AN ASSESSMENT OF CLIMATE CHANGE MITIGATION STRATEGIES OF THE INDIAN CEMENT INDUSTRY

Ph.D. THESIS

by

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ROORKEE

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in the thesis entitled **"AN ASSESSMENT OF CLIMATE CHANGE MITIGATION STRATEGIES OF THE INDIAN CEMENT INDUSTRY"** in partial fulfilment of the requirements for the award of the degree of Doctor of Philosophy and submitted in the Department of Mechanical and Industrial Engineering of the Indian Institute of Technology Roorkee, Roorkee is an authentic record of my own work carried out during a period from July, 2015 to June, 2019 under the supervision of Prof. Pramod Kumar Jain, Professor, Department of Mechanical and Industrial Engineering and Dr. Anbanandam Ramesh, Associate Professor, Department of Management Studies, Indian Institute of Technology Roorkee, Roorkee.

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

(SACHIN BALSARA)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

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The Ph.D. Viva-Voce Examination of Mr. Sachin Balsara, Research Scholar, has been held on 23-09-2019.

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This is to certify that the student as made all the correction in the thesis.

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Abstract

Cement is a fundamental requirement of modern society and the concrete, a cement-based product is the highest manufactured and second highest consumed product after water on earth, but across the world, the production of cement is the most energy and emission intensive industry. Globally, India is the second largest cement producer as well as the consumer. Presently, the cement industry of India is the third largest energy consumer and second largest greenhouse gases (GHGs) emitter. Continuous greenhouse gas (GHG) emissions are responsible for global warming and extreme climate change. Thus, the cement industry is currently under pressure to reduce GHG emissions (GHGEs). However, reducing the GHGEs of the cement industry especially for developing country like India is not an easy task. Cement manufacturing industry needs to focus on significant climate change mitigation strategies to reduce the GHGEs to sustain its production. Implementation of Climate change mitigation strategies in the industry leads to a reduction in emissions of GHGs, climate risks, pollutants and another negative impact on the environment. Thus, in order to implement climate change mitigation strategies in the cement industry, a careful analysis of barriers that hinder the emission reduction must be taken. However, most existing research on the barriers to mitigation measures is focused on developed countries. Among the most important emerging economies, India, the second largest producer and consumer of cement faces challenges to implement emission reduction measures. To bridge this gap, this research identifies and evaluates the barriers and solutions to overcome these barriers in the context of India. This objective of research employs a three-phase methodology based on fuzzy analytical hierarchy process (AHP) and fuzzy technique for order performance by similarity to ideal solution (TOPSIS) to identify barriers and solutions to overcome these barriers to climate change mitigation strategies adoption in Indian cement industry. Fuzzy AHP is employed to prioritize these barriers, and to rank solutions of these barriers, Fuzzy TOPSIS is employed. Ten Indian cement manufacturing industry is taken to illustrate the proposed three-phase methodology. Finally, the result of the analysis offers an effective decision support tool to the Indian cement industry to eliminate and overcome barriers to mitigation strategies adoption and build a green image in the market of the Indian cement industry.

Our Next objective of the research is to evaluate the drivers to climate change mitigation strategies of the Indian cement industry. In the present study, a model is projected by applying the Analytical Hierarchy Process (AHP) and Interpretive structural modeling (ISM) techniques

to assess the drivers to climate change mitigation strategies of the cement industry. The AHP technique help in establishing the priorities of the drivers to climate change mitigation strategies, while ISM technique forms the relationships among them.

Our final objective of the research is to identify and evaluate significant climate change mitigation strategies of the cement manufacturing industry in the context of India. Extant literature review and expert opinion are used to identify climate change mitigation strategies of the cement manufacturing industry. In this objective, model projects by applying both AHP and DEMATEL techniques to assess the climate change mitigation strategies of the cement industry. The AHP technique helps in establishing the priorities of climate change mitigation strategies, while the DEMATEL technique forms the causal relationships among them. Present model will help supply chain analysts to develop both short-term and long-term decisive measures for effectively managing and reducing GHGEs.

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SACHIN BALSARA

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List of Abbreviations

AFR : Alternate fuel and raw material

AHP : Analytic Hierarchy Process

BEE : Bureau of Energy Efficiency

Bt : Billion metric tonns

CDM : Clean Development Mechanism

CI : Consistency index

CO_2 : Carbon dioxide

CO_2Es : Carbon dioxide emissions

COP : Conference of Parties

CPP : Captive power plant

CR : Consistency ration

DEMATEL : Decision Making Trial and Evaluation Laboratory Method

ESCM : Environmental supply chain management

FAHP : Fuzzy Analytic Hierarchy Process

FTOPSIS : Fuzzy The Technique for Order of Preference by Similarity to Ideal Solution

GDP : Gross Domestic Product

GHG : Greenhouse gas

GHGEs : Greenhouse gas emissions

GHGs : Greenhouse gases

IEA : International Energy Agency

INDC : Intended Nationally Determined Contribution

IPCC : Intergovernmental Panel on Climate Change

ISM : Interpretive Structural Modelling

MCDM : Multiple Criteria Decision Making

MICMAC : Cross-impact matrix multiplication applied to classification analysis

Mt : Million metric tonns

MtoE : Million tonnes of oil Equivalent

NAPCC : National Action Plan on Climate Change

OPC : Ordinary Portland Cement

PAT : Perform, Achieve and Trade

PPC : Portland Pozzolana Cement

PSC : Portland Slag Cement

RI : Random consistency ration

SSIM : Structural Self Interaction Matrix

TFN : Triangular Fuzzy Number

UNFCCC : United Nation Framework Convention on Climate Change

WHR : Waste heat recovery

Chapter 1

Introduction

Preview

This chapter presents the background of the study and an outlook of the cement industry. This chapter discusses the basic definition of climate change, mitigation, and adaptation. This chapter highlights various climate change mitigation strategies options, its driver and barriers to the adoption of mitigation measures. It also covers the motivation of the study and organization of the thesis.

1.1 Background

The economic and population growth all around the world has increased massive resource consumption and production activities. This growth could be realized through the availability of a wide range of products and services; created and managed by business organizations to meet the dynamic requirements of consumers sustainably. Sustainable development represents a comprehensive industrial progress perspective that respects social needs, global ecosystems and economic activities (Jokar and Mokhtar, 2018). Research and initiatives on sustainability have been concerned with reducing the greenhouse gases (GHGs), pollution, waste from the manufacturing of goods and thus, increasing the resource efficiency through improved manufacturing process and innovation in product design at the plant and product levels, and, more lately, through system-wide innovations across value chains or production networks (IPCC, 2014a). Thus, concern for organization effect on the environment is one of the paramount pillars of sustainable development.

Although climate change is one among many threats to sustainable development, thus to achieve sustainable development, limiting the effects of climate change is necessary (Elijido-ten, 2017). Climate change, as the archetypal environmental problem of current times, poses severe risks and challenges to populations globally. Climate change affects the functioning and structure of the ecosystem, and hurts species and their habitats and adversely affects water availability, food security, and human health. This is one of the most dangerous and complex environmental issues man has ever created (Lin and Ahmad, 2017).

United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as "*a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods*".

Intergovernmental Panel on Climate Change (IPCC, 2014b) in their meeting pointed out that manufacturing organizations are responsible for major environmental problems like waste generation, resources depletion, environmental pollution and greenhouse gas emissions (GHGEs). The atmospheric concentration of these GHGs is extremely likely the dominant cause of climate change. Continued GHGEs will enhance global warming and will cause long-lasting changes in the climate system (IPCC, 2014b). The global GHGEs continued to rise by an annual growth rate of 3.4% from 2000 to 2008, much higher than the previous decade (with an increased rate of 1% from 1990 to 2000). While GHGEs decreased in the United States and the European Union, other countries increased their GHGEs. Among these countries, China's GHGEs increased by 4.2%, and India's increased by 4.4% in 2013 than in 2012 (Shao et al., 2016).

Carbon dioxide (CO_2) is one of the major GHGs and largely contributes to climate change (Wei and Cen, 2019). Therefore, controlling CO_2 emissions (CO_2Es) plays an important role in setting the problem of climate change. Curbing the growth of CO_2Es to hold the global average temperature rise below 2 °C above pre-industrial levels has been recognized as a worldwide challenge after the "*Paris Climate Change Conference 2015*". It was stated in the Fifth Assessment Report of the IPCC (2014b) that CO_2Es from industry originate primarily from material processing, and the International Energy Agency (IEA, 2017) reported that three sectors namely electricity and heat, transport and industry take up 85% of the global CO_2Es. Thus, a few key sectors are responsible for the majority of CO_2Es. Industrial sector uses the largest amount of energy among all end-use sectors, consuming approximately 54% of total world energy and it contributes around 37% of global GHGEs that have raised 65% since 1971, and in most countries, CO_2Es contributes greater than 90% of GHGEs from the industrial sector (Barkhordar et al., 2018; Worrell et al., 2009). GHG emission reduction is particularly critical in the cement, pulp and paper, iron and steel, chemicals and petrochemicals and aluminum industries (Akimoto et al., 2010; Schmidt et al., 2008). Globally, these industries currently contribute about 77% of total direct CO_2Es whereas, in India, their contribution is about 82% (Trudeau et al., 2011).

The contribution of the non-metallic sector to global CO_2Es is increasing. During 1971-2010, CO_2Es of the global non-metallic sector have skyrocketed from 0.6 billion tons (Bt) to 2.6

Bt with an average annual growth rate of 3.8%, while the average annual growth rates of global CO_2Es was a mere 2%. Meanwhile, the share of CO_2Es from the non-metallic sector in global CO_2Es achieved 7.7% by 2010 relative to 4% in 1971. The cement industry plays a vital role in non-metallic sector CO_2Es. Fig.1.1 depicts the structure of non-metallic sector CO_2Es in 2010. The global cement process CO_2Es achieve 1.65 Bt, accounting for 64% of the direct CO_2Es in the global non-metallic sector (Wang et al., 2017). Cement production refers to a resource and energy-intensive manufacturing process, consuming nearly 12–15% of the total industrial energy consumption (Madlool et al., 2011). Cement production is also a large emitter of CO_2 and took up 5–8% of global anthropogenic CO_2Es from cement production. This would make the cement industry one of the top five individual sources of GHGs, and the second largest industrial source after the steel industry (Summerbell et al., 2016).

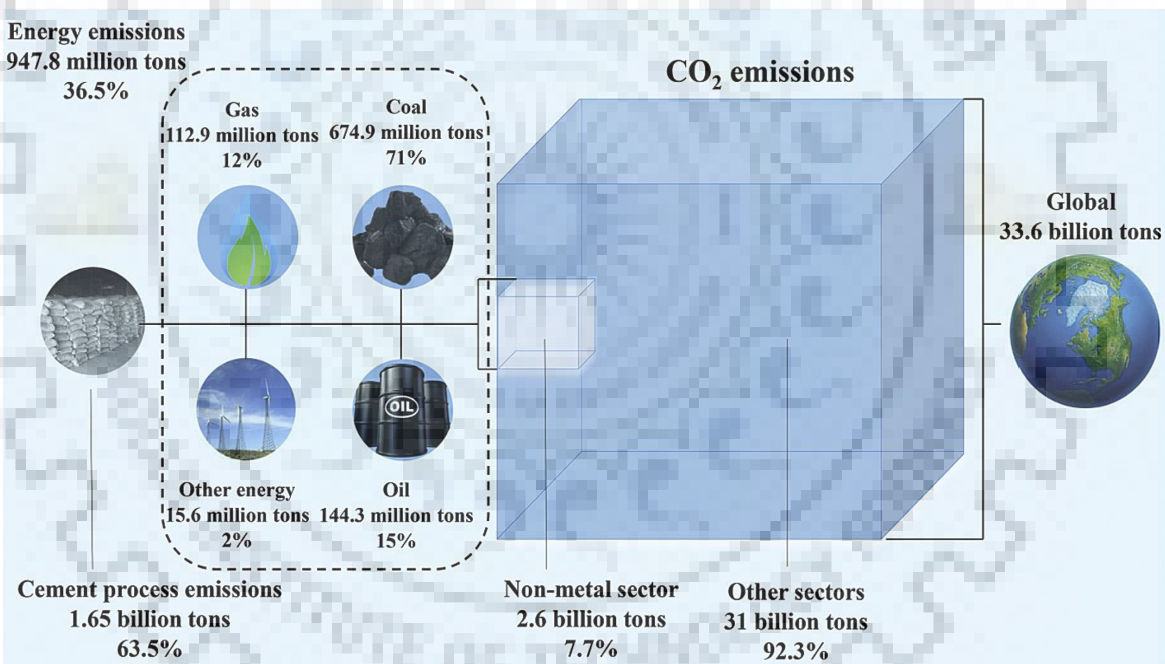


Figure 1.1: The global and non-metallic sector CO_2 emissions sources structure in 2010 (Wang et al., 2017). With permission from Elsevier.

To avoid harmful climate impacts, mitigation strategies should be promoted by business organizations (IPCC, 2014a). Therefore, cement industry sustainably conducts its business, by implementing and adopting climate change mitigation strategies (Cement Industry Federation, 2003). Sustained and substantial reductions in GHGEs will limit climate change and its associated risks (IPCC, 2014b). There has been increased global conversation regarding climate change tactics for effective reducing in GHGEs like Kyoto Protocol (UNFCC, 1997), Copenhagen conference (Bodansky, 2010) and recently the Paris Agreement (UNFCCC, 2015) which is the global agreement to combat climate change that incorporate accountability for all nations (Dimitrov, 2016; Rogelj et al., 2016). According to this accord, countries submitted action plans that communicate their intentions for addressing the range of issues, which can relate to avoiding, copying or adapting with climate change, their targets and actions for reducing GHGEs (Rogelj et al., 2016). Summary of Intended Nationally determined Contribution (INDC) by top greenhouse gas (GHG) emitters at Paris Agreement 2015 shown in Table 1.1 In addition to International pressure, there is an increase in regulatory, consumer, shareholder and societal pressure to reduce GHGEs (Cadez and Czerny, 2016).

1.2 An outlook of the cement industry

The only thing that humans consume more of, by volume, than water is cement based concrete (Hasanbeigi et al., 2012; Sakai, 2009). Cement is a fundamental requirement of modern society. It is the primary building material and is synonymous with construction activity. Cement used extensively in infrastructure development, industrial sector, urban housing and employment generation (CII, 2015). Infrastructure is a backbone of social-economic development of any country and its institutions. Cement is always considered as a barometer of progress in a developing country. The per capita consumption of cement is accepted as an important indicator of the country's economic growth. In addition to these, the primacy of cement industry would continue as all over the world cement remains paramount for the infrastructure development and near the future, no other material would possibly substitute it (IMY, 2017). Thus, for the economic growth and expansion of any country cement industry plays a vital role. On the other hand, cement industry contributes anthropogenic CO_2Es significantly (Feiz et al., 2015). Manufacturing of cement accounts for about 5–8% of total global anthropogenic CO_2Es (Kajaste and Hurme, 2016).

India presently stands as the fourth largest emitter of GHGs, ranking next to China, USA and Russia (CII, 2010). GHGEs from the Indian cement industry has raised from 7.32 Million tons (Mt) in 1993 to 16.73 Mt in 2003, and during this period, its share in total CO_2Es has raised from 3.3% to 4.8% (Mandal and Madheswaran, 2011). At present, the cement industry is the second largest CO_2 emitter among all the industrial activities of India (IEA, 2013) contributing 9% of the total national emissions inventory, emitted 52 Mt of CO_2 in 2013 (Garg et al., 2017). Thus, the cement manufacturing process is an emission-intensive sector, with the potential to create a substantial environmental footprint, preferably by emitting GHGs (Cement Industry Federation, 2003).

Table 1.1: Total GHGEs (in Million metric tons of carbon dioxide equivalent, $MtCO_2eq$) of top emitter country, their contribution, per capita CO_2Es (in metric tonne per capita, Mt/Capita) for the year 2015 and their INDC

Country	GHGEs [1] ($MtCO_2eq$)	Contribution	Per capita CO_2Es[2] (2012) (Mt/Capita)	INDC at Paris Agreement 2015[3]
China	10975.50	24.49 %	7.42	Carbon intensity reduction by 60–65% below their 2005 levels by 2030
European Union	7919.14	17.67 %	6.91	Reduction domestic GHGEs by at least 40% below 1990 levels by 2030
United States	6235.10	13.91 %	16.30	Net GHG emissions reduce by 26–28% below 2005 levels by 2025
India	3013.77	6.72 %	1.59	Emissions intensity reduce by 33–35% below 2005 levels by 2030
Russian Federation	2322.22	5.18 %	12.78	Anthropogenic GHGEs reduce by 25–30% below 1990 levels by 2030
Japan	1344.58	3.00 %	9.63	Energy-related CO_2Es reduced by 25%, compared with 2013 levels by 2030
World	44815.54	100%	4.99	

[1] World resources institute USA, 2017. Country greenhouse gas emissions data. http://datasets.wri.org/dataset/cait-country (accessed on 20 November 2017),
[2]The World Bank USA, 2017. World development indicator. http://databank.worldbank.org/data/reports.aspx?source=2&series=EN.ATM.CO2E.PC&country=# (accessed on 20 November 2017),
[3] International energy agency France, 2015. World energy outlook special report https://www.iea.org/publications/freepublications/publication/WEO2015SpecialReportonEnergyandClimateChange.pdf (accessed on 20 November 2017)

1.3 Mitigation and Adaptation

As per IPCC (2014a) climate change mitigation is "*human intervention to reduce the sources or enhance the sinks of GHGs*", and adaptation is "*the process of adjustment to actual or expected climate and its effects*". Because mitigation is intended to reduce the harmful effects of climate change, it is part of a broader policy framework that also includes adaptation to climate impacts.

Mitigation, together with adaptation to climate change, contributes to the objective expressed in Article 2 of the UNFCCC. It states "*The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties (COP) may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*" (UNFCCC, 1992).

The world's societies will need to both mitigate and adapt to climate change if it is to avoid harmful climate impacts effectively. The two strategies are complementary. More generally, the two strategies are related because increasing levels of mitigation imply less future need for adaptation. Countries' past and future contributions to the accumulation of GHGs in the atmosphere are different, and countries face varying challenges and circumstances and have different capacities to address mitigation and adaptation. There is no single pathway to stabilize GHG concentrations at any level; instead, the literature points to a wide range of mitigation pathways that might meet any concentration level. Limiting GHG concentrations will require a portfolio of options because no single option is sufficient to reduce GHGs concentrations and eventually eliminate net CO_2Es. A portfolio approach can be tailored to local circumstances to take into account other priorities such as those associated with sustainable development. Technology options include a range of energy supply technologies such as nuclear power, solar energy, wind power, and hydroelectric power, as well as bio-energy and fossil resources with carbon dioxide capture and storage. In addition, a range of end-use technologies will be needed to reduce energy consumption, and therefore the need for low-carbon energy, and to allow the use of low-carbon fuels in transportation, buildings, and industry. Halting deforestation and encouraging an increase in the forested land will help to halt or reverse land use change CO_2Es. Many of these options must be deployed to some degree to stabilize GHG concentrations.

1.4 Climate change mitigation strategies adoption in the cement industry

Climate change mitigation strategies are required in the cement industry for effective implementation of environmental and waste regulations and directives. It is essential for developed as well as for developing nations because of growing concern on GHGEs and pollution generated through informal waste management practices. Emission reduction is also another source of additional revenue generation for many companies, which can also help in improving the overall corporate image by complying with Government regulations. This inspired us to deal with the comprehensive details and issues related to successful climate change mitigation strategies implementation, specifically to management and analysis of the various common climate change mitigation measures, their drivers and barriers for the cement manufacturing industry in India.

1.5 Various climate change mitigation strategies in the cement industry

There is little empirical or theoretical literature concerning the management of GHGEs, as literature concerning Environment Supply Chain Management (ESCM) has generally covered the management of energy consumption or gaseous emissions to a lesser degree (Lee 2011). Further, it is highlighted that ESCM literature has failed to engage to a sufficient degree with the full range of strategies available to reduce GHGEs within products (Bocken and Allwood 2012).

Cement production is one of the most energy-intensive industries in the world. It is one of the major sources of anthropogenic GHGEs among industrial activities. Production of cement accounts for about 5-8% of total global anthropogenic CO_2Es. Hence, it is desirable to identify and evaluate the relative importance weight of the common climate change mitigation strategies of the cement industry. However, it will be impossible to implement all the mitigation strategies simultaneously to manage, control and reduce the GHGEs from the cement industry. Hence, industries should identify some mitigation strategies, which have essentially to be, manage and controlled to reduce the GHGEs from the cement production.

1.6 Drivers for implementing climate change mitigation strategies in the cement industry

The term driver is used for the factors that have the potential to force corporations to take climate response action even when they would not have ordinarily wanted to do so (Okereke, 2007). In the context of climate change policies, drivers are understood as activities, processes or patterns that produce positive incentives for climate action (Reckien et al., 2015). A driver is considered as a variable that motivates the attainment of climate change mitigation strategies in any industry. A range of driving factors has been highlighted as responsible for businesses shifting stance towards climate change mitigation, including competitive pressures, fluctuating energy prices, market shifts and stakeholder demands (Jeswani et al. 2008; Kolk and Pinkse 2008). Although a range of factors can be identified by explaining why a business organization would engage with climate change mitigation objectives, have their level of importance at various stages of implementation. Thus, managers should consider the drivers in such a way that they do not overlook the importance and effect of other drivers in the process of implementation of climate change mitigation strategies among the Indian cement industry.

1.7 Barriers to implementing climate change mitigation strategies in the cement industry

It has been seen that climate change mitigation practices in developed countries derived by enforcing legislation on manufacturers to take extended responsibility for pollutants and GHG reduction. However, it is in the initial stage in developing countries, including India (Srivastava, 2007). The climate change mitigation strategies implementation is difficult in developing economies like India because of the lack of societal pressure, environmental issues, and price sensitive market. The successful climate change mitigation strategies implementation needs economic and financial support from the Government, along with coordination and cooperation from supply chain partners. There are many reasons which are influencing organizations to adopt climate change mitigation practices, but the presence of barriers make climate change mitigation strategies implementation difficult, and effect of these barriers cannot be overcome at the same time. Even the same barrier may require different treatment and priority for the same type of organizations due to the varied nature of resources, capabilities, and strategies. Hence, it is desirable to prioritize the barriers and ranked the solutions to overcome these barriers to adopt climate change mitigation practices efficiently in the cement industry.

1.8 Motivation of the study

The serious threat of global climate change is primarily caused by the GHGEs, and there is a need for urgent collective action to achieve a transition to low carbon and more resource efficient economy. The report to the UK Government by Sir Nicholas Stern described climate change as "The greatest market failure ever seen" (Stern, 2006). The report recommended that there was a need to invest one per cent of global gross domestic product (GDP) per annum to avoid the worst effects of climate change. Stern himself has subsequently acknowledged that climate change is occurring faster than expected and other economists have argued that stopping or significantly slowing climate change will require greater investment in cutting GHGEs. It is now widely accepted by economists and policymakers that to avert dangerous climate change severe reductions in GHGEs are essential probably of 80% or more by 2050, against a 1990 baseline (Vickers et al. 2009).

Climate change is arguably the greatest market failure the world has ever seen, and it may affect generations to come. Therefore, there is an urgent need to identify the market leaders and define an industry benchmark, in terms of carbon emissions mitigation strategy, and overall commitment towards moving to a low-emissions economy. This imperative is especially strong in the context of the developing countries. Owing to the high levels of risks posed to countries like India, the immediate need to shift to a low carbon growth path is clear. The developed countries have efficient resources and technologies to tackle mitigation measures but the matter of the fact is that it is in a nascent stage in India.

The global anthropogenic GHGEs lead to changes in climate. Global industrial GHGEs accounted for just over 30% of global GHGEs in 2010. GHGEs from industry grew at an average annual rate of 3.5% globally between 2005 and 2010. For industry, reduction of GHGEs is particularly critical in the cement, pulp and paper, iron and steel, chemicals and petrochemicals and aluminum, the five most energy and emission intensive sectors (Akimoto et al., 2010; Schmidt et al., 2008). Over the last century, cement based concrete has become the highest manufactured product on earth in terms of volume and also it is the most consumed product on earth after water (Hasanbeigi et al., 2012; Sakai, 2009). Also, cement production is one of the most energy-intensive industry in the world (Madlool et al., 2012). It is one of the major sources of anthropogenic CO_2Es among industrial activities (Feiz et al., 2015).

Implementing climate change mitigation strategies is a strategic decision and highly depends on the management of the company. It is a long-term decision and requires a huge amount of capital investment. It has been observed that some companies that have implemented emission reduction practices have generated huge revenues and profits, so it has economic and commercial viability apart from other benefits. This study helps in understanding the various emission reduction activities, which are to be performed by the cement industry. It will also help in identifying the various barriers of mitigation adoption in the Indian cement industry so companies can design their strategies accordingly. This study can be helpful to the practitioners and the researchers to have the insight of emission reduction perspectives. Hence, this motivated us to deal with the comprehensive details and issues related to successful climate change mitigation strategies adoption, specifically to management and analysis of the drivers and barriers for the cement manufacturing industry in India.

1.9 Organization of the Thesis

The organization of the present research work has been covered in seven Chapters illustrated in Fig. 1.2, however; a brief outline of each chapter is given below:

Chapter 1 Presents the basic background and an outlook of the cement industry. It highlights the importance of the adoption of mitigation measures in the cement industry. The basic definitions of climate change, mitigation, and adaptation are discussed. The need for the drivers and barriers to implementing climate change mitigation strategies in the cement industry is also discussed. This chapter also provides the details on the motivation of the work and organization of the thesis.

Chapter 2 Provides an in-depth and exhaustive review of the literature on climate change mitigation strategies of the cement industry. It presents the overview of the cement manufacturing process and overview of the Indian cement industry. An extensive review of literature on drivers and barriers to climate change mitigation strategies of the cement industry is also presented in this chapter. The solutions to overcome these barriers are also discussed. After that, an extensive review of past studies on climate change mitigation measures was done. Through an extensive review of the literature, various gaps have been identified. The identification of these gaps have led to the formulation of research objectives for this thesis, and there are four research objectives were formulated based on the literature review and identified gaps. The data collection methods and procedures, sample design, target populations, data analysis and interpreting of the information have also discussed in this chapter.

Chapter 3 Presents the research approach followed for the accomplishment of the research objectives. A conceptual framework and developing a model is proposed for overcoming barriers, drivers and various climate change mitigation strategies of the cement industry, involved a detailed discussion about various steps of five MCDM techniques namely - AHP, Fuzzy AHP, Fuzzy TOPSIS, ISM, and DEMATEL. The data collection methods and procedures, sample design, target populations, data analysis and interpreting of the information have also been discussed.

Chapter 4 Provides details about the identification, finalization, and prioritization of the climate change mitigation adoption barriers. It also identifies, finalizes and suggests solutions overcome these barriers. Then, this chapter proposes a flexible model to prioritize the solutions to overcome these barriers. For this, an integrated approach based on the fuzzy AHP-fuzzy TOPSIS methods has been developed and used in this chapter. From the framework, five main factors of barriers, twenty-six sub-factors of barriers and fourteen barrier overcoming solutions were identified. The FAHP analysis is employed to rank the barriers to climate change mitigation strategies. Further, to rank barrier overcoming solutions, FTOPSIS analysis was used.

Chapter 5 Provides details about the identification, finalization, and prioritization of the climate change mitigation adoption drivers. In this chapter, a model is projected by applying the AHP and ISM techniques to assess the common drivers to climate change mitigation strategies of the cement industry. According to the study outcomes, there are thirty drivers related to climate change mitigation strategies practices are identified.

Chapter 6 Aimed to assess various common climate change mitigation strategies of the cement industry. This objective applied combined AHP-DEMATEL approach to evaluating the various climate change mitigation strategies of the Indian cement industry. AHP analysis ranked the significant sub-factors for effective reducing of GHGEs. While, the DEMATEL technique initiated the cause and effect relationship between the factors, gives long-term improvement options.

Chapter 7 Provides a comprehensive overview of the research work conducted and the major findings, along with the contribution of the present study in the existing set of literature. Besides, this chapter also provides the managerial implications of the present study. The last section of this chapter provides the limitation of the study. This chapter concludes by highlighting the suggestions related to the scope of future work.

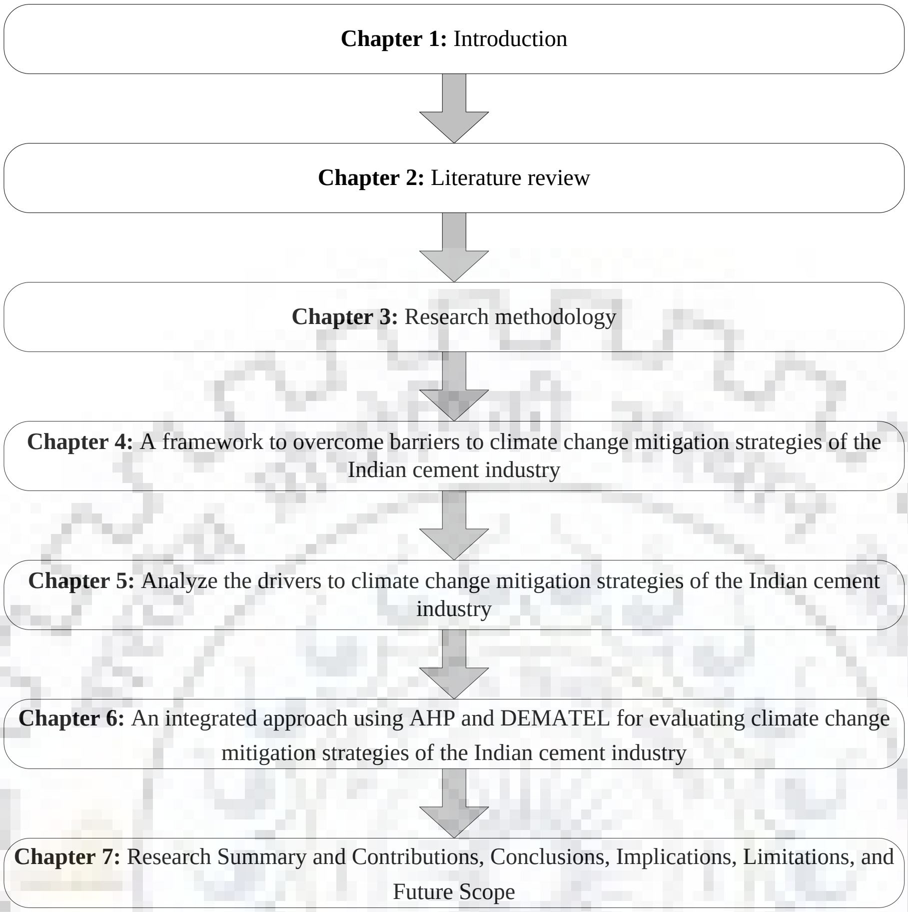


Figure 1.2: Outline of the thesis

1.10 Chapter summary

This chapter presents the basic background and an outlook of the cement industry. It highlights the importance of the adoption of mitigation measures in the cement industry and discussed various climate change mitigation measures in the cement industry. The basic definitions of climate change, mitigation, and adaptation are discussed. The need for the drivers and barriers to implementing climate change mitigation strategies in the cement industry is also discussed. This chapter also provides the details on the motivation of the work, and in the last section, the complete organization of the thesis is provided. Further, in this, all sections mentioned in this chapter are discussed in detail in the subsequent chapters.

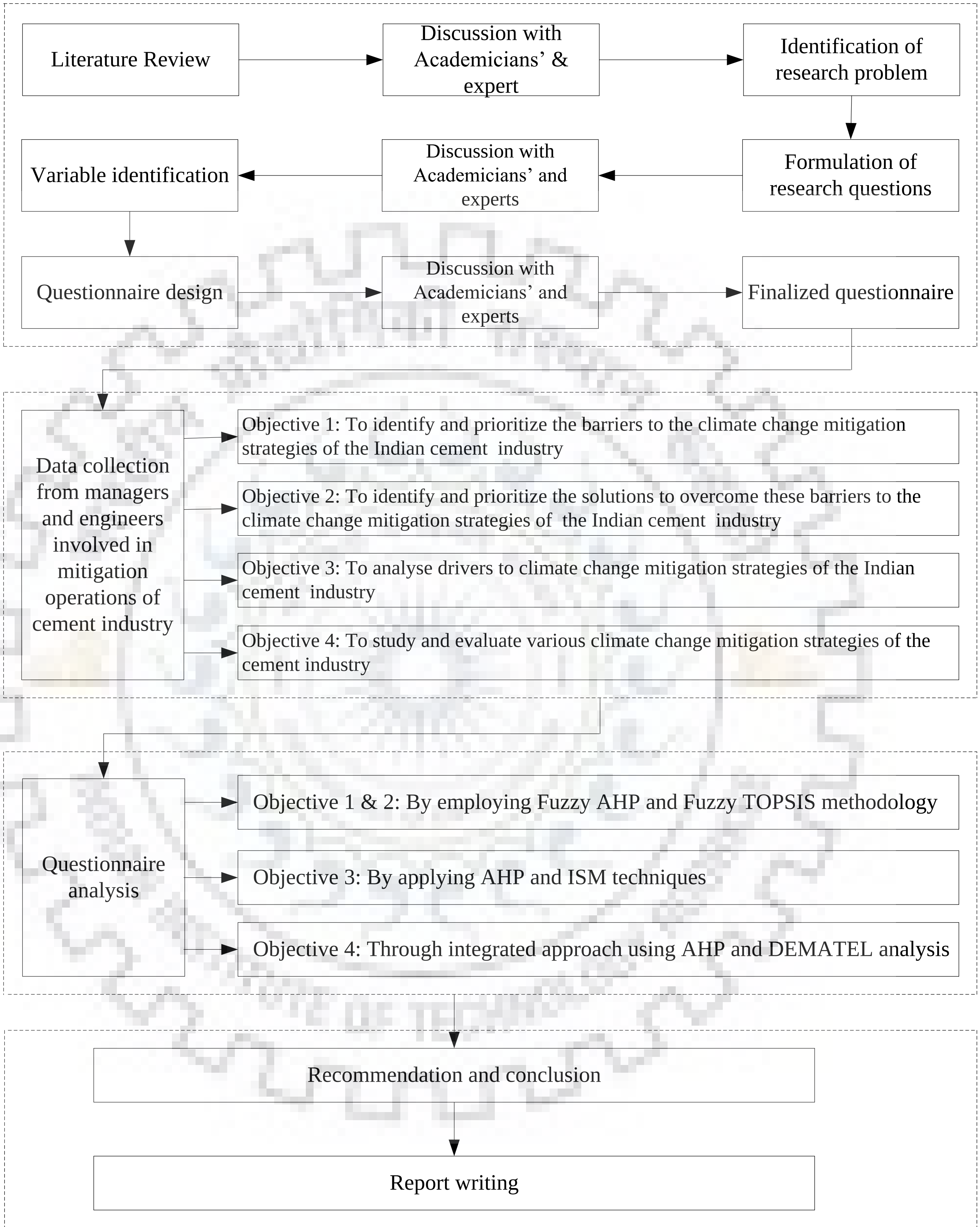


Figure 1.3: Research Design

Chapter 2

Literature Review

Preview

This chapter deals with an extensive and in-depth literature review. This chapter covers an overview of the cement manufacturing process, an overview of the Indian cement industry, and explores the various common mitigation strategies, drivers behind implementing these climate change mitigation strategies, barriers and solutions to overcome these barriers in the Indian context. It also identifies the research gaps, problem descriptions, and objectives of the present research work.

2.1 Literature Review at a Glance

Fink (2005) defines literature review as *"A literature review is a systematic, explicit, and reproducible method for identifying, evaluating, and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners"*. On similar lines, Easterby-Smith et al., (2002) suggested that *"A review of literature is a systematic, clear and valid approach for identifying, reviewing and analyzing the explicitly existing body of knowledge in the particular area"*. A review of literature assists in recognizing the conceptual and theoretical content of the recorded documents (Meredith, 1993) and helps in the theoretical development of the research area. The Specific and relevant topics, themes, methods, approaches, and issues have been identified and summarized is the objectives have been accomplished with the help of systematic review and analysis of literature.

There is a huge amount of literature available on climate change mitigation, and it is difficult and not feasible to explore all research articles and papers. To obtain maximum output, only recent and specific topics and issues are included in the review. The literature review considered both qualitative and quantitative aspects for a better understanding of the content and relevancy of the research area.

2.2 Literature collection, category selection, and analysis

Evolution of research on climate chain mitigation, emission reduction, low carbon supply chain, sustainable supply chain, and green supply chain has intensified over the years. Literature collection has been conducted in two phases:

In the first phase, for searching the literature, we chose the keywords “carbon * emission”, which also comprised, for example, “carbon dioxide emission”. Additionally, we used the chemical symbol CO_2 (“CO_2 * emission”). Because CO_2 belongs to the family of GHG, we also decided to use the terms “greenhouse gas* emission” as well as “GHG* emission”. Moreover, the issue that we addressed is climate change; therefore, we also used the term “climat* change *”, which includes “climate change mitigation” as well as “climatic change”, "emission reduction" "cement * emissions" which includes "cement industry emission" and "cement production emission". Other keywords were also used for searching articles namely, barriers to emission reduction, barriers to climate change mitigation, drivers or enablers to emission reduction, drivers/enablers to climate change mitigation, emission reduction strategies/measures, climate change mitigation strategies/measures, cement industry, etc. combinations of words have also been utilized. These keywords have been used in Web of Science, Scopus, Science direct, Google Scholar and Google search databases to collect articles published in journals, conference proceedings, and books. Only English language based papers and articles were considered and sorted while literature searches.

In the second phase, the collected papers and literature were scrutinized and sorted for the further literature search. The further category selection of literature search attributed to various common climate change mitigation options, implementation drivers, adoption barriers and its solutions to overcome mitigation barriers in the cement industry. The keywords mentioned above has been used to search the articles with leading publishers, including Elsevier, Taylor and Francis, Emerald, Wiley, Sage, Springer, Informs, Inderscience, Growing science, etc. The major focus of the literature selected for review is emission reduction.

Category selections of the studies on the cement industry have been specified into four groups. These four groups are (1) barriers to climate change mitigation adoption, (2) exploring solutions to overcome these barriers, (3) drivers to climate change mitigation and (4) various strategies of climate change mitigation and literature framework for the study are shown in Fig. 2.1. Then selected studies and articles for review of the literature as mentioned above under four categories were studied and analyzed thoroughly to obtain comprehensive details of the recent and relevant studies related to climate change mitigation strategies of cement industry. This assessment and analysis will identify and summarizes the research gaps found in the literature related to each category mentioned above.

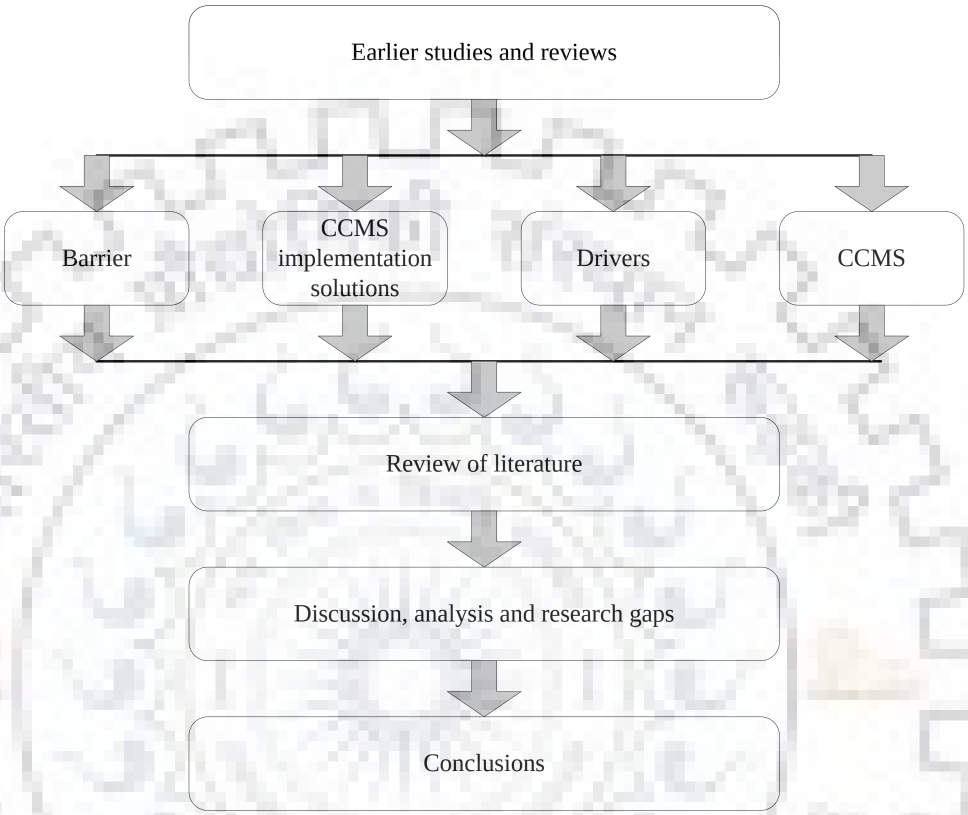


Figure 2.1: Literature frameworks for the study

2.3 Overview of the cement manufacturing process

Two basic types of production processes and a number of different kiln types produce cement. Depending on the water content of the raw material feedstock, the process is termed either ‘’wet’’ or ‘’dry’’. In wet process, the energy consumption is great because evaporation of more than 30% slurry water takes place before heating the raw materials to the required temperature for calcination. The general cement manufacturing (dry process) process, the sources of GHGEs, Energy consumption, and waste heat flow during cement manufacturing are shown in Fig.2.2. The process of cement manufacturing is not straightforward. It demands a number of steps that need specialized equipment. Every stage requires energy input, and this leads to GHGEs. Therefore, a roadmap focusing on improving energy efficiency and reducing emissions must carefully examine opportunities at each step of the process.

