in environmental loss, the by-product gas optimization is necessary (Kong *et al.*, 2010). Maintaining the balance of by-product gases is an important task for optimal scheduling of by-product energy (Zhang *et al.*, 2011).

By-product ash: High amount of coal burning is involved in steel making thus producing high amount of ash and dust. In India approximately 160 million tonnes of fly ash is presently generated annually with a utilization rate of approximately 60% (Yao *et al.*, 2015). The remaining 40% is disposed as waste in landfills. More aggressive efforts have been undertaken recently to recycle fly ash (Ilic *et al.*, 2003). For example, about 20% of the fly ash generated is being used in concrete production. Other uses include road base construction, soil amendment, zeolite synthesis and as filler in polymers (Cho *et al.*, 2005). Fly ash is also widely used in brick making. Similarly, in stainless steel making dust contains good amount of heavy metals such as Ni and Cr. Thermal molten technology is used to form glass-ceramics by combination of incineration fly ash and dust with the ratio of 9:1 (Cheng, 2003). Fly ash can also be used along with quicklime to immobilize lead, hexavalent and trivalent chromium which are present in artificial contaminated clay sand soils (Dermatas and Meng, 2003). However, despite its widespread usage, the fly ash is observed not be completely consumed which has a negative impact on environment.

By-product slag: The production of the pig iron has increased progressively in the recent years. Approximately 300 kg of slag is generated per ton of iron and has been widely used as a successful replacement material for Portland cement (Escalante *et al.*, 2001). Ladle slag is a by-product from further refining of the molten steel after coming out of a Basic Oxygen Furnace (BOF) or an Electric Arc Furnace (EAF). The chemical composition of ladle slag is significantly different from that of steel furnace slag in that the former has a very low FeO content, a higher Al_2O_3 content (Shi, 2002). Blast furnace and steel slags can be used for civil engineering purpose, metallurgical purpose and as fertilisers (Motz and Geiseler, 2001 and Jiang *et al.*, 2018). Recovery of metals from the slags and its utilisation are important not only for environment, but also for protecting the metal resources (Shen and Forssberg, 2003). The utilization rate of steel slag is 98.4% in Japan, 87.0% in Europe and 84.4% in the United States (Guo *et al.*, 2018). Metallurgical by-product furnace slags were also used as sorbents for metal ions (Feng *et al.*, 2004). The use of steel slag as one of the cementing component should be given priority according to technical, economic and environmental considerations (Shi, 2004).

The researchers have investigated the properties and hydration of blended cements which is made up of steel slag and found that he slag cements demand lesser water than the pure cement (Kourounis *et al.*, 2007). Ground Granulated Blast Furnace Slag (GGBFS) and steelmaking slag have been used as a raw material for cement production which also contains aluminum, calcium, iron, and silicon oxides. The properties of concrete are influenced by reactivity, availability and suitability of the slag (Chen *et al.*, 2007). The research work investigates that steel slag can be used as raw material for the production of cement clinker in Portland (Tsakiridis *et al.*, 2008). Thus with such wide spread usage of slag, it would be huge loss if the slags are not utilized. The issues of supplier development for usage of slag, deep localization and rural employability with context of value added products from slag should be explored in Indian context.

***Water contamination*:** The iron and steel industry requires significant amount of water and can directly affect local water bodies in absence of wastewater disposal system. Majority of water in steel plant are used in cooling and cleaning. Different processes use water input and the waste water output as output. It has both quantity and quality losses (Gao *et al.*, 2011). This wastewater can contain a wide range of toxic pollutants, such as dissolved metals including Cd, petroleum-derived products, volatile phenol, arsenic, etc. (Mortier *et al.*, 2007). For example, in the continuous casting of steel slabs, water is used to cool the mould in the initial point of solidification, where it made direct contact with metal's newly solidified surface (Sengupta *et al.*, 2005) and gets contaminated. Thus steel industry has major impact on the local, regional and global water resources (Gu *et al.*, 2015). The water quality of discharged wastewater plays a more significant role in damaging the natural environment and comprehensive assessment of multi-pollutants in wastewater from both quality and quantity is still a gap (Sun *et al.*, 2019).

Water recycle and reuse: Enormous amount of water is consumed in Iron and Steel Industry. In 2004, the water consumption of the iron and steel industry in China was 4 × 10^9 m3, which accounted for 10% of the annual industrial water consumption (Gu *et al.*, 2015). Water reuse and recycle is required to maintain balance in nature and sustainability of human life on the earth. There is still much work to do to improve water recycling technology (Anderson, 2003). Reusing of resources either by the same production unit or by different industry are very essential for protecting the environment (Das *et al.*, 2007). Recycling will minimize ecological footprint (Yellishetty *et al.*, 2011).

Soil contamination: Coal mining activities, mine fires and windblown dust are the chief contributors of soil pollution (Pandey *et al.*, 2016). Various pollutants discharged untreated through air and water at the time of steel making causes soil contamination when it mixed with soil. Each year, millions of tonnes of 'new' trace metals are produced from the mines and subsequently redistributed in the biosphere. Many studies have been conducted worldwide focusing on the anthropogenic causations of toxic metal pollution in soils (Chakraborty *et al.*, 2017). Researchers (Laghlimi *et al.*, 2015) found heavy soil contamination near Zaida mine, Morroco. The greatly increased circulation of toxic metals through the soils, water and air and their inevitable transfer to the human food chain remains an important environmental issue (Nriagu and Pacyna, 1988). Bulk of cyanide occurrence in environment is mainly due to metal finishing and mining industries. It is widely discussed and examined due to its potential toxicity and environmental impact (Dash *et al.*, 2009). Sequential washing techniques using single or double agents like NaOH and HCL were applied on arsenic contaminated soils in an abandoned iron-ore mine area. Arsenic containing area pollutes natural water which is in contact with arsenic contaminated soil area (Pandey *et al.*, 2004). Phyto-remediation is a remediation strategy for improving the area of mining from contamination, which employs plants to remove non-volatile and immiscible soil contents by up taking these contaminations from soil through these fast growing plants (Khan *et al.*, 2000).