2.3.1 Surface mining/quarrying raw materials

Limestone, marl or chalks are a natural accumulation of calcareous deposits. They supply calcium carbonate ($CaCO_3$) that is used as raw material for cement production. Since these are extracted from surface mines/quarries; the source of raw material should be located as close as possible to cement manufacturing plant for energy efficiency.

2.3.2 Crushing

The raw material is fed through primary/secondary crushers after it is excavated and transported to the cement plant. There, it is broken down into small pieces which are approximately 10 centimeters in size.

2.3.3 and 2.3.4 Prehomogenisation and raw meal grinding

For the end use of a particular batch of cement, a homogenize-mixer of required chemical composition is obtained by mixing different raw materials. This process is called Prehomogenisation. The chemical composition of the mix is achieved by using little amounts of "corrective" materials such as iron ore, bauxite, shale, clay or sand, which provide extra iron oxide (Fe_2O_3), alumina (Al_2O_3), and silica (SiO_2) to the process. A "raw meal" is produced by milled the crushed pieces together. The chemistry of raw materials and the raw meal is vigilantly examined and controlled to guarantee high cement quality.

2.3.5 Coal grinding/kiln fuel preparation

To produce required heat for calcination, the coal is milled into fine powders, which enable its feeding into the kiln as a fuel.

2.3.6 Preheating

There are a number of ways to improve the efficiency of the process, one of which is to preheat the raw material (using a pre-heater) just before it goes into the kiln. This preheating of material quickens the chemical reactions. The raw material is passed through a series of vertical cyclones in the pre-heater, which makes the raw material to come in contact with hot gases flowing in the opposite direction. The stages of cyclones in a kiln depends on the moisture content of the raw material. As these gases are exhausted from the kilns, efficiency is gained by using the heat generated by one production process to provide the energy needed for another.

2.3.7 Precalcining

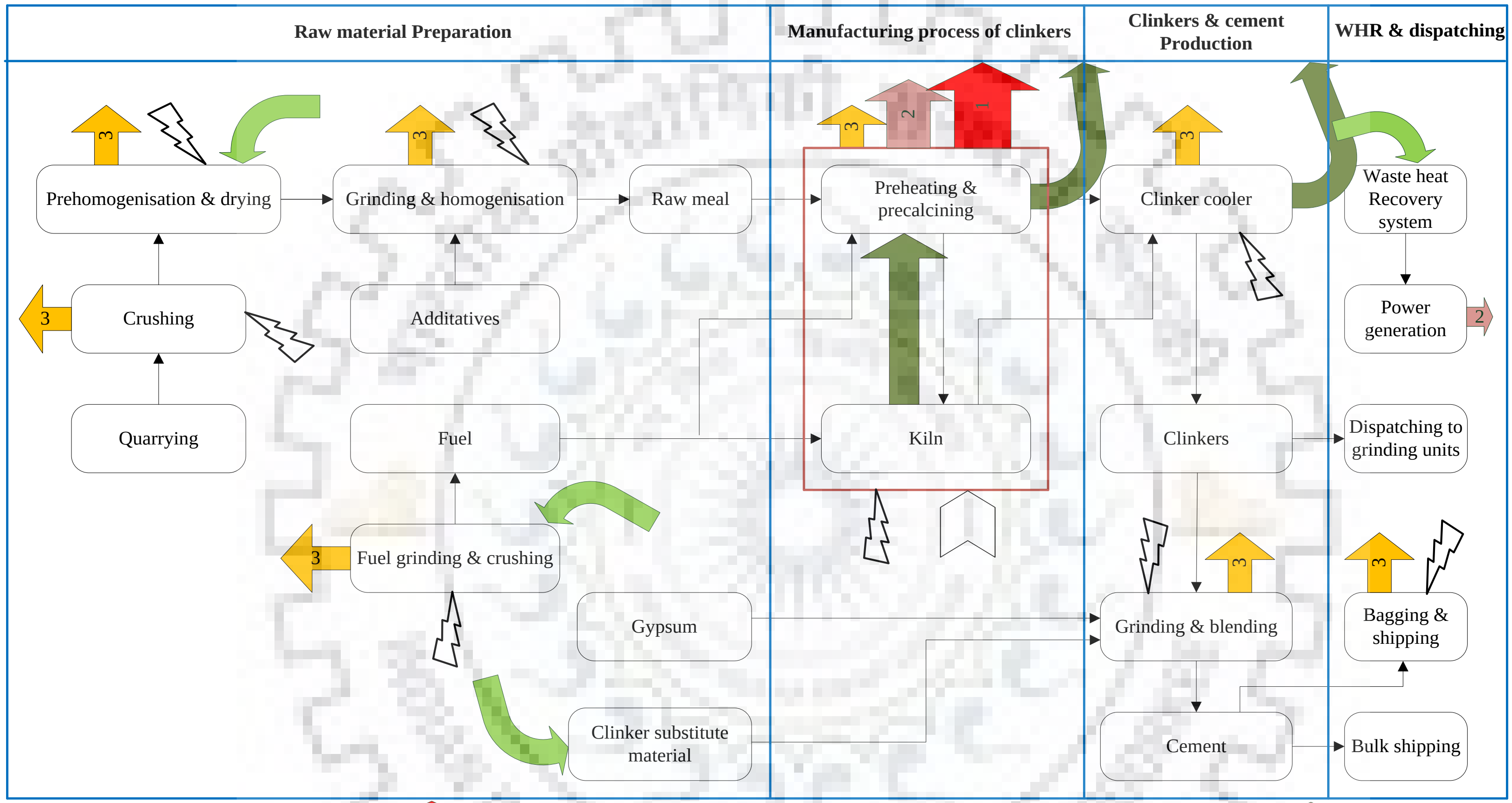
The decomposition of limestone to lime is nothing but chemical reactions, called Calcination. These reactions, which also requires energy inputs, are triggered at two places in the manufacturing process. First, it is stimulated in the "precalciner" which is a chamber at the bottom of pre-heater and above the kiln where combustion takes place, and second within the kiln itself. The chemical decomposition of limestone in lime is the first point where emission is produced and it is 60-65% of total emission produced in the production of cement. A large portion (about 65%) of the remainder of total emission is produced in fuel combustion needed to generate heat in precalciner.

2.3.8 Clinker production in the rotary kiln

In the next step of cement manufacturing; the precalcined meal enters into the kiln, where partial melting of meal happens due to chemical and physical reactions caused by the high temperature of 1450°C. The kiln rotates at 2-3 rpm and fuel is simultaneously fired directly into kiln. Because of the rotations of the kiln, the material slides and tumbles down towards the flame, through progressively hotter zones. An intermediate product "clinker" is produced here, which is the main material in cement and it is commonly traded.

2.3.9 Cooling and storing

Incoming combustion air-cools the hot clinker that is dropped onto a grate cooler after coming out of the kiln. This process minimizes the loss of energy from the system. Typically, in a cement plant, there are facilities to store the clinker between clinker production and components of plants, which handle blending and/or grinding.



This arrow shows material flow, [red arrow 1] shows around 50% of total GHG Emissions from chemicals processes (Direct emissions), [arrow 2] indicates around 40% of GHG emissions mostly originated from fuel combustion in kiln, [arrow 3] shows about 5 to 6% of overall GHG emissions are from electric power consumptions (Indirect emissions), and rest of total GHG emissions are from mining, quarrying, transportation etc.. [lightning symbol] Shows electric energy consumption, [pentagon symbol] indicates thermal energy consumptions at kiln while [green arrow] this arrow shows waste heat flow from the system and [light green arrow] this arrow shows waste heat utilize in the system.

Figure 2.2: An overview of energy consumption and GHG emissions for the cement industry

2.3.10 Blending

Blending is a process in which materials such as slag, fly ash, limestone or other chemical components are used to reduce the quantity of clinker needed for a particular batch of cement production. The end product is often called "blended cement" and it can be customized according to the end-use. For example, all cement types contain around 4-5% gypsum to control the setting time of the product.

2.3.11 Cement grinding

A grey powder is produced by grinding the cooled clinker and/or blended mixture. This grey powder is referred as Ordinary Portland Cement (OPC). Sometimes, the blended mixture is ground with other minerals to make blended cement, as mentioned in the previous step. It is long established to use "ball mills" for grinding in cement plants but new efficient technologies are coming every day. In many present-day modern plants, roller presses and vertical mills are used. The efficiency of the industry could further improve by wider development.

2.3.12 Storing in the cement silo

After homogenization, the product is finally kept in cement silos for storage. It is either dispatched to a packing station or to a silo truck.

2.4 Overview of the cement industry and various common climate change mitigation strategies of the cement industry

These sections discuss in detail literature related to the cement industry and various common climate change mitigation strategies of the cement industry.

2.4.1 Overview of Indian Cement Industry - Status and Growth

One of the major energy and emission intensive manufacturing industry is the cement industry (Soni et al., 2017). It has been growing at a rapid pace during the late 20th and early 21st centuries. The history of Indian Cement industry started with a manufacturing capacity of mere 0.85 Mt in 1914-16 when a cement plant was set-up at Porbandar (Gujarat), has attained phenomenal growth to the current level of around 300 Mt as on 31st March 2015. Partial decontrol in1982, then total decontrol in 1989 and post-de-licensing of the industry and policy reforms initiated in1991 have contributed to the growth of the cement sector in India and its adoption of the latest technologies (IMY, 2017b). About 50% of Indian cement industry is less than ten years old, having the latest energy efficient technologies, efficient pollution control devices and process control equipment which immensely conserve energy, fuel, raw material and thereby reduces the GHGEs substantially (IEA, 2013; IMY, 2017a)

India, like other developing countries, is suffering the brunt of climate change (Rattani, 2018). According to the Global Climate Risk Index 2017, developed by German watch analyses which quantify the impacts of extreme weather events, India is ranked as the fourth most vulnerable country (Kreft et al., 2017). To address global warming issues, India has launched a National Action Plan on Climate Change (NAPCC) with National Missions which promote sustainable development while addressing global warming issues effectively (Chandel et al., 2016). India committed to reducing gross domestic product emission intensity by 33-35% during 2005–2030 in the Paris Climate Change Agreement 2015, as against its existing commitment of 20-25% reduction during 2005–2020 (UNFCCC, 2015) but, the growing emissions may reflect adversely on achieving India's Paris commitment target (Garg et al., 2017) as global cement production has continued to expand from 2568 million tonnes (Mt) in 2006 to 4100 Mt in 2015 as shown in Table 2.1. In the world, China (2,350 Mt) is the largest manufacturer of cement, sharing more than 57% to the world production, followed by India (300 Mt) 7% (IMY, 2018). Hence, India is the second largest cement manufacturer and consumer-led by the extensive development in the infrastructure and construction sector (BEE, 2017a). By implementing the modern technologies and low carbon practices, the thermal and electric energy consumption of Indian cement industry has been decreased significantly from about 855 kcal/kg clinker and 120 kWh/t cement for dry kilns (1991) (CII, 2010) to 667 kcal/kg clinker and 67 kWh/t cement respectively (Garg et al., 2017; CII, 2015), which is similar to Japan's best efficient figures of 660 kcal/kg clinker and 65kWh/t cement (IMY, 2017a; Planning Commission, 2011). Thus, the achievement of reducing the significant carbon footprint of Indian cement industry from 1.12 tCO_2/t cement in 1996 (IEA, 2013) to 0.719 tCO_2/t cement in 2010 (Woywadt and Henrich, 2015; IEA, 2013).

Although, the Indian cement industry is one of the most efficient in the world, yet, it still produces 137 Mt of GHGs in 2010, which is 7% of India's total man-made GHGEs. The Indian cement industry should make a robust attempt to reduce its carbon footprint by adopting low carbon practices (IEA, 2013). Along with existing Government regulations and policies, the

NAPCC and Paris Climate Change Agreement 2015 seem to be an important driver for emission reduction in India.

2.4.2 Global and Indian cement production

Over the last two decades India is the second largest cement producer and consumer-led by the extensive development in the infrastructure and construction sector (BEE, 2017a) accounting for 7.31% of world cement production, manufactured 300 Mt cement in 2015, with an annual installed capacity of 356 Mt from 209 large and more than 360 mini cement plants (IMY, 2017a). Even though the private and public sector are indulged in cement production, the private sector alone contributes about 97% of total production (CII, 2010). Due to the state-of-the-art technologies in the cement manufacturing, the cement industry of India has not only fulfilled domestic demands but also performed well in the international market since the Import and Export Indian policy incorporated in the Foreign Trade Policy is free for cement (IMY, 2017a). The Capacity, Production, Growth, Export, and Import of cement and clinkers of Indian Cement Industry shown in Table 2.2.

Though India is the second largest cement producer and consumer, its per capita cement consumption is substantially low, about 150 kg in 2008 (Planning Commission, 2014),188 kg in 2010 (CII, 2010; IEA, 2013) and 195 kg in 2015 (Ministry of Mines, 2017) compared to 1,216 kg in Korea (2003), 626 kg in China (2003), 471 kg in Japan (2003), 385 kg in the US (2003), 362 kg in Germany (2003), 191 kg in Brazil (2003) while the world average is 355 kg (2007) (Bhushan, 2010) and 520 kg (2014) (IMY, 2017a).

Table 2.1: Cement production by principal countries of the world in Mt

Country	In a million ton, Mt				% of 2014	% of 2015
	2012	2013	2014	2015		
World	3800	4080	4180	4100	100	100
China	2210	2420	2480	2350	59.33	57.31
India	270	280	260	300	6.20	7.31
USA	74.9	77.4	83.2	84.3	1.99	2.05
Turkey	63.9	71.3	75.0	71.4	1.79	1.74
Brazil	68.8	70.0	72.0	65.3	1.72	1.59
Russia	61.5	66.4	68.4	62.1	1.63	1.51
Iran	70.0	72.0	65.0	58.6	1.55	1.42
Indonesia	32.0	56.0	65.0	58.0	1.55	1.41
Korea, Rep. of	48.0	47.3	63.2	51.7	1.51	1.26
Vietnam	60.0	58.0	60.5	67.4	1.44	1.64
Saudi Arabia	50.0	57.0	55.0	61.9	1.31	1.50
Japan	51.3	57.4	53.8	54.8	1.28	1.33
Egypt	46.1	50.0	50.0	55.0	1.19	1.34
Other countries	523.7	536.0	573.0	760	17.44	18.53

Source: IMY (2017a); IMY (2018)

Table 2.2: Capacity, Production, and Growth of Cement and Export and import of cement and clinkers of Indian Cement Industry, 2010-11 to 2014-15 (In Million ton, Mt)

Year	Annual Capacity	% Growth	Production	% Growth	Consumption (Domestic)	% Growth	Export		Total Export	Import		Total Import
							Cement	Clinker		Cement	Clinker	
2010-11	296.48	7.12	216.28	5.53	226.00	10.40	3.49	1.08	4.57	1.09	0.18	1.27
2011-12	306.21	3.28	230.25	6.45	241.80	6.99	3.39	1.26	4.65	1.01	0.14	1.15
2012-13	324.94	6.11	235.11	2.11	N.A.	N.A.	2.91	0.78	3.69	1.28	0.55	1.83
2013-14	350.00	7.71	256.04	8.90	N.A.	N.A.	5.14	2.42	7.56	0.77	0.08	0.85
2014-15	356.00	1.71	276.93	8.15	N.A.	N.A.	6.28	3.97	10.25	0.08	0.04	0.12
2015-16	479.35	34.65	283.45	2.35	N.A.	N.A.	6.22	2.84	9.06	0.95	0.28	1.23

Source: IMY (2017a); IMY (2016); IMY (2015); IMY (2014)

2.4.3 Specific energy consumption

Cement production is a highly energy-intensive process, and the energy cost is about 35–45% of the total production cost. Out of this, thermal energy constitutes around 70%, whereas electrical energy about 30%, which may vary from plant to plant and local conditions (Gielen and Taylor, 2009; S. Peddanna, 2015). The thermal and electric energy consumption of Indian cement plants has been decreasing significantly for last two decades and are replaced by the modern technologies and environmental practices, from about 855 kcal/kg clinker and 120 kWh/t cement for dry kilns (1991) (Schumacher and Sathaye, 1999; CII, 2010) to 788 kcal/kg clinker and 87 kWh/t cement (2002) (Bhushan, 2010) further to 725 kcal/kg clinker and 80 kWh/t cement (2006) (Garg et al., 2017; CII, 2015; IEA, 2013; CII, 2010; Planning Commission, 2008), considerably below than the global average of 934 kcal/kg clinker and 107 kWh/t cement (IEA, 2013). Presently, Indian cement industry achieved the best figure of thermal and electrical energy consumption which about 667 kcal/kg clinker and 67 kWh/t cement respectively (Garg et al., 2017; CII, 2015; IEA, 2013; CII, 2010) which is similar to Japan's best efficient figures of 660 kcal/kg clinker and 65kWh/t cement (IMY, 2017a; Planning Commission, 2011).

2.4.4 Blended cement

The manufacture of Ordinary Portland Cement (OPC) is more costly and carbon-intensive than making blended cement. Blended cement is a uniform mix of OPC and blending materials. The blending materials enhance its properties for different uses. These are the industrial waste such as silica fumes, fly ash, limestone and slag. This waste is easily procurable at a very low cost which reduces the manufacturing cost of the blended cement. Increasing the capacity of Industries at almost no capital cost, enables the efficient disposal of industrial wastes (Bhushan, 2010), reducing energy consumption (Morrow et al., 2014) and GHGEs (Kajaste and Hurme, 2016a) as it reduces the environmental impact and also the emission intensity. It’s a win-win situation for the manufacturer and the consumer (Planning Commission, 2011).

In 2000-01 in India, the market share of blended cement was only 37% (IEA, 2013), in the year 2004-05 it was 55.6% (Gielen and Taylor, 2009), while in the year 2007 further it is increased to 68% compared to only 4% in the US (2002), 26% in Japan (2005), 40% in China (2005), and 52% in the EU (2003). In the Indian market share of blended cement production has reached around 75% (Planning Commission, 2011). Thus Indian cement industry has been gradually expanding the share of blended cement in its overall cement mix. The shares of various types of cement from 2001-02 to 2005-06 and the typical average clinker-to-cement ratio of cement manufactured in India in the financial year 2009 and 2010 are presented in Table 2.3.

Table 2.3: Share of cement type and typical clinker-to-cement ratio in India

Type of cement	Total production of cement (%)							Clinker to cement ratio
	2001-02	2002-03	2003-04	2004-05	2005-06	2009	2010	
Ordinary Portland Cement (OPC)	56.3	50.3	45.5	43.8	39.3	25	24	0.95
Portland Pozzolana Cement (PPC)	31.5	38.7	44.3	47.2	52.2	66	65	0.69
Portland Slag Cement (PSC)	11.6	10.4	9.5	8.4	8.0	8	8	0.57
Others	0.5	0.5	0.5	0.5	0.4	1	3	N.A.

Source: IEA (2013); Mandal and Madheswaran (2011); CII (2010)

2.4.5 Alternate fuel and raw material (AFR)

The specific primary energy consumption of Indian cement industry is low; it can be further reduced by burning hazardous and combustible wastes as an alternative fuel in the kiln. Otherwise, that may go to the landfill without treatment. So the use of alternate fuels helps in conservation of fossil fuels (IEA, 2013; Planning Commission, 2011; Bhushan, 2010). In the cement industry, global average utilization of alternative fuel is currently 4.3% of total thermal energy consumption (IEA, 2013) while in some countries, the average utilization of alternate fuel is about 40-50% (Gielen and Taylor, 2009) Japanese cement industry, for example, utilizes about 450 kg of waste/ton of cement produced (CII, 2010). In Indian Cement Industry, utilization of the alternative fuel is at a very low rate of 0.6% as compared to the global average of thermal energy consumption (IEA, 2013; Gielen and Taylor, 2009). In the Indian Cement Industry, the thermal substitution rate (TSR) values range from 0.5-1% (CMA, 2016; CII, 2015; Planning Commission, 2011).

2.4.6 Waste Heat Recovery (WHR)

Co-generation of power through cost-effective WHR (Dutta and Mukherjee, 2010) reduces dependence on external electricity by generating electricity onsite from the recovery of waste heat (Morrow et al., 2014). Based on the kiln technology and chosen process 8–10 kWh/t clinker can be generated from exit gas of cooler further potential of 9–12 kWh/t clinker from the kiln (preheated) gases. Cumulatively, 8–22 kWh/t clinker (12–25%) of the electricity consumption can be produced by utilizing WHR technologies without any significant alteration in kiln operation (IEA, 2013; Bhushan, 2010; CSI/ECRA, 2009). The WHR potential of the Indian cement industry is estimated at close to 550 MW, while the installed capacity to date is only 110 MW (Bhushan, 2010; IEA, 2013).

2.4.7 Coal and captive power plant (CPP)

Carbon-intensive fuel such as coal is the major fuel stock for cement manufacturing in India, primarily because it is a readily available and low-cost domestic resource. Apart from coal, pet coke (by-product produced in refineries having a high calorific value of around 7762 Kcal/kg) accounts for 10–15% of the fuel mix. Imported coal is also used, but is significantly more expensive (IEA, 2013).

In 2009, energy mix of Indian cement industry consists of Coal and lignite accounted for 83.2%, petroleum, 12.3%, purchased power, 4.2% renewable and wastes accounted for less than 1% of the total primary energy consumption (Bhushan, 2010). About 60% of the electricity used in Indian cement plants by today is from CPPs (predominantly coal-fired), which have an average CO_2E factor of 1.2 $kgCO_2/kWh$ of electricity produced (IEA, 2013). Table 2.4 shows procurement and consumption of fuel for Indian cement industry including for captive power plants from 2007–08 to 2014–15.

2.4.8 Perform, Achieve and Trade (PAT)

Bureau of Energy Efficiency (BEE) of India has developed a PAT scheme, to reduce energy consumption primarily by enhancing energy efficiency in Indian energy-intensive industries, including the cement sector. PAT is a market-based mechanism to enhance cost effectiveness through certification of excess energy savings in energy-intensive industries that can be traded (BEE, 2017b). The achieved saving for cement sector under PAT cycle- I (2012–15) is 1.480 Million tonnes of oil equivalent (MtoE), which is around 81.6% higher than the saving target of

0.815 MtoE. PAT has triggered energy efficiency. Consequently, the cement sector of India is currently globally the best efficient (BEE, 2017a).

Table 2.4: Procurement and consumption of fuel for Indian cement industry including for captive power plants (2000–01 to 2014–15) in Million tonnes (Mt)

Year	Domestic Coal	Imported Coal	Pet Coke, Lignite and other fuel	Total Procurement	Actual Consumption
2007–08	19.56	6.08	3.20	28.84	27.33
2008–09	20.46	6.97	2.77	30.20	29.57
2009–10	15.15	6.95	4.15	26.25	25.80
2010–11	16.82	8.48	3.54	28.84	28.06
2011–12	14.95	9.40	5.46	29.80	28.30
2012–13	14.31	9.27	6.24	29.82	27.37
2013–14	13.14	9.08	7.71	29.93	28.85
2014–15	11.23	10.88	7.84	29.95	29.57
2015–16	9.77	10.51	9.42	29.70	29.04

Source: Cement Manufacturers' Association (2017)

2.4.9 Clean Development Mechanism (CDM) Projects

There are 25 CDM Projects Registered from Indian cement industry from 2006 to 2016 (Planning Commission, 2011). Total Estimated emission reduction (Certified emission reductions, CERs) in metric tonnes of CO_2eq per annum are 2317795 from 2006 to 2016[4] generally in the field of Optimum utilization of clinkers, WHR power projects, partial replacement of fossil fuel by biomass and alternative fuels, energy efficiency by up gradation and modification of equipments and systems from Indian cement industry.

[4]https://cdm.unfccc.int/Projects/projsearch.html (accessed on 06.11.2017)

2.4.10 Emissions

India presently stands as the fourth largest emitter of GHGs, ranking next to China, United States of America and Russia. However, the per capita emission of India is far below than world average level (CII, 2010). Annual GHGEs from the Indian cement industry has raised from 7.32

Mt in 1993 to 16.73 Mt in 2003, and during this period, its share in total CO_2Es has raised from 3.3-4.8% (Mandal and Madheswaran, 2011). At present, the cement industry is the third largest energy consumer and second largest CO_2 emitter in India's manufacturing sector (IEA, 2013) contributing 9% of the total national emissions inventory, emitted 52 Mt of CO_2 in 2013 (Garg et al., 2017). Achievement of reducing significant carbon footprint of Indian cement industry from 1.12 tCO_2/t cement in 1996 (IEA, 2013) to 0.82 tCO_2/t cement in 2007 (Planning Commission, 2011) further to 0.719 tCO_2/t cement in 2010 (Woywadt and Henrich, 2015; IEA, 2013). Table 2.5 shows major cement producing countries CO_2Es in 2007

Table 2.5: Cement production, emission factor and CO_2 emission of major cement producing countries in 2007

Country	Cement Production (Mt)	Emission Factor (tCO_2/t cement)	CO_2E (Mt)
China	1354.0	1.14	1543.56
India	171.0	0.82	140.22
Japan	71.4	0.74	52.55

Source: Planning Commission (2011)

The cement industry has a unique profile since the majority of GHGEs are coming from the process emission, not caused by fuel combustion emissions. Around 60% of total CO_2Es from clinker production are released directly from the calcination of limestone as calcination of one tonne of limestone gives rise to 0.44 tonne of CO_2 and as a rough estimate, total CO_2E per tonne of cement range from 0.85 to 1.15 tonne. Of the remaining 40%, mostly originate from the burning of fuel in the kiln. Indirect emissions from electrical power consumption contribute about 6% to overall CO_2Es (ECA, 2013; IL&FS Ecosmart Limited, 2010a) some 5% of CO_2Es are associated with other activities like quarry mining and transportation (Hasanbeigi et al., 2012). For every 1 kW/Mt cement reduction in specific electric energy consumption, CO_2E will be reduced by 0.9 to1.6 kg CO2/t cement, and for every 10 kcal/kg clinker reduction in specific thermal energy consumption, CO_2E will be reduced by 2.6 to 3.6 kg/t cement (CII, 2010). The mass balance for an OPC plant specified 0.4 tonne CO_2Es from the process of calcinations and 0.2 tonnes from the combustion of fuel for every tonne of cement. However, lowering the clinker ratio can help in reducing total emissions per tonne of cement since both the fuel consumption and specific process emissions depend on the clinker cement ratio (Bhushan, 2010) thus clinker substitution is key contributors to the overall reduction of CO_2Es (Kajaste and Hurme, 2016a). For every 1% increase in additives in blended cement production, CO_2Es will be reduced by approximately 4.0–6.5 kg per tonne of cement, keeping all other parameters constant (CII, 2010).

The use of high calorific value alternate fuels in cement kilns reduces coal consumption, and hence, GHGEs reduce significantly (Gielen and Taylor, 2009; Kajaste and Hurme, 2016a). If efforts are taken to replace the conventional fossil fuel with alternate fuel by at least 10%, this will result in reducing the emissions by about 22 kgCO_2/t cement (CII, 2010). Improved energy efficiency, coupled with power generation through low (or zero) emission technologies or the use of alternative fuels, can significantly reduce CO_2Es from CPPs also it has the potential to improve the national energy security by reducing the electricity required for cement manufacturing from public utilities (IEA, 2013).

2.5 Review of Drivers of and Barriers to climate change mitigation strategies implementation

Dutta and Mukherjee (2010) studied steel, aluminum, and cement industry of India and projected their energy demand and potential of any decrease in their energy consumption in the future. They also explored the possibilities of reduction in energy consumption in these industries using alternative situations for 2001–2031. Their study proposed that some possible energy efficiency improving techniques exist in these sectors. Exploring these options will definitely ensure cost-effectiveness and competitiveness of these three key sectors in the global market.

Hasanbeigi et al. (2010) used a bottom-up electricity Conservation Supply Curve (CSC) model to estimate the cost-effective and the total technical electricity-efficiency potential for Thai cement industry in 2008. It is shown by the results of the analysis that a voluntarily agreed energy-related CO_2 tax for the cement industry is the most effective and efficient policy scenario.

Mandal and Madheswaran (2010) used Data Envelopment Analysis and Directional Distance Function technique to calculate environmental efficiency of Indian cement industry within a joint production framework of both desirable and undesirable output. Their observed results show that the cement industry of India has sufficient potential to increase their environmental efficiency. The results also show that if environmental regulations are imposed on the cement sector of India, it is capable to grow desirable output and shrink undesirable output with certain input.

Ali et al. (2011) studied various techniques to decrease CO_2 emission and its generation by burning the fuels in cement plants. It was presented in the review that a substantial quantity of emission can be decreased by using various techniques and energy savings measures.

Madlool et al. (2011) estimated the use of energy in various sections of the cement industry. Various sections are specific energy consumption, types of energy use, details of the cement manufacturing process, various energy-saving measures. The study was conducted to identify the wastage of energy so necessary measures could be taken to decrease the consumption of energy.

Schneider et al. (2011) investigated the challenges of reducing the emission of GHGs and conservation of material which the cement industry is facing worldwide. The use of the highly efficient method and other sources of energy, which are limited in abundance, are the main pillars of the cement-manufacturing units. Because of this, a new additive can be used as a constituent in the upcoming years.

Benhelal et al. (2013) analyzed the worldwide strategies and possibilities of reduction in CO_2 emissions in the cement industry. The most hopeful methods as well as the hurdles against global development are presented and comprehensively explained. Energy saving, carbon separation and storage, and utilizing alternative fuels are three major plans to mitigate the CO_2 emissions, discussed elaborately in this review.

Ekincioglu et al. (2013) studied the cement manufacturing in a Turkish cement company where alternative fuels, raw materials, by-products, and energy efficient methods are used. They used this study to express the sustainability of building materials in the construction industry of Turkey.

Li et al. (2013) did a comparative study of different techniques for capturing CO_2. For example, Post-combustion capture with chemical absorption, Oxyfuel, and Carbonate looping technologies for the cement manufacturing process. They also analyzed the economic and financial issues in deploying CO_2 capture in the cement industry. Financial help form public and/or CO_2 capture are required to spark large-scale CCS demonstration projects in the cement industry.

Madlool et al. (2013) analyzed and studied earlier work done on energy saving techniques used to increase energy efficiency and CO_2 emission reductions in the cement industry. Largest amounts of thermal energy savings, electrical energy savings and emission reductions to date were recorded.

Ostad-Ahmad-Ghorabi and Attari (2013) discussed the environmental evaluation of the cement industry in Iran. To advance environmental evaluation, a set of appropriate 15 indicators have been developed by cooperating with experts from university, industry, and policymakers. By using the TOPSIS method, indicators were prioritized, and improvement strategies for this industrial sector were derived. The result shows that indicator Inefficiency level in the execution of ISO 14000 has the highest priority, followed by the intensity of CO_2 emission.

Morrow et al. (2014) reviewed energy efficiency actions relevant to the cement sector of India. A forward-looking bottom-up Conservation Supply Curve model utilizes forecasted Indian cement demand, current adoption estimates for energy efficiency measures, and a stock roll-over methodology for the cement industry. The estimates from this study give a comprehensive perspective to the Indian cement industries and policymakers about the energy efficiency potential and its associated costs over the next twenty years.

Petek Gursel et al. (2014) conducted Life-cycle inventory (LCI) analysis of concrete production for understanding and lowering the environmental impact of concrete and other buildings materials. This article reviews the strengths and weaknesses of concrete LCIs and offers a research roadmap to improve the quality of future cement and concrete LCIs and meet the needs of major life-cycle assessment users.

Venmans (2014) applied neo-classical economic theory as well as insights from transaction cost economics and behavioral economics to understand why hurdle rates, even when omitted costs and risk are taken into account, are higher than the weighted average cost of capital. The results indicate that the voluntary agreement and the emission-trading scheme are complementary, addressing different barriers in different contexts.

Feiz et al (2015) applied a concept in cement production cluster in Germany in about three plants and the gravity of continuous assessment and improvement has been proven. It has been a prominent fact that entrenched and efficient production system necessitates everlasting efforts of discovering the loopholes in the existing production system and then actualizing the elucidation, though it demands consideration of enormous parameters, which has to be evaluated with precision, and then the best solution has to be chosen.

Li et al. (2015) calculated CO_2 emissions of China's cement sector using Life Cycle Assessment method. It was showed in results that carbon emissions of Portland cement clinker, Portland cement are lower in China compared to developed nations.

Nguyen and Hens (2015) scrutinized the difference between pre and post-certification of the cement plants as per the repercussion of ISO- complaint Environment Management System in the cement industry of Vietnam. The results were assimilated between certified and non-certified cement plants, by availing various environmental indicators and examinations. Consequently, certified plants executed better than the non-certified ones when accompanied by proper administration and operational aspects.

Tesema and Worell (2015) analyzed the possibilities of energy savings and decrease in emission by benchmarking or standardizing the energy performance for the cement industry in Ethiopia. The standardizing showed that when it was compared with international practice, the intensity of energy of local cement facilities is high. It implied a noteworthy possibility for an increase in energy efficiency. The major hurdles in adoption of energy efficiency measures are subsidized power supply, financial constraints, lack of sector targets, energy supply constraints, lack of information on opportunities, lack of infrastructure for alternative fuels, and limited coordination between government and cement plants.

Vargas and Halog (2015) presented a system dynamics model by simulating five different cement life-cycle scenarios to quantify the net CO2 reductions when using upgrading processes of fly ash. A material flow analysis was carried out to describe the scenarios and to simplify the life-cycle approach. It was found that the upgrading process modelled can have a maximum value of energy per tonne of fly ash and still be able to produce net reductions.

Wen et al. (2015) evaluated the capability of energy saving and reduction in CO_2 emissions in China's cement industry by developing a model based on Asian-Pacific Integrated Model between 2010 and 2020. Adjustment of the structure is found to be the most important approach to decrease the CO_2 emissions and energy savings.

Cao et al. (2016) developed an accurate and comprehensive CO_2 emission factor for the Chinese cement industry by a factory-level database of 197 cement production lines from 21 provinces covering various capacity scales. Based on this database, process, fuel, electricity and synthesized emission factor were computed. Furthermore, bootstrap simulation and Monte Carlo simulation were applied to evaluate the uncertainty of these factors. The simulated results indicate that the revised output method produces more accurate estimation for the process emission factor than the revised input method and unrevised output method.

Gao et al. (2016) analyzed the material flow and its consumption in the process of cement manufacturing. In this analysis, improvement in managing the resource used in the manufacturing of cement is studied. The results showed that energy and resources might be recovered from heat loss and waste gas. To improve the material utilization, a planned and conscious effort is required, particularly in raw meal and cement mill units.

Kajaste and Hurme (2016) established that GHG emissions in the cement industry are linked with clinker substitutes, main energy source, electricity emissions, geographic location, and technology used. They implemented a climate impact management matrix on a cradle-to-gate basis to study regional CO_2 emissions in the cement industry. The study exhibited that the variation of process technology and thermal energy use related CO_2 emissions is notable than the emissions due to electricity. Additionally, a comparative study was done on the CO_2 abatement costs of various investment projects by using a uniform capital recovery factor.

Liu et al. (2016) investigated the data gathered from 78 cement companies in China and presented the impact of carbon pricing to encourage the spread of low carbon technologies (LCT). Lack of finance and policy uncertainty was two main hurdles in adoption of LCT. The study further showed that the cement sector in China know major energy saving and LCT and already doing that but are lagging behind in carbon management.

Salas et al. (2016) presented literature review serves for describing the environmental impacts, clarifying the methodological approaches in life cycle assessment, and identifying the main alternatives to improve the environmental performance of cement production. These studies identified the improvement of energy efficiency, the use of alternative fuels, clinker substitution, and carbon capture and storage as the main solutions for mitigating environmental impacts caused by cement production. carbon capture and storage has a high improvement potential; however, it presents technical and economic barriers to its implementation

Summerbell et al. (2016) analyzed production data to examine variation in the fuel-derived emissions with the help of two mathematical models, to estimate the potential for operational improvement. Limited capital budgets and potentially long payback periods on investing energy-efficient technologies can slow the rate at which such technologies are introduced, so a reduction in carbon emissions lags behind technological advances. This paper concluded that there exists significant opportunity to reduce the emissions from cement plants by operational means, and that fuel mix and excess air ratio should be the focus of future research.

Abadie et al. (2017) concentrated on evaluating the risk connected with the price of European Union Emission Trading System allowances in the coming years. They modelled a stochastic process with parameters calculated using the market process. It was also shown that by using Real Options Analysis the optimal conditions for retrofitting a wet cement plant to convert it to a dry cement plant under uncertainty of the price of carbon allowances.

Herrera et al. (2017) conducted a survey among energy managers to find the hurdles that obstruct the implementation of energy efficiency measures in cement industry of Colombia. It was found by the study that the major hurdle to the penetration of energy efficiency technologies is the hidden costs associated with the implementation of emission reduction technologies.

Liu et al. (2017) analyzed the cost-effectiveness to evaluate the new technologies available in cement industry of China. The result showed the requirement to design the technology promotion roadmap. It was obtained by setting up a multi-objective optimization model. It proved to be the top solution for achieving energy saving, pollution, and emission abatement compared to single-objective optimization models.

Matar and Elshurafa (2017) examined the effects of profit and CO_2 emissions, two competing objectives, in Saudi Arabia cement industry. It was found in the study that the environmental regulations and behavioral considerations depending on the price of CO_2 have a big effect on the process of decision making of the cement industry. Also for a low carbon price, the industry would have to care for emissions considerably in order to mitigate it and for a higher carbon price, behavioral considerations have a limited impact in the wake of profits.

Zuberi and Patel (2017) studied the ways to improve energy efficiency and possibilities of CO_2 declining using energy efficiency cost curves in the Swiss cement industry. The investigation resulted in the improved insight into the energy efficiency gap that can help in making better effective policies.

Di Filippo et al. (2018) compared three instruments meant to correct the critical market failure of wide-scale adoption of mitigation technologies in the concrete supply chain, including, carbon-pricing policies, command and control policies and voluntary incentives. They evaluated each policy instrument for its capacity to reduce emissions cost-effectively, guarantee emission reductions, spur technological innovation, and generate revenue. Analysis indicates that carbon-pricing policies favor these criteria along the concrete supply chain.

Scrivener et al. (2018) presented the possibility to make a coupled substitution of cement with calcined clay and limestone. A blend of calcined clay with limestone allows higher levels of substitution down to clinker contents of around 50% with similar mechanical properties and improvement in some aspects of durability. The replacement of clinker with limestone in these blends lowers both the cost and the environmental impact.

Verma et al. (2018) conducted a study to determine the levels of water-soluble hexavalent chromium in seven different cement samples from New Delhi, India. They suggested that Indian manufacturers should also be subjected to regulatory control forcing them to process the cement to reduce its hexavalent chromium level, which could decrease the occurrence of occupational allergic contact dermatitis caused by cement in exposed workers in India.

Mirhosseini et al. (2019) Harvested waste heat from cement kiln shell by a thermoelectric system. By using a comprehensive numerical simulation, the temperature on the absorber is obtained and utilized as the hot side boundary condition of the thermoelectric generator system. The results show the optimum leg length obtained by analyzing cost per power ratio is shorter than the leg length corresponding to the maximum peak power output at a fixed fill factor.

Raffetti et al. (2019) aimed to summarize the evidence on the health effects of people exposed to ambient air pollution by cement plants by systematic review. Almost all the studies found positive associations between cement plant exposure and respiratory diseases and symptoms. An excess risk of cancer incidence and mortality in both children and adults, mainly concerning respiratory tract cancers was also reported in some studies. Higher values of heavy metals and a biomarker of renal toxicity were found in the exposed compared to unexposed populations.