***By-product waste in the form of metal and minerals*:** The production of steel in integrated iron- and steel-making plants generates large quantities of solid waste materials such as blast furnace and steel furnace slags, electric arc furnace (EAF) dusts and various sludges (Szekely, 1996). It had been reported that a typical plant produces over 400 kg of solid waste per tonne of steel output (Yadav *et al.*, 2001). Dusts, scale and sludge produced by the steel industry can either be recycled back to the iron and steel process (blast furnace, basic oxygen furnace or electric arc furnace) or used externally as raw materials in other industries (known as industrial ecology) (Freitas *et al.*, 2008). Traditionally, the removal of metals from wastes has been carried out predominantly by acid leaching at low pH (1.5–2.0) and techniques have recently been developed to effect the removal of heavy metals such as Pb, Cd, Cr and Ni contained in EAF dusts (Zunkel, 1997). Verification is widely used and also safe process for treatment of hazardous wastes and converting it into leach resistant materials (Colombo *et al.*, 2003). Significant quantities of valuable materials and metals contain in sludge and slags are generated as by-product from steel industries. It is easily possible to recover some values by physical or chemical mineral processing techniques such as crushing, separation, flotation, magnet, grinding, classification, hydro-cyclone, leaching or roasting (Das *et al.*, 2007).

***Air contamination*:** Air contamination is due to the release of toxic gases and materials released into air during the processes of steel making. In manufacturing material deprivation and poor material conditions increase causes of air pollution (Jerrett *et al.*, 2004). A systematic investigation of solid and gaseous atmospheric emissions was conducted from some coke oven batteries of largest integrated steel manufacturing plant in Italy and it was found that the samples contain polycyclic aromatic hydrocarbons more than limiting values (Liberti *et al.*, 2006). In general, the main contribution of pollution is due to Sulphur which is due to coal, flux, heavy oil, and many recycled materials (Tsai *et al.*, 2007). The iron and steel industry is classified into three groups on the basis of auxiliary energy source i.e. first which uses coal as fuel, second which uses heavy oil as fuel and third which uses electric arc furnace. The pollution source profiles are obtained by average of their ratios of individual polycyclic aromatic hydrocarbon concentrations to the total concentration of polycyclic aromatic hydrocarbons (PAHs) (Yang *et al.*, 2002). Theoretically implementation of Energy Conservation Supply Curves (ECSC) concludes that there is potential to reduce 28% energy, 27% CO2eq emission, 3% of particulate matter, and 22% of SO_2 emission (Zhang *et al.*, 2014). Integrated steel production generates chemical pollution containing compounds that can induce genetic damage, elevate DNA mutation and risk of developing germline more frequently due to air contamination near the steel mills (Somers *et al.*, 2002).

Through literature review, it is evident that there are various wastages and losses those occur in the steel manufacturing supply chain which have negative impacts either directly or indirectly to the environment. Researchers have provided various feasible and possible solutions for utilizing the wastages to minimize losses and environmental hazards such as such as road construction, asphalt concrete, agricultural fertilizer, and soil improvement (Jiang *et al.*, 2018). Many companies have adopted various steps to utilize the wastages generating across the steel supply chain and Government has been active in creating a legislative and institutional framework to realize it (Guo *et al.*, 2018). However, no such literature is available and no study has been carried out to quantify the environmental losses in steel manufacturing supply chain.

6.3 Proposed Methodology for Analyzing Environmental Loss Factors

A comprehensive approach for evaluating and comparing the overall environmental performance of steel supply chain is not available. An effort has been made in the current work to evaluate the comparative environmental performance of the steel companies in India. This will definitely help to access the environmental performance of steel manufacturing companies operating under similar infrastructure and resources. At the top management level, the environmental performance evaluation will set the benchmark for the companies. At the same time, one can access individual factor performance in comparison to its peers and can put focus on these factors where the scores are less. Thus, it will help and direct the steel manufacturing company for further environmental performance improvement. This proposed method using Taguchi Loss Function (TLF) may be used as a guideline for the manufacturing organizations in general and steel manufacturing in specific to evaluate and compare their environmental performance with their peers for its assessment and enhancement. Therefore, the current work will add value to environmental supply chain literature in general and environmental steel supply chain performance literature in specific.

Taguchi Loss Function (TLF) is helpful in determining the composite score in the situation when various attributes tend to deviate from the nominal or desired value. These deviations are measure by quadratic loss function (Sharma and Kumar, 2015). TLF and Design of Experiments (DOEs) are helpful to measure supply chain service quality (Seth *et al.*, 2006). Many researchers had applied TLF, DOE and both in different areas to draw useful results and to evaluate supply chains (Ordoobadi 2009, Ordoobadi 2010, Sharma and Balan 2013, Sivakumar, 2015, Azadeh *et al.*, 2016; Rosyidi *et al.*, 2017, Luthra *et al.*, 2017 and Routroy *et al.*, 2018).

The proposed methodology can be broadly classified into four basic steps as mentioned below:

- Identification of environmental loss factors and TLF for them
- Evaluation of environmental loss score for each factor using appropriate TLF
- Calculation of total score using DOEs in different environmental conditions
- Rank the steel manufacturing supply chains considering aggregate average score

The details are discussed below:

***Identification of environmental loss factors and TLF for them*:**

In order to identify the environmental loss factors for steel manufacturing supply chain, one has to consider both primary data and secondary information. Then, the identified environmental loss factors should be categorized based on nature (i.e. "smaller the better" or "nominal the best" or "larger the better"). The target limit of environmental loss factor should also be fixed. The actual performance should be captured for each factor along different steel manufacturing supply chains.