Shanks et al. (2019) estimated the potential for reducing demand by material flow analysis in the cement industry by combining published data, analytic assumptions, and interviews in the UK as the case study. They argue that availability of waste fuels and competition for biomass may be a limiting factor also they found that the substitution of cement with calcined clay and limestone has the biggest potential to reduce cement demand and carbon emissions in the UK.

Table 2.6 shows the past studies discussed barriers to climate change mitigation strategies of the cement industry while Table 2.7 shows past studies on Climate change mitigation strategies of the cement industry.

Table 2.6: Past studies discussed barriers to climate change mitigation strategies of the cement industry

Author (Year)	**Barriers to climate change mitigation measures found in the cement industry**	**Methodology**	**Region/Context**
Dutta and Mukherjee (2010)	Barriers to low energy consumption are available technology and government policies	MARKAL model	India
Hasanbeigi et al. (2010)	Barriers to emission reduction investment are observed risk, financial limitation, and high payback periods and low internal rates of return, management attention towards production and other issues, lack of information	Conservation supply curves	Thailand
Madlool et al. (2011)	Barriers to emissions are plant-specific operational conditions, initial capital costs are high, inadequate government policies, lack of technical knowledge and investors' preferences	Review	----
Imbabi et al. (2012)	Limitations to the production of blended cement are availability, cost, standards, and regulations of the clinker substitute materials and. In addition to this use of alternate fuels faces legal and political barriers	Review	UK, US, and Gulf
Benhelal et al. (2013)	Barriers to mitigation measures are low energy prices, limited capital investment, production concerns, facility uncertainty, reliability concerns, legislation, and planning, limited time and number of staff, policy, availability of raw materials, properties of produced cement and national standards and market acceptance of blended cement	Review	
Hasanbeigi et al. (2013)	Various non- monetary barriers to emission reduction are a lower priority, uncertainty about emerging technologies and lack of information.	Conservation supply curve	China
Wang et al. (2013)	Barriers to mitigation strategy are higher costs, lack of convincible indicators and lack of applying innovative green technologies	Logarithmic Mean Divisia Index method	China
Brunke and Blesl (2014)	Longer payback time is the main barrier to the adoption of emission reduction technology	Conservation cost curves	Germany
Feiz et al. (2015)	Barriers to improving CO_2 performance of the cement industry are competing priorities such as pressure for short-term profits, lack of awareness of environmental issues and lack of information or expertise	Integrated assessment framework consists	Germany
Ishak and Hashim (2015)	Lack of intelligence and high financial costs are the barriers faced by the cement industry while cogeneration using waste heat recovery	Review	-----
Rahman et al. (2015)	Utilization of alternative fuels in cement kilns is facing some barriers such as environmental, social, quality issues and high moisture content.	Review	Australia
Tesema and Worrell (2015)	Barriers to emission reduction measures are lack of capital, lack of infrastructure for alternative fuels, energy supply constraints, subsidized power supply, limited coordination between government and cement plants, lack of information on opportunities, and lack of sector targets	Conservation supply curves	Ethiopia

Author (Year)	Barriers to climate change mitigation measures found in the cement industry	Methodology	Region/Context
Vargas and Halog (2015)	Communication between companies is found the main barrier preventing the expansion of wider use of fly ash for making blended cement	Simulation	-----
Zhang et al. (2015)	Barriers to implementation of mitigation measures are lack of awareness, lack of professional skills of staff, lack of information, capital constraints, the varying characteristics of alternative fuel and technical challenges	ECSC GAINS model	China
Huang et al. (2016)	Barriers to the use of alternative fuels are lack of legislative support for waste incineration, availability and a lack of public acceptance and understanding and barriers to the application of blended cement are existing product standards	ARIMA model	Taiwan
Kajaste and Hurme (2016)	Barriers to CO_2E reduction measures are low CO_2 prices in emission trading systems, the lower service life of key equipment, the cement quality is strictly standardized and regulated, high financial requirements for a new plant and the cement market is price dominated	Life cycle assessment	------
Liu et al. (2016)	The barrier for the implementation GHG emission trading scheme and a carbon tax is strong resistance from industry and barriers to adoption of low carbon technology are lack of capital, high upfront costs, and policy uncertainty	Survey analysis	China
Salas et al. (2016)	Carbon capture and storage technology implementation faces both technical and economic barriers	Life cycle assessment	Literature review
Summerbell et al. (2016)	Barriers to investment in emission reduction technologies are insufficient financial budget and long payback periods	Energy consumption model	UK
Herrera et al. (2017)	Barriers to the implementation of mitigation measures are imperfect information, adverse selection, a boss to employee relationships, a form of information, limited rationality, access to capital, hidden costs, credibility, risk, and heterogeneity	Technological obsolescence analysis	Colombia
Li et al. (2017)	Lack of a full understanding of the benefits and costs of low carbon technologies are the barriers for implementing emission reduction measures effectively	Stock-based and MARKAL model	China
Liu et al. (2017)	Lack of information at investment timing in emission reduction technologies is the main barrier	Simulation model	China
Zuberi and Patel (2017)	Lack of data and low final energy prices are the main barriers to emission reduction also some non-monetary barriers are permit issues limiting the installation of an additional preheater stage, space issues associated with the installation of more efficient classifiers and unavailability of the suitable waste fuels	Energy efficiency cost curves	Switzerland
Present study	Barriers to climate change mitigation strategies in the Indian cement industry	Fuzzy AHP-TOPSIS	India

2.6 Solutions to overcome barriers of climate change mitigation strategies implemented in the cement industry

Cement manufacturing industry needs to actively incorporate emission reduction strategies in response to burgeoning needs of climate change as a cement manufacturing process is emission intensive (Herrera et al., 2017; Feiz et al., 2015; Benhelal et al., 2013). Although the Indian cement industry is most efficient in the world (Garg et al., 2017; CII, 2015), face many obstacles in further developing emission reduction strategies. Literature and experts suggest valuable solutions for the cement industry to overcome these obstacles while implementing mitigation strategies. Through literature and experts opinion a list of potential other solutions are identified, which are shown in Table 2.7.

Table 2.7: Solutions for implementing change mitigation strategies in the cement industry

Code	Solutions	References
S1	Establishment of financial resources, capabilities and contingency plans for mitigation measures	K. L. Scrivener et al., 2018; Cormos and Cormos, 2017; Herrera et al., 2017; Summerbell et al., 2016; Tesema and Worrell, 2015; S. Zhang et al., 2015
S2	Top management commitment and incorporation of climate change mitigation measures in corporate strategies	Herrera et al., 2017; Xianbing Liu et al., 2017; Supino et al., 2016; Nguyen and Hens, 2015; CDP India, 2013
S3	Provision of well-defined and environmental supportive government policies and directions	Jokar and Mokhtar, 2018; Talaei et al., 2018; Herrera et al., 2017; Xianbing Liu et al., 2017; Salas et al., 2016; Ke et al., 2012; Dutta and Mukherjee, 2010
S4	Awareness and education of the customers and society about low carbon products and benefits of emission reduction	Jokar and Mokhtar, 2018; K. L. Scrivener et al., 2018; Vargas and Halog, 2015
S5	Conduct seminar, motivational programs and arranging funds for supply chain partners to build their commitment about emission reduction	K. L. Scrivener et al., 2018; Herrera et al., 2017; Zhang and Mabee, 2016; Xianbing Liu et al., 2016; Feiz et al., 2015; Nguyen and Hens, 2015; Madlool et al., 2011
S6	Multiple supplier policies based on environment criteria	Di Filippo et al., 2018; Martin Schneider, 2015; Nguyen and Hens, 2015
S7	Building environmental collaboration and partnerships within and across the industrial sector at a different level	K. L. Scrivener et al., 2018; Supino et al., 2016; Tesema and Worrell, 2015; Vargas and Halog, 2015; Petek Gursel et al., 2014
S8	Training and education of employee to increase their competency regarding climate change mitigation	Herrera et al., 2017; Summerbell et al., 2016; Klemeš et al., 2012; Madlool et al., 2011; Dutta and Mukherjee, 2010
S9	To develop and upgrade on state-of-the-art-technology being used in the specific sectors for the implementation of the emission reduction target.	Herrera et al., 2017; Xuewei Liu et al., 2017; Xu et al., 2014; Ansari and Seifi, 2013; Madlool et al., 2011; Dutta and Mukherjee, 2010

Code	Solutions	References
S10	R & D facilities in collaboration between industries, educational institutes, and the Government	Feng et al., 2018; Tesema and Worrell, 2015; Ostad-Ahmad-Ghorabi and Attari, 2013; Imbabi et al., 2012
S11	Implementation of policies for the use of alternate substituting material and waste as a fuel including biomass	Shanks et al., 2019; Jiang et al., 2018; Herrera et al., 2017; Zhang and Mabee, 2016; Gao et al., 2015; Madlool et al., 2011
S12	The government should implement "Pollutants have to pay" Principle	**Industry expert's opinion**
S13	The government should enhance the workforce for monitoring pollution prevention and reduction activities	Raffetti et al., 2019; Mirzakhani et al., 2017; Su et al., 2013; Dutta and Mukherjee, 2010
S14	Govt. should create a healthy environment for Carbon market/emission trading systems	Bhandari and Shrimali, 2018; Ostad-Ahmad-Ghorabi and Attari, 2013

Table 2.8: Past studies on Climate change mitigation strategies of the cement industry

Author(s) year	Methodology/Method	Country	Key Findings
Ali et al. (2011)	Literature Review		The storage of captured CO_2, from flue gases, into the soil or ocean is one of the most cost-effective ways of decreasing emissions from cement production. It can decrease emissions by 65-70%. Reduction in clinker/cement ration by the addition of various additives can also decrease CO_2 emissions. Replacement of fossil fuels with alternative fuels can also help in the reduction of CO_2 emission in cement manufacturing.
Madlool et al. (2011)	State of the art review		Use of alternative fuels or waste heat recovery could be a good mitigation solution. A dry process found to be more energy efficient compared to the wet process VRM, high pressure grinding rolls or horizontal/ring roller mill can be considered viable options due to the low specific energy consumption. Raw meal process control for vertical mills in the dry process can reduce SEC by 6% with a payback period of about 1 year. Use of an adjustable speed drive for kiln fan for clinker making found to be saved about 30% of energy consumption with a payback period of about 2–3 years. Conversion to reciprocating grate cooler for clinker making in rotary kilns may save more than 8% of energy consumption in clinker production with a payback period of 1–2 years
Hasanbeigi et al. (2012)	Technical review		This paper consolidated available information on eighteen emerging technologies for the cement industry, to provide engineers, researchers, investors, cement companies, policymakers, and other interested parties with easy access to a well-structured database of information on these technologies
Ke et al. (2012)	Cement production projection	China	Policies which emphasize on limiting the total production of cement are an effective way to decrease CO_2 emissions and total consumption of energy, whereas energy efficiency is the most important policy measure that talks about the reducing the energy and emissions intensity of the cement industry
Benhelal et al. (2013)	Review		In this paper three well thought out approaches viz. energy saving approach, carbon separation and storage approach, and utilizing alternate materials approach are discussed. These approaches are based on the analysis of factors causing the CO_2 emissions during the cement production and the process of cement production.
Hasanbeigi et al. (2013)	Bottom-up Conservation Supply Curve model	China	The cumulative cost-effective electricity savings potential for the Chinese cement industry for 2010–2030 is estimated to be 247 TWh. The CO_2 emission reduction associated with cost-effective electricity savings is 138 Mt CO_2. The fuel CSC model for the cement industry suggests cumulative cost-effective fuel savings potential of 4106 PJ
Madlool et al. (2013)	State of the art review		The energy-saving measures studied were shown to be effective ways to improve energy efficiency and reduce greenhouse gas emissions. The amounts of thermal energy savings, electrical energy savings, and emission reductions were seen to vary from 0.05 GJ/t, 0.08

Author(s) year	Methodology/Method	Country	Key Findings
			kWh/t and 0.1 $kgCO_2$/t to 3.4 GJ/t, 35 kW h/t and 212.54 $kgCO_2$/t, respectively
Morrow et al. (2014)	Bottom-up Conservation Supply Curve model	India	For India's cement industry, increased production of blended cement and kiln shell heat loss reduction are the two most cost-effective fuels savings measures. The two most cost-effective electricity savings measures are the installation of high-efficiency fan for raw mill vent fan with inverter and high-efficiency motors. The largest electricity saving potential is from low-temperature waste heat recovery power generation, It is estimated that from 2010 to 2030, cumulative cost-effective electricity savings are 83 TWh, with an associated 82 Mt CO_2 emissions reduction; and cumulative cost-effective fuel savings are 1029 PJ, with an associated CO_2 emission reduction of 97 Mt CO_2 for India's cement industry
Gao et al. (2015)	Input and output method	China	All of the process emissions by the input method are lower than those by the output method. About 13 kg and 11 kg process emissions based on input method are lower than output method for NSP kiln and shaft kilns, respectively
Salas et al. (2016)	Literature Review		The application of the best available technologies and using dry processes are the most effective measures regarding energy efficiency. These studies also identified that the use of alternative fuels, clinker substitution, and carbon capture and storage as the main solutions for mitigating environmental impacts caused by cement production
Cormos and Cormos (2017)	modelling and simulation	Romania	The analysis focusing on mass and energy integration aspects of the carbon capture unit as well as quantification of main techno-economic and environmental indicators of the cement plant with carbon capture. For comparison reason, a cement plant without carbon capture was also considered to assess the energy and cost penalties for the carbon capture designs. The analysis shows that the calcium looping system has significant technical and economic advantages compared to the gas-liquid absorption case
Matar and Elshurafa (2017)	Striking a balance between profit and carbon dioxide emissions in the Saudi cement industry	Saudi Arabia	This paper presents a multi-criteria analysis to examine how two competing objectives, profit, and CO_2 emissions affect the performance of the cement industry in Saudi Arabia. This paper found environmental regulations and depending on the CO_2 price, behavioural considerations have a major impact on the decision-making process of cement manufacturers, for a low carbon price, the industry would have to care for emissions considerably to mitigate it
Mirzakhani et al. (2017)	Pinch Analysis	Denmark	This research focused on the development of a rapid approach for benchmarking of an existing plant concerning energy consumption and subsequently estimating an achievable scope for energy saving. To realize this goal, five different pyro-process units were simulated and then targeted using Pinch Analysis approach. Having done this conceptual analysis, the obtained results showed an energy saving potential of up to 24%
Huh et al.	The mixed MDCEV	South	This study analyzed the inter-fuel substitution paths for the cement industry, along with its

Author(s) year	Methodology/Method	Country	Key Findings
(2018)	model	Korea	impacts on emissions reduction. The results show that firms' marginal utilities from using bituminous coal are still larger than those from other alternative fuels. Further, this study also provides policy implications for the government, which plays a crucial role in designing incentives for firms to use alternative fuels more often
Miller et al. (2018)	Life-cycle assessment		This research examined future viable global CO_2 mitigation strategies for the cement industry. This paper shows that the 2 °C scenario targets for 2050 can be met through increased use of calcined clay and engineered filler with dispersants. The introduction of new Portland clinker-based cement alternatives, use of alkali-activated materials, and improvement of efficiency of cement use could further contribute to reduction goals also there are currently available technologies for reduction that could be rapidly implemented
Scrivener et al. (2018)			This paper investigated potential economically viable solutions for a low-CO_2 cement-based materials industry. The research found that increased use of low-CO_2 supplements as partial replacements for Portland cement clinker and more efficient use of Portland cement clinker in mortars and concretes. These two product-based approaches can deliver substantial additional reductions in their global CO_2 emissions, reducing the need for costly investment in carbon capture and storage over the next 20–30 years
Carrasco et al. (2019)	Experimental setup	Germany	The present study reported the results of several combustion tests employing a downscaled commercial kiln burner to determine its adequacy for oxyfuel operation mode. It was observed that under oxyfuel mode additional parameters in burner configuration like total oxygen concentration and oxygen distribution in primary and secondary gas are key variables to adjust flame formation and obtain similar results as in conventional air firing
Farfan et al. (2019)		Global	This research proposes a global potential analysis of Carbon capture and utilization (CCU) as a possible solution for the CO_2 emissions of cement production. Cement CCU may establish a substantial route to use CO_2 for synthetic hydrocarbons production and thus contribute towards mitigating the non-substitutable CO_2 content of the limestone-based raw material. The production of renewable electricity based synthetic hydrocarbon fuels by CO_2 captured from cement plants, counts for a potential to produce between 3639 TWhth and 7355 TWhth of liquid hydrocarbons, or 6298 TWhth and 12723 TWhth of synthetic natural gas, or a mix of both at the expected global cement peak production in 2040
Naeimi et al. (2019)		Iran	This paper has studied the feasibility of technical design of WHR from a gas engine to use in electrical power generation at Tehran Cement factory. Based on the obtained results, the amount of recovered heat was 23931 kJ/s and 21253 kJ/s, respectively. Also, the efficiencies of the power generation cycles were equal to 23.5% and 22.2%, respectively

2.7 Research Gaps

After reviewing, the seminal literature related to the climate change mitigation barriers following relevant research gaps is identified. (Shanks et al., 2019; Xuewei Liu et al., 2017) Claims that continuous manufacturing of cement has increased the consumption of raw materials, consumption of fossils fuels, and other resources and caused several climate change externalities in the form of GHGEs and other industrial waste. In line to above, IPCC (2014) suggested that implementation of climate change mitigation strategies could help in reduce the GHGEs and hence reduce the harmful environmental impact of the organizations. However, while adopting emission reduction strategies into the cement manufacturing system, organizations face several barriers. Therefore, an urgent need to address prominent barriers of climate change mitigation strategies in cement industry of developing nations. However, literature suggests that there are very few studies that focus on barriers to climate change mitigation strategies adoption in emission-intensive cement industry in developing nation context (Table 2.6). Also, there is an almost negligible study in the context of developing countries like India, and almost all of the past studies are being conducted in developed economies. There is no study conducted to evaluate the importance of the barriers so that their importance can be known. Lastly, there is no study available that proposes a solution to overcome these barriers. Therefore, in the backdrop of this, the first objective of the current study is to identify and prioritize the barriers and simultaneously the second objective is to list the solutions to overcoming these barriers to emission reduction measures in the context of the Indian cement industry.

For any industry, there is a considerable role of mitigation strategies in reducing the GHGEs hence producing low carbon and sustainable products. It seems that many industries across the world share the same drivers when trying to adopt emission reduction measures. However, the country-specific regulations, policies, social issue, market conditions, laws, etc., might influence the significance of drivers, as well as generate particular ones. Literature review shows that both academicians and professionals are interested in analyzing drivers to mitigation strategies. Section 2.4.1 highlights the research gap in climate change mitigation strategies in the Indian context. Due to NAPCC and commitment of emission reduction in Paris Climate Change Agreement 2015, climate change issue-gaining importance in India on top priority.

Similarly, the Indian cement industry is willing to reduce emission by upgrading in emerging technologies and with advanced manufacturing facilities. Section 2.5 points out that although their many barriers to adopt mitigation strategies at the same time, there are many drivers to reduce emission in the cement industry. In addition to these, mitigation strategies are considered by the cement industry as an integrated part of their corporate strategy. There is wide applicability of hybrid AHP and ISM. However, to the best of our knowledge, the present research is the initial attempt of using AHP and ISM methodology for evaluating the relative importance weight and establishes the relationships among each driver to climate change mitigation strategies of emission and energy-intensive cement industry.

The Indian cement industry is responsible for emissions at the national level as well as global level; by adopting mitigation strategies, Indian cement industry not only reduce the emissions and conserve natural resources but, also improve the environment, which is necessary for human well being. Hence, it is essential for the cement industry to think of climate change. Mitigation strategies play a significant role in reducing the GHGEs of any industry hence producing low carbon and sustainable products. Many studies have been carried out for climate change mitigation strategies in carbon-intensive industries (Balsara et al., 2019; Cadez and Czerny, 2016; Singh et al., 2015; Wahyuni and Ratnatunga, 2015; Tang and Luo, 2014; Hashmi and Al-Habib, 2013; Weinhofer and Busch, 2013; Bocken and Allwood, 2012; Lee, 2012; Botto et al., 2011; Lee, 2011; Muthu et al, 2011; Pasqualino et al., 2011; Weinhofer and Hoffmann, 2010; Jeswani et al., 2008; Jones and Levy, 2007; Kolk and Pinkse, 2005; Kolk and Pinkse, 2004). All the studies mentioned above focused on reducing the carbon footprint of some industry or some products, however, this is the first kind of study, which evaluate the relative importance weight and establish the relationships among each common climate change mitigation strategies of manufacturing industries.

Cement manufacturing is a highly carbon-intensive industry. Notably some studies pursued in the field of cement manufacturing, but most of these studies have been done in the context of developed countries (Shanks et al., 2019; Emodi et al., 2019; Miller et al., 2018; Talaei et al., 2018; Cormos and Cormos, 2017; Matar and Elshurafa, 2017; Cao et al., 2016; Gao et al., 2016; Salas et al., 2016; Feiz et al., 2015; Gao et al., 2015; Ishak and Hashim, 2015; Benhelal et al., 2013; Hasanbeigi et al., 2013; Madlool et al., 2013; Wang et al., 2013; Hasanbeigi et al., 2012; Ke et al., 2012; Ali et al., 2011; Madlool et al., 2011). There are very few studies that are done in India, the second largest producer and consumer of cement (Soni et al., 2017; Kajaste and Hurme, 2016; Morrow et al., 2014; Mandal and Madheswaran, 2011; Dutta and Mukherjee, 2010; Mandal and Madheswaran, 2010;Mandal, 2010; Gielen and Taylor, 2009). Further, all the previous studies on assessment of GHGEs and energy consumption of cement industry have used a variety of methodology. However, to the best of our knowledge, this study is a first attempt at using AHP and DEMATEL methodology. Integrating both the methodologies for evaluating the best option among the common climate change mitigation strategies of the cement industry and establish the interaction among them

2.8 Problems descriptions

From a strategic view, the climate change mitigation strategies implementation provides significant resources conservation, environmental protection and improves the environmental-economic performance (MoEF, 2012; MoEF, 2004). Many authors have stated that developed nations have included climate change mitigation measures is a mandatory part of operations while developing countries are still struggling to integrate climate change mitigation strategies in operations (Rao, 2002). Emission reduction measures are still in a state of infancy in emerging economies like India. Hence, complete and grave analysis of climate change mitigation strategies adoption is desirable. To achieve desired objectives, this work is categorized under these dimensions, i.e. management and prioritization of barriers to various common climate change mitigation strategies and ranking the solutions to overcome these barriers, then, evaluating drivers to climate change mitigation strategies implementations, finally, management and analysis of various common climate change mitigation strategies. Hence, efficient, dedicated and robust emission reduction measures are required for mitigating the climate change, especially in the cement manufacturing industry. Also, the highlighted research gaps discussed in the above section justify the need for this research work. Considering the need as well as to justify the purpose of this study, three research problems have been undertaken in this work and are stated as:

- There is relatively scarce literature related to management and analysis of various common climate change mitigation strategies implementation barriers, and very few publications have presented robust identification and analysis of these.

Moreover, during the literature review, a gap was identified which was related to the analysis of management and analysis of various common climate change mitigation strategies barriers to classify, prioritize and evaluate them for determining their relative concern in Indian cement industry. There are many reasons, which are influencing organizations to adopt management, and analysis of various common climate change mitigation practices but the presence of barriers makes management and analysis of various common climate change mitigation strategies implementation difficult and effect of these barriers cannot be overcome at the same time. Hence, it is desirable to overcome these barriers to adopt management and analysis of various common climate change mitigation strategies efficiently. The first important gap which has been recognized after in-depth literature is that none of the studies which has proposed and prioritized the solutions to overcome the barriers of management and analysis of various common climate change mitigation strategies adoption. Thus, a flexible framework based on the fuzzy AHP and fuzzy TOPSIS approach is suggested to overcome the barriers of management and analysis of various common climate change mitigation strategies adoption.

- Secondly, an important observation for the literature is that drivers to adoption of climate change mitigation practices to perform various emission reduction activities by the cement manufacturing organization. We consider emission reduction drivers as factors that motivate firms to engage in climate change mitigation initiatives. The drivers of climate change mitigation measures can provide significant benefits and offer efficient emission reduction of cement production by employing the state of art infrastructure, resource, and technology. However, selection of such drivers from numerous alternatives is difficult and involves various criteria on which organization should focus. Therefore, it is important that selection criteria should focus on a priority basis. This research work develops a framework to evaluate the drivers of climate change mitigation strategies implementation and utilize combined AHP and ISM approach to select the most promising drivers among alternatives for the cement industry.

- Finally, Continuous manufacturing of cement has increased the consumption of raw materials, fossils fuels, and other resources and caused increased GHGEs and other industrial waste also another important observation from the literature is that there is lack of studies to emission reduction measures for cement manufacturing industry in India although Indian cement plant is most efficient plants across the world still there is lack of awareness especially in the area of GHGEs. To achieve these companies have to take strategic decision to develop mitigation strategies under the realistic scenario. Hence, there is a need to implement climate change mitigation strategies for analyzing the emission reduction practices as well as optimize the cement manufacturing process. This study is concerned with implementing climate change mitigation measures may be significant that can reduce the GHGEs of Indian cement industry. This will maximize total emission reduction opportunity and determine the optimal mitigation strategies under uncertain environment and will consider processing cost of cement manufacturing and revenue generated from emission reduction. This will allows the highest-level use of other industrial waste for material substitution and kiln fuel. Hence, industries should identify some mitigation strategies, which have essentially to be, manage and controlled to reduce the GHGEs from the cement industry through an integrated approach by employing analytical hierarchy process (AHP), decision-making trial and evaluation laboratory (DEMATEL) technique.

2.9 Research objectives

The literature review shows that there are still large gaps in the literature of emission reduction measures in the cement industry, which needs to be addressed. The extensive literature review and identification of the gaps have to lead to the formulation of the research objectives. The following research objectives have been formulated for this study and are listed below:

Objective 1: To identify and prioritize the barriers to climate change mitigation strategies of the Indian cement industry.

Objective 2: To develop a flexible framework to prioritize the solutions to overcome the barriers to climate change mitigation strategies of the Indian cement industry.

To achieve the first objective, and to overcome the climate change mitigation strategies adoption barriers, there is a need to identify the barriers to climate change mitigation strategies adoption. It requires a comprehensive study of emission reduction practices and determines the factors, which hinder the successful adoption of low carbon practices. Hence, list all the possible barriers, which affect the adoption of mitigation strategies. After listing the potential barriers and their consequences, it is required to determine how these recognized barriers can be overcome. To overcome these barriers, various solutions and mitigation measures have been identified and these identified solutions are ranked to overcome these barriers on a priority basis.

Objective 3: To identify and analyze drivers to climate change mitigation strategies of the Indian cement industry.

A range of driving factors has been highlighted as responsible for businesses shifting stance towards climate change mitigation. Although a range of factors can be identified by explaining why businesses and organizations would engage with climate change mitigation objectives, have their level of importance at various stages of implementation. Thus, there is a need to identify the drivers to climate change mitigation strategies adoption. However, according to the industrial point of view, it is difficult to give equal importance to all driving factors. Therefore, industries must know which driver should be given more importance regarding engaging climate change mitigation. Hence, they have to identify all the possible drivers, which motivates the cement industry to the adoption of mitigation strategies. Thus, these identified drivers are ranked to implement climate change mitigation strategies.

Objective 4: To identify and evaluate various climate change mitigation strategies of the Indian cement industry.

To achieve this objective, a comprehensive literature review and examination of emission reduction practices in the cement manufacturing industry is required. Thus, from the literature review and consult with experts total twenty-four emission reduction strategies have been identified. Then integrated approach using AHP- DEMATEL is applied to get final rank. AHP is applied to get the relative weights of the climate change mitigation strategies, and DEMATEL is applied to analyze the relationship of the casual interaction among these mitigation strategies.

2.10 Chapter summary

This chapter contains a systematic literature review to address the issue of implementation of climate change mitigation strategies. The Literature collection and analysis framework are proposed, which categorizes research work themes under four dimensions. Further, based on the literature, identified themes were, various emission reduction options, drivers and climate change mitigation strategies adoption barriers and its solution to overcome these barriers. A systematic literature review provides conceptual content and development in the research area and support in the theoretical foundation. This chapter shows the various gaps in the literature under identified themes, which grounds the problems undertaken for this work for the Indian cement industry. To resolve the problem and fulfill the desired objectives, this chapter provides a strong foundation for the need for climate change mitigation strategies to manage the emission reduction options efficiently from an industrial context.

Chapter 3

Research Methodology

Preview

This chapter proposes a research methodology used for barriers to climate change mitigation strategies adoption and prioritizes the barriers overcome solutions, analyzing drivers and evaluating various common climate change mitigation strategies. Besides, it extended the details of the proposed and used research methods and techniques. The data collection methods and procedures, sample design, target populations, data analysis and interpreting of the information have also been discussed.

3.1 Research design

The research design is the first stage of the research methodology, which draws a roadmap for the entire study. Yin (2009) described that research design is a logical chain that connects the empirical data to the study's initial research questions and ultimately, its conclusion. Here in the present study, the exploratory research design is a category is used. Exploratory research technique includes a comprehensive study of the literature on climate change mitigation strategies and has been used to achieve the objectives of the present study. These research designs provide a holistic and structured preview of the research problem.

3.2 Questionnaire design

The questionnaire is designed based on literature review and experts opinions for the objectives mentioned in Chapter 2, which consists of climate change mitigation strategies adoption barriers and solutions to overcome these barriers in the cement industry, drivers to implementing climate change mitigation strategies and various climate change mitigation strategies in the cement industry. The questionnaire has been divided into three sections. Section 1 consists of identification of the climate change mitigation strategies adoption barriers and solutions to overcome these barriers (Refer Appendix A, Table A.4.1, and Table A.4.2), Section 2 presents identification of the drivers to climate change mitigation strategies (Refer Appendix A, Table

A.5.1, and Table A.5.2), and Section 3 deals with identification and evaluation of the common climate change mitigation strategies (Refer Appendix A, Table A.6.1 and Table A.6.2).

In the objective 1 and 2; Twenty-six barriers under five categories and fourteen solutions to overcome these barriers are identified from the literature review and experts opinions, In the objective 3, thirty drivers to climate change mitigation strategies are identified and finalized from the literature review and experts consultations. Further, in the next a similar procedure has been followed for objective 4, with the help of extensive literature review and expert's opinions twenty-four climate change mitigation strategies have been finalized and categorized into five groups. Finally, the questionnaire is facilitated

- To analyze and prioritize barriers to climate change mitigation strategies and the solutions to overcome these barriers,
- To establish relationships among drivers to climate change mitigation strategies and
- To evaluate and establish relationships among the common climate change mitigation strategies.

Details of these activities have been given in Chapters 4, 5, and 6.

3.3 Sample designs

The selection of suitable and feasible samples is necessary to fulfill the objective of the research. There could be several stages in the designing of samples such as, identifying the target population, defining the sampling structure, choosing the sampling method, estimating the sample size, etc. The main concern during the sample selection is whether the sample is industry specific or not. These are arguments that the sample should be taken from a wide range of industries. However, literature and expert judgments uncover that each industry faces specific challenges. Hence, the sample should be industry-specific, which gives more applicability to the research findings for that industry (Senthil et al., 2014). Another concern regarding the selecting of the sample is linked to the kind of respondents needed for the research. The accomplishment of research depends on the selection of suitable respondents. In this work, respondents have been selected from the middle and senior-level managers and engineers and the top management personnel of the cement industry. The adoption of emission reduction initiatives into companies operations and policies and extending to supply chain is very strategic. Hence, only middle to upper-level management personnel have been selected as the respondents. These respondents were expected to be involved in emission reduction operation of the industry.

3.4 Target population

The target population is determined in terms of elements, time and extent. In this research work southern, a central and western region of India is selected for data collection due to proximity, convenience, and the existence of major cement industry. The target population for the present work is given below:

Elements - Management and technical personnel (Middle and upper-level managers and engineers)

Time - June 2017 to July 2017

Extent - Southern, Central and Western region of India.

3.5 Elements - Management and technical personnel (Middle and upper-level managers and engineers)

Primary data was collected by personal interview for the present work. The elements of the study are management professionals and technical personnel of the cement manufacturing industry in India. Since the adoption and extension of climate change mitigation strategies initiatives requires strategic decision-making, only middle level and top-level managers and engineers were targeted for the responses. The second reason for the selection of middle and top level managers and engineers was that strategic decision makers could provide the appropriate information regarding the decisions of implementation of emission reduction initiatives at various levels of business in the supply chain.

In the process of data collection, the authorities were appointed by applying purposive snowball sampling method for recognizing the respondents who would be capable of giving the requisite information (Raju and Becker, 2013; Kabra et al., 2015). The selection of professionals was decided based on certain criteria such as their individual industrial and consultancy experiences, qualification level (helpful in decision-making skills), expertise in the area, (their background), etc. Identified professionals are highly skilled personnel in their field and having good knowledge of emission reduction activities. Middle and senior rank engineers and managers with divergent accountability were selected during the data collection process because they are an integral member of the strategic decision-making group (Carter et al., 1998). The selected industrial experts were remarkably proficient in their discipline, having industrial experience of above 10 years. The respondent's position and department, experience and respective plant capacity are display in Table 3.1. The questionnaire was created to obtain experts' viewpoint on the cement industry. Before data collection, we thoroughly explained the objective and utility of the research to each respondent. We also outlined the potential advantages of the research then experts were asked to rate the questionnaire based on a linguistic value. Sample questionnaires are shown in Appendix A.

Table 3.1: Respondents position and department, Experience and respective plant production capacity

Respondent	Respondents position, department	Experience in years	Production capacity of respective industry in million ton per annum (MTPA)
1	DGM, Process	15	9 (Four Units)
2	DGM, Grinding	19	5 (Four Units)
3	Sr. GM, Mechanical	21	3
4	Sr. Engineer, Production	12	10 (Four Units)
5	Sr. Manager, Production	22	2.72 (Two Unit)
6	Process and Production Head	24	7 (Two Unit)
7	Sr. Manager Project	23	3
8	Sr. Engineer, Mechanical	11	3
9	Sr. Engineer, process	10	13 (Six Units)
10	Ex-Whole time director	35	4 (Two Units)

3.6 Demographics analysis for the respondents

This section analyzed and discussed the information relevant to the respondent's profile considered for this research. This information includes respondents work experience, respondent’s expertise in the area, etc. The details are given below:

3.6.1 Industrial and consultancy experience of the respondents

The industrial and consultancy experience of the respondents is important to access their knowledge of emission reduction operations. Data collected on the work experience of respondents (in years) is revealed in Table 3.2. The information in Table 3.2 is illustrated in a pie chart, as shown in Fig. 3.1.

Table 3.2: Industrial and consultancy experience of the respondents

Respondents industrial and consultancy experience (In years)	**Frequency**	**Percent**
5-10 years	1	10
11-15 years	3	30
16-20 years	1	10
More than 20 years	5	50
Total	**10**	**100**

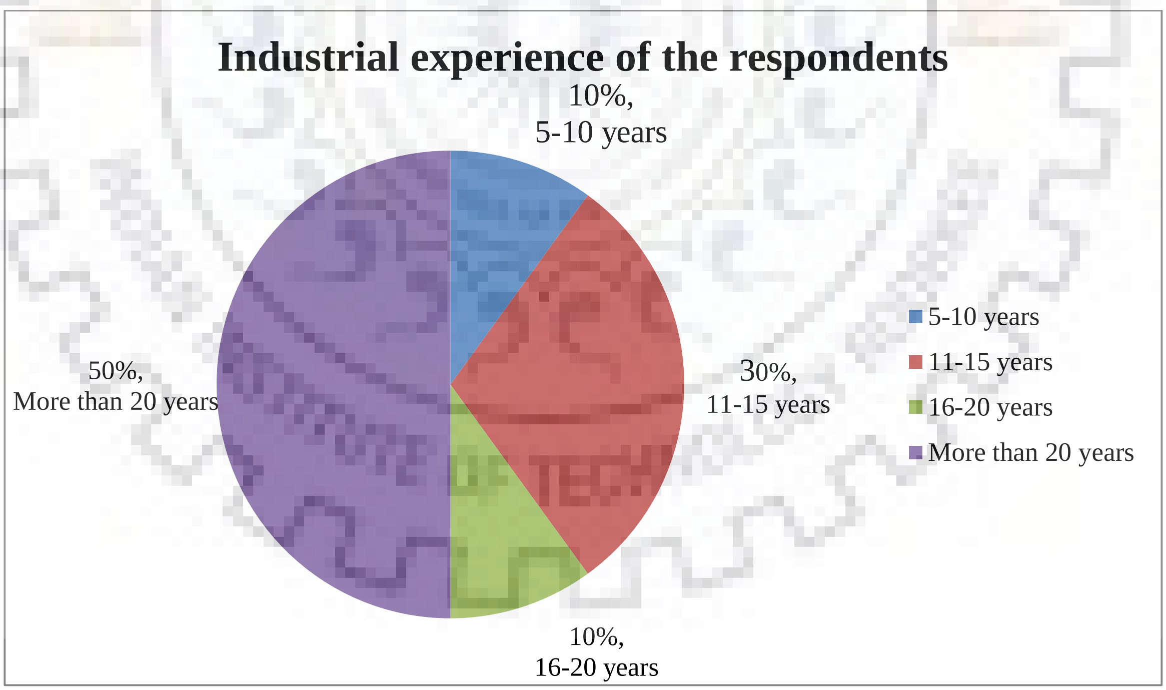


Figure 3.1: Industrial and consultancy experience of the respondents

Fifty percent (50%) of respondents are having experience more than 20 years, ten percent (10%) are between 16–20 years, thirty percent (30%) are between 11–15 years, and again ten percent

(10%) are having experience 5–10 years, which means that ninety percent (90%) of respondents are having experience of more than 10 years. It provides a reasonable association of respondents with higher experience.

3.6.2 Profile of the respondents

The profile of the respondents is important to access have the right information on climate change mitigation strategies adoption. Data collected on the profile of the respondents are presented in Table 3.3. The information on the profile of the respondents in Table 3.3 is illustrated in a pie chart, as shown in Fig. 3.2.

Table 3.3: Profile of the respondents

Profile of the respondents (In Numbers)	**Frequency**	**Percent**
Director	01	10
Deputy General Manager	02	20
Senior General Manager GM	01	10
Senior Engineer	03	30
Senior Manager	02	20
Head, Process, and production	01	10
Total	10	100

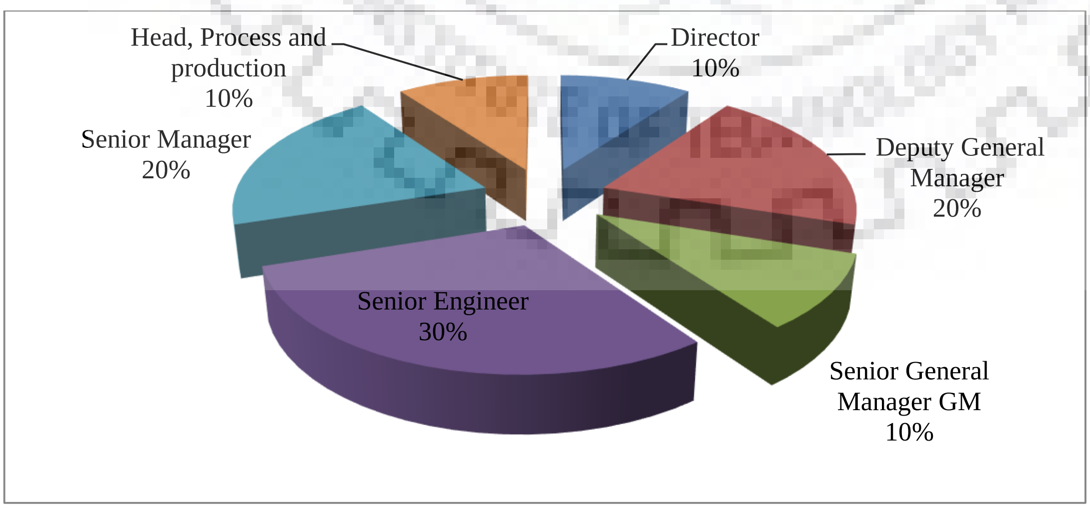


Figure 3.2: Profile of the respondents

There are thirty percent (30%) of respondents belong to Senior engineers category, twenty percent (20%) of respondents are deputy general manager again twenty percent (20%) of respondents are Senior Managers, ten percentage (10%) of respondents are Director, ten percentage (10%) of respondents are senior general manager and the remaining ten percent (10%) of respondents are head, Process, and production.

3.7 Data collection procedures

Data collection was done for the objectives 1, 2, 3 and 4:

1) To identify the most common barriers to the successful implementation of climate change mitigation practices (see Chapter 4 for more details).

2) To analyze and evaluate the listed barriers for ascertaining and confirming their priority (see Chapter 4 for more details).

3) To propose and analyze the solutions to overcome the emission reduction adoption barriers (see Chapter 4 for more details).

4) To identify drivers to climate change mitigation strategies of the cement industry (see Chapter 5 for more details).

5) To evaluate the relative importance weight of each driver to climate change mitigation strategies of the cement industry (see Chapter 5 for more details).

6) To establish the interrelations between each driver to climate change mitigation strategies of the cement industry (see Chapter 5 for more details).

7) To identify the common climate change mitigation strategies of the cement industry (see Chapter 6 for more details).

8) To evaluate the relative importance weight of each climate change mitigation strategies of the cement industry (see Chapter 6 for more details).

9) To establish the interactions between climate change mitigation strategies of the cement industry (see Chapter 6 for more details).

The main source of data collection to fulfill the aim of this research is the cement industry functioning in the southern, central and western part of India. The companies were contacted through personal visit, along with a cover letter (Appendix B). This cover letter contained the introduction of researcher and the aim of the research. Different approaches were used to get responses from the organization's respondents and also were guaranteed for the privacy of their data. Many times connections have been made via phone calls. Then finally, organizations were agreed to take part in the process, were shortlisted. The data needed for the present research work was collected through several sources: archival data, which incorporated organization websites and company log records and documents, interviews with managers and engineers, and visual information observed.

(1) This data was analyzed earlier for the appointment, and it was supplemented during the appointment in companies. It provides common information about products, production activities, and low carbon management practices. Ideally, multiple sources of evidence are helpful in aspects such as triangulation, detailed understanding of the phenomena, etc.

(2) The experts were contacted personally for collecting the necessary data through questionnaire required for this work. The data were collected at the location of the company. The duration of the interview was approximately 60-120 minutes. Instantaneously after the visits, additional notes were gathered about the complete information of the expert. It assists in revealing specific notions and pertinent details about the systems, which allows focusing on the key aspects that needed to be assessed.

(3) The companies were visited several times. It was usually led by middle and upper management and technical personnel (given in Table 3.1), who disclosed and described how they performed tasks and implemented different emission reduction initiatives on various levels in business.

(4) In the process of data collection, an expert panel of professionals has been formed. After finalizing the expert panel, the next task was to collect the data. Finally, the expert responses were collected. Finally, data were collected in approximately two months from June 2017 to July 2017.

3.8 Data analysis

Data from various sources is collected, reviewed, and analyzed to accomplish the desired objectives. There may be a variety of specific data analysis methods to analyze the data to reach tentative conclusions. Various decision making analysis methods are used in this work to analyze the data collected from the various cement industry operating in India. The detailed application of these research methods, along with their findings, is given in subsequent chapters of the thesis.

3.9 Proposed research methods

In this work, Multiple criteria decision-making (MCDM) techniques are used as a methodology to obtain the desired results. (Yin, 2009) Suggested that case based study and research are significant tools for better understanding of the real-life problems that arise in operations management areas. It has also been found that industrial expert's inputs and interactions would provide comprehensive and detailed insight into a problem. Hence, the expert’s inputs are utilized in this study to get a better understanding of this subject and provide an optimized solution.

3.10 Research techniques used in this study

To accomplish the first and second objective of this research combined Fuzzy AHP-Fuzzy TOPSIS techniques are utilized. Twenty-six barriers and fourteen solutions to overcome these barriers were recognized from literature and by receiving inputs from the experts. These identified barriers have been prioritized with the help of fuzzy AHP. After that, fuzzy TOPSIS is used to rank the solutions to overcome climate change mitigation measures adoption barriers. To accomplish the third objective of this research, combined AHP-ISM techniques are utilized. There are thirty drivers to climate change mitigation strategies finalized. These identified drivers have been analyzed with the help of AHP by proving weight to the factors and subfactors. After that, ISM is used to find driving and dependence factors. Further, Finally, to accomplish the fourth objective of this research, combined AHP-DEMATEL techniques are utilized. Twenty-four climate change mitigation strategies under five main factors were identified and finalize from literature and by receiving inputs from the experts. These identified emission reduction strategies have been prioritized with the help of AHP, an MCDM tool based on quantitative and qualitative attributes. After that, DEMATEL is used to find the interaction between factors and subfactors. A brief overview of the research methods by uncovering previous contributions made by various authors in the area has been discussed. The four proposed methods for this work are:

1) AHP and Fuzzy AHP

2) Fuzzy TOPSIS

3) ISM

4) DEMATEL

3.10.1 Analytic Hierarchy Process (AHP) and Fuzzy Analytic Hierarchy Process (FAHP)

3.10.1.1 Analytic Hierarchy Process (AHP)

AHP is well known and widely used mathematical structured decision-making tool in various business. AHP technique used in various area such as in Green supply chain management (Gupta and Barua, 2016, Govindan et al., 2014; Mathiyazhagan et al., 2014), Cleaner production (Tseng, Lin, and Chiu, 2009), Energy planning (Pohekar and Ramachandran, 2004), Clinical research (Whiting et al., 2011), Project management (Al-Harbi, 2001), Vendor selection (Tam and Tummala, 2001), Healthcare (Ryan, 2001), Maintenance (Bevilacqua and Braglia, 2000), Transportation (Tzeng et al., 2005), Weapon selection (Dağdevire et al., 2009), Marketing (Wind and Saaty, 1980), Supplier selection (Liu and Hai, 2005), Waste management (Morrissey and Browne, 2004) and Manufacturing system (Shang and Sueyoshi, 1995) and Analysis of spare parts (Gajpal et al., 1994).

AHP is an MCDM tool, which is well known and widely used mathematical structured decision-making tool in various business (Kumar and Samuel, 2017). AHP initially developed by Thomas L. Saaty (1980) is a very accepted technique to handle complicated MCDM complications, including multiple quantitative and qualitative factors.

The steps of the AHP methodology are described follows:

Step 1: Establish a pairwise comparison decision matrix

Based on Saaty scale (Table 3.4), experts give their judgment. Hence, a judgment matrix is formed (designated as 'A'), which is further used for calculating priorities of variables.

A= [aij]   while a_{ij} represents a quantified judgment on a pair of variables

Table 3.4: Significance of scores in AHP

Score	Definition
1	Both factors are equally important
3	One factor moderately important over another
5	One factor strongly important over another
7	One factor very strongly important over another
9	One factor extremely important over another
2,4,6,8	Intermediate value between two adjacent judgments

Source: Saaty (1980)

Step 2: Normalize the decision matrix and calculate the priorities of this matrix.

For this purpose, each set of column values is summed. Then, each value is divided by its respective column total value. Finally, the average of rows is calculated, and the relative weights of criteria w_i are obtained.

Step 3: Do consistency checks

The relative weights, which would also present the eigenvalues of criteria, should verify

$$A * w_i = \lambda_{max} * w_i \; ; \qquad i = 1,2,.......n \qquad (3.10.1.1.1)$$

where A represents the pairwise comparison decision matrix, n represents the order of matrix and λ_{max} gives the highest eigenvalue. Then the consistency index (CI), which measures the inconsistencies of pairwise comparisons is calculated as

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \qquad (3.10.1.1.2)$$

The last ratio that has to be calculated is Consistency ration (CR). Generally, if CR is less than 0.1, the judgments are consistent and acceptable so that the derived weights can be used (Chan et al., 2006). Otherwise, the pair-wise comparison matrix should be modified to remove the inconsistency.

The formulation of CR is

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad (3.10.1.1.3)$$

where random index (RI) denotes the average RI with the value obtained by different orders of the pair wise comparison matrices. An average RI for the matrices of order 1-10 was generated by using a sample size of 500. To check for consistency, the table of RIs of the matrices of order 1-10 can be used as seen in Saaty (1987) or obtain from Table 3.5.

Table 3.5: Random consistency index (RI)

Order of matrix (n)	1	2	3	4	5	6	7	8	9	10
Random index (RI)	0.00	0.00	0.52	0.89	1.11	1.25	1.32	1.41	1.45	1.49

Source: Saaty (1980)

3.10.1.2 Fuzzy set theory

Mathematical modelling in ambiguous and uncertain contexts require reasoning much akin to human decision making. Classical methods of mathematical representation dealing in precise values/ boundaries are inappropriate and inadequate both in capturing inexact values and their processing for decision making. Fuzzy set theory in this background provides the mathematical means to represent imprecision and decision making analogous to human reasoning (Tiwari et al., 2013). This theory implements grouping of data and classes with hazily defined boundaries; in other words, fuzzy boundaries. This theory's primary contribution is its ability to represent vague data. In a fuzzy set, each member is assigned membership grade value between 0 and 1 by use of membership functions. The spread of numerical values is captured through terms such as 'large', 'medium' and 'small'. The symbol of '~' on a letter represents a fuzzy set member.

A triangular fuzzy number (TFN) denoted as a triplet (n_1, n_2, n_3) represents the smallest possible value, the most promising value and the largest possible value that describe a fuzzy event. A fuzzy number $\tilde{N}$ expresses the meaning of 'about N'. A typical TFN representation is shown in Fig. 3.3. This representation is interpreted as membership functions and holds the following conditions

(i) n_1 to n_2 is increasing function

(ii) n_2 to n_3 is decreasing function

(iii) $n_3 \geq n_2 \geq n_1$

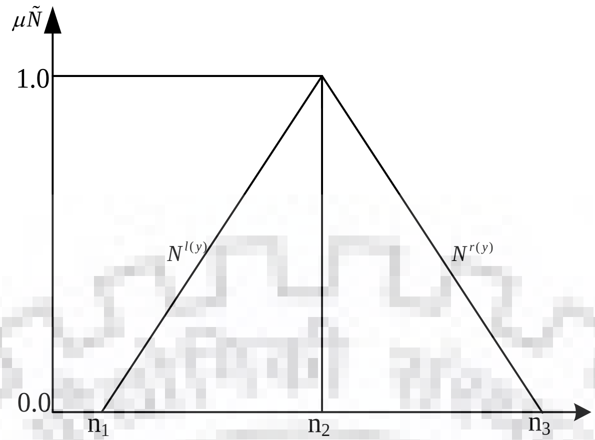


Figure 3.3: Graphical representation of TFN $\tilde{N}$

Some fundamental definitions of the fuzzy numbers and fuzzy sets are discussed

Definition 1: A TFN membership function of a real number in the interval [0, 1] is defined as:

$$\mu(xI\tilde{N}) = \begin{cases} (x-n_1)/(n_2-n_1), & x \in [n_1, n_2] \\ (n_3-x)/(n_3-n_2), & x \in [n_2, n_3] \\ 0, & otherwise \end{cases} \quad (3.10.1.2.1)$$

The corresponding left and right representation of the degree of membership depict the fuzzy number:

$$\tilde{N} = (N^{l(y)}, N^{r(y)}) = (n_1 + (n_2 - n_1)y, n_3 + (n_3 - n_2)y), \quad y \in [0, 1] \quad (3.10.1.2.2)$$

where the left and right-side representation are given by $l(y)$ and $r(y)$ respectively.

A crisp numerical value '*r*' can be expressed as (*r*, *r*, *r*).

Definition 2: Convexity of $\tilde{N}$ in the universe of discourse Y is given by the necessary condition:

$$\mu_x(\gamma N_1+(1-\gamma)N_2) \geq \min(\mu_x(N_1), \mu_x(N_2)) \quad (3.10.1.2.3)$$

for all N_1, N_2 in Y and all $\gamma \in [0, 1]$, min here denoting the minimum operator.

Definition 3: the largest membership grade attained by any element in a set is called the “height” of the Set. Normalization of the fuzzy set $\tilde{N}$ in the universe of discourse Y is entailed by $\tilde{N}$ equal to 1.

Definition 4: A fuzzy matrix $\tilde{U}$ is a matrix in which at least one element is a fuzzy number.

The fuzzy addition $\oplus$ and subtraction of two TFNs result into a TFN, whereas the multiplication $\otimes$ of two TFNs yields an approximate TFN. If $\tilde{N}_1$ = (n_{11}, n_{12}, n_{13}) and $\tilde{N}_2$ = (n_{21}, n_{22}, n_{23}) are two TFNs, then the mathematical operations between them are executed as follows:

$$\tilde{N}_1 \oplus \tilde{N}_2 = (n_{11} + n_{21}, n_{12} + n_{22}, n_{13} + n_{23}) \quad (3.10.1.2.4)$$

$$\tilde{N}_1 \odot \tilde{N}_2 = (n_{11} - n_{23}, n_{12} - n_{22}, n_{13} - n_{21}) \quad (3.10.1.2.5)$$

$$\tilde{N}_1 \otimes \tilde{N}_2 \cong (n_{11} \times n_{21}, n_{12} \times n_{22}, n_{13} \times n_{23}) \quad (3.10.1.2.6)$$

$$\lambda \otimes \tilde{N}_1 = (\lambda n_{11}, \lambda n_{12}, \lambda n_{13}), \quad \text{where } \lambda > 0, \lambda \in R \quad (3.10.1.2.7)$$

$$\tilde{N}_1^{-1} = \left(\frac{1}{n_{13}}, \frac{1}{n_{12}}, \frac{1}{n_{11}} \right) \quad (3.10.1.2.8)$$

3.10.1.3 Fuzzy Analytic Hierarchy Process (FAHP)

FAHP as the fuzzy extension of AHP can handle both qualitative as well as quantitative data in MADM problems in imprecise environs. Under this approach, TFNs numbers are used for capturing the relative significance factors. The extent analysis method is then used to calculate the pairwise comparison of synthetic extent value. In this, the weight vectors of factors and sub-factors are decided to establish the final priority weights of the factors and sub-factors. The highest priority would be given to the factor with the highest weight.

The FAHP approach used by the authors is elaborated as follows:

Let P= {p_1, p_2, . . . , p_n} and Q={q_1, q_2, . . . , q_m}represent the object and the goal set respectively, then using the extent analysis method given by Chang (1996) and further by Chan et al., (2008), Samvedi et al., (2012) The m extent analysis values for each object are denoted as

$N_{0i}^{1}, N_{0i}^{2}, ...N_{0i}^{m},$ where i=1,2,.....,n.

where all the N_{0i}^{j} (j=1, 2, . . . , m) are TFNs.

The value of the extent analysis of the *i*th object for *m*th goal is represented as N_{0i}^{m}.

Step 1. Fuzzy synthetic extent value (F_i) with respect to the *i*th criterion is defined as,

$$F_i = \sum_{j=1}^{m} N_{oi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} N_{oi}^{j} \right]^{-1} \quad (3.10.2.3.1)$$

$$\sum_{j=1}^{m} N_{oi}^{j} = \left(\sum_{j=1}^{m} n_{1j}, \sum_{j=1}^{m} n_{2j}, \sum_{j=1}^{m} n_{3j}, \right) \quad (3.10.2.3.2)$$

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} N_{oi}^{j} \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} n_{3i}}, \frac{1}{\sum_{i=1}^{n} n_{2i}}, \frac{1}{\sum_{i=1}^{n} n_{1i}} \right) \quad (3.10.2.3.3)$$

Step 2. The degree of possibility of N1= (n_{11}, n_{12}, n_{13}) ≥ N2=(n_{21}, n_{22}, n_{23}) is defined as

$$V(N_1 \geq N_2) = \sup_{x \geq y} \left[\min(\mu_{N1}(x), (\mu_{N2}(y)) \right], \quad (3.10.2.3.4)$$

when a pair (x,y) exists such that x≥y and $\mu_{N1}(x) = \mu_{N2}(y) = 1$, then we have

$V(N_1 \geq N_2) = 1$. since N_1 and N_2 are convex fuzzy numbers so, (3.10.2.3.5)

$V(N_1 \geq N_2) = 1$ if $n_{11} \geq n_{21}$ (3.10.2.3.6)

and $V(N_2 \geq N_1) = hgt(N_1 \cap N_2) = \mu_{N1}(d)$, (3.10.2.3.7)

where d is the ordinate of the highest intersection point D between μ_{N1} and μ_{N2} (Fig. 3.4).

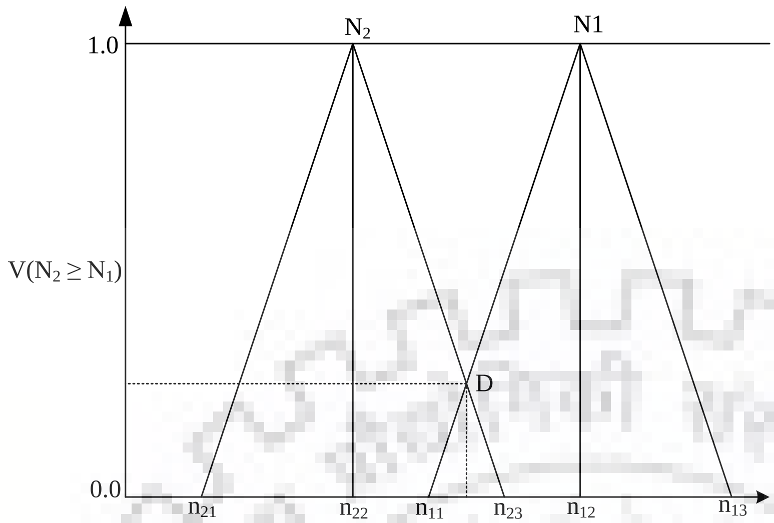


Figure 3.4: The intersection of N_1 and N_2

The ordinate of D, when $N_1 = (n_{11}, n_{12}, n_{13})$ and $N_2 = (n_{21}, n_{22}, n_{23})$ is computed by

$$V(N_2 \geq N_1) = hgt(N_1 \cap N_2) = \frac{n_{11} - n_{23}}{(n_{22} - n_{23}) - (n_{12} - n_{11})} \quad (3.10.2.3.8)$$

Both the values of $V(N_1 \geq N_2)$ and $V(N_2 \geq N_1)$ are required for the comparison of N_1 and N_2,

Step 3. The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $N_i(i=1, 2, \ldots, k)$ can be defined by

$$V(N \geq N_1, N_2, \ldots, N_k) = V[N \geq N_1] \text{ and } (N \geq N_2) \text{ and } \ldots \text{ and } (N \geq N_k)] \quad (3.10.2.3.9)$$

$$= \mathit{min} V(N \geq N_i), \quad i = 1, 2, \ldots, k \quad (3.10.2.3.10)$$

If $m(P_i) = \mathit{min}\ V(Fi \geq F_k)$, (3.10.2.3.11)

for $k = 1, 2, \ldots, n$; $k \neq i$. then the weight vector is given by

$$W_p = (m(P_1), m(P_2), \ldots, m(P_n))^T, \quad (3.10.2.3.12)$$

where $P_i (i = 1, 2, \ldots, n)$ are n elements.

Step 4. After normalizing W_p, we get the normalized weight vectors

$$W = (w(P_1), w(P_2), \ldots, w(P_n)) \quad (3.10.2.3.13)$$

where W is a non-fuzzy number, and this gives the priority weights of one alternative over others.

3.10.2 Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS)

TOPSIS is an MCDM technique based on distances of an attribute value from the positive and negative ideal solution values (Hwang and Yoon, 1981). The attribute value must be at least and maximum distances respectively from the negative and positive solutions.

TOPSIS being a classical mathematical modelling technique depicts individual preferences as crisp values. The ambiguity of real-life scenarios and the imprecision in human judgment are better represented by linguistic variables as compared to crisp numerical values (Shaw et al., 2013; Dağdeviren et al., 2009; Chen and Tsao, 2008; Chu, 2002). FTOPSIS is thus a better-suited method for decision making in fuzzy environs of real-life problems (Mavi et al., 2016; Patil and Kant, 2014; Senthil et al., 2014).

The steps of FTOPSIS method are as follows.

Step 1: Assign the linguistic rating values based on the scale given in Table 3.6 for the alternative concerning factors

Table 3.6: Linguistic scale for solutions selection

Linguistic variables	**Corresponding TFN**
VP	(1,1,3)
P	(1,3,5)
M	(3,5,7)
G	(5,7,9)
VG	(7,9,11)

VP- "Very poor", P- "Poor", M- "Medium", G- "Good", VG- " Very good".

Step 2: Calculate aggregate fuzzy ratings for the alternatives

If the fuzzy ratings of all experts are described as TFN $R_k = (a_k,b_k,c_k)$, k=1,2,3, …K then the aggregated fuzzy rating is given where

$$a = \min_k\{a_k\}, b = \frac{1}{k}\sum_{k=1}^{k} b_k, c = \max_k\{c_{k\}} \quad (3.10.2.1)$$

Step 3: Normalize the fuzzy decision matrix

The normalized fuzzy decision matrix is given by:

$$\tilde{R} = [\tilde{r}_{ij}]_{mxn} \quad i = 1,2,......m; \; j = 1,2,.......,n \tag{3.10.2.2}$$

where

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right) \text{ and } c_j^* = \max_i c_{ij} \text{ (benefit criteria)} \tag{3.10.2.3}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}} \right) \text{ and } a_j^- = \min_i a_{ij} \text{ (cost criteria)} \tag{3.10.2.4}$$

Step 4: The weighted normalized matrix $\tilde{V}$ for criteria is computed by multiplying the weights (w_j) of evaluation criteria with the normalized fuzzy decision matrix $\tilde{r}_{ij}$

$$\tilde{V} = [\tilde{v}_{ij}]_{mxn} \; i = 1,2,......m; \; j = 1,2,.......,n \text{ where } \tilde{v}_{ij} = \tilde{r}_{ij}(\cdot)w_j \tag{3.10.2.5}$$

Step 5: Compute the fuzzy ideal solution (FPIS) and fuzzy negative ideal solution (FNIS)

The FPIS and FNIS of the alternatives are calculated as follows:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^* ...., \tilde{v}_n^*) \text{ where } \tilde{v}_j^* = (\tilde{c}_j^*, \tilde{c}_j^*, \tilde{c}_j^*) \text{ and } \tilde{c}_j^* = \max_i \{\tilde{c}_{ij}\}, \tag{3.10.4.6}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^- ...., \tilde{v}_n^-) \text{ where } \tilde{v}_j^- = (\tilde{a}_j^-, \tilde{a}_j^-, \tilde{a}_j^-) \text{ and } \tilde{a}_j^- = \min_i \{\tilde{a}_{ij}\}, \tag{3.10.2.7}$$

$\forall i = 1,2,......,m; \quad j = 1,2,....,n.$

Step 6: Calculate the distance of each alternative from FPIS and FNIS

$$d_i^+ = \sum_{j=1}^{n} dv(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i=1,2,....,m, \tag{3.10.2.8}$$

$$d_i^- = \sum_{j=1}^{n} dv(\tilde{v}_{ij}, \tilde{v}_j^*), \quad i=1,2,...,m, \tag{3.10.2.9}$$

Step 7: Compute the closeness coefficient (CC_i) of each alternative.

The closeness coefficient of each alternative is calculated as:

$$CC_i = \frac{d_i^-}{d_i^- + d_i^+} \quad (3.10.2.10)$$

Step 8: The strategies are prioritized in descending order based on the CCi value

Table 3.7: Combined Fuzzy AHP- Fuzzy TOPSIS modelling techniques used in a diverse stream in the recent literature

S. No.	Authors	Studies
1.	Kabra and Ramesh, 2015	Analyzing drivers and barriers of coordination in humanitarian supply chain management under fuzzy environment
2.	Prakash and Barua, 2015	Integration of AHP-TOPSIS method for prioritizing the solutions of reverse logistics adoption to overcome its barriers under fuzzy environment
3.	Mangla et al., 2015	Prioritizing the responses to manage risks in the green supply chain: An Indian plastic manufacturer perspective
4.	Patil and Kant, 2014	A fuzzy AHP-TOPSIS framework for ranking the solutions of Knowledge Management adoption in Supply Chain to overcome its barriers
5.	Im and Cho, 2013	A systematic approach for developing a new business model using morphological analysis and integrated fuzzy approach
6.	Viswanadham and Samvedi, 2013	A two-step Fuzzy AHP-TOPSIS framework for identifying both performance-based and risk-based decision criteria of supplier selection
7.	Choudhary and Shankar, 2012	A STEEP-fuzzy AHP-TOPSIS framework for evaluation and selection of thermal power plant location: A case study from India
8.	Muralidhar et al., 2012	Evaluation of Green Supply Chain Management Strategies Using Fuzzy AHP and TOPSIS
9.	Rostamzadeh and Sofian, 2011	Prioritizing effective 7Ms to improve production systems performance using fuzzy AHP and fuzzy TOPSIS (case study)
10.	Torfi et al., 2010	Fuzzy AHP to determine the relative weights of evaluation criteria and Fuzzy TOPSIS to rank the alternatives
11.	Perçin, 2009	Evaluation of third-party logistics (3PL) providers by using a two-phase AHP and TOPSIS methodology
12.	Büyüközkan et al., 2008)	Selection of the strategic alliance partner in the logistics value chain

3.10.3 Interpretive Structural Modelling (ISM)

ISM, developed by Warfield (Warfield, 1974), is a methodology of systemic structural modelling, which has been widely applied in identifying and summarizing relationships among variables. It is an interactive learning process in which a set of unique, interrelated variables are structured into a comprehensive systemic model presented as a hierarchy graph (Agarwal et al., 2007; Sage, 1977; Warfield, 1974). ISM provides a means by which people can synthesize an objective hierarchy of the variables by mathematical deduction, given the pairwise relations among the variables (Song et al., 2017). Thus, the model obtained represents the structure of a complex issue or problem, a system or field of study, as a carefully designed pattern, which contains graphics and words that provide insights into the relationships between the various variables in a hierarchical manner (Nishat et al., 2006). ISM has been used in several studies as shown in Table 3.8

Table 3.8: Summary of the use of ISM analysis in various studies

S. No.	Authors	Studies
1.	Kamble et al. (2019)	To Analyze the implementation barriers of dual cycling in port container terminal using ISM
2.	Kumar and Dixit, 2018	To the analysis of barriers affecting the implementation of e-waste practice
3.	Song et al. (2017)	Discussed the vulnerability factors of urban rail transit system using ISM, Using ISM
4.	Kumar and Rahman (2017)	Analyze the enablers of sustainable supply chain
5.	Patil and Warkhedkar (2016)	Discussed knowledge management and its implementation in Indian automobile ancillary industries
6.	Dubey and Singh (2015)	Understanding the complex relationship among JIT, lean behavior, TQM and their antecedents using ISM
7.	Hussain et al. (2015)	Evaluate sustainable supply chain alternatives
8.	Mathiyazhagan et al. (2013)	Discussed the barriers to GSCM using ISM
9.	Diabat and Govindan (2011)	Investigated enablers of sustainable SCM in the Indian textile industry
10.	Kannan et al. (2009)	To select the reverse logistics provider
11.	Qureshi et al. (2008)	Identified and classified the key criteria and their role in the assessment of 3PL services providers
12.	Jharkharia and Shankar (2005)	Studied IT-enablement of supply chains
13.	Mandal and Deshmukh (1994)	Selecting vendor using ISM method

The ISM methodology has various steps are as follows (Ruiz-Benitez et al., 2018; Sushil, 2012; Kannan et al., 2009; Ravi and Shankar, 2005)

Step 1: Structural self-interaction matrix (SSIM)

ISM model represents a finite set of n variables in a system represented by S = (s_1,…, s_i;…; s_n). SSIM is built up based on contextual relationships of pair of variables (s_i and s_j). To establish the contextual relationship among the variables for developing these SSIM, a set of question are asked from the experts, i.e. variable i lead to variable j or vice versa. Four symbols are used for the type of relationship that exists between the two variables under consideration.

V = Variable i will help achieve variable j;

A = Variable j will help achieve variable i;

X = Variable i and j will help achieve each other; and

O = Variables i and j are unrelated.

The SSIM for the variable under consideration is then prepared by filling in the expert's responses on each pair-wise interaction between the variables.

Step 2: Reachability matrix

The SSIM was converted into a binary matrix, also denominated initial reachability matrix, by replacing the nomenclature (V, A, X, and O) with $e_{ij} = 1$ if s_i leads to s_j and 0 otherwise. For a better understanding, the rules applied to convert the entries in the SSIM into binary digits are the following:

• if the (i, j) entry in the SSIM is V, then the (i, j) entry in the reachability matrix becomes 1, and the (j, i) entry becomes 0;

• if the (i, j) entry in the SSIM is A, then the (i, j) entry in the reachability matrix becomes 0, and the (j, i) entry becomes 1;

• if the (i, j) entry in the SSIM is X, then the (i, j) entry in the reachability matrix becomes 1, and the (j, i) entry also becomes 1; and

• if the (i, j) entry in the SSIM is O, then the (i, j) entry in the reachability matrix becomes 0, and the (j, i) entry also becomes 0.

The reachability matrix thus derived from following these rules is known as the Initial reachability matrix

Step 3: Final reachability matrix

Subsequently, to convert the Initial reachability matrix into the Final reachability matrix transitivity rule is applying. This implies that if s_i leads to s_j, and s_j leads to s_k, then s_i should lead to s_k. That is, s_i exerts an indirect influence on s_k. If the transitivity rule is found not to be satisfied, the SSIM is reviewed and modified by giving specific feedback about the transitive relationship to the experts. From the revised SSIM, the reachability matrix is again worked out and tested for the transitivity rule. This process is repeated until the reachability matrix meets the requirements of the transitivity rule. Thus, the reachability matrix is obtained by incorporating the transitivity is known as Final reachability matrix.

Step 4: Partitions on the final reachability matrix

This step consists in partitioning the Final reachability matrix obtained above into different levels. This provides the reachability and antecedent set for each variable (i.e., s_i). These are represented by Eq. (a) and (b) respectively

$$R(s_i) = \{s_j \in S / e_{ij}=1\} \cup \{s_i \in S\} \quad (3.10.3.1)$$

$$A(s_i) = \{s_j \in S / e_{ij}=1\} \{s_i \in S\} \quad (3.10.3.2)$$

The intersection set of each variable is computed as follows:

$$I(si) = R(s_i) \cap A(s_i) \quad (3.10.3.3)$$

The reachability, antecedent, and intersection set found for each variable in the system. A variable is plotted on the top position of the ISM model (level I) if $R(s_i) = I(s_i)$ and then is separated from the remaining variables. This process is repeated to assign variables in Level II, being these then deleted. This iterative process finishes when all variables have been already assigned to a level.

Step 5: Formation of ISM-based model

From the Final reachability matrix, the structural model is generated. If the relationship exists between the variables j and i, an arrow pointing from i to j shows this. This resulting graph is called a Digraph. Thus, the structural model is derived from the connective information contained in the digraph. The details of variables are indicated in the respective boxes with indicated relations as worked out in the digraph, thus obtaining the interpretive structural model for the variable. The interpretive structural model depicts the variables and their reachability to the higher-level variables and provides a clear picture with an understanding of the inter-relationships among the variables.

Step 6: Cross-impact matrix multiplication applied to classification (MICMAC) analysis

The objective of the MICMAC analysis is to analyze the driver power and the dependence power of the variables (Ravi and Shankar, 2005). The variables are classified into four clusters. The first cluster consists of the 'Autonomous variables' that have weak driver power and weak dependence. These variables are relatively disconnected from the system, with which they have only a few links, which may be strong. The second cluster consists of the 'Dependent variables' that have weak driver power but strong dependence. The third cluster has the 'Linkage variables' that have strong driving power and strong dependence. These variables are unstable in the fact that any action on these variables will have an effect on others and feedback on themselves. The fourth cluster includes the 'Independent variables' having strong driving power but weak dependence. It is observed that a variable with a very strong driving power called the key variables falls into the category of independent or linkage variables. All the above Steps of ISM are shown in Fig. 3.5.

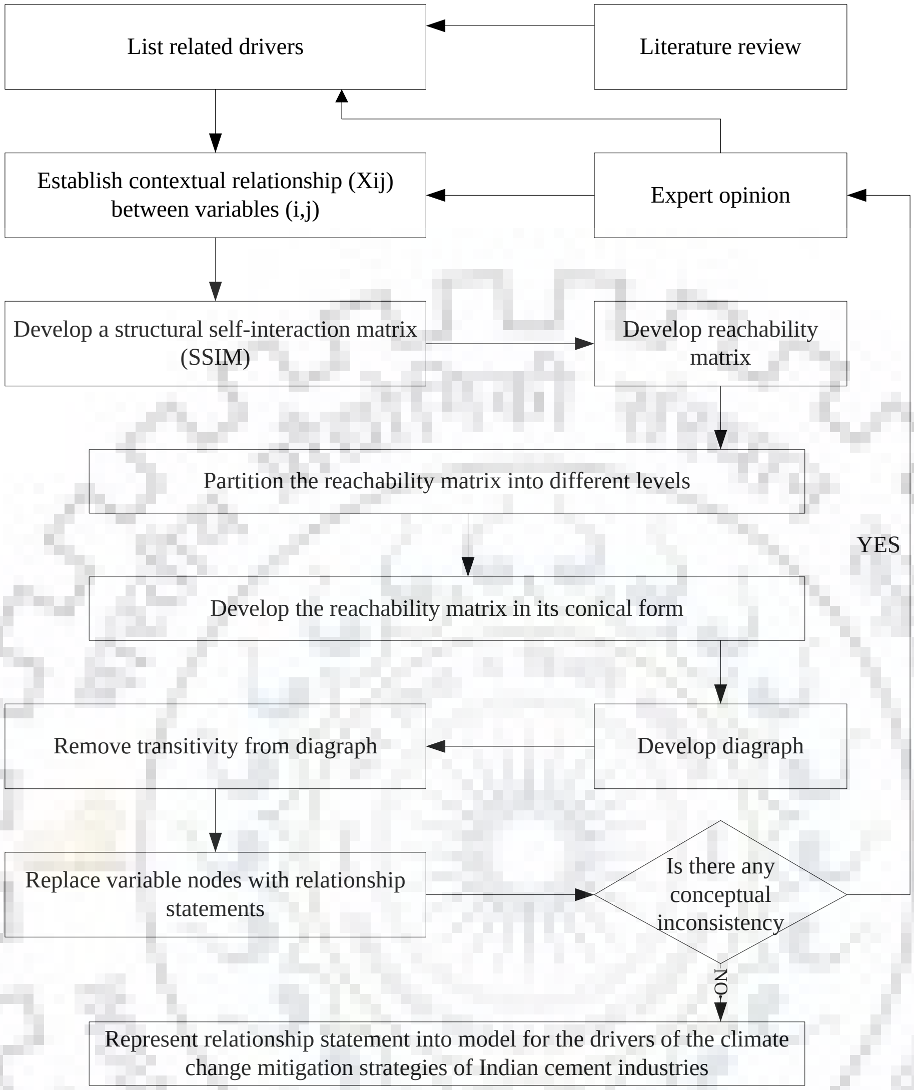


Figure 3.5: Flow diagram for preparing the ISM model

Table 3.9: Combined AHP- ISM modelling techniques used in a diverse stream in the recent literature

S. No.	Authors	Studies
1.	Chen et al., 2017	Analysis of Influencing Factors of Engineering Project Corruption Based on ISM and AHP
2.	Kumar and Rahman, 2017	Analyzing enablers of the sustainable supply chain: ISM and fuzzy AHP approach
3.	Song et al., 2017	Using an AHP-ISM Based Method to Study the Vulnerability Factors of Urban Rail Transit System
4.	Beikkhakhian et al., 2015	The application of the ISM model in evaluating agile suppliers selection criteria and ranking suppliers using fuzzy TOPSIS-AHP methods
5.	Ravikumar et al., 2015	Evaluating lean implementation performance in Indian

S. No.	Authors	Studies
		MSMEs using ISM and AHP models
6.	Duleba et al., 2013	An analysis of the connections of factors in a public transport system by AHP-ISM
7.	Saleeshya et al., 2012	A combined AHP and ISM-based model to assess the agility of the supply chain - a case study
8.	Sharma and Singh, 2012	Knowledge Sharing Barriers: An Integrated Approach of ISM and AHP
9.	Chan, 2003	Interactive selection model for supplier selection process: an analytical hierarchy process approach

3.10.4 Decision Making Trial and Evaluation Laboratory Method (DEMATEL)

The Science and Human Affair Program of the Battelle Memorial Institute of Geneva between 1972 and 1979 originally established the DEMATEL technique. This technique intended to resolve the complicated and intertwined problem group (Wu and Chang, 2015). As compared to interpretive structural modelling (ISM), this technique utilizes the structural modelling technique to diagnose the interrelationship between the factors through developing diagraphs to portray cause and effect causal relationship and the strengths of influence between the factors (Tzeng et al., 2007; Wu and Tsai, 2012). Application of DEMATEL approach applied in the area of Green innovation (Gupta and Barua, 2018), Waste management (Wang et al., 2018), Human resource management (Sayyadi Tooranloo et al., 2017), Manufacturing practices (Madan Shankar et al., 2017), Barriers to coastal shipping development (Venkatesh et al., 2017) and Carbon management (Hsu et al, 2013), etc.

The steps of DEMATEL technique discussed as follow

Step 1: Calculate the initial average matrix: Between any two factors direct influence is assessed by each expert using an integer score of 0, 1, 2, 3 and 4 meaning "no influence", "very low influence", "low influence", "high influence", and "very high influence" respectively. The character 'x_{ij}' represent the degree to which the expert concludes that factor i affects factor j. The diagonal factors, i=j are assigned to zero, indicates "no influence" then n × n nonnegative matrix will be constructed for each expert as $X^k = [x_{ij}^k]$, where k is several experts with $1 \leq k \leq H$, and n is the number of factors. If there are H experts, X^1, X^2, X^3 ... and X^H are constructed. To consolidate all opinions from H experts, the average matrix $A=[a_{ij}]$ is constructed as follows.

$$a_{ij} = \frac{1}{H}\sum_{k=1}^{H} x_{ij}^{k} \qquad (3.10.4.1)$$

Step 2: Calculate the normalized initial direct relation matrix D by

$$D = A \times S, \qquad (3.10.4.2)$$

$$\text{where } S = \min\left[\frac{1}{\max \sum_{j=1}^{n} a_{ij}}, \frac{1}{\max \sum_{i=1}^{n} a_{ij}}\right] \qquad (3.10.4.3)$$

Step 3: Compute the total relation matrix T by

$$T = \frac{D}{(I - D)} \qquad (3.10.4.4)$$

where 'I' is the identity matrix.

Let r_i be the sum of an ith row in matrix T, then r_i summarizes both direct and indirect effects given by factor i to the other factors, whereas c_j be the sum of a jth column in matrix T, then c_j shows both direct and indirect effects by factor j from the other factors. The sum (r_i + c_j) exhibits the total effects given and received by factor i. Besides it also indicates the degree of importance of factor i on the entire system. On the other hand, the difference (r_i-c_j) exhibits the net effect that factor i contributes to the system. Specifically, if (r_i-c_j) is positive, then, factor i is a net cause group, while factor i is a net receiver group if (r_i-c_j) is negative.

Step 4: Compute the threshold value to construct the digraph. Matrix T reflects how one factor affects another such that it is necessary for a decision maker to set up a threshold value to filter out some negligible effects by highlighting the effects greater than the threshold value in a digraph. The threshold value can be determined by computing the average of the factors in Matrix T. The digraph can be gathered by plotting the dataset of (r_i+c_j, r_i-c_j).