***Evaluation of environmental loss scores for each factor using appropriate TLF*:**

Taguchi loss function for each environmental loss factor for measuring its score should be selected using the standard functions such as cubic ["Smaller the better" $L(y) = k_1 \times (y - T)^3$; "Larger the better" $L(y) = k_2 \times (T - y)^3$ and "Nominal the better" $L(y) = k_1 \times (|y - T|)^3 + k_2 \times (|T - y|)^3$ Where, L(y) = loss at the particular current value of the attribute; k_1 *and* k_2 are the constants; T= Target value of the attribute and y= current value of the attribute], exponential ["Smaller the better" $L(y) = exp[(k_1 \times y) - 1]$; "Larger the better" $L(y) = exp[(k_2 \times (T - y)) - 1]$ and "Nominal the better" $L(y) = exp[(k_1 \times y) - 1] + exp[(k_2 \times (T - y)) - 1]]$ and quadratic ["Smaller the better" $L(y) = k_1 \times (y - T)^2$; "Larger the better"

$L(y) = k_2 \times (T - y)^2$; "Nominal the better" $L(y) = k_1 \times (y - T)^2 + k_2 \times (T - y)^2$].

The value of $k_1$or $k_2$or $k_1$and k_2 should be calculated using appropriate function related to each environmental loss factor. The L (loss) score for every factor should be evaluated using particular y value from the specification limit by the expert's opinion. The L_{ij} is the loss score where 'i' denotes factor and j denotes the function.

***Calculation of total score using DOEs in different environment conditions*:**

The N= 1+ NV(L-1) has to be calculated according Design of Experiment, where N equal to number of experiments to be conducted, NV equals to number of factors, L equal to number of functions used. The loss scores are calculated for each steel manufacturing supply chain using the formula (i.e. $\sum_{i=1}^{n}\sum_{j=1}^{3} L_{ij}$ where j=1 represents cubic function, *j*=2 represents exponential function and *j*=3 represents quadratic function).

***Rank the steel manufacturing supply chains considering aggregate average loss score*:**

The aggregate average loss score should be calculated by summing the loss score for all experiments and dividing it with number of experiments. The ranking of steel manufacturing supply chain should be made on the basis of aggregate average loss score and also performance of each steel manufacturing supply chain can be accessed along each factor.

The step-by-step algorithm is mentioned in the section below:

Step 1: First step is to define the objective of the problem and select number of alternatives. For the current study, the objective of the problem is to compare and determine the environmental performance of steel manufacturing supply chain and three number of alternatives are taken.

Step 2: Choose the environmental loss attribute corresponding to alternatives.

Step 3: Establish the set of relevant environment loss for respective attributes in steel manufacturing supply chain in a specific environment. Categorize the given attributes based on their types of nature which are generally these three "smaller the better" or "nominal the best" or "larger the better". For example, air contamination comes in "smaller the better" category because reduction of air pollution leads to less environmental loss.

Step 4: Fix the target limit score of each attribute. Fix lower limit for larger the better category and set upper limit for smaller the better category whereas fix upper and lower limit both for nominal the better category. If the attribute falls in "nominal the best" category, three types of trends may be possible: If the attribute falls under nominal the best, three types of trends may be possible: First one is target value can be asymmetric w.r.t. upper and lower specified limits. Second one is Loss at both (lower and upper) the specification limits can be different. Third one is two halves on either side of the target may not follow same kind of functions.

Step 5: Select the Taguchi loss function for each attribute for measuring its environment loss score using the standard formulas as noted below. Although various types of functions exit but in the current study, three types of functions (i.e. cubic, exponential and quadratic) are considered.

***Cubic function*:**

- "Smaller the better" $L(y) = k_1 \times (y - T)^3$
- "Larger the better" $L(y) = k_2 \times (T - y)^3$
- "Nominal the better" $L(y) = k_1 \times (|y - T|)^3 + k_2 \times (|T - y|)^3$

***Exponential Function*:**

- "Smaller the better" $L(y) = exp[(k_1 \times y) - 1]$
- "Larger the better" $L(y) = exp[(k_2 \times (T - y)) - 1]$
- "Nominal the better"

$$L(y) = exp[(k_1 \times y) - 1] + exp[(k_2 \times (T - y)) - 1]$$

***Quadratic Function*:**

- "Smaller the better" $L(y) = k_1 \times (y - T)^2$
- "Larger the better" $L(y) = k_2 \times (T - y)^2$
- "Nominal the better" $L(y) = k_1 \times (y - T)^2 + k_2 \times (T - y)^2$

where, $L(y)$ = loss at the particular current value of the attribute; k_1 & k_2 are the constants; T = Target value of the attribute & y= current value of the attribute

Step 6: Calculate k_1 and/or k_2 using each of the functions for the attribute under consideration. To calculate k_1 and/or k_2, loss (L) and the lower and/or upper limit have to be defined. The loss is taken 10 if the attribute limits are taken in the scale of 1-10 or else loss is considered in rupees if the limit is taken in rupees. Loss depends on the upper and lower limit.

- For smaller the better and loss (L) as 10, in cubic function $k_1 = 10/y^3$ where y is the upper limit, if the function is exponential, use $k_1 = \ln(11)/y$ and if it is polynomial, $k_1 = 10/y^2$
- If the attribute falls under larger the better category, calculate k_2 instead of k_1. Use the three types of functions to calculate k_2 and L as 10. The lower limit decided by the expert's opinion.
- If the attribute falls under nominal the better, calculate k_2 and k_1. The lower and upper limit decided by the expert's opinion.