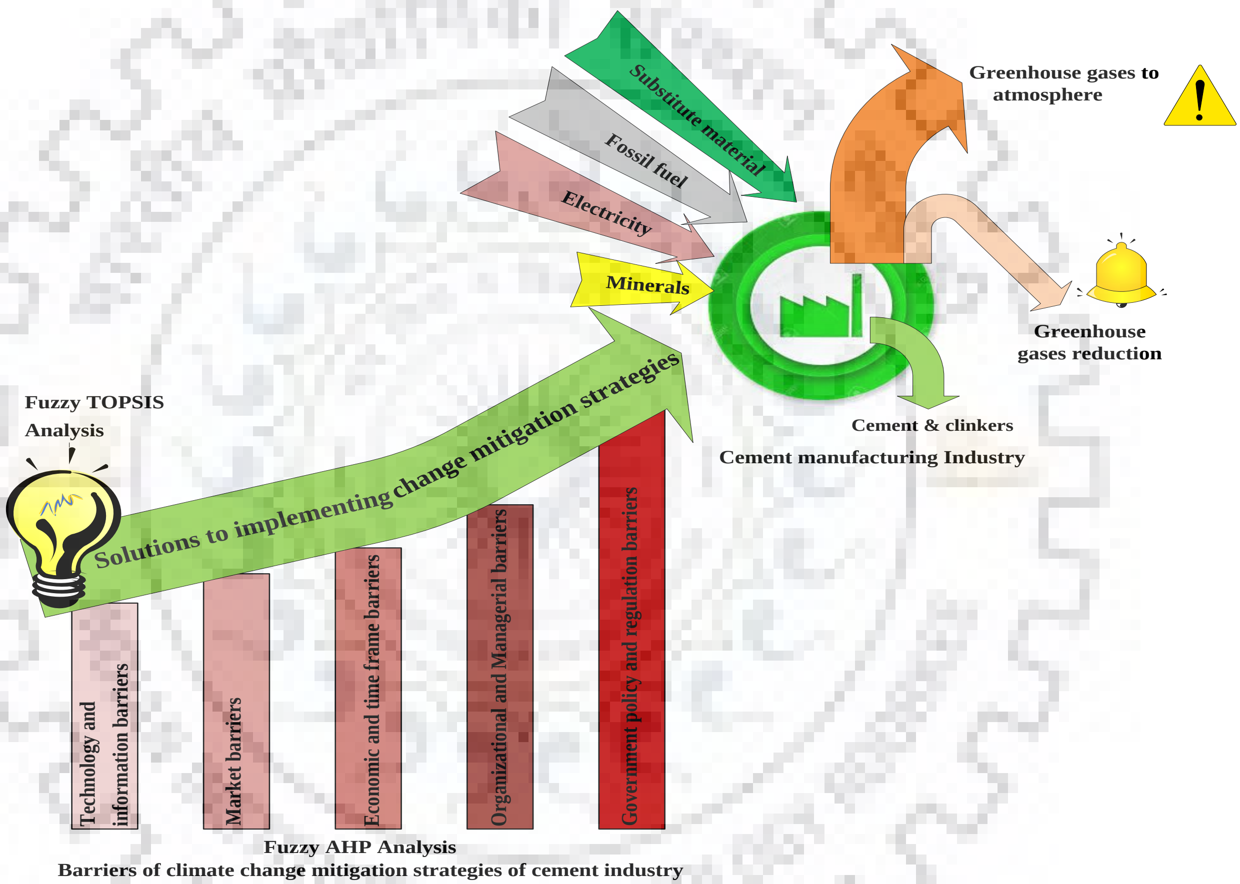
3.11 Chapter summary

This chapter discusses the research methodology used for analyzing and managing the successful emission reduction practices and decision making areas and issues related to successful climate change mitigation adoption and implementation, specifically to management and analysis of the barriers and barrier overcome solution, drivers and various common emission reduction measures in the context of the Indian cement industry. In the initial part of this chapter, a conceptual framework and model is proposed to achieve the objectives of the study. In the later part, a brief detail on the research methodology adopted for this work is provided to achieve the raised research objectives. A critical analysis of the research methods proposed and used in this study is also given in the subsequent section. It will provide an overview of the various tools and techniques towards the effective implementation of climate change mitigation practices. It has also been concluded that MCDM methods have a significant part in analyzing GHGEs problems. The detail on research methodology includes the data collection method, sample design, etc. The data collection procedure and data analysis to interpret the information have also been provided.

Chapter 4

A framework to overcome barriers to climate change mitigation strategies of the Indian cement industry

Graphical abstract



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Part of this chapter has been submitted in Environmental Science and Pollution Research (Springer)

Balsara S, Jain P.K., and Ramesh A. (2018) A framework to overcome barriers to climate change mitigation strategies of Indian cement manufacturing industry under fuzzy environment (under review) Environmental Science and Pollution Research (Springer)

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Preview

This chapter provides details about the identification, finalization, and prioritization of the barriers to climate change mitigation strategies of the Indian cement industry. It also identifies, finalizes and suggests solutions to overcome these barriers. Then, this chapter proposes a flexible model to prioritize the solutions to overcome these barriers. For this, an integrated approach based on the fuzzy AHP and fuzzy TOPSIS methods has been developed and used in this chapter.

4.1 Introduction

Cement is a fundamental requirement of modern society. Human consumes more volume of cement than water (Scrivener et al., 2018; Hasanbeigi et al., 2012; Sakai, 2009). It is the primary building material and become synonymous with construction activity (Amrina and Vilsi, 2015). Cement is used extensively in infrastructure development, industrial sector, urban housing, and employment generation (Gao et al., 2016; CII, 2015). Thus, for the economic growth and expansion of any country, the cement manufacturing industry plays a vital role. On the other side, the cement industry is considered an important source of anthropogenic CO_2Es among industrial activities (Talaei et al., 2018; Feiz et al., 2015). Manufacturing of cement accounts for about 5-8% of total global anthropogenic CO_2Es (Shanks et al., 2019). The cement industry is the second largest CO_2 emitter among all the industrial activities of India (IEA, 2013). Hence, the cement manufacturing process is an emission-intensive sector, with the potential to create a substantial environmental footprint, preferably by emitting GHGs (Naeimi et al., 2019). Continued GHGEs will enhance global warming and will cause long-lasting changes in the climate system (IPCC, 2014b). To effectively avoid harmful climate impacts the world's societies will need to mitigate to climate change (IPCC, 2014a) thus cement industry sustainably conducts its business, by integrating climate change mitigation strategies into its supply chain (Cormos and Cormos, 2017).

The cement industry is giving its best efforts to adopt green practices to reduce GHGEs along with gaining a competitive advantage over other, create a green corporate image and sustain in the long run (Maddalena et al., 2018). However, while implementing climate change mitigation strategies, the cement industry faces a variety of barriers (Gao et al., 2016). Thus, there is a growing need for the cement industry to address and overcome these barriers.

To rank barriers and solutions to overcome these barriers, a three-phase methodology is proposed, as shown in Fig. 4.1. The first phase involves identification of the barriers and its solutions to implement mitigation strategies in the Indian cement industry from the literature review and with the technical expert consultation. Through a detailed literature survey and discussion with technical experts, a total of twenty-six barriers were identified which were categorized into five main categories. Similarly, through literature review and technical expert's consultations, fourteen solutions were finalized for the study. The second phase involved the ranking of the barriers, Fuzzy AHP given by Saaty (1980) is used to rank the barriers. In the third phase, Fuzzy TOPSIS methodology (Hwang and Yoon, 1981) is used to rank the solutions concerning barriers. However, due to the presence of inaccurate and uncertain data, analyzing and prioritizing barriers and its solutions is difficult thus it is projected to apply the fuzzy set approach (Zadeh, L.A. 1996) with the AHP and TOPSIS methodology to cope with the uncertainty and inherent ambiguity.

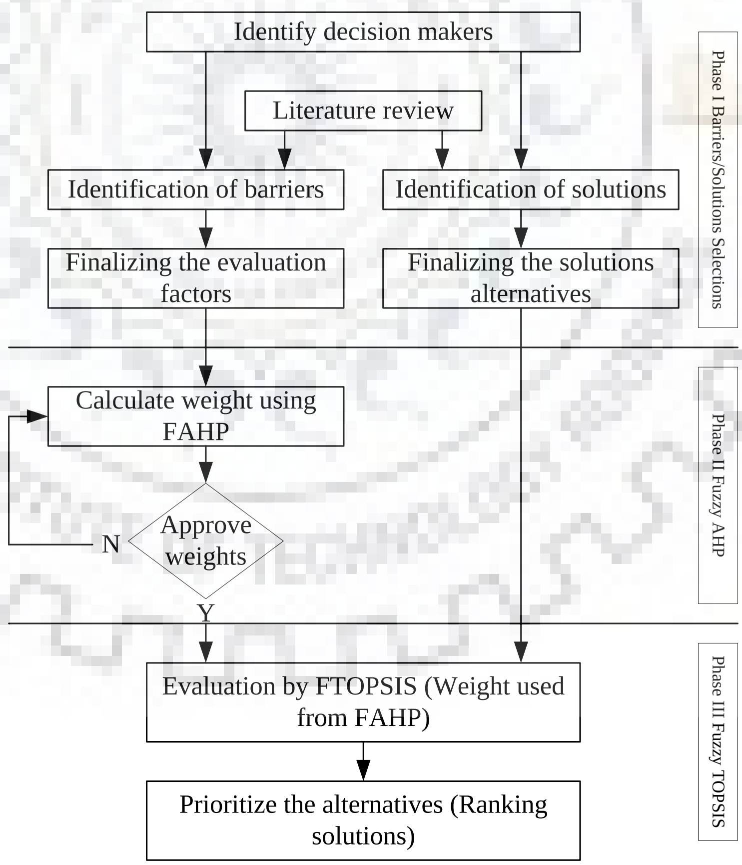


Figure 4.1: Schematic diagram of the methodology

4.2 Barriers to the implementation of climate change mitigation strategies in the cement industry

Implementation of Climate change mitigation strategies in the industry leads to GHGEs reduction, reduction in climate risks, health risk, pollutants and another negative impact on the environment and the human health (Raffetti et al., 2019). However, the Implementation of climate change mitigation strategies faces several issues in the emission-intensive cement industry that need to be resolved (Gao et al., 2016a). To identify and finalize the barriers and barriers overcoming solutions to climate change mitigation strategies, a thorough review of literature is conducted. After discussion with industry experts, five major factors of barriers category, twenty-six sub-factors and fourteen barriers overcoming solutions were finalized and listed in Tables 4.1 and Table 4.2 respectively. The listed barriers are explained in following subsections.

4.2.1 Economic and time frame barriers

Adoption mitigation measures in cement industry often incur addition cost (Herrera et al., 2017), The cost includes understanding, accepting and acknowledging to government mitigation policies (Vickers et al., 2009), high initial cost of mitigation technology (Madlool et al., 2011), high overhead costs and the cost of analyzing and collecting information, inconvenience, production disruptions etc. (Herrera et al., 2017). Cement industry also faces difficulty in accessing financial capital or limited access to capital for emission reduction measures (Xianbing Liu et al., 2016). Apart from these, there is no incentive built in budgetary systems that stimulate low carbon innovation (Di Filippo et al., 2018). Also, it is difficult to quantify the financial performance or poor financial performance, i.e. low returns and relatively more extended payback period on investments of some mitigation measures (Summerbell et al., 2016) are significant barriers faced by the cement industry under this category.

4.2.2 Market barriers

Market barriers include carbon market uncertainty; Uncertainty about the carbon market is likely to lead to delays in investments on green technologies; the current price makes carbon a low-priority issue for many firms. Insufficient community pressures, low media pressure and weak public awareness to reduce the emissions (Herrera et al., 2017; Feiz et al., 2015) is another barrier in this category. Availability, cost, quality, waste legislation of waste fuels is limiting factor of alternate kiln fuel (Shanks et al., 2019; Gao et al., 2016) and Availability, price, quality, regulation and standards of alternative substituting materials are critical barriers to climate change mitigation strategies in the cement industry (Shanks et al., 2019; K. Scrivener et al., 2018). Market acceptance and technical performance of concrete produced with blended cement also hinders cement organizations in adopting climate change mitigation strategies (Benhelal et al., 2013).

4.2.3 Organizational and Managerial barriers

GHGEs reduction becomes a low priority since reductions would irrevocably impact essential services (Benhelal et al., 2013) also competing priorities inhibit commitment to carbon reduction (Feiz et al., 2015). Cement industry considers that expansion of market share and production capacity is more important than implementing climate change mitigation strategies for emission reduction (Scrivener et al., 2018). Management resistance to change (Herrera et al., 2017) and lack of environmental commitment of management (Nguyen and Hens, 2015) are other important barriers to effective implementing mitigation measures in the cement industry. Most of the cement industry firms have found difficulty while implementing options of mitigation measures, mainly because they lack information, awareness as well as human and financial resources (Feiz et al., 2015). Sometimes managers lack the necessary technical as well as the managerial capacity to implement emission reduction measures (Herrera et al., 2017) because of the limited human capacity for management decisions (Petek Gursel et al., 2014; Schneider et al., 2011). Lack of Integration of climate change mitigation strategies into corporate strategies (Herrera et al., 2017; Worrell and Galitsky, 2008) because management and employees are unaware of environmental and economic benefits of emission reduction (Vargas and Halog, 2015). Low awareness along with a perception that available tools and techniques of emission reduction measures are costly and unsuited to the needs of organizations (Di Filippo et al., 2018; Feiz et al., 2015). Also integrating emission reduction projects into current manufacturing systems frequently face problems with infrastructure, space, retrofitting challenges and other resources (Ishak and Hashim, 2015; Tesema and Worrell, 2015).

4.2.4 Government policy and regulation barriers

Impact of non-energy policies on the organization is a substantial barrier to implement emission reduction strategies (IPCC, 2014a). No provision of economic incentives from the government like grants and exemption of taxes for the establishment of emission reduction equipment and technologies (Di Filippo et al., 2018; Ostad-Ahmad-Ghorabi and Attari, 2013) is another a significant barrier faced by the cement industry. Low levels of regulations compliance due to lack of awareness coupled with a perception that enforcement is weak and emission reduction measures are not considered as priority task if there is weak enforcement of regulations (Di Filippo et al., 2018; Nguyen and Hens, 2015) is also a significant barrier. Further, a range of barriers have been identified highlighted responsible for business shifted stance towards climate change mitigation include uncertain policy framework, little or absence of regulation and policies, uncertain about government's action and future government policy (Abadie et al., 2017; Matar and Elshurafa, 2017). Policy and regulation frameworks lack basic specification for the implementation of emission reduction measures in the cement industry (Benhelal et al., 2013; Madlool et al., 2011).

4.2.5 Technology and information barriers

Technology and information barriers include technical risks such as production disruption risk and uncertainty (Herrera et al., 2017; IPCC, 2014a). The cement industry has faced difficulty in implementing climate change mitigation strategies, mainly because of expertise human resources (Madlool et al., 2011) and lack of adequate evaluation measures or methodological issues, by specifying how GHGEs should be managed and measured (Cao et al., 2016). Employee training programs for emission reduction measures are insufficient at shop floor level also education level of operators and staff is not appropriate for implementing emission reduction measures (Scrivener et al., 2018; Summerbell et al., 2016), most employees have a lack of knowledge of emission reduction strategies (Madlool et al., 2011) are barriers often face by cement industry. Another range of identified barriers have been responsible for emissions reduction include lack of technological development, and proven alternative technologies are rare or inappropriate hence organizations cannot make environmental improvements (Summerbell et al., 2016; Xianbing Liu et al., 2016).

Table 4.1: Factors and sub-factors of barriers to climate change mitigation strategies of the cement industry

Main Factor	**Code**	**Sub-factor**	**References**
Economic and time frame barriers (EB)	EB1	Mitigation measures often incur an additional and high capital cost	Herrera et al., 2017; Li et al., 2013; Worrell and Galitsky, 2008
	EB2	Difficulty in accessing financial capital for emission reduction measures	Herrera et al., 2017; Xianbing Liu et al., 2016; Tesema and Worrell, 2015; Venmans, 2014
	EB3	No incentive built in budgetary systems that stimulate low carbon innovation	Di Filippo et al., 2018; Ostad-Ahmad-Ghorabi and Attari, 2013
	EB4	Poor financial performance of emission mitigation measures	Li et al., 2013
	EB5	Longer project development time and longer payback period	Herrera et al., 2017; Summerbell et al., 2016; Madlool et al., 2011
Market barriers (MB)	MB1	Carbon market uncertainty	**Industry expert's opinion**
	MB2	Weak stakeholder awareness and pressure	Herrera et al., 2017; Feiz et al., 2015
	MB3	The waste fuel including biomass constrains	Shanks et al., 2019; CSI/ECRA, 2017; Gao et al., 2016; Zorpas, 2016
	MB4	The alternative substituting material constraints	Shanks et al., 2019; Qureshi et al., 2019; Scrivener et al., 2018; Ekincioglu et al., 2013; ECA, 2013
	MB5	Market Acceptance of low carbon cement (blended cement)	Benhelal et al., 2013; ECA, 2013; CSI/ECRA, 2009
	MB6	Supplier obduracy	Di Filippo et al., 2018; Herrera et al., 2017
Organizational and Managerial barriers (OB)	OB1	Emission mitigation relatively low priority, other priorities for capital investment	Herrera et al., 2017; Feiz et al., 2015; Benhelal et al., 2013
	OB2	Lack of top management commitment	Herrera et al., 2017; Subramanian and Abdulrahman, 2017; Nguyen and Hens, 2015
	OB3	Limited information, data, and inadequate management capacity	Herrera et al., 2017; Feiz et al., 2015; Petek Gursel et al., 2014; Schneider et al., 2011
	OB4	Lack of integration of climate change strategy into corporate strategies	Herrera et al., 2017; Vargas and Halog, 2015; Worrell and Galitsky, 2008
	OB5	Additional Infrastructure requirement and retrofit challenges	Herrera et al., 2017; Ishak and Hashim, 2015; Tesema and

Main Factor	Code	Sub-factor	References
			Worrell, 2015
	OB6	Lack of R&D facilities at the organization	**Industry expert's opinion**
Government policy and regulation barriers (GB)	GB1	Impact of Non-energy policies	IPCC, 2014a
	GB2	The absence of economic incentive policies	Di Filippo et al., 2018; Ostad-Ahmad-Ghorabi and Attari, 2013
	GB3	Low level of compliance with regulation	Di Filippo et al., 2018; Nguyen and Hens, 2015
	GB4	Uncertainty and lack of government policies or regulations	Abadie et al., 2017; Matar and Elshurafa, 2017; Xuewei Liu et al., 2017; Xianbing Liu, Fan, and Li, 2016; Benhelal et al., 2013; Madlool et al., 2011
Technology and information barriers (TB)	TB1	Technical risk and uncertainty	Herrera et al., 2017; IPCC, 2014a
	TB2	Lack of effective evaluation measures for emission mitigation	Cao et al., 2016; Xianbing Liu et al., 2016
	TB3	Lack of access to external technical support	Xianbing Liu et al., 2016
	TB4	Lack of technical training on emission reduction	Scrivener et al., 2018; Summerbell et al., 2016
	TB5	Nonavailability or lack of low carbon technologies	Summerbell et al., 2016; Xianbing Liu et al., 2016

4.3 Solutions to overcome barriers to implementation of climate change mitigation strategies of the cement industry

Cement manufacturing industry needs to actively incorporate emission reduction strategies in response to burgeoning needs of climate change as a cement manufacturing process is emission intensive (Herrera et al., 2017; Feiz et al., 2015; Benhelal et al., 2013). Although the Indian cement industry is most efficient in the world (Garg et al., 2017; CII, 2015), face many obstacles in further developing emission reduction strategies. Literature and experts suggest valuable solutions for the cement industry to overcome these obstacles while implementing mitigation strategies. These solutions include Financial resources, capabilities and contingency plans establishment for mitigation measures (Scrivener et al., 2018; Herrera et al., 2017; Summerbell et al., 2016), Commitment of top management for emission reduction (Herrera et al., 2017; Xianbing Liu et al., 2017; Supino et al., 2016). The government should provide subsidies, tax exemption, incentives and low interest loan for mitigation measures for producing green products (Jokar and Mokhtar, 2018; Talaei et al., 2018), Multiple supplier policy based on environment performance (Di Filippo et al., 2018; Martin Schneider, 2015; Nguyen and Hens, 2015), Training and education of employee (Herrera et al., 2017; Summerbell et al., 2016; Klemeš et al., 2012), Implementation of policies for use of alternate material and the waste fuel (Shanks et al., 2019; Jiang et al., 2018; CSI/ECRA, 2017). Similarly, through literature and experts opinion a list of potential other solutions are identified, which are shown in Table 4.2.

Table 4.2: Solutions for implementing change mitigation strategies of the cement industry

Code	Solutions	Descriptions	References
S1	Establishment of financial resources, capabilities and contingency plans for mitigation measures	The organization should arrange financial resources, capabilities and contingency plans for efficient and effective implementation of emission reduction measures	Scrivener et al., 2018; Cormos and Cormos, 2017; Herrera et al., 2017; Summerbell et al., 2016; Tesema and Worrell, 2015; S. Zhang et al., 2015
S2	Top management commitment and incorporation of climate change mitigation measures incorporate strategies	The commitment of top management in adopting emission reduction target is significant also it is significant to integrate mitigation strategy into a corporate strategy by creating awareness among the employee as well as other stakeholders	Herrera et al., 2017; Xianbing Liu et al., 2017; Supino et al., 2016; Nguyen and Hens, 2015; CDP India, 2013
S3	Provision of well-defined and environmental supportive government policies and directions	Policies of government and effective legislative orientations regarding providing capital, low-interest rate loan, some subsidies, incentives and tax exemption on low carbon product and practices	Jokar and Mokhtar, 2018; Talaei et al., 2018; Herrera et al., 2017; Xianbing Liu et al., 2017; Salas et al., 2016; Ke et al., 2012; Dutta and Mukherjee, 2010
S4	Awareness and education of the customers and society about low carbon products and benefits of emission reduction	To create environmental awareness among consumers and society which increase the effectiveness of emission reduction initiative and sustainability	Jokar and Mokhtar, 2018; Scrivener et al., 2018; Vargas and Halog, 2015
S5	Conduct seminar, motivational programs and arranging funds for supply chain partners to build their commitment	For the knowledge of supply chain partners about green initiatives and strategies, organizations should conduct a seminar and motivational programs also establishing and arranging funds for supply	Scrivener et al., 2018; Herrera et al., 2017; Zhang and Mabee, 2016; Xianbing Liu et al.,

Code	Solutions	Descriptions	References
	about emission reduction	chain partners to build their commitment to emission reduction initiatives. It would help lower the carbon footprint of the product and the organization.	2016; Feiz et al., 2015; Nguyen and Hens, 2015; Madlool et al., 2011
S6	Multiple supplier policies based on environment criteria	To reduce the supplier risks and uncertainty based on environmental criteria, multiple supplier policies helps the organizations to fulfil their economic-ecological gains in emission reduction at the industrial perspective	Di Filippo et al., 2018; Martin Schneider, 2015; Nguyen and Hens, 2015
S7	Building environmental collaboration and partnerships within and across the industrial sector at a different level	This solution is useful in achieving the emission reduction goal of organizations by building environmental collaboration and partnerships within and across the industrial sector at a different level.	Scrivener et al., 2018; Supino et al., 2016; Tesema and Worrell, 2015; Vargas and Halog, 2015; Petek Gursel et al., 2014
S8	Training and education of employee to increase their competency regarding climate change mitigation	Sound knowledge and understanding through training and education of low carbon measures among employees will increase the low carbon supply chain success rate	Herrera et al., 2017; Summerbell et al., 2016; Klemeš et al., 2012; Madlool et al., 2011; Dutta and Mukherjee, 2010
S9	To develop and upgrade on state-of-the-art-technology being used in the specific sectors for the implementation of the emission reduction target.	For efficient and effective employment of emission reduction strategies in the supply chain, managers should have sound proficiency of new state-of-the-art-technology applicability in various sectors	Herrera et al., 2017; Xuewei Liu et al., 2017; Xu et al., 2014; Ansari and Seifi, 2013; Madlool et al., 2011; Dutta and Mukherjee, 2010
S10	R & D facilities in collaboration between industries, educational institutes, and the Government	The collaborative R&D facilities help in the attainment of emission reduction target effectively also, to stimulate breakthrough technologies, the organization should provide access to R&D funds	Feng et al., 2018; Tesema and Worrell, 2015; Ostad-Ahmad-Ghorabi and Attari, 2013; Imbabi et al., 2012
S11	Implementation of policies for the use of alternate substituting material and waste as a	The government should draft policies that reward the use of alternative materials and the waste as a kiln fuel to replace natural materials and to conserve natural resources	Shanks et al., 2019; Jiang et al., 2018; Herrera et al., 2017; Zhang and Mabee,

Code	Solutions	Descriptions	References
	fuel including biomass		2016; Gao et al., 2015; Madlool et al., 2011
S12	The government should implement "Pollutants have to pay" Principle	This principle forces polluters to pay for damages fully	**Industry expert's opinion**
S13	The government should enhance the workforce for monitoring pollution prevention and reduction activities	In India, pollution monitoring is being carried out by pollution control committees, central pollution control board and state pollution control boards, etc. The government should enhance the workforce for monitoring the pollution to reduce the emission and other pollutants	Raffetti et al., 2019; Mirzakhani et al., 2017; Su et al., 2013; Dutta and Mukherjee, 2010
S14	Govt. should create a healthy environment for Carbon market/emission trading systems	Carbon markets aim to reduce GHGEs by setting emissions limits and enabling the carbon credits trading. The government should establish the market parameters and its regulation, including the rules for creating, issuing and distributing carbon credits, setting enforcement, and trading rules, etc.	Bhandari and Shrimali, 2018; Ostad-Ahmad-Ghorabi and Attari, 2013

4.4 Application of proposed research framework

4.4.1 Case illustration: The Indian cement industry

Cement plants in India are among the most efficient plants in the world. However, they contribute 9% of the total national GHGs inventory. Thus, growing GHGEs and continuously increasing demand for cement are the main enablers that motivate the cement industry to find a solution for emission reduction. Indian cement industry can achieve further efficiency by adopting emerging mitigation strategies. This will make the cement industry of India cost effective and more competitive in the global market. Here, the integrated Fuzzy AHP-TOPSIS framework is used to rank the barriers and barriers overcome solutions to emission reduction strategies in the Indian cement industry. This framework consists of three phases explained as follows.

Phase I: Identifying the barriers and its solutions to overcome

Through literature review and opinion of experts who were actively involved in processes of cement manufacturing, Twenty-six barriers under five main factor category (Table 4.1) and

Fourteen solutions (Table 4.2) were identified, then these five main factors, twenty-six sub-factors and fourteen barriers overcoming solutions are formed decision hierarchy as shown in Fig. 4.2. This study targets ten cement industry of India; the survey questionnaires were individually distributed to the authorities who actively engaged in the cement manufacturing process, during two months from June to July 2017. Middle and senior rank engineers and managers with divergent accountability were selected during the data collection process because they are an integral member of the strategic decision-making group (Carter et al., 1998). The selected industrial experts were remarkably proficient in their discipline, having industrial experience of above 10 years. The detailed respondent profiles are given in Table 3.1.

The questionnaire was created to obtain experts' viewpoint on the various barriers involved during the implementation of climate change mitigation strategies in the cement manufacturing industry. We thoroughly explained the objective, utility and potential advantages of the research to each respondent before data collection, then as per linguistic value mention in Table 4.3 and Table, 4.4 experts were asked to rate the barriers and its solution to overcome barriers of implementing climate change mitigation strategies in cement industry.

Table 4.3: Triangular fuzzy conversion scale

Intensity of importance	Fuzzy number	Linguistic variable	Membership function
1	$\tilde{1}$	Equally preferred/important (EI)	(1,1,3)
3	$\tilde{3}$	Weakly preferred /important (WI)	(1,3,5)
5	$\tilde{5}$	Strongly more preferred/important (SMI)	(3,5,7)
7	$\tilde{7}$	Very strongly preferred/important (VSI)	(5,7,9)
9	$\tilde{9}$	Extremely more preferred/important (EMI)	(7,9,11)

Table 4.4: Linguistic scale for solutions selection

Linguistic variables	Corresponding TFN
Very Poor (VP)	(1,1,3)
Poor (P)	(1,3,5)
Medium (M)	(3,5,7)
Good (G)	(5,7,9)
Very Good (VG)	(7,9,11)

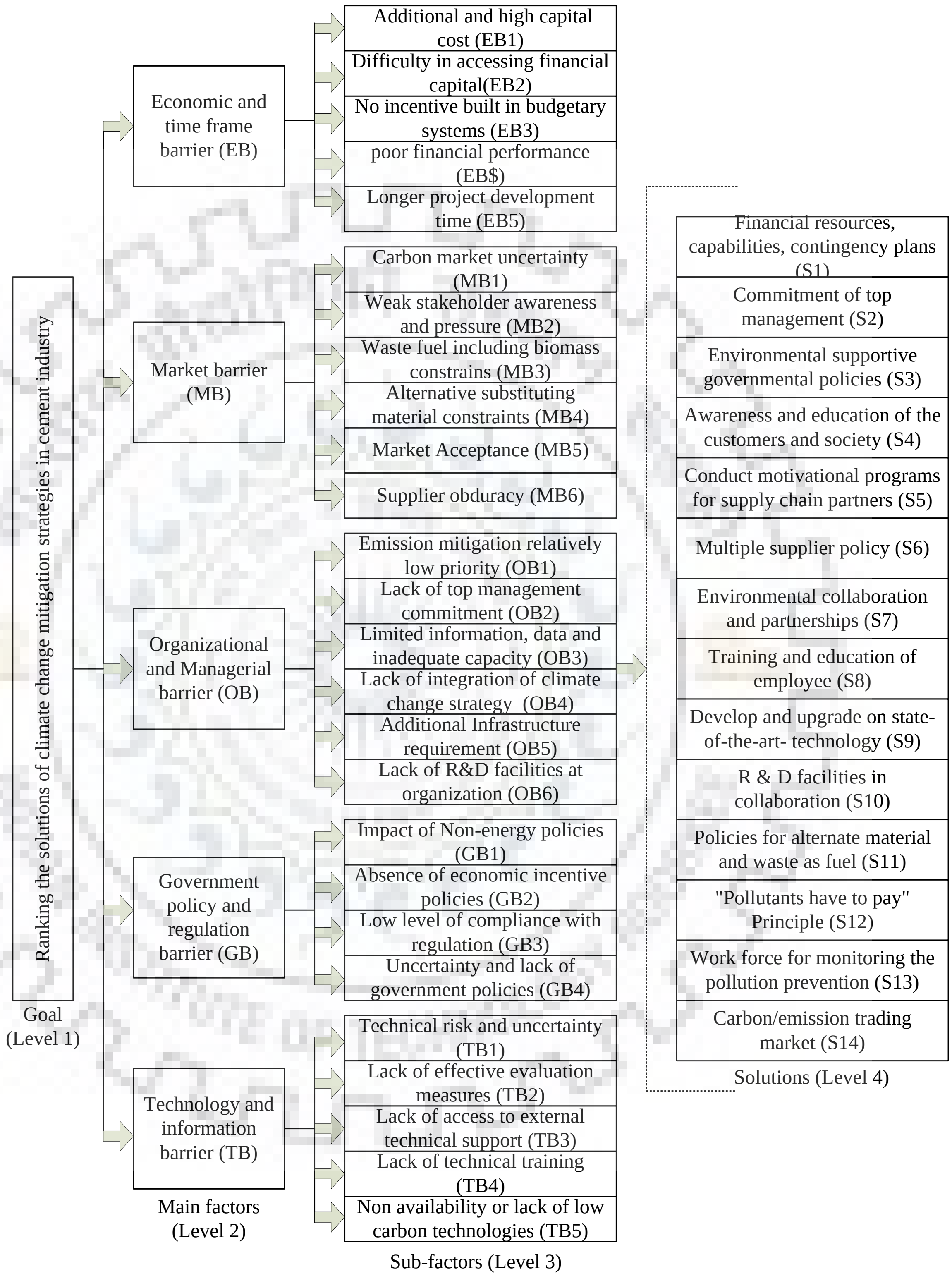


Figure 4.2: Decision hierarchy model

Phase II: Calculate the weight of the barriers using FAHP

The importance of the barrier is calculated by using FAHP by constructing pairwise comparison matrix of the main factors (Table 4.5-4.6) and sub-factors (Table 4.7-4.11) from the scale given in Table 4.3, and the results were calculated from these pairwise comparison matrix given in Table 4.12

Table 4.5: Pair-wise comparison matrix of the main factor (Expert 1) (Linguistic variable)

	EB	MB	OB	GB	TB
EB	EI	WI			VSI
MB		EI			SMI
OB	WI	SMI	EI		VSI
GB	VSI	EMI	WI	EI	EMI
TB					EI

Table 4.6: Pair-wise comparison matrix of the main factor (Expert 1)

	EB	MB	OB	GB	TB
EB	(1,1,3)	(1,3,5)	(0.2.0.33,1)	(0.11,0.14,0.2)	(5,7,9)
MB	(0.2,0.33,1)	(1,1,3)	(0.14,0.2,0.33)	(0.09,0.11,0.143)	(3,5,7)
OB	(1,3,5)	(3,5,7)	(1,1,3)	(0.2,0.33,1)	(5,7,9)
GB	(5,7,9)	(7,9,11)	(1,3,5)	(1,1,3)	(7,9,11)
TB	(0.11,0.14,0.2)	(0.14,0.2,0.33)	(0.11,0.14,0.2)	(0.09,0.11,0.14)	(1,1,3)

Table 4.7: Pair-wise comparison matrix of the EBs (Expert 1)

	EB1	EB2	EB3	EB4	EB5
EB1	(1,1,3)	(7,9,11)	(1,3,5)	(3,5,7)	(5,7,9)
EB2	(0.09,0.11,0.14)	(1,1,3)	(0.09,0.11,0.14)	(0.2,0.33,1)	(0.2,0.33,1)
EB3	(0.2,0.33,1)	(7,9,11)	(1,1,3)	(5,7,9)	(1,3,5)
EB4	(0.14,0.2,0.33)	(1,3,5)	(0.11,0.14,0.2)	(1,1,3)	(1,3,5)
EB5	(0.11,0.14,0.2)	(1,3,5)	(0.2,0.33,1)	(0.2,0.33,1)	(1,1,3)

Table 4.8: Pair-wise comparison matrix of the MBs (Expert 1)

	MB1	MB2	MB3	MB4	MB5	MB6
MB1	(1,1,3)	(0.09,0.11,0.14)	(0.09,0.11,0.14)	(0.11,0.14,0.2)	(0.2,0.33,1)	(1,3,5)
MB2	(7,9,11)	(1,1,3)	(0.2,0.33,1)	(3,5,7)	(5,7,9)	(7,9,11)
MB3	(7,9,11)	(1,3,5)	(1,1,3)	(3,5,7)	(7,9,11)	(7,9,11)
MB4	(5,7,9)	(0.14,0.2,0.33)	(0.14,0.2,0.33)	(1,1,3)	(1,3,5)	(5,7,9)
MB5	(1,3,5)	(0.11,0.14,0.2)	(0.09,0.11,0.14)	(0.2,0.33,1)	(1,1,3)	(3,5,7)
MB6	(0.2,0.33,1)	(0.09,0.11,0.14)	(0.09,0.11,0.14)	(0.11,0.14,0.2)	(0.14,0.2,0.33)	(1,1,3)

Table 4.9: Pair-wise comparison matrix of the OBs (Expert 1)

	OB1	OB2	OB3	OB4	OB5	OB6
OB1	(1,1,3)	(3,5,7)	(7,9,11)	(5,7,9)	(5,7,9)	(1,3,5)
OB2	(0.14,0.2,0.33)	(1,1,3)	(5,7,9)	(5,7,9)	(3,5,7)	(0.2,0.33,1)
OB3	(0.09,0.11,0.14)	(0.09,0.11,0.14)	(1,1,3)	(0.09,0.11,0.14)	(0.09,0.11,0.14)	(0.09,0.11,0.14)
OB4	(0.09,0.11,0.14)	(0.09,0.11,0.14)	(5,7,9)	(1,1,3)	(0.2,0.33,1)	(0.2,0.33,1)
OB5	(0.11,0.14,0.2)	(0.14,0.2,0.33)	(5,7,9)	(1,3,5)	(1,1,3)	(0.2,0.33,1)
OB6	(0.2,0.33,1)	(1,3,5)	(5,7,9)	(1,3,5)	(1,3,5)	(1,1,3)

Table 4.10: Pair-wise comparison matrix of the GBs (Expert 1)

	GB1	GB2	GB3	GB4
GB1	(1,1,3)	(0.09,0.11,0.14)	(0.14,0.2,0.33)	(0.09,0.11,0.14)
GB2	(7,9,11)	(1,1,3)	(5,7,9)	(1,3,5)
GB3	(3,5,7)	(0.11,0.14,0.2)	(1,1,3)	(0.14,0.2,0.33)
GB4	(7,9,11)	(0.2,0.33,1)	(3,5,7)	(1,1,3)

Table 4.11: Pair-wise comparison matrix of the TBs (Expert 1)

	TB1	TB2	TB3	TB4	TB5
TB1	(1,1,3)	(0.2,0.33,1)	(0.14,0.2,0.33)	(0.14,0.2,0.33)	(0.2,0.33,1)
TB2	(1,3,5)	(1,1,3)	(0.2,0.33,1)	(0.33,1,1)	(1,3,5)
TB3	(3,5,7)	(1,3,5)	(1,1,3)	(1,3,5)	(3,5,7)
TB4	(3,5,7)	(1,1,3)	(0.2,0.33,1)	(1,1,3)	(1,3,5)
TB5	(1,3,5)	(0.2,0.33,1)	(0.14,0.2,0.33)	(0.2,0.33,1)	(1,1,3)

Table 4.12: The final ranking of barriers to climate change mitigation strategies of cement industry adoption

Main Factor	Weight	Code	Weight	Global weight	Global rank
Economic and time frame barrier	0.1820	EB1	0.409	0.0744	4
		EB2	0.045	0.0081	18
		EB3	0.312	0.0568	8
		EB4	0.155	0.0282	12
		EB5	0.078	0.0142	15
Market barrier	0.1276	MB1	0.022	0.0028	24
		MB2	0.318	0.0405	11
		MB3	0.365	0.0465	9
		MB4	0.187	0.0238	14
		MB5	0.072	0.0091	17
		MB6	0.037	0.0047	19
Organizational and Managerial barrier	0.2835	OB1	0.290	0.0822	3
		OB2	0.215	0.0609	6
		OB3	0.016	0.0045	20
		OB4	0.086	0.0243	13

Main Factor	Weight	Code	Weight	Global weight	Global rank
		OB5	0.157	0.0445	10
		OB6	0.236	0.0669	5
Government policy and regulation barrier	0.3930	GB1	0.032	0.0125	16
		GB2	0.458	0.1799	1
		GB3	0.152	0.0597	7
		GB4	0.358	0.1406	2
Technology and information barrier	0.0138	TB1	0.079	0.0010	26
		TB2	0.212	0.0029	23
		TB3	0.303	0.0041	21
		TB4	0.256	0.0035	22
		TB5	0.150	0.0020	25

Phase III: Ranking the solutions to overcome barriers using FTOPSIS

On applying linguistic variables Table 4.4, linguistic scale evaluation matrix was formed as shown in Table 4.13. Then, the fuzzy evaluation matrix was constructed, as shown in Table 4.14 by converting a linguistic variable into corresponding TFN. Here linguistic scale matrix (Table 4.13) and fuzzy evaluation matrix (Table 4.14) of expert 1 is given only because of space constraints. By using equation (3.10.2.1) aggregate, fuzzy solutions ratings were computed, as shown in Table 4.15. Here, all the factors are considered as cost criteria since the objective of the present study is to minimize the barrier effects and normalized fuzzy decision matrix for solutions (Table 4.16) was formed by using equation (3.10.2.4). Further, the weighted normalized fuzzy decision matrix for solutions (Table 4.17) was formed by using equation (3.10.2.5). Finally, the final ranking of the solutions (Table 4.18) was obtained by using equations (3.10.2.8, 3.10.2.9 and 3.10.2.10).