Use the given functions to calculate k_1 and k_2 considering certain loss at lower limit and certain at upper limit. For example, if any factor falls in the category of nominal the best and cubic function, then $k_1 = c_1/(U - T)^3$ and $k_2 = c_2/(T - L)^3$ where c_1 & c_2 are loss associated with U i.e. upper limit and L i.e. lower limit. For exponential function, $k_1 = \ln(1 + c_1)/(U - T)$ and $k_2 = \ln(1 + c_2)/(T - L)$

For quadratic function, $k_1 = c_1/(U - T)^2$ and $k_2 = c_2/(T - L)^2$

Step 7: Determine loss score L for each attribute using particular y value determined from the expert's opinion i.e. specification limit for the particular company. L_{ij} is the loss score, where 'i' denotes attribute number and j denotes function number.

Step 8: Calculate $N = 1 + NV(L-1)$ according Design of experiment, where N equal to number of experiments to be conducted, NV equal to number of attributes, L equal to number of functions used. For this particular case here NV equal to 13, L equal to 3, the orthogonal array constructed is given below.

Step 9: Compute the loss scores for the orthogonal array as mentioned below and calculate through this formula $\sum_{i=1}^{n}\sum_{j=1}^{3} L_{ij}$ where j=1 represent Cubic function, j=2 represent Exponential function and j=3 represent Quadratic function. Repeat the same for each alternative.

Step 10: Select and rank them according to their loss score and minimum loss score is better than among other.

6.4 Application of Proposed Methodology to Steel Manufacturing Supply Chain

With abundance of Iron ore and coal, India's steel sector is immune to any dependence on other country. The steel industry is truly global industry in India. As the industry is energy intensive, the steel manufactures have to play a significant role to reduce environment losses and achieve desired environmental sustainability. A big concern across world is to reduce environmental impact and remain competitive. Therefore, there is an ever increase demand to evaluate the environmental performance of the steel manufacturing supply chains. Therefore, there is a need to continuously measure the environmental performance of the supply chain and minimize environmental losses wherever possible. To study the environmental losses in Indian steel supply chain, the three prominent Indian steel companies; Company A, Company B and Company C (name of the companies are disguised for maintaining the confidentiality of data shared by them) were approached. All the three companies operate integrated steel plant and use BF route to manufacture crude steel. The brief profile of Company A, Company B and Company C those selected for the study are discussed below.

Company A is having an integrated steel plant of 6 million-ton capacity. The company shares a very good reputation in the industry and is actively involved in CSR activities. The company is professionally managed and have strong cliental base in automotive and infrastructure sector. Company B is having an integrated steel plant of 11 million tonnes capacity. The company is currently the fastest growing among its peers. It is highly professionally managed with strong presence in both domestic and export market. The company enjoys diversified product base. Company C is having an integrated steel plant with 4 million tonnes capacity. The company is highly concerned about environment and has distinction of planting one million trees around the plant premises as a step towards environment sustainability. The product portfolio is suitable for infrastructure and industrial development. The proposed methodology discussed in the Section 3 was used to analyze the environmental supply chain performance of these three steel manufacturing companies. The detail discussion regarding this is discussed in Section 4.1.

6.5 Results and Discussion

Industrial visits were made to these three companies (i.e. A, B and C) for understanding the various aspects of waste management in general and environmental loss factors in specific. The primary and secondary data were collected through formal and informal discussion with professionals of different departments such as environment, CSR, supply chain, production planning and control, quality and R&D of these companies to understand and evaluate the existing status of these companies with respect to waste management. The ten identified environmental loss factors mentioned in Section 2 were discussed. These factors were found to have significant environmental impact and were considered for the environmental performance analysis of these three companies. A total of 21 loss attributes related to ten identified environmental loss factors were discussed in the three companies as mentioned in Table 6.2.

However, 13 loss attributes out of the 21 identified loss attributes were finally selected for performance measurement and comparison after an extensive sessions of discussion with the experts. The expert panel comprises of officials from different functional departments to get the comprehensive opinion. These experts include environment department heads of Company A, B and C, production and quality heads of Company B and Company C, general manager (CSR) of Company A, head CSR of Company B and Company C, in charge of mining operation of Company B, head of mining of operating of Company A, general manager of waste water treatment plant of Company A and Y, and vice president of waste water treat plant of Company C. These loss attributes were categorized and tabulated in Table 6.3 in consultation with experts.

Table 6.2: Loss attributes for the environmental loss factors

Environment loss factors	Loss attributes
Energy loss	Sensible heat loss
	Energy loss due to steam
	Energy loss due to solid heated material(slag and ash)
	Energy losses due to flue gases
Electricity loss	Optimal loading of grid
By-product gases	Carbon monoxide gas losses
	Methane and hydrogen gas losses
	Rest of gas losses (Rests are less than 5%)
By-product ash	Under Utilization of ash
By-product slag	Under Utilization of slag
Water contamination	Nutrients and Organic Pollutants
	Metal emissions to water
Water recycle and reuse	Percentage water recycle and reuse
Soil contamination	Acids, organic and inorganic pollutants
By-product waste in form of metals and minerals	Percentage waste recovery
Air contamination	Greenhouse Gases (Equivalent CO_2)
	Acid Rain, Eutrophication and Smog Precursors (SO_2, NOx, NH_3 and CO)
	Dust and Particles
	Ozone Depleting Substances
	Volatile Organic Compounds
	Metal emissions to air

Table 6.3: Categorization of selected loss attributes according to Taguchi loss function

Environment loss factors	Loss attributes	Category (s,n,l)
Energy loss	Energy loss due to steam	smaller is better
	Energy loss due to solid heated material (slag and ash)	smaller is better
	Energy loss due to hot flue gas	smaller is better
Electricity loss	Minimal fluctuation on grid load	nominal is better
By-product gases	Methane and Hydrogen gas loss	smaller is better
By-product ash	Underutilization of ash	smaller is better
By-product slag	Underutilization of slag	smaller is better
Water contamination	Pollutants in water	smaller is better
Water recycle and reuse	Percentage of water recycle and reuse	larger is better
Soil contamination	Acids, organic and inorganic pollutants	smaller is better
By-product waste in form of metals and minerals	Percentage of waste recovery	larger is better
Air contamination	Greenhouse gases (equivalent CO_2)	smaller is better
	Dust and Particles	smaller is better