Table 4.13: Linguistic scale evaluation matrix for the solutions (Expert 1)

	EB1	EB2	EB3	----	----	TB3	TB4	TB5
S1	G	VG	VG	----	----	VG	G	G
S2	M	G	G	----	----	G	G	G
S3	VG	VG	VG	----	----	G	G	M
----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----
S12	M	G	G	----	----	M	M	M
S13	M	P	G	----	----	G	G	G
S14	G	G	VG	----	----	P	P	P

Table 4.14: Fuzzy evaluation matrix for solutions (Expert 1)

	EB1	EB2	EB3	----	----	TB3	TB4	TB5
S1	(5,7,9)	(7,9,11)	(7,9,11)	----	----	(7,9,11)	(5,7,9)	(5,7,9)
S2	(3,5,7)	(5,7,9)	(5,7,9)	----	----	(5,7,9)	(5,7,9)	(5,7,9)
S3	(7,9,11)	(7,9,11)	(7,9,11)	----	----	(5,7,9)	(5,7,9)	(3,5,7)
----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----
S12	(3,5,7)	(5,7,9)	(5,7,9)	----	----	(3,5,7)	(3,5,7)	(3,5,7)
S13	(3,5,7)	(1,3,5)	(5,7,9)	----	----	(5,7,9)	(5,7,9)	(5,7,9)
S14	(5,7,9)	(5,7,9)	(7,9,11)	----	----	(1,3,5)	(1,3,5)	(1,3,5)

Table 4.15: Aggregate fuzzy decision matrix for solutions

	EB1	EB2	EB3	----	----	TB3	TB4	TB5
S1	(5,8,11)	(5,8.2,11)	(5,7.8,11)	----	----	(3,6.4,11)	(3,6.2,9)	(3,6.4,9)
S2	(3,6.6,9)	(3,6.8,9)	(5,7.2,11)	----	----	(3,7,11)	(3,7,11)	(3,6.8,9)
S3	(7,8.2,11)	(5,8.4,11)	(5,7.6,11)	----	----	(5,7,9)	(5,6.8,9)	(3,6.8,9)
----	----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----	----
S12	(3,6.6,11)	(1,5.4,9)	(3,6.2,9)	----	----	(1,4.6,7)	(1,5,9)	(1,4.6,9)
S13	(1,4.6,9)	(1,3.4,7)	(1,5.4,9)	----	----	(1,6,9)	(1,5.8,9)	(1,5,9)
S14	(3,6.8,11)	(1,6.4,9)	(3,6.4,9)	----	----	(1,4.4,9)	(1,5,9)	(1,5,9)

Table 4.16: Normalized fuzzy decision matrix for solutions

	EB1	EB2	EB3	-	TB3	TB4	TB5
S1	(0.09,0.12,0.2)	(0.09,0.12,0.2)	(0.09,0.12,0.2)	-	(0.09,0.15,0.33)	(0.11,0.16,0.33)	(0.11,0.15,0.33)
S2	(0.11,0.15,0.33)	(0.11,0.14,0.33)	(0.09,0.13,0.2)	-	(0.09,0.14,0.33)	(0.09,0.14,0.33)	(0.11,0.14,0.33)
S3	(0.09,0.12,0.14)	(0.09,0.11,0.2)	(0.09,0.13,0.2)	-	(0.11,0.14,0.2)	(0.11,0.14,0.2)	(0.11,0.14,0.33)
---	---	---	---	-	---	---	---
---	---	---	---	-	---	---	---
S12	(0.11,0.15,0.33)	(0.11,0.18,1)	(0.11,0.16,0.33)	-	(0.14,0.21,1)	(0.11,0.2,1)	(0.11,0.21,1)
S13	(0.11,0.21,1)	(0.14,0.29,1)	(0.11,0.18,1)	-	(0.11,0.16,1)	(0.11,0.17,1)	(0.11,0.2,1)
S14	(0.09,0.14,0.33)	(0.11,0.15,1)	(0.11,0.15,0.33)	-	(0.11,0.22,1)	(0.11,0.2,1)	(0.11,0.2,1)

Table 4.17: Weighted normalized fuzzy decision matrix for solutions

	EB1	EB2	EB3	----	TB3	TB4	TB5
S1	(0.0068,0.0093,0.1490)	(0.0007,0.0010,0.0016)	(0.0052,0.0073,0.0114)	----	(0.0004,0.0007,0.0014)	(0.0004,0.0006,0.0012)	(0.0002,0.0003,0.0007)
S2	(0.0083,0.0113,0.0248)	(0.0009,0.0012,0.0027)	(0.0052,0.0079,0.0114)	----	(0.0004,0.0006,0.0014)	(0.0003,0.0005,0.0012)	(0.0002,0.0003,0.0007)
S3	(0.0068,0.0091,0.0106)	(0.001,0.001,0.0016)	(0.0052,0.0075,0.0114)	----	(0.0005,0.0006,0.0008)	(0.0004,0.0005,0.0007)	(0.0002,0.0003,0.0007)
----	----	----	----	----	----	----	----
----	----	----	----	----	----	----	----
S12	(0.0068,0.0113,0.0248)	(0.0009,0.0015,0.0082)	(0.0063,0.0092,0.0190)	----	(0.0006,0.0009,0.0042)	(0.0004,0.0007,0.0035)	(0.0002,0.0005,0.0025)
S13	(0.0083,0.0162,0.0744)	(0.0012,0.0024,0.0082)	(0.0063,0.0105,0.00569)	----	(0.0005,0.0007,0.0042)	(0.0004,0.0007,0.0035)	(0.0002,0.0004,0.0021)
S14	(0.0068,0.0109,0.0248)	(0.009,0.0013,0.0082)	(0.0063,0.089,0.019)	----	(0.0005,0.001,0.0042)	(0.0004,0.0007,0.0035)	(0.0002,0.0004,0.0021)

Table 4.18: Closeness coefficient and a final ranking of the solutions

Code	Solutions	d_i*	d_i-	CC_i	rank
S1	Establishment of financial resources, capabilities and contingency plans for mitigation measures	0.3265	25.7071	0.9874	4
S2	Top management commitment and incorporation of climate change mitigation measures in corporate strategies	0.2495	25.7669	0.9904	2
S3	Provision of well-defined and environmental supportive governmental policies and directions	0.2211	25.7892	0.9915	1
S4	Awareness and education of the customers and society about low carbon products, emission reduction and climate change as a part of CSR activities	0.5671	25.5478	0.9782	14
S5	Conduct seminar, motivational programs and arranging funds for supply chain partners to build their commitment about emission reduction	0.4944	25.6027	0.9810	13
S6	Multiple supplier policy based on environment	0.4708	25.6022	0.9819	11

Code	Solutions	d_i*	d_i-	CC_i	rank
	criteria				
S7	Building environmental collaboration and partnerships within and across the industrial sector at a different level	0.2773	25.7437	0.9893	3
S8	Training and education of employee to increase their competency regarding climate change mitigation	0.4141	25.6590	0.9841	8
S9	To develop and upgrade on state-of-the-art-technology being used in the specific sectors for the implementation of emission reduction target, the Government could encourage norms for the use of industrial energy efficient equipment	0.4610	25.6243	0.9823	10
S10	R & D facilities in collaboration between plants, educational institutes and Government	0.4736	25.6174	0.9818	12
S11	Implementation of policies for the use of alternate substituting material and the waste as a fuel including biomass	0.3666	25.6828	0.9859	6
S12	Government should implement "Pollutants have to pay" Principle	0.3624	25.6874	0.9860	5
S13	The government should enhance the workforce for monitoring the pollution prevention and reduction activities in cement plants	0.4296	25.5427	0.9834	9
S14	Govt. should create the Healthy environment for Carbon market/emission trading systems	0.3957	25.6661	0.9848	7

4.5 Result analysis and discussion

The computational result of the proposed model in Section 4.4 shows the importance of climate change mitigation strategies and its barriers in a comprehensive manner. A list of a total of five barriers dimensions with twenty-six sub-dimensions is analyzed with the help of FAHP method. The detailed result discussion is presented in Sub-section 4.5.1-4.5.3.

4.5.1 Barrier main factor ranking using Fuzzy AHP

The results of the Fuzzy AHP analysis are shown in Tables 4.5-4.12. Table 4.5 shows the pair-wise comparison matrix obtained from Expert 1 judgment for the main barrier factor and Table 4.7-4.11 shows a pair-wise comparison of each main factor by Expert 1 judgment. Table 4.12 depicts the final ranking of each barrier to climate change mitigation strategies in cement industry adoption. The overall ranking is based on the global weight values of the AHP method. The global weights were obtained by multiplying the relative weight of the main factor values with the relative weights of each sub-factor.

We infer from Table 4.12 that Government policy and regulations related barriers (GB) are ranked first among the main factors. For many cement industry, Government policy and regulations are the main barriers in the adoption of emission reduction strategies (Di Filippo et al., 2018; Abadie et al., 2017). Organizational and managerial barriers (OB) is ranked second. Carbon emission becomes a low priority for top management (Herrera et al., 2017; Benhelal et al., 2013). Economic and time frame barrier (EB) receives the next place in the analysis. Emission reduction options often incur high capital investment and there no incentives in the budgetary system that stimulate low carbon innovation (Herrera et al., 2017; Worrell & Galitsky, 2008)is the barriers in this category while Market barrier (MB) ranks fourth. The alternate fuel and alternate clinker substituting material constraint (Shanks et al., 2019; CSI/ECRA, 2017) and market acceptance of blended cement is another barrier (Benhelal et al., 2013) in this category. Technology and information barriers (TB) is placed in the last position among the main category barriers. The lack of technical training on emission reduction measures (Scrivener et al., 2018; Summerbell et al., 2016)) and technical risk and uncertainty (Herrera et al., 2017; IPCC, 2014a) are major impediments for the adoption of climate change mitigation measures in the cement industry

The following sections discuss the result of each subfactor barrier in the global ranking, based on the AHP analysis.

4.5.2 Barrier ranking for mitigation measures of the Indian cement industry using AHP

4.5.2.1 Government policy and regulations related barriers

In this category, two barriers shared the biggest priority in the general ranking position: The absence of financial, economic incentive policies (GB2) and the uncertainty and lack of government policies or regulations (GB4). As per Di Filippo et al., (2018), many of the emission-reducing measures are available for the cement industry, but the incumbent industry is not likely to reduce emissions without an incentive. The cement industry is subject to uncertainty in future climate policy (Abadie et al., 2017). Madlool et al. (2011) observed that due to the lack of government policies, many economically viable technologies to reduce emissions not fully utilized. Low level of compliance with regulation (GB3) is the next barrier in GB category. Nguyen & Hens (2015) studied that non-certified ISO 14001 plants peers achieved only a moderate degree of regulatory compliance. Finally, the last one in this category is the impact of non-energy policies (GB1) barrier. Even though energy consumption can be a significant cost for industry, the impact of non-energy policies becomes a barrier, which limits industrial sector steps to minimize emissions use via energy efficiency measures (IPCC, 2014a).

4.5.2.2 Organizational and managerial barriers

Other priorities for capital investments fundamentally considered before the implementation of emission reduction measures also energy issues being assigned a low priority in organizations because of the low position of energy managers (Herrera et al., 2017). Table 4.12 presents that, in the OB factor, Emission mitigation relatively low priority, and other priorities for capital investment (OB1) barrier ranks third in the global ranking and first in this category. Lack of R&D facilities for implementation of climate change mitigation strategies implementation at the organization (OB6) barrier comes next, attaining the fifth position in the global ranking. Then, Lack of top management commitment (OB2) barrier ranks third in OB category and sixth in the global ranking. The commitment to environmental issues not integrated into non-certified originations, as the environment was no longer considered an assigned responsibility (Nguyen and Hens, 2015). Additional infrastructure requirement and retrofit challenges (OB5) ranked tenth in global ranking and fourth in OB category barriers. Based on our survey by Tesema and Worrell, (2015), the key barriers to implementation of emission reduction measures in the cement industry is the insufficient infrastructure for alternative fuels. For energy efficient technologies, retrofitting costs imposed a limitation (Ishak and Hashim, 2015).

The two last barriers in this category are Lack of integration of climate change strategy into corporate strategies (OB4) barrier, and Limited information, data, and inadequate management capacity (OB3) barrier. By barrier OB4, Vargas and Halog, (2015) pointed out that some companies and individual users are often reluctant to incorporate low carbon cement and low carbon strategy. Confirming barrier OB3, Benhelal et al., (2013) observed that main barriers against emission reduction measures are limited information, limited time and the number of staff.

4.5.2.3 Economic and time frame barriers

Economic and time frame barriers category is comprised of five barriers. Mitigation measures often incur additional and high capital cost (EB1) barrier comes fourth in the global list and first in this category and. Many of the available mitigation measures require significant new capital investments or costly new processes, both of which translate into a higher unit cost for end products (Di Filippo et al., 2018). The succeeding barrier is No incentive built in budgetary systems that stimulate low carbon innovation (EB3). Hasanbeigi et al., (2012) claim that to stimulate low carbon innovation, organizations faces the barrier of the lack of financial incentive. Longer project development time and longer payback period (EB5) and Difficulty in accessing financial capital for emission reduction measures (EB2) barriers are fourth and fifth rank in EB category, respectively. Brunke and Blesl (2014) reported that longer payback time is the main barrier to the adoption of emission reduction technology. Herrera et al. (2017) found that access to capital had a substantial weighting compared to other barriers while implementing emission reduction measures.

4.5.2.4 Market barriers

The alternate fuels, including biomass constrain (MB3) and weak stakeholder awareness and pressure (MB2), are the first and second barriers in this category, respectively. The availability of alternate fuel and competition for biomass are the limiting factor for kiln fuel (Shanks et al., 2019; CSI/ECRA, 2017). Di Filippo et al., (2018) pointed out that currently, incentives to low carbon measures adoption are insufficient because the damages to society caused by GHGEs are borne by neither buyers nor sellers of concrete products, and can be ignored when making purchasing decisions. The third barrier of the category is the alternative substituting material constraints (MB4). The local availability, cost, and quality of clinker substituting material is a global challenge (Shanks et al., 2019; Ekincioglu et al., 2013). Next is Market acceptance of low carbon cement (MB5). Benhelal et al. (2013) stated that some markets are still incompatibility between the national standards and the properties of blended cement. Supply obduracy is the next barrier in the category of MB. Undetermined costs of the cement industry are due to the lack of information provided by suppliers (Herrera et al., 2017). Finally, Carbon market uncertainty (MB1) barrier, ranked 24 as per AHP analysis.

4.5.2.5 Technology and information barriers

Lack of access to external technical support (TB3) and Lack of technical training on emission reduction (TB4) have 21 and 22 global rankings. CO_2Es reduction by better technical training is a preferred option of cleaner production of the cement industry (Summerbell et al., 2016). Lack of effective evaluation measures for emission mitigation (TB2) barrier and Non-availability of lack of low carbon technologies (TB5) are another two barriers in this category. Due to the lack of measurement and statistics of GHGEs within their companies, the cement industry is not aware of their actual emissions (Xianbing Liu et al., 2016). Finally, technical risk and uncertainty (TB1) ranking last among the 26 barriers. Herrera et al. (2017) found that the main barrier to implementing low carbon measures in some cement industry is the technical risk of production disruption.

4.5.3 Barriers overcome solutions ranking by using Fuzzy TOPSIS methodology

The closeness coefficient score and a final ranking of the solutions to overcome the above barriers are shown in Table 4.18. We infer from Table 4.18 that the first among the solution is "Provision of well defined and environment supportive government policies and direction (S3)". The government needs to implement incentives, provides low interest subsidized loan, tax exemption, etc. for companies using environmentally friendly and sustainable production technologies for reducing emissions (Salas et al., 2016; Ostad-Ahmad-Ghorabi and Attari, 2013). The second-ranked solution is "Top management commitment, and incorporation of mitigation measures incorporate strategies (S2)". For the impact of manufacturing processes on the environment, management is responsible; thus, based on international standards, management has developed environmental management systems so that it creates environmental awareness among the employee as well as on other stakeholders (Herrera et al., 2017). Third among the solutions is "Building environmental collaboration and partnerships within and across the industrial sector at a different level (S7)". The result of the research by Supino et al., (2016) point out the urgency for a collaborative approach among the business community, all supply chain actors, policymakers, and institutions, to cut down the GHGEs from the cement industry. The fourth solution is the "Establishment of financial resources, capabilities and contingency plans for mitigation measures (S1)". Lack of capital was an important barrier to the adoption of low carbon measure (Xianbing Liu et al., 2016); hence, the cement industry should arrange capital from various sources to mitigate climate change. Next solution is the government should implement "Pollutants have to pay" Principle (S12). The sixth solution is "Implementation of policies for the use of alternate substituting material and waste as a fuel, including biomass (S11)". Madlool et al. (2011) noticed that coal is the major source of kiln fuel. Thus, alternate fuel can be considered as an option to reduce GHGEs and environmental pollution too. The result of analysis by Shanks et al., (2019) show that in terms of material demand reduction, substituting cement has the greatest potential. Hence, the government should draft strong policies regarding the use of alternative fuel and clinker substituting materials in the cement industry. The seventh solution is "Government should create a healthy environment for Carbon market/emission trading systems (S14)". The government should establish the carbon trading market parameters, and its regulation, including the rules for creating, issuing and distributing carbon credits, setting enforcement, and trading rules, etc. since the objective of carbon trading market is to reduce GHGEs by setting emissions limits and enabling the carbon credits trading. The next solution is "Training and education of employee to increase their competency regarding climate change mitigation (S8)". The decision-making process for the adoption of carbon management options depends majorly on training and education of employee (Herrera et al., 2017). "The government should enhance the workforce for monitoring pollution prevention and reduction activities (S13)" is the ninth barrier to overcome solution. Audit and monitoring of energy consumption are the direct tools which are employed to help reduce GHGEs (Su et al., 2013). The tenth solution is "To develop and upgrade on state-of-the-art-technology being used in the specific sectors for the implementation of emission reduction target (S9)". The cement industry is moving towards state-of-the-art-technology, more energy efficient equipment and processes to cut down GHGEs in the cement industry (Madlool et al., 2011).

4.6 Chapter summary

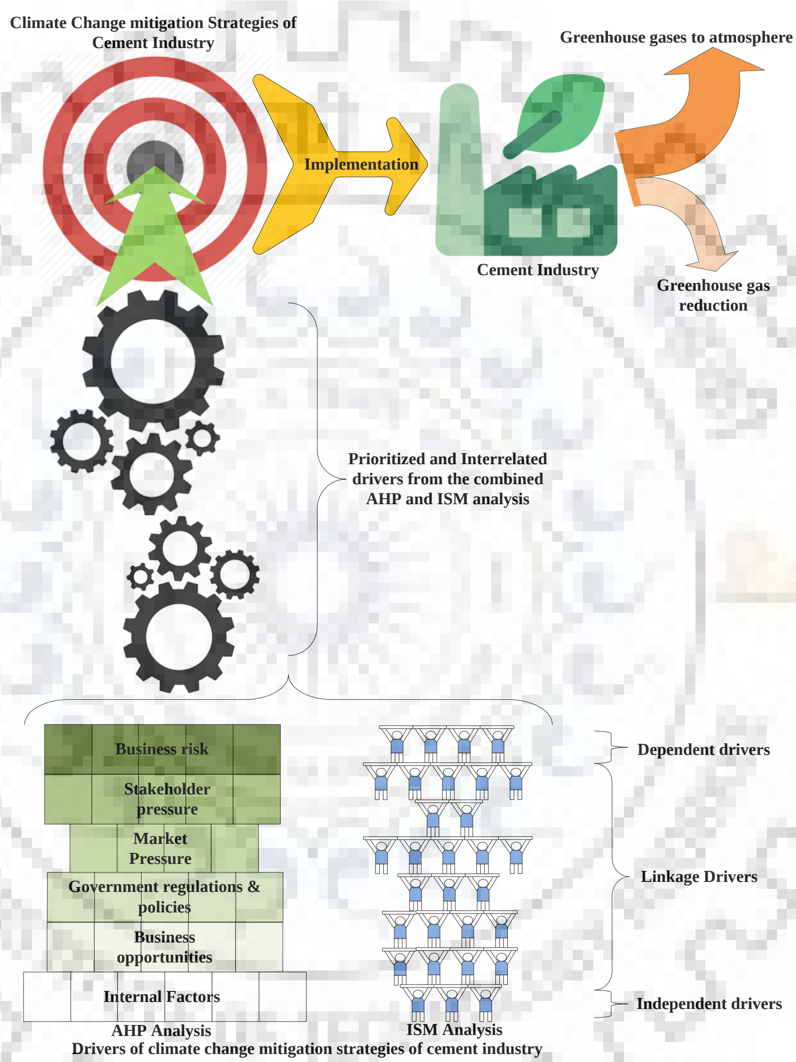
This chapter presents a robust MCDM method for prioritizing the solutions to overcome barriers to climate change mitigation strategies. Total twenty-six barriers have been identified. To overcome these barriers, fourteen solutions are presented. Then integrated Fuzzy AHP-TOPSIS is applied to get final rank. Fuzzy AHP is applied to get the relative weights of the barriers, and Fuzzy TOPSIS is applied to prioritize the solutions. The result exhibits that solution S3, i.e.

Provision of well-defined and environmental supportive government policies, and directions are the highest ranked solutions in this case to climate change mitigation measure adoption. The proposed framework is supported by an empirical case of the Indian cement industry to overcome its barriers to climate change mitigation strategies adoption. The findings of this chapter would help manage and overcome the barriers to effective implementation to climate change mitigation practices, but also enable in enhancing the ecological-economic gains. Moreover, prioritization of the solutions supports organizations to make policy for solution implementation to overcome its barriers to climate change mitigation strategies adoption.

Chapter 5

Analyze the drivers to climate change mitigation strategies of the Indian cement industry

Graphical abstract



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Part of this chapter has been submitted in Journal of Cleaner Production (Elsevier): Balsara S, Jain P.K. and Ramesh A. (2018) Analyzing drivers to climate change mitigation strategies of Indian cement industry (under review) Journal of Cleaner Production

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Preview

This chapter provides details about the identification, finalization, and prioritization of the drivers to the climate change mitigation strategies implementation in the Indian cement industry. This chapter proposes a flexible model to prioritize these drivers to the climate change mitigation strategies. For this, an integrated approach based on the AHP and ISM methods has been developed and used in this chapter.

5.1 Introduction

Among the worldwide, industrial activities contribute around 37% of global GHGEs (Worrell et al., 2009). For industry, reduction of GHGEs is particularly critical in the cement, pulp and paper, iron and steel, chemicals and petrochemicals and aluminum, the five most energy and emission intensive sectors (Akimoto et al., 2010; Schmidt et al., 2008). Production of cement is one of the major sources of anthropogenic CO_2Es (Feiz et al., 2015; Gao et al., 2015; IPCC, 2014a; Benhelal et al., 2013; IEA, 2013; Ali et al., 2011). The cement industry is the second largest CO_2 emitter among all the industrial activities of India (IEA, 2013). Thus, the cement manufacturing process has the potential to create a substantial environmental footprint, preferably by emitting GHGs (Naeimi et al., 2019). Climate change mitigation measures help the cement industry to reduce GHGEs along with gaining a competitive advantage over other, create a green corporate image and sustain in the long run (Maddalena et al., 2018). Hence, the need of the hour is to identify drivers to mitigation strategies of the cement industry of a developing economy.

A three-phase methodology used to rank these drivers, as shown in Fig. 5.1. First phase: Identify the drivers to implement mitigation strategies in the Indian cement industry from the literature review and with the technical expert consultation. Through a detailed review of literature and discussion with technical experts, a total of thirty drivers were identified which were categorized into six main categories. These are presented in Table 5.1, Second phase: To rank these drivers, the AHP methodology (Saaty, 1980) is used. Third phase: ISM methodology (Warfield, 1974) gives interrelationship among the drivers.

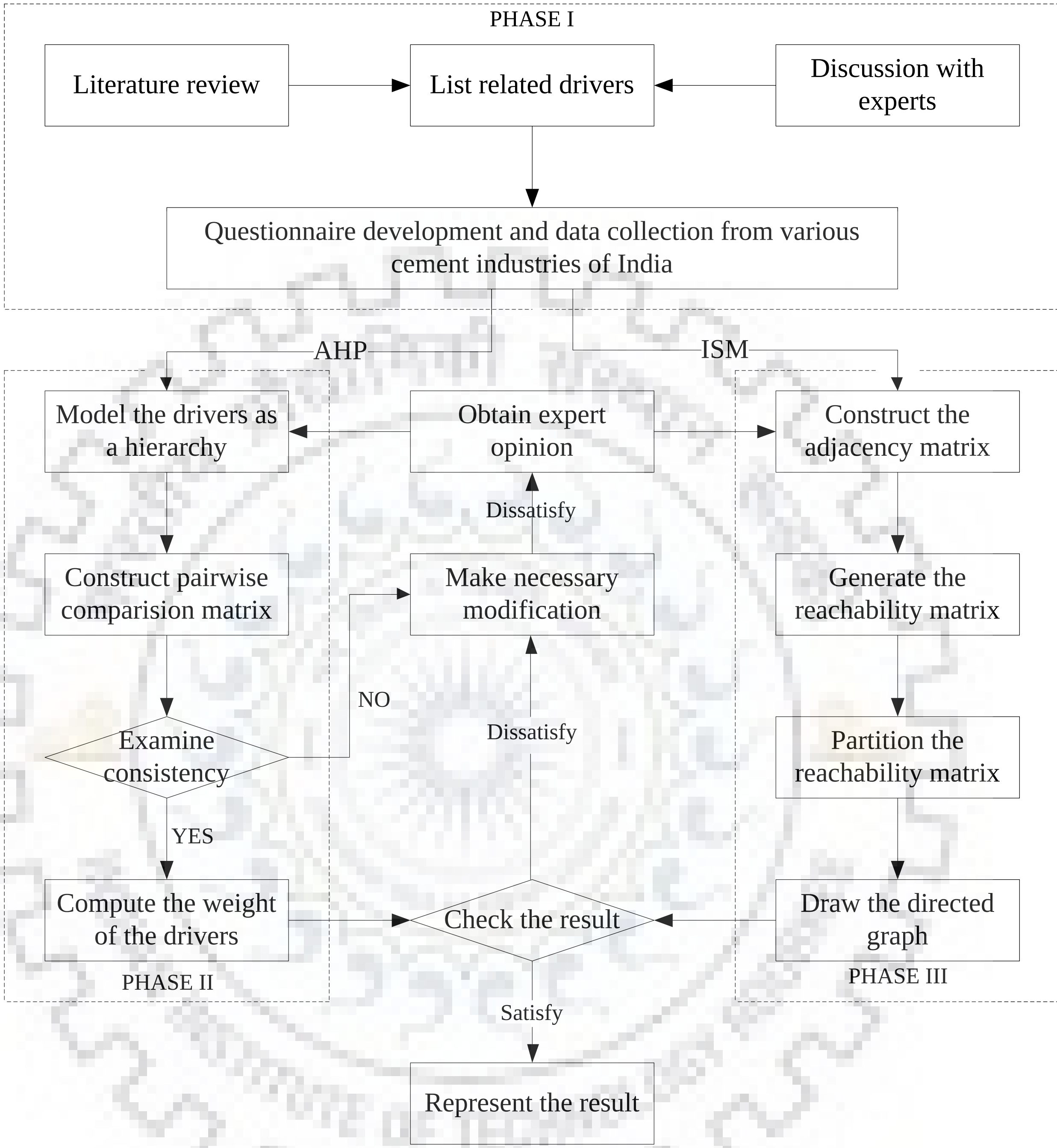

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Figure 5.1: A proposed research framework

5.2 Drivers to climate change mitigation strategies

Across the world, many studies analyzed the drivers of mitigation strategies. After reviewing the seminal literature and discussing it with industry experts, thirty drivers have been identified.

These identified drivers with their references are listed and categorized in Table 5.1. Based on their meaning and similarities, they are categorized under six main factors.

- **Business risk (BR):** This cluster of risk majorly focused on fluctuations in price of energy and raw material, legal issues, physical threat, and technological innovation.
- **Role of Government regulations and policies (GR):** this main factor refers to compliance of Government regulation and environment pollution penalties.
- **Internal factors (IF):** this main factor includes internal management issues related to the adoption of mitigation measures.
- **Market pressure (MP):** this main factor includes market-related competitive issues and brand image related issues.
- **Stakeholder engagement/pressure (SP):** this main factor refers to the investor, supplier, local public, society and customer pressure/demand for emission reduction.
- **Business opportunity (BO):** this main factor deals with revenue generation, new market, investment related and product and process modification related opportunity.

Stricter standards and regulations (Cai et al., 2016), exploiting raw material resources (Luo, Dubey, et al., 2017), continuously increasing pollution (Zhang et al., 2015) and its effects on health (Guimarães et al., 2018) are some factors, which boosts the significance of climate change mitigation strategies among cement industry. Climate change mitigation strategies have an important role in energy conservation, enhance energy efficiency and reducing emission at all stages of industrial activities (IPCC, 2014a). Some cement industries resist to implement mitigation strategies because of technical obsolescence, hidden costs, limited staff time and access to capital (Herrera et al., 2017), whereas some cement industry have implemented climate change mitigation strategies as a crucial task to advance their competitiveness, energy conservation, cost reduction, emission reduction, improve brand image (Kazancoglu et al., 2018). In other words, mitigation strategies are considered as a significant part of cement production activities due to a variety of reasons (Xuewei Liu et al., 2017).

Various past researches have discussed multiple drivers to climate change mitigation strategies. To address climate change challenges, the Government has progressively squeezed out the subsidies, the consequence of this action is increased prices for fossil fuel (Ostad-Ahmad-Ghorabi and Attari, 2013). Thus, the rise in fossil fuel price promotes energy conservation and emission reduction measures in the cement industry (Wang and Li, 2016). Similarly, the raw material price has also an important role in cost evaluation (Mirhosseini et al., 2019). Large fluctuations and uncertainty in raw material and energy prices seem to be an important barrier to emission reduction (Zuberi and Patel, 2017). Hence, to increase international competitive ability, cement industry feels highly pressured by these fluctuating prices, which may mean that they are more likely to adopt emission reduction and energy saving technologies (Xianbing Liu et al., 2016). A legal framework also encourages the cement industry to use of emission reduction technologies to abate the GHGEs (Wen et al., 2015). Risk of extreme weather events because of increasing global mean temperature also threatened the system (Benhelal et al., 2013). Fear of failure while innovation, technological change, and technological obsolescence, firms could suffer monetary losses/product failure, lead to loss of competitive advantage (Herrera et al., 2017; Govindan et al., 2014)

Due to environmental threats and worries of global warming phenomenon, Government regulations and policies severely forced cement industries to devote more time and budget to implement promising emission mitigation measures in their plants (Benhelal et al., 2013). Mathiyazhagan et al. (2014) reported that carbon mitigation strategies can be implemented through high penalties for environmental pollution. Neri et al. (2018) proposed a framework model of drivers for the adoption of measures in all areas of industrial sustainability stated that the objective of GHGEs reduction within the industry and prioritizing efforts to reduce emissions are reliant on top management. Improving risk management is another important aspect of positive decision-making. Managers need to reduce mitigation's risk and uncertainty through risk management; thus, risk reduction improves certainty, transparency and, brings value to the industry (Sa et al., 2017). Cost and emission reduction through the use of alternate fuels, clinker substitute materials, and other operational improvements are significant mitigation strategies to reduce the consumption of fossil fuel and other natural resources (Gao et al., 2015). Also, due to the high environmental impact and increased environmental awareness among the employee, the cement industry is ready to engage in new sustainable industrial practices (Vargas and Halog 2015). While, many industries consider emission reduction activities and commitment to sustainable development as a corporate social and ethical responsibility (Kazancoglu et al., 2018)

A study carried out by Herrera et al. (2017) found that green market competitive pressure encourages the cement industry towards the incorporation of emerging emission reduction technologies with higher efficiency. Strong market demands for low carbon products have motivated the cement industry toward innovation and modernization (Li et al., 2015). Rehman et al., (2016) present an empirical assessment and guides about measuring the impact of low carbon practices on organizational performance concluded that emission reduction practices benefit not only through long-term cost savings but equally, from brand image enhancement with stakeholders. In addition to these, NGOs and media pressure for emission reduction is another significant driver to climate change mitigation strategies adoption among industry (Neri et al., 2018)

About climate change objectives, investors play a critical role. They are encouraging industry to measure and disclose their emissions, to allow the associated risks and opportunities to be priced into investment (Long and Young, 2016). Also, due to increasing public pressure, the cement industry has been compelled to evaluate environmental performance to establish a corporate environmental strategy (Kazancoglu et al., 2018). Cement plant exposure may also have a health impact, mainly higher risk of respiratory symptoms, lung function decline, the excess risk of cancer and risk of cardiovascular diseases on both workers and the general population (Raffetti et al., 2019). Customers are also aware of sustainability issues they demand low emission along with the green product (Neri et al., 2018).

Cement industry earns extra revenue from the implementation of carbon reduction projects in their industry, via clean development mechanism (CDM) project, by selling the certified emission reductions thus making mitigation technology cost-effective (Hasanbeigi et al., 2010) also generates a stream of revenue by selling blended cement, which uses other industrial waste as clinker substituting material. Apart from these, the cement industry seizes the opportunity to minimize the use of fossil fuel by using waste as an alternative fuel (Rahman et al., 2015). The analysis suggested by Dutta and Mukherjee, (2010) that the technology transfer through foreign firms investments have brought the cement industry to world-class energy efficient technologies (Dutta and Mukherjee, 2010). The greatest opportunities to reduce GHGEs along with energy consumption associated with cement production will be obtained with improvements in pyro processing (Ali et al., 2011), heat recovery system (Benhelal et al., 2013), Switching from high-carbon fuels to lower-carbon fuels (Di Filippo et al., 2018) and by increased use of clinker substitutes (Scrivener et al., 2018).

Table 5.1: Drivers to climate change mitigation strategies in the cement industry

Driver name	References
Business risk (BR)	
Cut in subsidies and increased taxes on fossil fuels (BR1)	Ostad-Ahmad-Ghorabi and Attari, 2013; Q. Wang and Li, 2016; CDP India, 2015; MoEF&CC, 2015b; CDP India, 2014; Planning Commission, 2014; CDP India, 2013; Planning Commission, 2011; Vickers et al., 2009
Fluctuating raw material prices (BR2)	Mirhosseini et al., 2019; Zuberi and Patel, 2017; Xianbing Liu et al., 2016; Gao et al., 2016; Long, 2013; Sullivan, 2010; Vickers et al., 2009; Okereke, 2007; Kolk and Pinkse, 2004
Litigation risk because of high emission profile of the company (BR3)	Shenoi et al., 2016; Wen et al., 2015; Long, 2013; Sullivan, 2010; Busch and Hoffmann, 2007; Lash and Wellington, 2007
Physical threat to assets and supply chain disruption (BR4)	Benhelal et al., 2013; Sullivan, 2010; Busch and Hoffmann, 2007; Lash and Wellington, 2007; Okereke, 2007; Kolk and Pinkse, 2004
Technological change and innovation (BR5)	Viswanadham, 2018; Herrera et al., 2017; Seth et al., 2016; Govindan et al., 2014; Feiz et al., 2015; Okereke, 2007
Role of Government regulations and policies (GR)	
Environmental regulation compliance (GR1)	Gupta and Barua, 2017; CDP India, 2014; Benhelal et al., 2013; Long, 2013; Sullivan, 2010; Vickers et al., 2009; Jeswani et al., 2008; Zhu et al., 2008; Hoffman, 2007; Okereke, 2007; Kolk and Pinkse, 2004
SEBI mandate Business Responsibility Reporting (BRR) (GR2)	SEBI, 2017; SEBI, 2015
Energy conservation (EC) act 2001 and energy auditing by accredited BEE certified Energy Auditor/Manager (GR3)	MoEF&CC, 2015a; MoEF&CC, 2015b; Planning Commission, 2014; MoEF, 2012; Planning Commission, 2011; MoEF, 2004
PAT Scheme by BEE, internal price on carbon emission (GR4)	BEE, 2017a; BEE, 2017b; CDP India, 2015; MoEF&CC, 2015a; MoEF&CC, 2015b; CDP India, 2014; CDP India, 2013; MoEF, 2012; Planning Commission, 2011
High penalty for environmental pollution (GR5)	Luo et al., 2017; Mathiyazhagan et al., 2014; Mathiyazhagan and Haq, 2013
Internal factors (IF)	
Top management involvement and commitment to emission reduction (IF1)	Neri et al., 2018; CDP India, 2013; Long, 2013; Sullivan, 2010; Jeswani et al., 2008; Kolk and Pinkse, 2004
Improving risk management (IF2)	Sa et al., 2017; IPCC, 2014c; Busch and Hoffmann, 2007; Hoffman, 2007; Kim, 2007

Driver name	References
Cost reduction through material substitution and operational improvement (IF3)	Kajaste and Hurme, 2016a; Salas et al., 2016; Gao et al., 2015; CDP India, 2014; IPCC, 2014a; Morrow et al., 2014; CDP India, 2013; Long, 2013; Jeswani et al., 2008; Hoffman, 2007; Kim, 2007; Kolk and Pinkse, 2004
Emission reduction through material substitution and operational improvement (IF4)	CSI/ECRA, 2017; Cadez and Czerny, 2016; Salas et al., 2016; Kajaste and Hurme, 2016a; Cao et al., 2016; Gao et al., 2015; Feiz et al., 2015; Morrow et al., 2014; Madlool et al., 2013; Benhelal et al., 2013; Madlool et al., 2011; Mandal and Madheswaran, 2010; Kolk and Pinkse, 2004
Environmental awareness of Employee (IF5)	CDP India, 2015; Vargas and Halog, 2015; CDP India, 2014; Jeswani et al., 2008; Kim, 2007; Kolk and Pinkse, 2004; Govindarajulu and Daily, 2004
Corporate social responsibility (CSR) and ethical responsibility (IF6)	Kazancoglu et al., 2018; MoEF&CC, 2015b; IPCC, 2014a; Mathiyazhagan et al., 2014; Long, 2013; Sullivan, 2010; Hoffman, 2007; Okereke, 2007; Kolk and Pinkse, 2004
Market pressure (MP)	
Greenmarket competitive pressure (MP1)	Herrera et al., 2017; CDP India, 2013; Long, 2013; Sullivan, 2010; McKinsey, 2008; Kolk and Pinkse, 2004
Demand for low carbon Products (MP2)	Li et al., 2015; CDP India, 2013; IEA, 2013; Long, 2013; Planning Commission, 2011; Gielen and Taylor, 2009; Vickers et al., 2009; McKinsey, 2008; Kolk and Pinkse, 2004
Enhanced brand image and corporate reputation/improved public image (MP3)	Seth et al., 2018; Rehman et al., 2016; IPCC, 2014a; CDP India, 2013; Long, 2013; Sullivan, 2010; Hoffman, 2007; Kim, 2007; Lash and Wellington, 2007; Kolk and Pinkse, 2004
Media and NGOs attention to climate change issue (MP4)	Neri et al., 2018; Mathiyazhagan et al., 2014; Long, 2013; Sullivan, 2010; Kim, 2007; Okereke, 2007; Kolk and Pinkse, 2004
Stakeholder engagement/pressure (SP)	
Investor demand (SP1)	CDP India, 2015; Long, 2013; Sullivan, 2010; Jeswani et al., 2008; Busch and Hoffmann, 2007; Hoffman, 2007; Lash and Wellington, 2007; Okereke, 2007
Supplier engagement (SP2)	Long, 2013; Lash and Wellington, 2007
Local public or societal pressure for emission reduction (SP3)	Kazancoglu et al., 2018; Seth et al., 2018; Mathiyazhagan et al., 2014; Lee and Kim, 2009
Health issue (SP4)	Raffetti et al., 2019; Verma et al., 2018; CPCB, 2016; Diabat et al., 2014; Mathiyazhagan et al., 2014; Mathiyazhagan and Haq, 2013; World Bank, 2013; Planning Commission, 2011; IL&FS Ecosmart Limited, 2010; CPCB, 2007
Demand from customers in	Neri et al., 2018; Mathiyazhagan et al., 2014;

Driver name	References
environmental protection requirements (SP5)	Mathiyazhagan and Haq, 2013; Wu et al., 2012
Business opportunity (BO)	
Earn through emission reduction certification (like CER) through carbon reduction projects (CDM/PAT) (BO1)	BEE, 2017a; Cadez and Czerny, 2016; Kajaste and Hurme, 2016a; IPCC, 2014a; Planning Commission, 2011; Hasanbeigi et al., 2010; Okereke, 2007; Kolk and Pinkse, 2004
Generate a stream of revenue from low carbon product (BO2)	**Industry expert's opinion**
Newmarket opportunity (BO3)	Rahman et al., 2015; Mathiyazhagan et al., 2014; Long, 2013; Vickers et al., 2009; McKinsey, 2008; Hoffman, 2007; Kim, 2007; Okereke, 2007; Kolk and Pinkse, 2004
Investment opportunity (BO4)	CDP India, 2013; Dutta and Mukherjee, 2010; Vickers et al., 2009; Hoffman, 2007; Okereke, 2007
Opportunity to modify product and process (BO5)	Di Filippo et al., 2018; Scrivener et al., 2018; Cadez and Czerny, 2016; Long, 2013; Ali et al., 2011; Vickers et al., 2009; Jeswani et al., 2008

5.3 Proposed research framework and its application

A proposed research framework for evaluating drivers to climate change mitigation strategies of the Indian cement industry is based on the combined AHP and ISM techniques consist of three phases, as shown in Fig. 5.1.

Phase I: Identification of drivers to climate change mitigation strategies of the cement industry and data collection

Phase I start with the identification of thirty drivers to climate change mitigation strategies of the cement industry. Initially, through a detailed literature survey, many drivers were identified and put for discussion with the cement industry expert. A cement industry expert has rich experience. After several rounds of discussion with an expert, some drivers were deleted/edited, and some new drivers were added in the context of the Indian cement industry and finally, a total of thirty drivers were identified which were categorized into six main factors as shown in Table 5.1. This study targets ten large cement industry of India; the survey questionnaires were personally administered to the authorities involved in the cement manufacturing process, during two months from June to July 2017. Middle and senior rank engineers and managers with divergent accountability were selected during the data collection process because they are an integral member of the strategic decision-making group (Carter et al., 1998). The selected industrial experts were remarkably proficient in their discipline, having industrial experience of above 10 years. The respondent's position and department, experience and respective plant capacity are display in Table 3.1. The questionnaire was created to obtain experts' viewpoint on the cement industry. Before data collection, we thoroughly explained the objective and utility of the research to each respondent. We also outlined the potential advantages of the research then experts were asked to rate the drivers to climate change mitigation strategies of the cement industry.