Then, a survey was conducted to rate these 13 loss attributes for all the three companies on the scale of 1-10 (1 indicates the best performance and 10 indicates the least performance). The performance rating obtained is tabulated in Table 6.4. The performance ratings of the three companies alongside each loss attributes were used to calculate the constants K_1 and K_2 for all the three functions i.e. cubic, exponential and quadratic. The values of constants K_1 and K_2 are calculated using step 5 of the algorithm and tabulated in Table 6.5. Then the environmental loss scores were calculated for Company A, Company B and Company C using the three functions viz. cubic, exponential and quadratic. The losses for each steel manufacturing supply chain are calculated and tabulated in Table 6.6, Table 6.7 and Table 6.8 for Company A, Company B and Company C respectively. As per step 8 of the algorithm, the number of experiments to be conducted is determined using formula N=1+ (NV (L-1). Here NV (number of loss attributes) is 13 and L (number of functions) is 3. The value of N calculates to 27. The orthogonal array constructed is given below in Table 6.9. Average score for three companies (i.e. Company A, Company B and Company C) along 27 experiments are 60.08, 72.2 and 71.48 respectively. Therefore, environmental performance of Company A is better in comparison to other.

Table 6.4: Performance ratings of three Indian steel manufacturers for each loss attribute

Loss attributes	Company A	Company B	Company C	Upper Limit	Lower limit	Target
Energy loss due to steam	7	5	6	8	--	0
Energy loss due to solid heated material (slag and ash)	7	5	5	8	--	0
Energy loss due to hot flue gas	4	3	3	8	--	0
Minimal fluctuation on grid load	6	7	7	8	3	5
Methane and Hydrogen gas loss	4	4	3	7	--	0
Underutilization of ash	3	3	9	--	2	0
Underutilization of slag	2	2	9	--	1	0
Pollutants in water	3	4	3	6		0
Percentage of water recycle and reuse	7	8	7	--	3	10
Acids, organic and inorganic pollutants	5	4	3	7	--	0
Percentage of waste recovery	5	4	4	7	--	0
Greenhouse gases (equivalent CO2)	4	4	3	6	--	0
Dust Particles	7	7	6	5	--	0

Table 6.5: Calculations of K_1 and K_2 for each loss attribute

Loss attributes	Cubic		Exponential		Quadratic	
	K1	K2	K1	K2	K1	K2
Energy loss due to steam	0.0195	NA	0.2997	NA	0.1562	NA
Energy loss due to solid heated material (slag and ash)	0.0195	NA	0.2997	NA	0.1562	NA
Energy loss due to hot flue gas	0.0195	NA	0.2997	NA	0.1562	NA
Minimal fluctuation on grid load	0.3703	1.25	0.7992	1.19894	1.1111	2.5
Methane and Hydrogen gas loss	0.0291	NA	0.3425	NA	0.2040	NA
Underutilization of ash	NA	1.25	NA	1.19894	NA	2.5
Underutilization of slag	NA	1.25	NA	1.19894	NA	2.5
Pollutants in water	0.0462	NA	0.3996	NA	0.2777	NA
Percentage of water recycle and reuse	NA	0.3703	NA	0.79929	NA	1.1111
Acids, organic and inorganic pollutants leaked into atmosphere	0.0291	NA	0.3425	NA	0.2040	NA
Percentage of waste recovery	0.0291	NA	0.3425	NA	0.2040	NA
Greenhouse gases (equivalent CO2)	0.0462	NA	0.3996	NA	0.2777	NA
Dust and Particles	0.08	NA	0.4795	NA	0.4	NA

Table 6.6: Loss scores of supply chain of company A

KPI	Score	Cubic	Exponential	Quadratic
Energy loss due to steam	7	6.6992	2.9986	7.6563
Energy loss due to solid heated material (slag & ash)	7	6.6992	2.9986	7.6563
Energy loss due to hot flue gas	4	1.2500	1.2201	2.5000
Minimal fluctuation on grid load	6	1.6204	44.6243	3.6111
Methane and Hydrogen gas loss	4	1.8659	1.4481	3.2653
Underutilization of ash	3	1.2500	1.2201	2.5000
Underutilization of slag	2	1.2500	1.2201	2.5000
Pollutants in water	3	1.2500	1.2201	2.5000
Percentage of water recycle and reuse	7	10.0000	4.0467	10.0000
Acids, organic and inorganic pollutants	5	3.6443	2.0397	5.1020
Percentage of waste recovery	5	3.6443	2.0397	5.1020
Greenhouse gases (equivalent CO2)	4	2.9630	1.8196	4.4444
Dust and particles	4	5.1200	2.5051	6.4000

Table 6.7: Loss scores of supply chain of company B

KPI	Score	Cubic	Exponential	Quadratic
Energy loss due to steam	5	2.4414	1.6466	3.9063
Energy loss due to solid heated material (slag and ash)	5	2.4414	1.6466	3.9063
Energy loss due to hot flue gas	3	0.5273	0.9041	1.4063
Minimal fluctuation on grid load	7	12.963	99.0304	14.4444
Methane and Hydrogen gas loss	4	1.8659	1.4481	3.2653
Underutilization of ash	3	1.2500	1.2201	2.5000
Underutilization of slag	2	1.2500	1.2201	2.5000
Pollutants in water	4	2.9630	1.8196	4.4444
Percentage of water recycle and reuse	8	2.9630	1.8196	4.4444
Acids, organic and inorganic pollutants	4	1.8659	1.4481	3.2653
Percentage of waste recovery	4	1.8659	1.4481	3.2653
Greenhouse gases (equivalent CO2)	4	2.9630	1.8196	4.4444
Dust and Particles	4	5.1200	2.5051	6.4000

Table 6.8: Loss scores of supply chain of company C

KPI	Score	Cubic	Exponential	Quadratic
Energy loss due to steam	6	4.2188	2.2220	5.6250
Energy loss due to solid heated material (slag and ash)	5	2.4414	1.6466	3.9063
Energy loss due to hot flue gas	3	0.5273	0.9041	1.4063
Minimal fluctuation on grid load	7	12.9630	99.0304	14.4444
Methane and Hydrogen gas loss	3	0.7872	1.0281	1.8367
Underutilization of ash	3	1.2500	1.2201	2.5000
Underutilization of slag	2	1.2500	1.2201	2.5000
Pollutants in water	3	1.2500	1.2201	2.5000
Percentage of water recycle and reuse	7	10.0000	4.0467	10.0000
Acids, organic and inorganic pollutants	3	0.7872	1.0281	1.8367
Percentage of waste recovery	4	1.8659	1.4481	3.2653
Greenhouse gases (equivalent CO2)	3	1.2500	1.2201	2.5000
Dust and Particles	3	2.1600	1.5507	3.6000

Table 6.9: Loss score for three companies and the average loss score for 27 experiments

Experiment No.	Loss Score of A	Loss Score of B	Loss Score of C	Average Score
1	47.2563	40.4797	40.7507	42.8289
2	33.8278	33.1213	34.1326	33.6939
3	58.0826	52.9024	50.6893	53.8914
4	83.1611	127.5853	124.7472	111.8312
5	89.7599	130.0138	128.8807	116.2182
6	87.0662	125.8523	128.8927	113.9371
7	48.7988	44.4911	45.8185	46.3695
8	55.1957	47.9882	48.8464	50.6768
9	47.7656	45.4997	42.3831	45.2161
10	42.3777	43.1558	38.3369	41.2901
11	46.1957	43.7770	42.9036	44.2921
12	45.3742	42.7608	43.9112	44.0154
13	41.1382	40.1116	40.8167	40.6888
14	41.7192	41.8013	43.2282	42.2496
15	37.8559	42.4581	35.7844	38.6995
16	88.2590	130.5645	129.8277	116.2171
17	82.6961	127.0898	123.6618	111.1492
18	88.9930	129.0613	128.6844	115.5796
19	90.9493	130.0412	131.2051	117.3985
20	94.4026	130.8412	132.6360	119.2933
21	89.4478	130.8545	126.7892	115.6972
22	49.4658	44.3633	46.4529	46.7606
23	41.4989	42.6680	40.2718	41.4796
24	45.9437	45.9265	45.1263	45.6655
25	45.3326	46.2065	41.5376	44.3589
26	48.6823	45.9380	47.0999	47.2401
27	50.8044	44.2782	46.6787	47.2538
Average score considering experiments	**60.08**	**72.2**	**71.48**	**67.93**

In the final step the loss score for the orthogonal array is calculated for each of the three alternatives. The total loss score for the three companies in 27 experiments along with the average loss is represented in Table 6.9. It is observed that along 14 experiments, the performance of Company A is better than Company B and Company C whereas Company A is better than Company C in all 27 experiments where it is true for 14 experiments in case of Company B. As the environmental performance of Company C is less in all the 27 experiments, it indicates that Company C should learn from Company A in order to enhance its environmental performance. Also loss score of Company A is also found to be less than the average loss score in most of the experiments (Figure 6.1).

Thus, the supply chain loss for each attribute is calculated for all the functions for these three companies and the total loss is found by summing all of these losses. The company having the least value of the total loss is the company having the highest level of supply chain efficiency and best environmental performance in steel manufacturing supply chain. In the current study, the Company A with minimal average loss score is found to be operating its supply chain with higher efficiency and has better environmental performance compared to the other two companies (B and C).

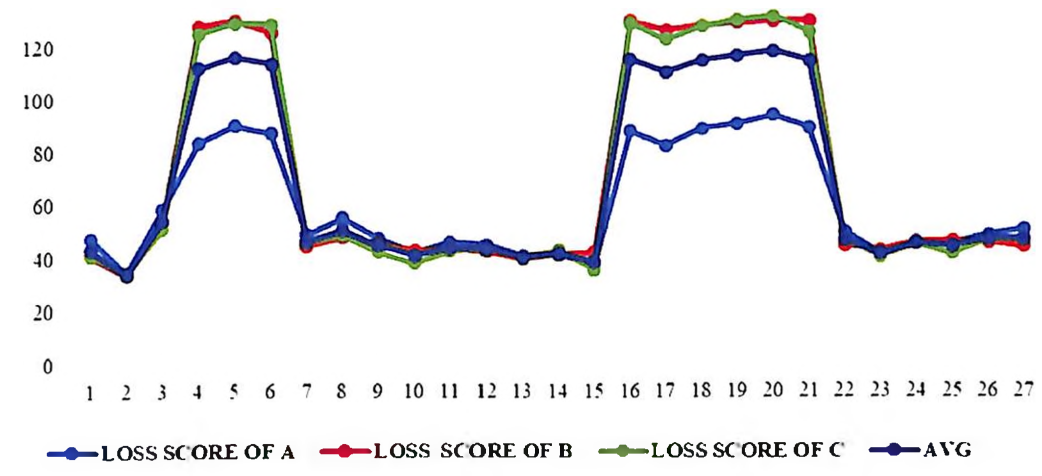

Figure 6.1: Loss score and the average loss score for 27 experiments

6.6 Practical Implications

The main contribution of the Chapter is to develop the quantitative model for accessing the performance of a supply chain on selected factors. In the case study, we had considered environment loss factors to evaluate environment performance of the steel manufacturing supply chain and compared the performance of the three leading steel companies. Through the loss score it can be identified that all the three companies score high on underutilization of slag and ash. Thus all the three companies are making best utilization of the ash and slag by-products. For each attribute, all the three companies have different score. All the three companies score least in an attribute 'Pollutants in Water'. Thus this could be considered as the major concern for all the companies as no one is able to control water pollution suitably. It is a major highlight that either a process improvement or the technology advancement is required to control water pollution. This study can be very helpful for top management to access their supply chain performance and identify the areas of improvement to remain competitive against their peers.