Phase II: Calculating the relative importance of identified drivers to climate change mitigation strategies of the cement industry by AHP

AHP technique is used to prioritize the identified drivers according to their relative importance. The pair wise matrices of the main factors and sub-factors are evaluated based on the scale given in Table 3.4. Geometric mean is the only one that keeps the first axiom of AHP alive (A=nB then B=1/nA). Thus, in this work, geometric mean of individual opinions is computed for determining the ranks of the factors (Mangla et al., 2016; Saaty, 2008). This step aimed at obtaining the respondents' knowledge in aggregation to achieve generalization of the results. Here, Table 5.2 is the pair-wise evaluation matrix of main factors; it is the result of a geometric mean of ten expert's priorities of importance since each industry experts may have different priorities of importance. The values in Table 5.2 are normalized for computing relative importance weight of criterion. Then, each value is divided by its respective column total value of this normalize decision matrix. Finally, the average of rows is calculated, and thus, the relative importance weights of a factor are obtained. After following these steps, Eigenvalues and Eigenvectors are calculated and is given as maximum Eigenvalue (λ_{max}) = 6.4830; Consistency index (C.I.) = 0.0966. The consistency ratio (C.R.) is calculated, which comes out to be 0.0779, which is acceptable since C.R. < 0.10. Hence, with the help of normalize decision matrix, relative importance weights are calculated. Likewise, the relative weights of all the subfactors are calculated, as shown in Table 5.3–5.8. The relative weights attained, and proportionate ranks for the main factor are shown in Table 5.9.

Table 5.2: Pair-wise evaluation matrix for the main group factors

	BR	GR	IF	MP	SP	BO
BR	1	5.2811	7.6858	4.3276	2.2586	6.8504
GR	0.1893	1	4.1289	0.3316	0.2419	2.2586
IF	0.1301	0.2421	1	0.2024	0.1625	0.5145
MP	0.2310	3.0156	4.9392	1	0.2024	0.1625
SP	0.4427	4.1339	6.1530	2.0476	1	5.0505
BO	0.1459	0.4427	1.9432	0.2406	0.1980	1

Table 5.3: Pair-wise comparison matrix of the BRs

	BR1	BR2	BR3	BR4	BR5
BR1	1	2.10744	0.14568	0.24064	2.25869
BR2	0.47451	1	0.13938	0.16458	2.16894
BR3	6.86436	7.17463	1	3.14046	7.96229
BR4	4.15559	6.07607	0.31842	1	6.05897
BR5	0.44273	0.46105	0.12559	0.16504	1

Table 5.4: Pair-wise comparison matrix of the GRs

	GR1	GR2	GR3	GR4	GR5
GR1	1	0.34128	2.16894	2.19464	0.31842
GR2	2.93015	1	2.10744	5.05059	2.0237
GR3	0.46105	0.47451	1	2.10744	0.31842
GR4	0.45566	0.198	0.47451	1	0.34128
GR5	3.14051	0.49414	3.14051	2.93015	1

Table 5.5: Pair-wise comparison matrix of the IFs

	IF1	IF2	IF3	IF4	IF5	IF6
IF1	1	3.10369	4.95934	6.05897	2.0237	4.0378
IF2	0.3222	1	3.05141	2.93016	0.24607	2.0237
IF3	0.20164	0.32772	1	2.08276	0.198	0.3222
IF4	0.16504	0.34128	0.48013	1	0.19442	0.32772
IF5	0.49414	4.06388	5.05051	5.1435	1	3.96485
IF6	0.24766	0.49414	3.10366	3.05139	0.25222	1

Table 5.6: Pair-wise comparison matrix of the MPs

	MP1	MP2	MP3	MP4
MP1	1	0.20164	2.16894	0.16761
MP2	4.95933	1	6.05897	2.10744
MP3	0.46105	0.16504	1	0.15714
MP4	5.96623	0.47451	6.36375	1

Table 5.7: Pair-wise comparison matrix of the SPs

	SP1	SP2	SP3	SP4	SP5
SP1	1	2.0237	0.20246	0.14374	0.198
SP2	0.49414	1	0.20164	0.16761	0.19363
SP3	4.93925	4.95933	1	0.31842	0.51459
SP4	6.95701	5.96623	3.14051	1	2.93016
SP5	5.05051	5.16449	1.94329	0.34128	1

Table 5.8: Pair-wise comparison matrix of the BOs

	BO1	BO2	BO3	BO4	BO5
BO1	1	3.05141	3.14046	0.31842	0.33553
BO2	0.32772	1	1.96631	0.24766	0.24064
BO3	0.31842	0.50857	1	0.24926	0.24219
BO4	3.14051	4.03779	4.01188	1	1.96631
BO5	2.98036	4.15559	4.12899	0.50857	1

Table 5.9: Proportionate ranks and their relative importance weights of the main factors

Main factors	Ranks	Relative importance weights
Business Risk (BR)	1	0.4224
Stakeholder pressure (SP)	2	0.2456
Market pressure (MP)	3	0.1595
Role of government regulations and policies (GR)	4	0.0882
Business opportunities (BO)	5	0.0500
Internal factors (IF)	6	0.0341

Similarly, Table 5.10 shows proportionate ranks and their relative importance weights of all the sub-factors. Furthermore, by multiplying the relative importance weight of sub-factors with their corresponding main factor importance weights, the global weights and their respective global rank of all the sub-factors are determined, as shown in Table 5.10. For all the main factors and sub-factors, the consistency ratio (C.R.) is below 0.10.

Table 5.10: Relative ranking of main factors and sub-factors to climate change mitigation strategies of the Indian cement industry

Main Factor	Relative Weights	Sub-factors	Relative Weights	Relative Rank	CI	CR	Global Weights	Global rank
BR	0.4224	BR1	0.0908	3	0.1066	0.0960	0.0383	8
		BR2	0.0646	4			0.0273	10
		BR3	0.5223	1			0.2206	1
		BR4	0.2780	2			0.1174	2
		BR5	0.0441	5			0.0186	13
GR	0.0882	GR1	0.1500	3	0.0946	0.0852	0.0132	17
		GR2	0.3777	1			0.0333	9
		GR3	0.1195	4			0.0105	20
		GR4	0.0699	5			0.0061	24
		GR5	0.2827	2			0.0249	11
IF	0.0341	IF1	0.3644	1	0.1202	0.0969	0.0124	18
		IF2	0.1322	3			0.0045	25
		IF3	0.0592	5			0.0020	29
		IF4	0.0431	6			0.0014	30
		IF5	0.2956	2			0.0100	21
		IF6	0.1052	4			0.0035	27
MP	0.1595	MP1	0.0945	3	0.0863	0.0970	0.0150	14
		MP2	0.4865	1			0.0776	4
		MP3	0.0592	4			0.0094	22
		MP4	0.3597	2			0.0573	6
SP	0.2456	SP1	0.0610	4	0.1035	0.0932	0.0149	15
		SP2	0.0470	5			0.0115	19
		SP3	0.1898	3			0.0466	7
		SP4	0.4573	1			0.1123	3
		SP5	0.2447	2			0.0601	5
BO	0.0500	BO1	0.1628	3	0.0879	0.0791	0.0081	23
		BO2	0.0857	4			0.0042	26
		BO3	0.0644	5			0.0032	28
		BO4	0.3904	1			0.0195	12
		BO5	0.2964	2			0.0148	16

Phase III: Determining interrelationship among the identified drivers to climate change mitigation strategies of the cement industry by ISM

Structural self-interaction matrix (SSIM)

Once the drivers are listed for analyzing the interactions, it is essential to establish the contextual relationship among the drivers for developing the SSIM based on the experts' response. Four symbols are used for the type of relationship that exists between the two variables under consideration.

V = Variable i will help achieve variable j;

A = Variable j will help achieve variable i;

X = Variable i and j will help achieve each other; and

O = Variables i and j are unrelated.

SSIM was developed for the thirty drivers to climate change mitigation strategies of the Indian cement industry. The SSIM is depicted in Table 5.11.

Reachability matrix

This Table 5.11 SSIM is used to develop the reachability matrix, indicating the relationship between the drivers in the binary digits 0 and 1. The reachability matrix, thus derived, is known as the Initial reachability matrix and is given in Table 5.12. Then, to convert the Initial reachability matrix into the Final reachability matrix transitivity rule is applying. Thus, the Final reachability matrix, as shown in Table 5.13, is obtained by incorporating the transitivity.

Level partition

From the final reachability matrix, the Level partition of thirty drivers to climate change mitigation strategies of cement industry is done. Example for Level 1 of driver IF3 is given. For driver IF3, reachability set drivers are IF2, IF3, IF4, IF5, MP1, MP3, SP1, SP2, BO1, BO2, BO3, BO5 and antecedent set drivers are BR1, BR2, BR3, BR4, BR5, GR1, GR2, GR3, GR4, GR5, IF1, IF2, IF3, IF4, IF5, IF6, MP1, MP2, MP3, MP4, SP1, SP2, SP3, SP4, SP5, BO1, BO2, BO3, BO4, BO5. Therefore, the intersection between the set is IF2, IF3, IF4, IF5, MP1, MP3, SP1, SP2, BO1, BO2, BO3, and BO5. The intersection drivers are the same as reachability set drivers. Hence, driver IF3 is in level I in the first iteration. Similarly, driver IF4, BO2, and BO3 are in level I during the first iteration. Level I is given the position of the top driver in the hierarchy of the ISM model (Kannan and Haq, 2007). During the second iteration, first level drivers, i.e. IF3, IF4, BO2, and BO3, are excluded from iteration. After the second iteration, Level II includes five drivers, i.e. IF2, IF6, MP1, MP3, and BO1. Similar iteration is repeated until the last level. For the present study, these iterations are completed in eight times; hence, eight levels are formed. Table 5.14 shows the detail of level partition along with their corresponding drivers.

Formation of ISM based model

Final reachability matrix is obtained by incorporating the transitivity. Thus, with the help of final reachability matrix, the ISM based model is formed, as shown in Fig. 5.2, which shows the relationship among the drivers by arrows.

MICMAC analysis

The driving power and the dependence of each of thirty drivers are shown in the last column and last row of Table 5.13 Final reachability matrix. In this table, an entry of '1' along the columns and rows indicates the dependence and driving power, respectively. Subsequently, the Driver power-dependence diagram of drivers to climate change mitigation strategies of the cement industry is constructed, which is shown in Fig. 5.3. As an illustration, it is observed from Table 5.13 that driver GR5 is having a driver power of 23 and a dependence of 12. Therefore, in Fig. 5.3, it is positioned at a place corresponding to a driver power of 23 and a dependency of 12, i.e. Cluster IV: Independent drivers. Similarly, all the thirty drivers to mitigation strategies are positioned at their corresponding coordinates in the Driver power-dependence diagram and their corresponding clusters as shown in Fig. 5.3.

Table 5.11: Structural self-interaction matrix (SSIM)

	BO5	BO4	BO3	BO2	BO1	SP5	SP4	SP3	SP2	SP1	MP4	MP3	MP2	MP1	IF6	IF5	IF4	IF3	IF2	IF1	GR5	GR4	GR3	GR2	GE1	BR5	BE4	BR3	BR2
BR1	V	V	V	O	V	A	A	A	V	V	A	O	A	V	O	V	V	V	V	V	X	V	V	O	V	V	O	A	X
Br2	V	V	O	O	V	A	A	A	V	V	A	O	A	V	O	V	O	V	V	V	X	V	V	O	O	V	O	A	
BR3	V	V	V	O	V	V	X	V	V	V	V	O	V	V	O	V	V	O	V	V	V	V	V	V	V	V	O		
BR4	O	O	O	O	O	V	O	V	V	V	V	O	O	O	O	V	O	O	V	V	O	O	O	O	O	V			
BR5	V	V	V	O	V	A	A	A	O	A	A	V	A	V	O	X	V	V	V	X	A	A	A	A	A				
GR1	V	V	V	O	V	A	A	A	O	O	A	V	A	V	V	V	V	V	V	O	A	X	X	A					
GR2	V	V	V	O	V	A	A	A	V	V	A	V	A	V	X	V	V	O	V	V	X	V	V						
GR3	V	V	V	O	V	A	O	A	O	O	A	O	A	V	O	O	V	V	V	O	A	X							
GR4	V	V	V	V	V	A	A	A	V	V	A	V	A	V	V	V	V	V	V	V	A								
GR5	V	V	V	V	V	A	A	A	V	V	A	O	A	V	O	V	V	O	V	V									
IF1	V	V	O	O	V	A	A	A	A	A	A	V	A	O	X	X	V	V	V										
IF2	A	A	O	V	A	A	O	A	A	A	A	X	A	A	X	A	X	V											
IF3	A	A	V	X	A	O	A	O	A	O	O	O	O	A	O	A	X												
IF4	A	A	O	V	X	A	A	A	A	A	A	A	A	A	A	A													
IF5	V	V	A	V	V	A	A	A	X	A	A	V	A	O	X														
IF6	O	O	O	O	O	O	O	A	A	O	O	V	A	O															
MP1	V	V	X	V	X	A	O	A	V	X	A	X	A																
MP2	V	V	V	V	V	X	A	X	V	V	X	V																	
MP3	A	A	A	O	A	O	O	O	A	A	O																		
MP4	V	V	V	O	V	X	A	X	V	V																			
SP1	V	V	A	O	V	A	A	A	X																				
SP2	V	O	A	V	V	A	A	A																					
SP3	V	V	V	O	V	X	A																						
SP4	V	V	O	O	O	V																							
SP5	V	V	V	O	V																								
BO1	A	O	X	V																									
BO2	A	A	A																										
BO3	V	O																											
BO4	X																												

Table 5.12: Initial reachability matrix

	BR 1	BR 2	BR 3	BE 4	BR 5	GE 1	GR 2	GR 3	GR 4	GR 5	IF 1	IF 2	IF 3	IF 4	IF 5	IF 6	MP 1	MP 2	MP 3	MP 4	SP 1	SP 2	SP 3	SP 4	SP 5	BO 1	BO 2	BO 3	BO 4	BO 5
BR1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	0	1	0	0	0	1	1	0	0	0	1	0	1	1	1
BR2	1	1	0	0	1	0	0	1	1	1	1	1	1	0	1	0	1	0	0	0	1	1	0	0	0	1	0	0	1	1
BR3	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1	1	1
BR4	0	0	0	1	1	0	0	0	0	0	1	1	0	0	1	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0
BR5	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	0	1	0	1	0	0	0	0	0	0	1	0	1	1	1
GR 1	0	0	0	0	1	1	0	1	1	0	0	1	1	1	1	1	1	0	1	0	0	0	0	0	0	1	0	1	1	1
GR 2	0	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	0	1	1	0	0	0	1	0	1	1	1
GR 3	0	0	0	0	1	1	0	1	1	0	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	1	1
GR 4	0	0	0	0	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1
GR 5	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	0	1	0	0	0	1	1	0	0	0	1	1	1	1	1
IF1	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1	0	0	1	0	0	1	0	0	0	1	0	0	1	1
IF2	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	1	0	0	0	0	0	0	0	1	0	0	0
IF3	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0
IF4	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
IF5	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1	0	0	1	0	0	1	0	0	0	1	1	0	1	1
IF6	0	0	0	0	0	0	1	0	0	0	1	1	0	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
MP 1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	1	0	1	1	0	0	0	1	1	1	1	1
MP 2	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1
MP 3	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
MP 4	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	1	1	0	1	1	0	1	1	1
SP1	0	0	0	0	1	0	0	0	0	0	1	1	0	1	1	0	1	0	1	0	1	1	0	0	0	1	0	0	1	1
SP2	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	1	0	1	1	0	0	0	1	1	0	0	1
SP3	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0	1	1	1	1	0	1	1	0	1	1	1
SP4	1	1	1	0	1	1	1	0	1	1	1	0	1	1	1	0	0	1	0	1	1	1	1	1	1	0	0	0	1	1
SP5	1	1	0	0	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	1	1	0	1	1	0	1	1	1
BO1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	1	0	1	0	0	0	0	0	0	1	1	1	0	0
BO2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
BO3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	1	1	0	0	0	1	1	1	0	1
BO4	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	1
BO5	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1	1

Table 5.13: Final reachability matrix

	B R1	BR2	BR 3	BE 4	BR 5	GE 1	GR 2	GR 3	GR 4	GR 5	IF 1	IF 2	IF 3	IF 4	IF 5	IF 6	MP 1	MP 2	MP 3	MP 4	SP 1	SP 2	SP 3	SP 4	SP 5	BO 1	BO 2	BO 3	BO 4	BO 5	Drl
BR1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	23
BR2	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	23
BR3	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	29
BR4	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	28
BR5	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	16
GR1	0	0	0	0	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	20
GR2	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	23
GR3	0	0	0	0	1	1	0	1	1	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	19
GR4	0	0	0	0	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	20
GR5	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	23
IF1	0	0	0	0	1	0	1	0	0	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	17
IF2	0	0	0	0	0	0	1	0	0	0	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	1	1	1	0	0	12
IF3	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	0	1	0	1	1	0	0	0	1	1	1	0	1	12
IF4	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	1	1	1	0	0	9
IF5	0	0	0	0	1	0	1	0	0	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	17
IF6	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	21
MP1	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	16
MP2	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	27
MP3	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	13
MP4	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	27
SP1	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	16
SP2	0	0	0	0	1	0	1	0	0	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	17
SP3	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	27
SP4	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	29
SP5	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	27
BO1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	14
BO2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	4
BO3	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1	0	1	0	1	1	0	0	0	1	1	1	1	1	16
BO4	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	1	1	1	1	1	11
BO5	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	1	1	1	1	1	11
Dep	11	11	2	1	22	15	18	15	15	12	23	29	30	30	25	28	29	7	29	7	25	25	7	2	7	29	30	30	26	27	567

Table 5.14: Level partition for drivers: Iteration I - VIII

Br.Code	Reachability Set	Antecedent Set	Intersection Set	Level
IF3	12,13,14,15,17,19,21,22,26,27,28,30	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30	12,13,14,15,17,19,21,22,26,27,28,30	I
IF4	12,13,14,16,17,19, 26,27,28	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30	12,13,14,16,17,19, 26,27,28	I
BO2	13,14, 27,28	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30	13,14, 27,28	I
BO3	5,11,12,13,14,15,16,17,19,21,22, 26,27,28,29,30	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,30	5,11,12,13,14,15,16,17,19,21,22, 26,27,28,29,30	I
IF2	7,11,12,15,16,17,19, 26	1,2,3,4,5,6,7,8,9,10,11,12,15,16,17,18,19,20,21,22,23,24,25,26,29,30	7, 11,12, 15,16,17,19, 26	II
IF6	5,6,7,8,9,10,11,12,15,16,17,19,21,22, 26, 29,30	1,2,3,4,5,6,7,8,9,10,11,12,15,16,17,18,19,20,21,22,23,24,25,26,29,30	5,6,7,8,9,10,11,12, 15,16,17,19,21,22, 26, 29,30	II
MP1	5,11,12,15,16,17,19,21,22, 26, 29,30	1,2,3,4,5,6,7,8,9,10,11,12,15,16,17,18,19,20,21,22,23,24,25,26,29,30	5,11,12,15,16,17,19,21,22, 26, 29,30	II
MP3	12,16,17,19,21,22, 26, 29,30	1,2,3,4,5,6,7,8,9,10,11,12,15,16,17,18,19,20,21,22,23,24,25,26,29,30	12,16,17,19,21,22, 26, 29,30	II
BO1	12,15,16,17,19,21,22 ,26, 29,30	1,2,3,4,5,6,7,8,9,10,11,12,15,16,17,18,19,20,21,22,23,24,25,26,29,30	12,15,16,17,19,21,22 ,26, 29,30	II
BO4	29,30	1,2,3,4,5,6,7,8,9,10,11,15,18,20,21,22,23,24,25,29,30	29,30	III
BO5	29,30	1,2,3,4,5,6,7,8,9,10,11,15,18,20,21,22,23,24,25,29,30	29,30	III
BR5	5, 11,15, 21,22	1,2,3,4,5,6,7,8,9,10,11,15, 18,20,21,22,23,24,25	5, 11,15, 21,22	IV
IF1	5,7,11,15, 21,22	1,2,3,4,5,6,7,8,9,10,11,15,18,20,21,22,23,24,25	5,7,11,15, 21,22	IV
IF5	5,7, 11,15, 21,22	1,2,3,4,5,6,7,8,9,10,11,15,18,20,21,22,23,24,25	5,7, 11,15, 21,22	IV
SP1	5, 11,15, 21,22	1,2,3,4,5,6,7,8,9,10,11,15,18,20,21,22,23,24,25	5, 11,15, 21,22	IV
SP2	5,7, 11,15, 21,22	1,2,3,4,5,6,7,8,9,10,11,15,	5,7, 11,15, 21,22	IV

Br.Code	Reachability Set	Antecedent Set	Intersection Set	Level
		18,20,21,22,23,24,25		
GR1	6,7,8,9	1,2,3,4,6,7,8,9,10,18,20, 23,24,25	6,7,8,9	V
GR3	6,8,9	1,2,3,4,6,7,8,9,10,18,20, 23,24,25	6,8,9	V
GR4	6,7,8,9	1,2,3,4,6,7,8,9,10,18,20, 23,24,25	6,7,8,9	V
BR1	1,2,7, 10	1,2,3,4, 7, 10, 18,20, 23,24,25	1,2,7,10	VI
BR2	1,2,7,10	1,2,3,4, 7, 10, 18,20, 23,24,25	1,2,7,10	VI
GR2	1,2,7,10	1,2,3,4,7,10, 18,20,23,24,25	1,2,7,10	VI
GR5	1,2,7,10	1,2,3,4, 7, 10,18,20, 23,24,25	1,2,7,10	VI
MP2	18,20,23,25	3,4,18,20,23,24,25	18,20,23,25	VII
MP4	18,20,23,25	3,4,18,20,23,24,25	18,20,23,25	VII
SP3	18,20,23,25	3,4,18,20,23,24,25	18,20,23,25	VII
SP5	18,20,23,25	3,4,18,20,23,24,25	18,20,23,25	VII
BR3	3,24,	3,24	3,24,	VIII
SP4	3, 24	3,24	3, 24	VIII
BE4	4	4	4	VIII

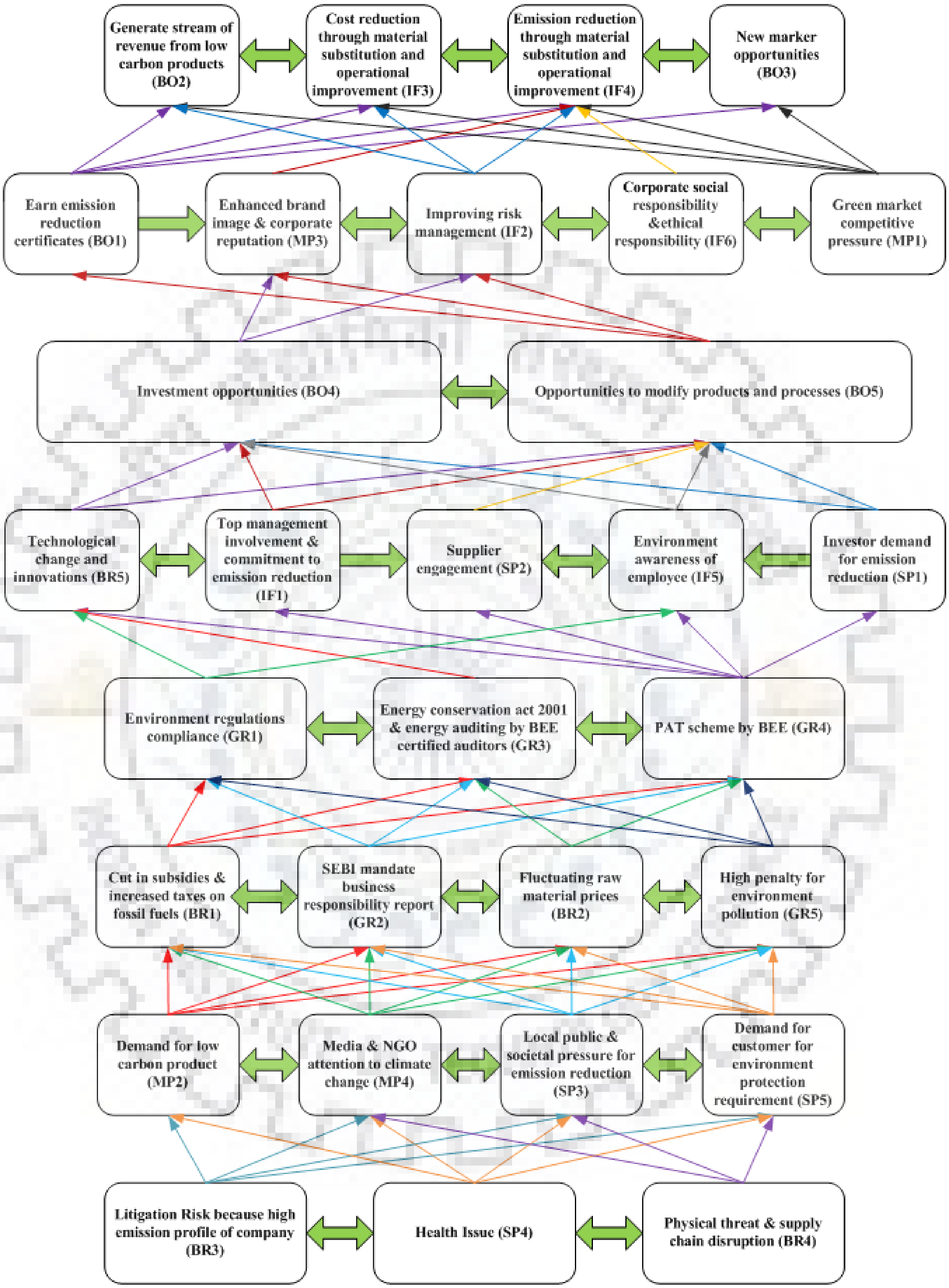


Figure 5.2: ISM based model for drivers to climate change mitigation strategies of the Indian cement industry

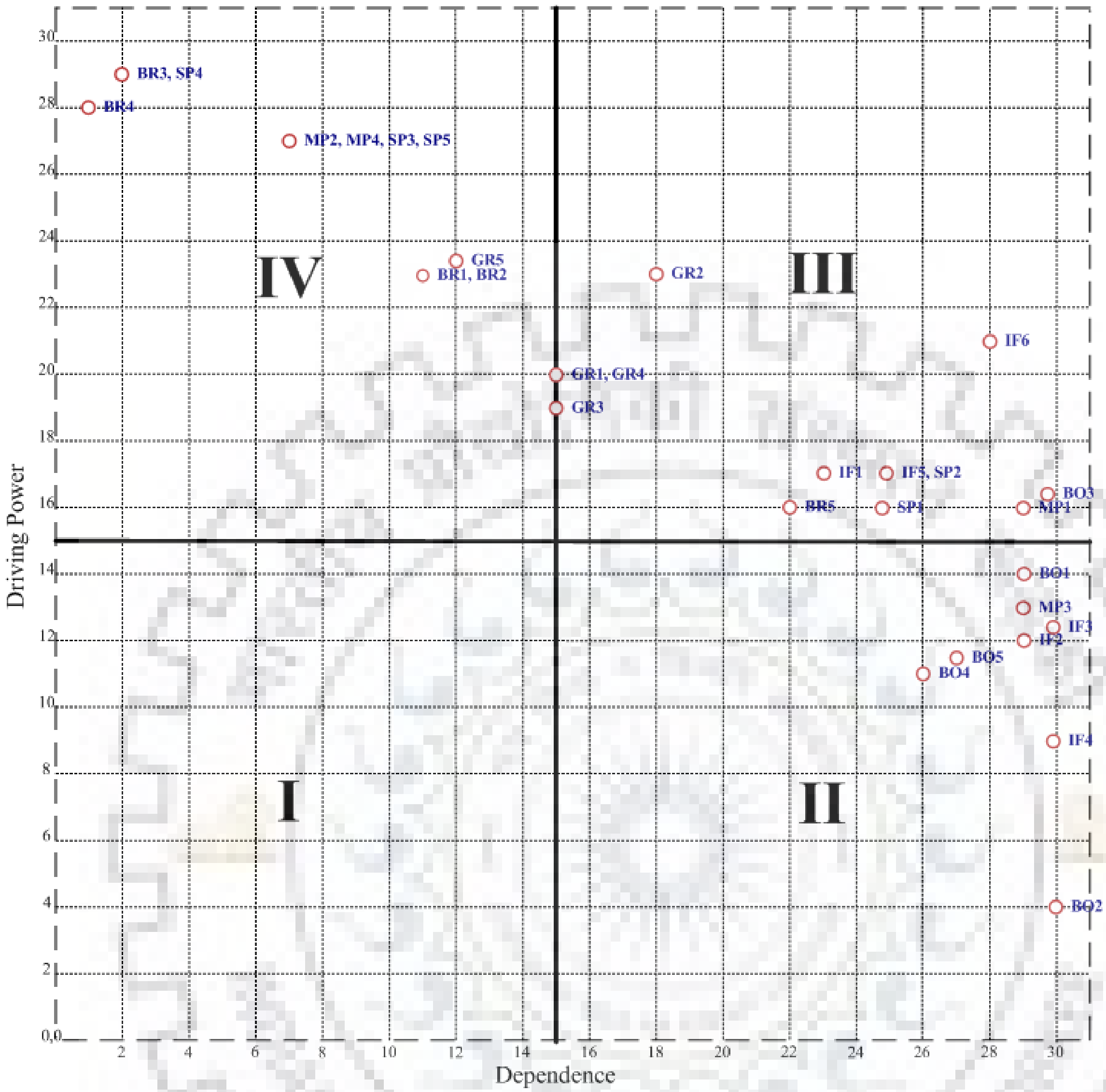


Figure 5.3: Driver power-dependence diagram of drivers to climate change mitigation strategies of the cement industry

5. 4 Results and discussion

5.4.1 Driver ranking of mitigation measures in the Indian cement industry using AHP

5.4.1.1 Business risk

Business risk (BR) ranks first in the main factor category. In this category, two drivers shared the biggest priority in the global and relative ranking position: Litigation risk (BR3) and Physical threat to assets and supply chain disruption (BR4). The results are in conformance with study by Raffetti et al., (2019) wherein they found that substantially reduced the emissions, including fine particulate, heavy metal, and sand the last decades, mainly because of legal risk, another important factor influencing corporate climate change strategy is a risk from physical damages associated with climate change (BR4) (Okereke, 2007; Skjaerseth and Skodvin, 2003). Climate change is likely to increase damages from extreme weather events, India, like other developing countries, is suffering the brunt of climate change and it has a limited capacity to deal with the climate change impacts and are hence more vulnerable (Rattani, 2018). Recently in Paris agreement (UNFCCC, 2015), India's INDC list the policies include fiscal instruments like cuts in subsidies and increase in taxes on fossil fuels to promote actions that address climate concerns (MoEF&CC, 2015b) and fluctuating raw material prices (BR2) is also important driving factor for businesses shifting stand towards climate change mitigation (Long, 2013).

5.4.1.2 Stakeholder engagement/pressure

Stakeholder pressure (SP) ranks second in the main factors. The cement industry is mainly air polluting industry (CPCB, 2016), and emission of air pollutants should be scored low to prevent adverse effects to human health (SP4), harm to the environment or creation of any nuisance situation. The generated dust from cement production classified as nuisance dust and nuisance dust has a long history of having a little adverse effect on the lungs. Excessive concentrations of nuisance dust in the workplace may lead to poor visibility, unpleasant deposits in eyes, ears, and nasal passages, and injury to the skin or mucous membranes by chemical or mechanical-action (CPCB, 2007). Customers' environmental protection demand (SP5) is the dominant factor in developing sustainable and green products (Mathiyazhagan et al., 2014; Wu et al., 2012). Local community pressure (SP3) is considered an important factor as compared to other pressure variables having a certain level of impacts on supply chain (Mathiyazhagan et al., 2014; Lee and Kim, 2009).

5.4.1.3 Market pressure

Next, market pressure (MP) ranks third among the main driving factors. Growing consumer demand relatively low carbon products (MP2) viewed as an opportunity rather than a risk (Long, 2013; McKinsey, 2008; Kolk and Pinkse, 2004). Manufacturing of blended cement a low carbon product increasing the capacity of industries at almost no capital cost, enables the efficient disposal of industrial wastes (Bhushan, 2010), reducing energy consumption (Morrow et al., 2014) and GHG emissions (Kajaste and Hurme, 2016) thus it reduces the environmental impact and also the emission intensity. It's a win-win situation for the manufacturer and the consumer (Planning Commission, 2011). In 2000-01 in India, the market share of low carbon cement was only 37% (IEA, 2013), in the year 2004-05 it was 55.6% (Gielen and Taylor, 2009), while in the year 2007 further it is increased to 68%. At present in Indian market share of low carbon cement production has reached around 75% (Planning Commission, 2011), thus Indian cement industry in its overall cement mix gradually expanding the share of low carbon cement. Increase pressure from environmental NGOs and media (MP4) have been shifting management attention towards environmental objectives to address global warming (Sullivan, 2010; Okereke, 2007; Kolk and Pinkse, 2004) is another significant driver.

5.4.1.4 Role of Government regulations and policies

Role of Government regulations and policies (GR) among main factors acquired the fourth priority. SEBI has mandated the requirement of Business Responsibility Report (BRR) (GR2) for the top 500 listed companies under Regulation 34(2)(f) of SEBI Regulations 2015 (SEBI, 2017). Penalties for creating pollution (GR5) is one of the ways that the Government can force cement companies to participate in emission reduction program (Hasanbeigi et al., 2010).

5.4.1.5 Business opportunity

Business opportunity obtains the fifth rank in the main factor. Waste energy recovery system gives an investment opportunity (BO4) for the industry to utilize the electricity generation from the waste energy for the internal electrical use that will reduce the operating cost on the electrical energy, these co-saving methods offer a win-win situation for both industry and environmentalist (Benhelal et al., 2013). Increased use of waste fuels is an efficient means for their disposal, providing a useful and ecologically responsible service to society. This flexibility is an opportunity for emissions reduction and the opportunity to process improvement (BO5) (Scrivener et al., 2018). Another opportunity for modification of product (BO5) is by introducing recovered material, such as fly ash, slag, industrial gypsum, into the cement mix, and finally introducing similarly recovered material into the raw meal (Summerbell et al., 2016) so that low carbon product is formed.

5.4.1.6 Internal factors

Internal factors are in the last position among the main factors categorizations. Top management (IF1) is responsible for the impact of their processes on the environment in the areas of influence, and they have even developed environmental management systems based on international standards (Herrera et al., 2017) also due to the increased environmental awareness among cement plant employee (IF5) are starting to use alternate fuel. The use of alternate fuel for cement clinker production is crucially important to the reduction of fuel emissions in cement manufacturing (Gao et al., 2015; Mikulčić et al., 2013).

5.4.2 ISM analysis

5.4.2.1 Level basis analysis of mitigation measures of the Indian cement industry

All drivers of mitigation measures are iterating in eight levels, as shown in Table 5.14. It is observed that level I includes four drivers, namely BO2, IF3, IF4, BO3, and five drivers are in level II, namely, BO1, MP3, IF2, IF6, and MP1. The lower level might suggest that these drivers are at the top of the hierarchy and not lead to other drivers above their level. In other words, these drivers are likely to be affected by other drivers. A higher level indicates that these drivers situated in the bottom of the hierarchy and can exert great influences on the implementation of mitigation measures. It is noticed that four drivers are in level VII, namely, MP2, MP4, SP3, and SP5, while level VIII contains only three drivers, namely, BR3, SP4, and BR4. All other drivers are classified to level III, level IV, level V and level VI, indicate that they not only influence the drivers in a higher level but also affected by these drivers in the lower level.

As shown in Fig. 3, this study demonstrates that the interactive relationships amongst drivers. It is noted that this does not provide a systematic roadmap for action but depict the chain of the influence of drivers in the system. These findings help to better understand the effect of these drivers by positioning them in a hierarchy structure. Based on the results of level partitioning, the hierarchical structural model can be developed. As shown in Fig. 3, at level VIII, Litigation risk (BR3), Health issue (SP4) and Physical threat (BR4) are at the bottom of the ISM hierarchy, indicate that these three drivers are the most significant drivers to the implementation of climate change mitigation strategies in the cement industry. Effectively dealing with these drivers will largely facilitate the implementation of mitigation measures in the Indian cement industry. It should be noted that drivers, Demand for low carbon products (MP2), Media and NGO attention (MP4), Local public and societal pressure (SP3) and Customer demand for environment protection (SP5) are located at the level VII of the hierarchy, exhibits considerable influences on the implementation of mitigation measures.

Meanwhile, 19 drivers from level II-level VI are at the middle portion of the ISM hierarchy. Among this, drivers BR1, GR2, BR2, and GR5 of level VI directly affect drivers GR1, GR3 and GR4 of level V, and play a role in connecting the level V and level VII. Likewise, drivers of level V play a connecting role between drivers of level IV and drivers of level VI. Similarly, the relation is for Level IV, Level III and Level II. These drivers play a connecting role in the hierarchy structure suggests they will affect the drivers in the lower levels and affected by the drivers in the higher levels.

At the same time, it can be inferred that main drivers are as follows: generate stream of revenue (BO2), Cost reduction (IF3), Emission reduction (IF4) and Newmarket opportunity (BO3), which are included in level I. These drivers are situating at the top of the ISM model, suggesting their lower influences to the climate change mitigation strategies adoption and they are likely to be affected by other drivers.

5.4.2.2 MICMAC analysis

For a better understanding of the interaction among drivers, we have developed a MICMAC analysis. As shown in Table 5.13, the driving power and dependence power for each driver are computed. The two-dimension chat is generated, as shown in Fig. 5.3. Then, these thirty drivers are classified into four groups.

Autonomous drivers (Cluster I): There is no autonomous drivers and their absence indicates that all the identified drivers to mitigation strategies of the Indian cement industry play a significant role. Autonomous variables do not have much influence on the system since they have weak drivers and weak dependents (Diabat et al., 2014).

Dependent drivers (Cluster II): Drivers in this cluster have strong dependence power and weak driving power. Thus, these drivers are in lower priority, in the sense that their resolution is highly dependent on the resolution of the drivers they depend on. In the present case, BO1, MP3, IF3, IF2, BO5, BO4, IF4 and BO2 are the dependent drivers. It means, these drivers have weak driving capability also; they are strongly dependent on one another. Emission and cost reduction through material substitution and operational improvement (IF3 and IF4) highly depend on availability and cost of substituting materials like granulated blast furnace slag, Fly ash (CSI/ECRA, 2017; Planning Commission, 2011). Drivers like Earn through emission reduction certification (BO1), Enhanced brand image and corporate reputation (MP3), Improving risk management (IF2) and Opportunity to modify products and process (BO5) are highly depends on

Technological change and innovation (BR5), Top management involvement (IF1), Investor demand for emission reduction (SP1) and Government regulations (GR1, GR3, GR4). Weak driving power and strong dependence power indicates that the industry is not taking it seriously, and these requirements are not high in terms of emission reduction.

Linkage drivers (Cluster III): These drives have both strong driving power and strong dependence power. Therefore, any action on these drivers will have a compounding effect on others as well as a feedback effect on them. These linkage drivers are Technological change and innovation (BR5), Investor demand (SP1), Supplier engagement (SP2), Greenmarket pressure (MP1), Newmarket opportunity (BO3), Top management involvement (IF1), Environmental awareness of employee (IF5) Corporate social responsibility (IF6), Energy conservation act 2001 (GR3), PAT Scheme by BEE (GR4), Environmental regulation compliance (GR1) and SEBI business responsibility reporting (GR2). These linkage drivers are unstable and can change if there are changes in the driving variables; hence, they can disturb the whole system (Qureshi, Kumar, and Kumar, 2008).

Independent drivers (Cluster IV): These drivers are considered as 'key drivers' due to their strong driving power and weak dependence power. It means they are dependent on other drivers. Therefore, these strong drivers may be treated as the root cause of all the drivers. These drivers are Cut in subsidies and increased taxes on fossil fuels (BR1), Fluctuating raw material prices (BR2), Physical threat (BR4), Litigation risk (BR3), High penalty (GR5), Demand for low carbon Products (MP2), Media and NGOs attention (MP4), Local public or societal pressure (SP3), Demand from customers in environmental protection requirements (SP5) and Health issue (SP4). For the Indian cement industry, significant independent drivers are Litigation risk (BR3), Health issue (SP4) and Physical threat (BR4). These three drivers are at the lowest level in the ISM model due to their high driving power and low dependence among all the identified drivers. Management should pay more concern to these drivers since all the other drivers of climate change mitigation strategies depend on these independent drivers of cluster IV.