6.7 Conclusions

An extensive literature review was carried out to identify losses in the supply chain of steel industry. Précised set of supply chain losses predominant in Indian steel industry were identified from the literature. A model is proposed using Taugchi Loss Function and Design of Experiment to compare the performance of three different supply chains. In order to explain the salient features of the proposed model, a case situation of the supply chain of the three Indian steel manufacturing companies is determined. The necessary information was collected from the three reputed Indian steel companies for the purpose of comparison. Three functions were considered for making the process more error-proof. Using the proposed methodology, the loss scores and total loss were calculated and compared. It was observed that Company A has the minimum loss score in comparison to other two companies. Company B is moderately efficient while Company C is least efficient among the three as it has highest loss score. As all the three companies are integrated steel plants and operate under similar conditions, it can be concluded that Company C and Company B needs to improve and reduce its supply chain losses. The study presented a new and fresh approach for measuring losses and is more effective and has less calculation than existing conventional loss evaluation techniques. Most of the research available in the field of environment performance is of qualitative nature, while the present methodology allows us to quantify the performance measurement and compare these performances.

6.7.1 Future Scope of Research

The methodology has been adopted to evaluate and compare the environmental performance of Indian steel companies. It can be further extended for the environmental performance study of steel companies in other countries with similar operating process such as China. This can help in macro assessment of environmental supply chain including waste management in Indian steel companies and may be used to draw parallel comparison on environmental performance between the fastest growing developing nations. Similar study can be extended to developing nations that can help to set benchmark for the companies. The various stakeholders including government can use the proposed methodology to evaluate the environmental performance of steel companies and can encourage successful companies related to environmental performance in terms of various ways such as the awards and incentives.

The methodology is highly versatile as it permits the use of more than one functions thereby ensuring better and error prof outcome. The methodology can be adopted to compare various other concerns of the supply chain for example agility of supply chain, process efficiency of supply chain, financial efficiency of supply chain etc. A hybrid multi-criteria decision approach could also be developed by combining Taguchi Loss Function approach, Design of Experiments and multi-attribute decision making tool such as Analytic Hierarchy Process (AHP), fuzzy AHP, Analytic Network Process (ANP), fuzzy ANP etc. in order to combine the total loss score of different situations for developing aggregate average score. This aggregate average score may be used to rank the alternatives.

CHAPTER - 7

Thesis Conclusions

The research study was conducted in context to Indian steel industry and its supply chain with a focus of environmental sustainability. The research is useful to various stake holders of the steel supply chain in India including steel manufacturer, Government, research organizations and society as a whole as the current research can form the basis for taking Indian steel manufacturing companies towards environmental sustainability. The said aspects focused in the current research work are summarized as follows:

- From literature review, it is evident that all the three important natural elements: air, water and soil are found to be getting affected by the environmental impacts due to the various operations starting from mining to production and logistics across the steel supply chain in India. It was observed that the area of mining, by-products, waste management and value added products from waste are the research focus of steel supply chain in general and in India in specific. However, the broad consideration of environmental sustainability along the steel supply chain in India and its performance measurement are missing.
- A methodology using fuzzy DEMATEL was proposed and applied to Indian steel manufacturing company to analyze the identified relevant ESEs for successful implementation of environmental sustainability program in the Indian steel manufacturing company. The following relevant observations related to ESEs in the were made:

- ✓ Competitors Environmental Sustainability strategy (CES), Environmental Compliance Certification (ECC), Government Regulation & Incentives (GRI), Influence of External Environment (IEF) and Controlling Measures for Air Pollution (ACS) were most important ESEs as they were found to be as the prominent ESEs in cause group. The three enablers (CES, GRI and IEF) (from identified five ESEs) are beyond the control of the company and are exclusively controlled and determined by the external agencies. The steel company should keep a close eye on them and implement appropriate strategy(s) to satisfy the requirements of these three ESEs. However, the focus must be given on Environmental Compliance Certification (ECC) and Controlling Measures for Air Pollution (ACS) on priority basis. It should adopt right strategy and technology to excel in this direction in pushing the green initiatives.

- A structural framework of the Environmental Sustainability Enablers (ESEs) of steel supply chain in India was developed using ISM-MICMAC analysis method for the steel manufacturer in selectively exercising the ESEs for controlling, managing and enhancing environmental sustainability. The following observations related to structural framework of the ESEs in the were made:
  - ✓ Government Regulations and Incentives (GRI) and Environmental Compliance Certification (ECC) are the most important ESEs for achieving environmental sustainability in Indian steel industries. Government should take appropriate steps and provide platform for its successful implementation at the ground. Top Management Involvement (TMI) also plays critical role for its adoption and make the steel business sustainable both business and environment front. These three ESEs are just act as fuel to run the environmental sustainability vehicle on

track and also have the potential to bring substantial changes in the environment sustainability of India steel companies.

- ✓ Water Pollution Controlling System (WCS), Air Pollution Controlling System (ACS) and Soil Pollution Controlling System (SCS) are the output factors to the structural framework of the ESEs. The performance of these output factors should be evaluated on periodic basis by both internal committee and external agency(s) along the different relevant operations of the steel supply chain.
- ✓ The relay factors who are in linkage cluster such as Value Added Products from waste (VAP), Technology Adoption for Environmental Sustainability (TAS), R&D Program for Environmental Sustainability (RES), Environmental Sustainability Measures (ESM), Environmental Sustainability Practices (ESP) and Environmental Sustainability Culture (ESC)) should be closely looked into for their implementation as it controls the output factors and get influenced by input factors.

- A simple and structured methodology using Graph Theoretic Approach (GTA) is proposed to quantify, evaluate and compare their environmental sustainability performance in supply chain for steel industry in general and Indian steel industry in specific. The proposed model has the ability to capture the performance and interdependencies of SCs, ESMs under each SC and also to quantify the environmental sustainability performance along the timeline in different situations. Broadly twelve Environmental Sustainability Measures (ESMs) were identified and they were classified into four Significant Categories (SCs) (i.e. strategic level Measures, operational level Measures, stimulating Measures and external Measures). This study is an attempt to assist a Steel Industry to assess its sustainability program and accordingly define its course of actions.

- A methodology is proposed to compare and evaluate the environmental performance of steel supply chains considering relevant environmental loss factors using Taguchi Loss Function and Design of Experiments. The different environment loss factors in steel manufacturing supply chain were studied and the significant factors were identified. Their combined contributions along the significant factors were estimated using Taguchi Loss Function and Design of Experiments comparing environment losses at different scenarios. It determines individual performance across each environmental loss factor and their combined impacts.

Future Scope

It is pertinent to mention here that the steel supply chain of China and India is nearly same. The future research can develop the models to compare the two supply chain assess the environmental sustainability performance. Due to expected three-fold increase in production capacity in India in next 10 years, any major modification in the supply is unlikely to happen. The production will large be routed through BF-EAF process. The research and modelling should be conducted keeping in mind the present Indian steel supply chain. The Indian steel production enhancement or capacity addition is expected to continue for another 15-20 years. However subsequently after that the reverse supply chain will also become prominent due to abundant availability of scrap. In that scenario, the steel chain and the associated parameters will differ. This likely shift in the supply chain in the future will require conducting the fresh research and including the necessary changes in the supply chain. The supply chain then may be comparable to the existing steel supply chain of few of the developed countries. It would then provide the larger opportunity to compare the environmental sustainability performance with both the developing nations and the developed nations.

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- Shishir Goyal and Srikanta Routroy, (**2021**) "Structural Framework of Environmental Sustainability Enablers for Enhancing Environmental Sustainability of Indian Steel Supply Chain", *Journal of Engineering, Design and Technology*, https://doi.org/10.1108/JEDT-03-2021-0118 [**Scopus; ESCI: Emerging Sources Citation Index**]

- Shishir Goyal, Srikanta Routroy and Aman Agarwal (**2020**), "Comparative Analysis of Environment Losses in Steel Manufacturing Supply Chain using Taguchi Loss Function and Design of Experiments", *Journal of Enterprise Information Management*, Vol. 33 No. 3, pp. 684-700. [**Scopus; Social Sciences Citation Index; 2019 Impact Factor: 2.659**].

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Papers to be communicated

- Literature Review of Environmental Aspects of Steel Supply Chain.

Papers in international conferences

- Shishir Goyal, Srikanta Routroy and Anupam Singhal **(2019)**, "Analysis of Waste Management Enablers of Steel Supply Chain: An Interpretive Structural Modelling", *International Conference on Evidence Based Management*, 1st-2nd February, 2019, BITS-Pilani, Pilani Campus

- Sishir Goyal and Srikanta Routroy (**2015**), "Various aspects of green issues in Indian steel supply chain: An overview", First International Conference on Evidence Based Management 2015, 20th -21st March, BITS-Pilani, Pilani Campus, pp. 626-631.

Shishir Goyal received a Bachelor's of Engineering in Mechanical Engineering from Visvesvaraya Technological University, Belgaum. He completed Master of Engineering in Manufacturing Systems Engineering from BITS-Pilani, Pilani Campus. Currently, he is pursuing a Ph.D. in supply chain management (in the Mechanical Engineering Department) at BITS-Pilani, Pilani Campus. In addition to it, he is working in Jindal Steel & Power Ltd as a Regional Product Manager. He has a total experience of over 13 years in the steel industry. He has undertaken and successfully executed several professional research activities, mainly stock management, material flow management, cash flow analytics, product development and business analytics. His broad areas of research interest lie in supply chain management, product development, green supply chain management, product development in sync with respective industry usage and business analytics. He has the distinction of successfully establishing the strategic business partnership in key projects. He successfully formed the partnership in refineries, airports and key establishments like Central Vista, Pragati Maidan redevelopment project etc. He has contributed in establishing distributor-dealer network and the related policies in the company. With the existing research in the Ph.D., he aims to contribute to steel industry, its most vital need, to help it to turn green.

Brief biography of the Supervisor

Srikanta Routroy has received Bachelor of Technology in Mechanical Engineering from College of Engineering and Technology, Bhubaneswar and Master of Technology in Industrial Engineering and Management from IIT, Kharagpur. He has completed his Ph.D. in the area of Supply Chain Management from Birla Institute of Technology & Science (BITS), Pilani in April 2005. At present, he is working as Professor (Mechanical Engineering Department) and Associate Dean, Student Welfare Division in Birla Institute of Technology & Science Pilani, Pilani Campus. He has more than twenty years of teaching experience both in under graduate and post graduate level. He has authored and co-authored more than 150 research papers in refereed National and International Journals and National and International Conferences. He has also authored two case studies in the area of Supply Chain Management and are published in The Case Centre. He has completed research projects from UGC, DST Rajasthan and Department of Food & Public Distribution, New Delhi. Currently, he is working on three sponsored projects such as DBT India accompanied with SINTEF Norway, Ministry of Steel, India and DST Rajasthan. His broad areas of research interest lie in supply chain management, development of value added product from waste, supplier development, green supply chain management, surimi supply chain, agile manufacturing, evolutionary optimization techniques, Artificial Neural Network and Multi-Criteria Decision Making (MCDM) methods. He has guided 05 Ph.D. and currently 09 Ph.D. students are working with him. He has also guided 20 M.E. Theses and 24 B.E. (dual degree) Theses. He is Fellow member of Institute of Engineers (FIE) and Senior Member, Indian Institution of Industrial Engineering, Navy Mumbai.