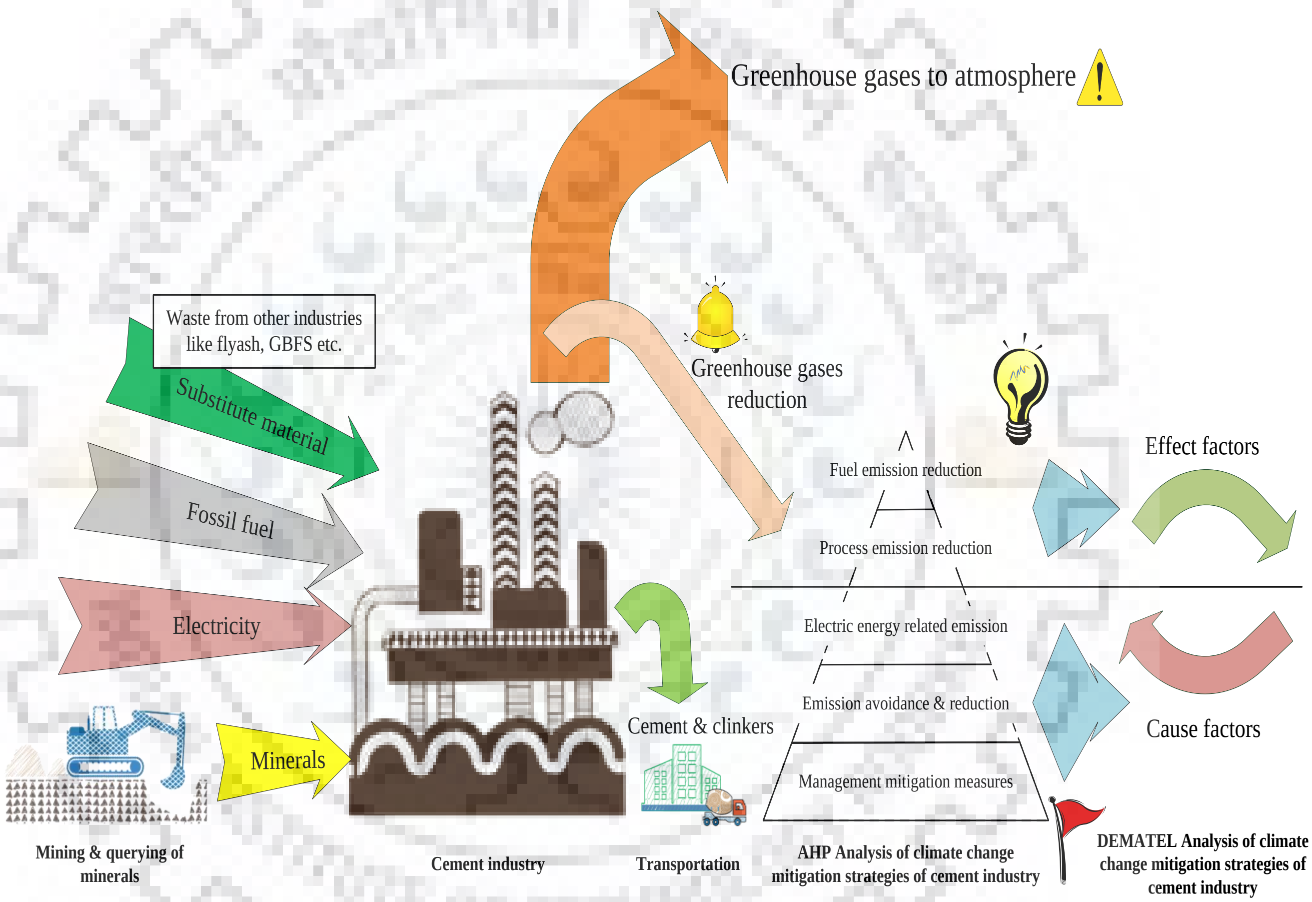
5.5 Chapter summary

This chapter presents an integrated AHP- ISM model to assess the drivers to climate change mitigation strategies adoption of cement industry. Total of thirty drivers has been identified and categorized into six main factors. AHP is applied to get the relative weights of the drivers and ISM is applied to find relationships among these drivers. The result exhibits that as per AHP analysis Business risk (BR) ranks first in the main factors while the driving factors, Litigation risk (BR3), Physical threat to assets has global rank 1st and 2nd. As per ISM level basis analysis the at final level iteration, there are three drivers: a Physical threat to assets and supply chain disruption (BR4), Litigation risk because of high emission profile of the company (BR3) and Health issue (SP4). These drivers play a dominant role in implementing climate change mitigation strategies in the Indian cement industry and these bottom-most level, factors driving the remaining drivers since they have high driving power and low dependency on other drivers. As per MICMAC basis analysis, the driving or independent drivers are at the bottom levels of the ISM diagram having strong drive power and are less dependent on other drivers. These drivers are Cut in subsidies and increased taxes on fossil fuels (BR1), Fluctuating raw material prices (BR2), Physical threat to assets and supply chain disruption (BR4), Litigation risk (BR3), High penalty for environmental pollution (GR5), Demand for low carbon Products (MP2), Media and NGOs attention (MP4), Local public or societal pressure (SP3), Demand from customers in environmental protection requirements (SP5) and Health issue (SP4). The findings of this chapter would help manage these drivers in the effective implementation of emission reduction practices in the cement industry.

Chapter 6

An integrated approach using AHP and DEMATEL for evaluating climate change mitigation strategies of the Indian cement manufacturing industry

Graphical abstract



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Preview

This chapter provides details about the identification, finalization, and prioritization of the climate change mitigation strategies of the Indian cement industry. Then, this chapter proposes a flexible model to prioritize these climate change mitigation strategies, for this, an integrated approach based on the AHP and DEMATEL methods has been developed and used in this chapter.

6.1 Introduction

Cement production is one of the most energy-intensive industry in the world (Madlool et al., 2012). It is one of the major sources of anthropogenic GHGEs among industrial activities (Wei and Cen, 2019; Feiz et al., 2015). However to reduce GHGEs is not an easy task for the cement industry as these are most susceptible due to a variety of problems, like resource constraints, difficult access to regulatory obligations, limited access to finance, incapable managers and advanced technologies (Herrera et al., 2017). These barriers are most prominent for developing countries like India. Climate change mitigation strategies help the cement manufacturing industry to reduce GHGEs effectively and efficiently. The need of the hour is to identify effective mitigation strategies to reduce GHGEs of the cement manufacturing industry of a developing economy.

An extant literature review has been done to identify climate change mitigation strategies of the cement industry. However, it will be impossible to implement all the mitigation strategies simultaneously. Hence, the industry should identify some mitigation strategies, which have essentially to be, manage and controlled to reduce the GHGEs from the cement industry through a three-phase integrated approach by employing AHP and DEMATEL techniques as shown in Fig. 6.1. In the first phase, identification of the various climate change mitigation strategies in the cement industry from the literature review and with the technical expert consultation. Through a detailed literature survey and discussion with technical experts, a total of twenty-four emission mitigation strategies were identified which were categorized into five main categories. In the second phase, the AHP technique (Saaty, 1980) has been used to rank the various factor according to their importance based on expert opinion and provides a chance for cement manufacturers to enhance their performance on a timely basis. Even though AHP is a dominant decision-making technique to prioritize the given factors but it is unable to determine the causal relationship between the various factors, which may limit the AHP technique to short-term decision-making measures (Najmi and Makui, 2010; Gandhi et al., 2016). In the third phase, the DEMATEL technique is used. DEMATEL technique generates casual relationship which illustrate the fundamental conception of contextual relationship and strengths of influence between the various factors so that the refine strategies can be taken from cause-effect viewpoints (Wu and Tsai, 2012) and help to develop long-term measures which are useful in accomplishing the conclusive objective (Chou et al., 2012). Table 6.1 describes common climate change mitigation strategies used in the cement manufacturing industry; Table 6.2 gives thermal and electric energy consumption also mitigation potential of different climate change strategies of cement manufacturing industry, Fig 6.2 shows indirect CO_2 reduction potential ($kgCO_2$/tcement) of various mitigation measures, Fig 6.3 shows direct CO_2 reduction potential ($kgCO_2$/tclinker) of various mitigation measures while Fig. 6.4 shows coverage of climate change mitigation strategies and its effect on main emission sources of cement industry.

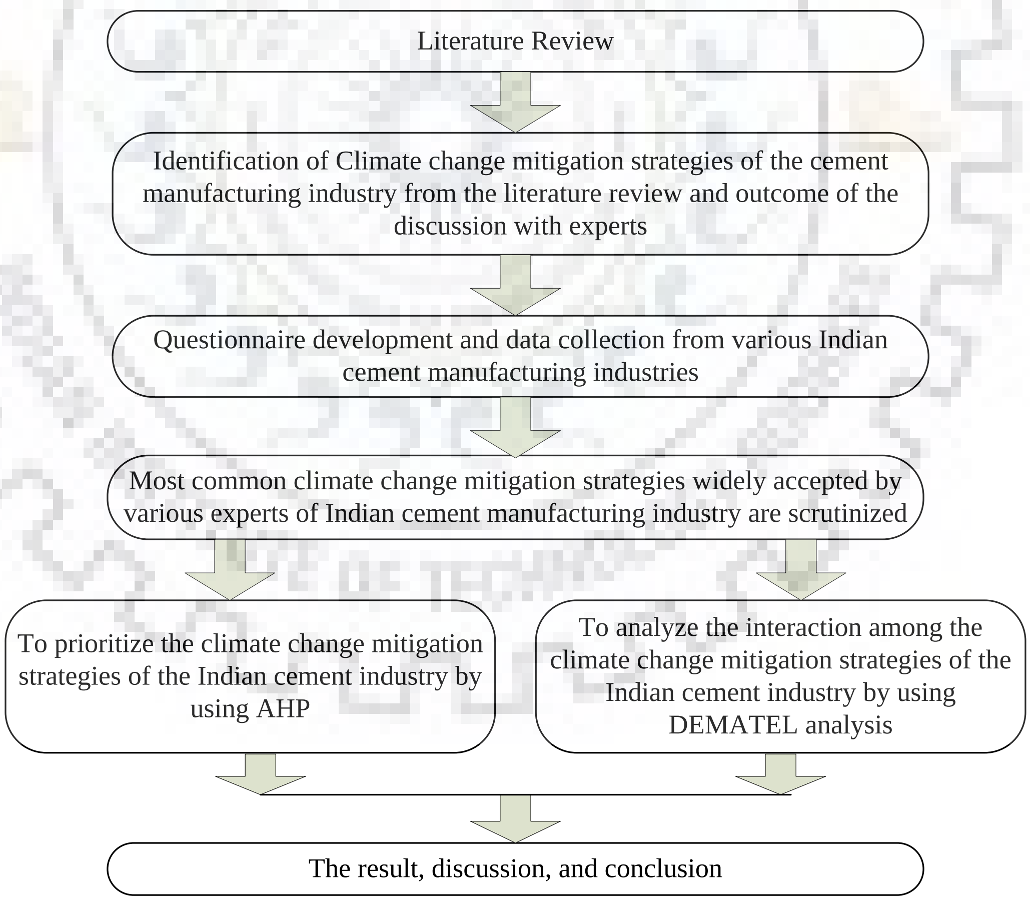

Figure 6.1: A proposed research framework

Table 6.1: Description of common climate change mitigation strategies used in the cement industry

SN	Mitigation strategies	Description	References
Electric energy-related emission reduction (EERE)			
1	Grinding (GRD)	The major focus area contributing to the significant reduction of specific energy demand are retrofitting and adoption of latest energy efficient technologies in grinding in existing plants, such as High pressure grinding roller (HPGR), vertical roller mill (VRM), roller press as compared to ball mills	Salas et al., 2016; Gao et al., 2015; Ishak and Hashim, 2015; Hasanbeigi et al., 2013; IEA, 2013; Madlool et al., 2011; Planning Commission, 2011; Bhushan, 2010
2	Grinding of raw material components separately (SGR)	Grinding the raw material components separately result in lower electric energy consumption for comminution of raw materials also the throughput of the grinding system is enhanced	CSI/ECRA, 2017; Hasanbeigi et al., 2013; Madlool et al., 2011
3	Separator (SPT)	High-efficiency separator give better particle size distribution, improves mill performance by avoiding the over grinding of material, rising of throughput and thereby reduction of the specific power consumption hence reduce the electric energy-related emissions	CII, 2015; Ishak and Hashim, 2015; Hasanbeigi et al., 2013; Madlool et al., 2013; Planning Commission, 2011; Bhushan, 2010
4	Variable speed or frequency drive (VSD)	Variable speed drive along with improved control strategies and high efficient motors reduce the electric energy consumption, enhance process controllability by the process control system, also reduced motor noise and eliminate the fan vibration.	CSI/ECRA, 2017; CII, 2015; Ishak and Hashim, 2015; Hasanbeigi et al., 2013; Madlool et al., 2011; Planning Commission, 2011
Process emission reduction (PER)			
5	Raw material substitution (RMS)	The utilization of alternative raw material like industrial waste which is already decarbonated offers a chance to reduce process related and fuel consumption related CO_2Es also reducing the requirement of virgin materials e.g., chrome sludge, lead-zinc slag, mine rejects, red mud, lime sludge, phosphorous furnace slag, phospho chalk, contaminated soils, cement kiln dust, granulated blast furnace slag (GBFS) etc.	IMY, 2017a; Cadez and Czerny, 2016; Gao et al., 2015; IPCC, 2014a; Ali et al., 2011; Sprengel and Busch, 2011; Tanaka, 2011; Jeswani et al.,2008; Rao, 2007; Rao and Holt, 2005; Schultz and Williamson, 2005
6	Clinker substitution (CLSB)	Some other industries byproduct/waste (e.g., GBFS, fly ash, pozzolanas, limestone, lime sludge, lead-zinc slag, phosphorus furnace slag, silica fume, etc.) is used as clinker substitutions, thereby reducing clinker volume, hence fuel, power, and process related GHGEs associated with clinker production is	CSI/ECRA, 2017; Salas et al., 2016; Ishak and Hashim, 2015; Benhelal et al., 2013; ECA, 2013; Hasanbeigi et al., 2013; Ke et al., 2012; Ali et al., 2011; Madlool et al., 2011;

SN	Mitigation strategies	Description	References
		reduced	Planning Commission, 2011
7	Reduce production and sales of emission-intensive cement (RPS)	Strategy in which organizations will not instantly cease manufacture of emission-intensive cement like OPC, but may rather engender a gradual shift away from emission-intensive cement production towards lower emission cement like blended cement, e.g., PPC, PSC, PLC, etc. without any change made to cement production process or technology and hence lower the sale of emission-intensive cement.	Cadez and Czerny, 2016; Rao et al., 2015 ; IPCC, 2014a; IEA, 2013; Planning Commission, 2011; Sprengel and Busch, 2011; Čadež and Czerny, 2010; CII, 2010; Schultz and Williamson, 2005
8	Newer technologies (NWT)	Several newer technologies, e.g., Mineralization, Oxy-fuel combustion, chemical absorption and membrane technologies, Mineral carbonation and Carbonate looping, Fluidized bed advanced kiln system, carbon capture utilization and storage, etc., could have significantly improved emissions reduction profile of Indian cement industry.	CSI/ECRA, 2017; Fetene et al., 2017; Salas et al., 2016; Ishak and Hashim, 2015; Behera et al., 2014; Benhelal et al., 2013; ECA, 2013; IEA, 2013; Hasanbeigi et al., 2012; Ke et al., 2012; Ali et al., 2011
9	Low carbon cement (LCC)	The strategies to reduce the power demand, fuel consumption, promote the consumption of low-grade limestone and conservation of high-grade limestone is to promoting low carbon cement, e.g., Geopolymer cement, element, Low lime cement, Limestone calcined clay cement, etc. will result in huge potential in the reduction of GHG emissions	CSI/ECRA, 2017; Gao et al., 2015; Saxena, 2015; Shashank, 2015; IEA, 2013; Madlool et al., 2013; Hasanbeigi et al., 2012; Madlool et al., 2011; CII, 2010; CSI/ECRA, 2009
Emission avoidance and reduction (EAR)			
10	Modern Burner (BNR)	Modern multichannel burner leading to decrease fuel energy demand, improves the combustion efficiency, reduction of heat consumption and NO_x emission. Furthermore, modern burners also permit the use of a significant amount of alternate fuels.	CSI/ECRA, 2017; Ishak and Hashim, 2015; Benhelal et al., 2013; Madlool et al., 2013; Planning Commission, 2011; CSI/ECRA, 2009
11	Fossil fuel switching (FFS)	In cement manufacturing, fuel related CO_2Es is about one-third of total emissions; thus, the overall CO_2 reduction potential of fuel switch is roughly one third. Some low carbon or carbon neutral fuel may use in cement manufacturing are heavy oil, natural gas, pure biomass, etc.	CSI/ECRA, 2017; Gao et al., 2015; Ishak and Hashim, 2015; ECA, 2013; Planning Commission, 2011; CSI/ECRA, 2009
12	Captive power plant (CPP)	CPP gives an enhancement in energy security by reducing the requirement of electricity from the grid, huge emissions reduction potential associated with energy efficiency improvements, the use of alternative fuels and renewable energy like wind power, solar photovoltaic(PV), biomass-based	IMY, 2017a; IEA, 2013

SN	Mitigation strategies	Description	References
		power production, small hydro generation. CPP is essential to move the cement industry's towards a low carbon economy.	
13	Alternate fuels and raw materials (AFR)	Co-processing is the use of alternative/waste-derived fuel including hazardous combustible wastes and materials like waste from pharmaceutical industries, used and scrapped tyres, municipal solid wastes (MSW), refuse-derived fuel (RDF) from MSW, effluent treatment plant (ETP) sludge, sewage sludge, paint sludge, expired consumer goods, waste oils and solvents, non recyclable plastics, textile and paper residue, pet coke etc. Alternate fuels dispose to recover material and energy from them. It has an immediate impact on the carbon profile since it substitutes clinkers and coal.	CSI/ECRA, 2017; CMA, 2016; Salas et al., 2016; CII, 2015; Gao et al., 2015; Ishak and Hashim, 2015; Singh et al., 2015; Benhelal et al., 2013; ECA, 2013; Hasanbeigi et al., 2013; IEA, 2013; Madlool et al., 2013; Ke et al., 2012; Madlool et al., 2011; Planning Commission, 2011; CII, 2010
14	Waste heat recovery (WHR)	Primarily waste heat from the system utilized for the drying of raw materials and then additional waste heat used for power generation without any change in kiln operation. Such a WHR system derives more energy from the same energy resource without requiring any additional fuel input to the system. Thus it offers a significant energy security enhancement and emission reduction opportunity.	CSI/ECRA, 2017; CMA, 2016; CII, 2015; Gao et al., 2015; Ishak and Hashim, 2015; Prabhu et al., 2015; Benhelal et al., 2013; Hasanbeigi et al., 2013; IEA, 2013; Madlool et al., 2013; Ali et al., 2011; Madlool et al., 2011; CII, 2010
15	Transport efficiency (TRE)	Any attempt to move basic raw materials, fuel, intermediate products (clinker), finished products through shorter distance by the efficient way, would make a significant difference to the fuel consumption, emission reduction as well as the cost of manufacturing hence it is essential to opt the cost-effective transportation. Consequently, rail transportation appears as a preferred alternative, last mile connectivity is assured by road transport, inland water, and sea transportation is also cost-effective, energy efficient and environmentally friendly transportation mode.	Chen et al., 2018; IMY, 2017a; Gao et al., 2015; Datta et al., 2015; ECA, 2013; Planning Commission, 2011; CII, 2010
Fuel emission reduction (FER)			
16	Automation, optimization and process	In the manufacturing industry, the most widely used practice to reduce GHGEs is automation and optimization of existing processes. Cross-cutting technologies and advanced automation measures such as electronic control system, improving the	Kumar and Lad, 2017; Cadez and Czerny, 2016; Giret et al., 2015; Ishak and Hashim, 2015; CII, 2015;Rathore, 2015;IPCC, 2014a; Benhelal et al., 2013;

SN	Mitigation strategies	Description	References
	control (AOP)	process control. They are also optimizing the performance of industrial processes and improve plant efficiency cost-effectively with energy conservation and emissions reduction benefits.	Hasanbeigi et al., 2013; Lad and Kulkarni, 2012; Tanaka, 2011; IL&FS Ecosmart Limited, 2010;CSI/ECRA, 2009; Oliver, 2008
17	Pre-heater (PRH)	The preheater cyclone is designed for heat transfer between kiln feed and kiln exhaust gases. Energy saving potential accomplished by reducing the kiln exhausts air temperature through heat energy recovery with an additional cyclone stage. Furthermore, additional cyclone stage generates a further pressure drop, which reduces the power consumption.	CSI/ECRA, 2017; Salas et al., 2016; Gao et al., 2015; Benhelal et al., 2013; Hasanbeigi et al., 2013; Madlool et al., 2013; Madlool et al., 2011; Planning Commission, 2011; APP, 2010
18	Kiln system (KLN)	Under the optimized conditions, the best thermal energy consumption can be achieved with pre-heater pre-calciners kilns (PH-PC). PH-PC kilns have higher production capacity, ensure good burnability of the raw material, enabled utilization of lower calorific value with high ash coals, all types of alternate fuels including biomass than older and conventional wet kilns.	CSI/ECRA, 2017; Salas et al., 2016; Gao et al., 2015; Ishak and Hashim, 2015; Benhelal et al., 2013; ECA, 2013; Hasanbeigi et al., 2013; Madlool et al., 2011; Planning Commission, 2011
19	Efficient cooler (CLR)	In the manufacturing of cement the heat energy of the hot clinker, escaping from the kiln is recovered in the clinker cooler. This recovered heat energy is utilized for warming up the combustion air. Grate cooler is the key efficient clinker cooler technology, Grate cooler has better clinker properties, further gaining in cooler heat recuperation efficiency with significantly lower exit air and clinker temperatures.	CSI/ECRA, 2017; Salas et al., 2016; CII, 2015; Ishak and Hashim, 2015; Benhelal et al., 2013; Madlool et al., 2013; Madlool et al., 2011; Planning Commission, 2011; CSI/ECRA, 2009
Management mitigation measures (MMM)			
20	Carbon sequestration (CSQ)	In addition to preventive mitigation strategies, the implementation of reforestation activities to enhance carbon sinks by the organization can also offset their CO_2Es is another an important mitigation strategy	Weinhofer and Hoffmann, 2010; Hoffman, 2007; Boiral, 2006
21	Carbon trading (CRT)	The organization can reduce CO_2Es in cooperation with other organization or government, either by trading Escerts and CER credits internally though BEE mechanisms called PAT scheme or externally by Kyoto protocol's flexible mechanisms, e.g., CDM or Joint Implementation (JI) without the necessity for changing their production processes or products	Cadez and Czerny, 2016; Lakshmi et al., 2012; S. Lee, 2012; Sprengel and Busch, 2011; Weinhofer and Hoffmann, 2010; Okereke, 2007; Pinkse, 2007; Schultz and Williamson, 2005; Kolk and Pinkse, 2005; Kolk and

SN	Mitigation strategies	Description	References
			Pinkse, 2004; Dunn, 2002
22	Consumer behaviour change (BHV)	High-grade cement or one day strength does not improve quality of construction as a whole and result in higher specific energy consumption, thus increase in GHGEs. To ratify this, the organization initiates a wide range of positive activities for reducing GHGEs including consumer behaviour change and public education about low carbon cement	Long and Young, 2016; IPCC, 2014a; Long, 2013; CII, 2010; Okereke, 2007
23	Collaboration (CLB)	Networking or collaboration within or across industrial sectors to promote efforts for emission reduction, energy saving, technology transfer, information sharing, experience sharing, knowledge transfer.	G. Kumar et al., 2018; IPCC, 2014a; IEA, 2013; Tanaka, 2011; Jeswani et al., 2008; Kolk and Pinkse, 2004; Dunn, 2002
24	Change in organization culture (ORC)	Change in organization culture concerning firm's acknowledgment to climate change is focusing on increasing the employee awareness, emission reduction commitment, energy consumptions reduction, education, and training, establishing the carbon management department and incorporate carbon strategies into the firm's performance assessment.	Luo et al., 2017; Lee, 2012; Planning Commission, 2011; CII, 2010; Jeswani et al., 2008; Okereke, 2007; Kolk and Pinkse, 2004

Table 6.2(A): Mitigation Potential of different climate change strategies of the cement industry

S.No.	Mitigation strategies (Unit)	Thermal energy consumption (kcal/kg cement)	Electric energy consumptio n(kWh/t cement)	Direct CO_2 reduction potential ($kgCO_2$/t cement)	Indirect CO_2 reduction potential (kg CO_2/t cement)
1	Grinding of cement with vertical roller mills (VRM) and roller presses	--	10 –16	--	7–11
2	High efficiency separators	--	2.3–5.08	--	1.1–5.2
3	Variable speed or frequency drive	--	3–9.15	--	1.5–5.2
4	Clinker substitution (amount of GBFS up to 0.70 [t/t cement])	Up to 380	--	Up to 390	
5	Clinker substitution (amount of coal fly ash 0.25-0.35 t/t cement)	Up to 86	2–15	Up to 90	1–8
6	Clinker substitution (amount of natural pozzolanas up to 0.35 t/t cement)	Up to 86	Up to 3	Up to 90	Up to 1.7
7	Clinker substitution (cement with 25 -35% by mass limestone)	Up to 86	Up to 5	Up to 88	Up to 2.6
8	Optimization of ball mills operating parameters	---	0.5–4		0.3–1.8
9	Auxiliary system efficiency	--	3–5	--	1–3
10	Separate grinding and blending by fineness	--	1.4–3.2	--	0.7–1.6
11	Increased cement performance by optimized particle size distribution (PSD)	Up to 43.7	--	Up to 45	--
12	Optimized use of grinding aids	--	0.5–2.3	--	0.3–1.1
13	Impact of very high/very low lime saturation factor	28.4–29.8	Increase of 9–25	Up to 19	Increase of 5-12
14	Other low carbonate cements - Belite cements	35.8–47.8	Increase of 20–40	13-17	Increase of 10–20

(CSI/ECRA, 2017; Kajaste and Hurme, 2016; CII, 2015; Morrow et al., 2014; Hasanbeigi et al., 2013; Ali et al., 2011; Madlool et al., 2011; CSI/ECRA, 2009)

Table 6.2(B): Mitigation Potential of different climate change strategies of the cement industry

S.No.	Mitigation strategies (Unit)	Thermal energy consumption (kcal/kg clinker)	Electric energy consumption(kWh/t clinker)	Direct CO2 reduction potential (kgCO2/t clinker)	Indirect CO2 reduction potential (kgCO2/t clinker)
1	Separate grinding of raw material components	--	0.8–1.7	--	0.4–0.9
2	Raw material substitution (for 10-15% replacement of raw materials by GBFS)	23.9 to 95.6	--	Up to 100	
3	Mineralization	11.9–43	--	4–16	--
4	Oxygen enrichment technology	23.9 –41.8	Increase of 10-35	9–15	Increase of 5-18
5	Fluidized bed advanced cement kiln	Up to 71.7	Increase of 9	Up to 27	Increase of 4–6
6	Modern multichannel burner	5.9–17.9	--	2.2–6.5	--
7	Fuel switching (coal/pet coke to oil/gas/pure biomass)	Decrease of 47.8 to increase of 23.9	--	40–60	
8	Alternate fuels, replacing fossil fuels	Increase of 47.8–71.7	Increase of 2–4	30–50	Increase of 1–2
9	Waste heat recovery (steam/ORC/Kalina cycle)	--	8–39	--	4–11
10	Upgrade plant automation control package	11.9–47.8	Up to 2.5	4–17	Up to 1.25
11	Pre-heater modification (cyclones with lower pressure drop)	--	0.6–2.6	--	0.16–1.09
12	Additional pre-heater cyclone stage(s) (4 to 5 or 5 to 6 stage pre-heater)	19.12–23.9	--	7–9	--
13	Change from long kilns to PH-PC kilns	215–669.2	Up to 5	80–250	Up to 2.5
14	Increase of the kiln capacity	35.8–47.8	2–4	13–18	1–2
15	Efficient clinker cooler technology	23.9–71.7	Increase of 1 to 6	22–26	Increase of 2–4
16	Pre-treatment of alternative fuel (grinding, drying)	Up to 38.2	Increase of 1–3	0–14	Increase of 0.6–1.6
17	Oxyfuel Technology	The decrease of 47.8 to Increase of 59.7	Increase of 117–180	530–835	Increase of 60–90
18	Post-combustion capture using absorption technologies	Increase of 239–836	Increase of 50–90	Up to 740	Increase of 25–60

S.No.	Mitigation strategies (Unit)	Thermal energy consumption (kcal/kg clinker)	Electric energy consumptio n(kWh/t clinker)	Direct CO2 reduction potential (kgCO2/t clinker)	Indirect CO2 reduction potential (kgCO2/t clinker)
19	Post-combustion capture using membrane processes	--	Increase up to 300	700–760	Increase up to 195
20	Post-combustion capture using solid sorbents: Ca looping	Increase of 167–334.6	--	760–800	--
21	Post-combustion capture using solid sorbents: Mineral carbonation	Increase up to 609.4	Increase of 300–700	Up to 750	--

(CSI/ECRA, 2017; Kajaste and Hurme, 2016; CII, 2015; Morrow et al., 2014; Hasanbeigi et al., 2013; Ali et al., 2011; Madlool et al., 2011; CSI/ECRA, 2009)

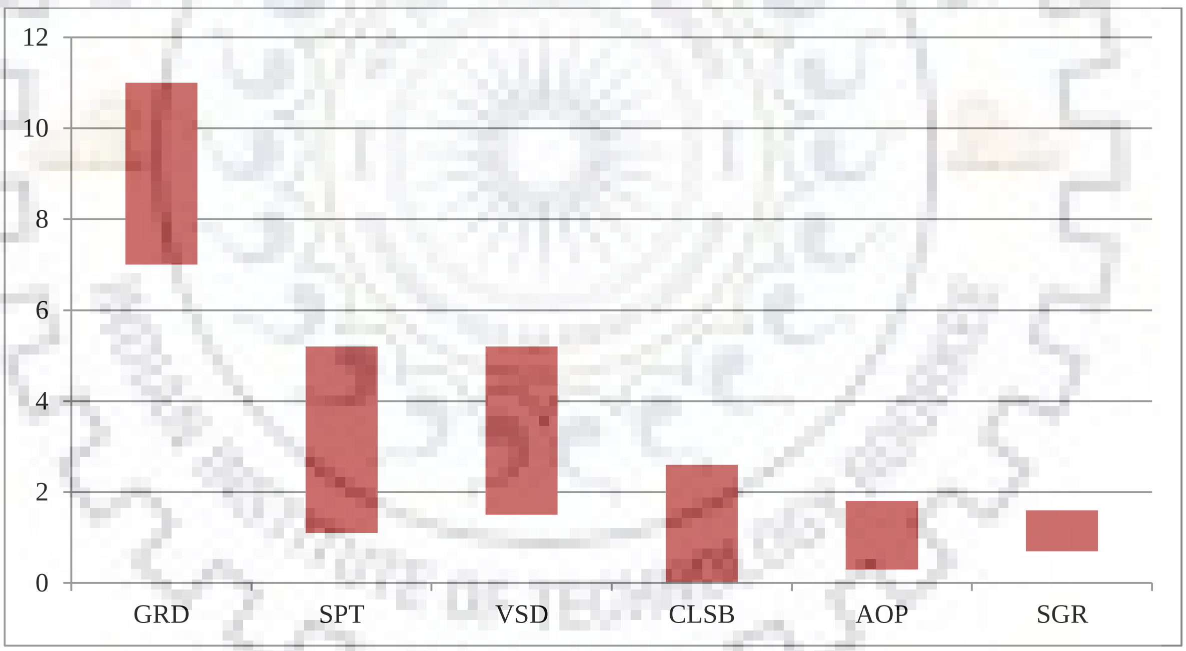

Figure 6.2: Indirect CO_2 reduction potential ($kgCO_2$/tcement) of various mitigation measures

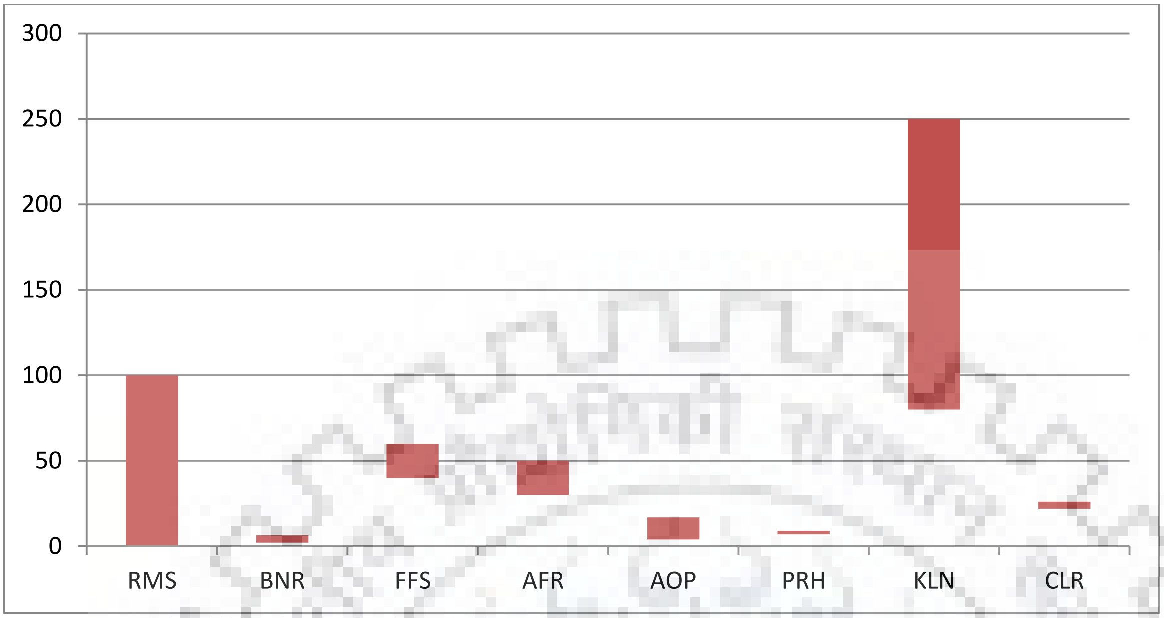

Figure 6.3: Direct CO_2 reduction potential ($kgCO_2$/tclinker) of various mitigation measures

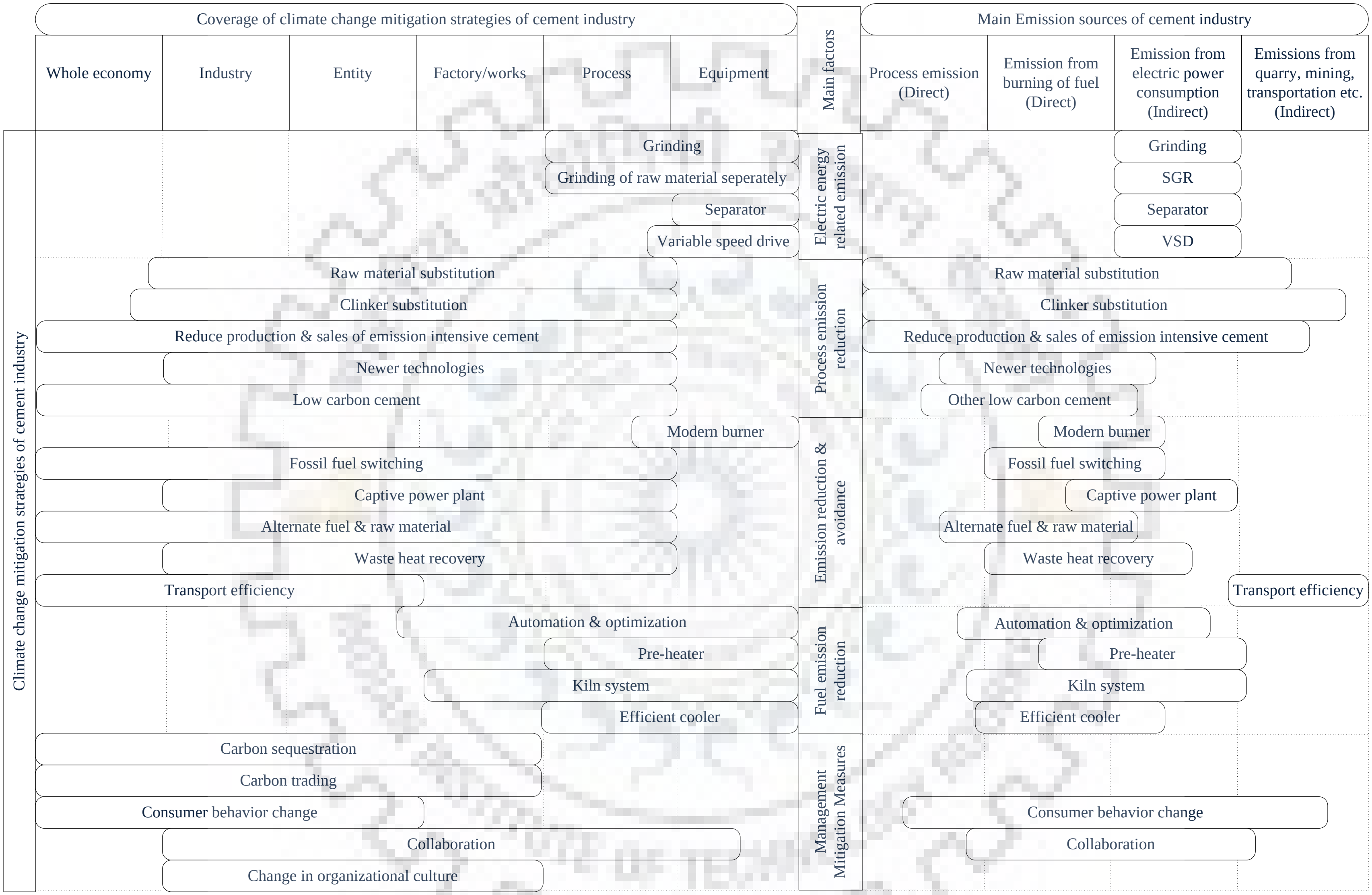

Figure 6.4: Coverage of climate change mitigation strategies and its effect on main emission sources of cement industry

6.2 Proposed research framework and its application

A proposed research framework for evaluating the climate change mitigation strategies of the Indian cement industry is based on the combined AHP and DEMATEL techniques consist of three phases.

Phase I: Identification of common climate change mitigation strategies for the cement industry and data collection.

Phase I start with identification of twenty-four the most common climate change mitigation strategies of the cement industry from literature resources and inputs from an industry expert as shown in Table 6.1 This study targets ten cement industry of India, the survey questionnaires were personally administered to the authorities involved in the cement manufacturing process, during two months from June to July 2017. Middle and senior rank engineers and managers with divergent accountability were selected during the data collection process because they are an integral member of the strategic decision-making group (Carter et al., 1998). The selected industrial experts were remarkably proficient in their discipline, having industrial experience of above ten years. The respondent's position and department, experience and respective plant capacity are display in Table 3.1. The questionnaire was created to obtain experts' viewpoint on the cement industry. Before data collection, we thoroughly explained the objective and utility of the research to each respondent. We also outlined the potential advantages of the research. Then Experts were asked to rate the common climate change mitigation strategies of the cement industry.

Then these identified twenty-four common climate change mitigation strategies of cement industry are categorized into five main factors; Electric energy emission reduction (EERE), Process emission reduction (PER), Emission avoidance and reduction (EAR), Fuel emission reduction (FER) and Management mitigation measures (MMM). The fundamental behind the categorization is meaningful correlations between the mitigation strategies.

Phase II: Calculating the relative importance of identified common climate change mitigation strategies of the cement industry by AHP

AHP technique is used to prioritize the identified common climate change mitigation strategies of cement industry according to their relative importance. For this purpose, a structural decision hierarchal is to establish to analyze the problem. It consists of three levels: an objective statement

(Level I), the main factors (Level II), and sub-factors (Level III), as shown in Fig. 6.3.

From each expert, the pairwise evaluation matrix for the main factor and each sub-factor constructed based on the Saaty's scale (Table 3.4). Primarily, to accumulate the individual ratings of the experts and for calculating the ranks of the factors, the geometric mean approach is used (Mangla et al., 2016). Table 6.3 shows the pair-wise evaluation matrix for the main group factors similarly from Table 6.4 to Table 6.8 shows pair-wise evaluation matrix of all five main factors, while Table 6.9 shows proportionate ranks and their relative importance weights of the main factors

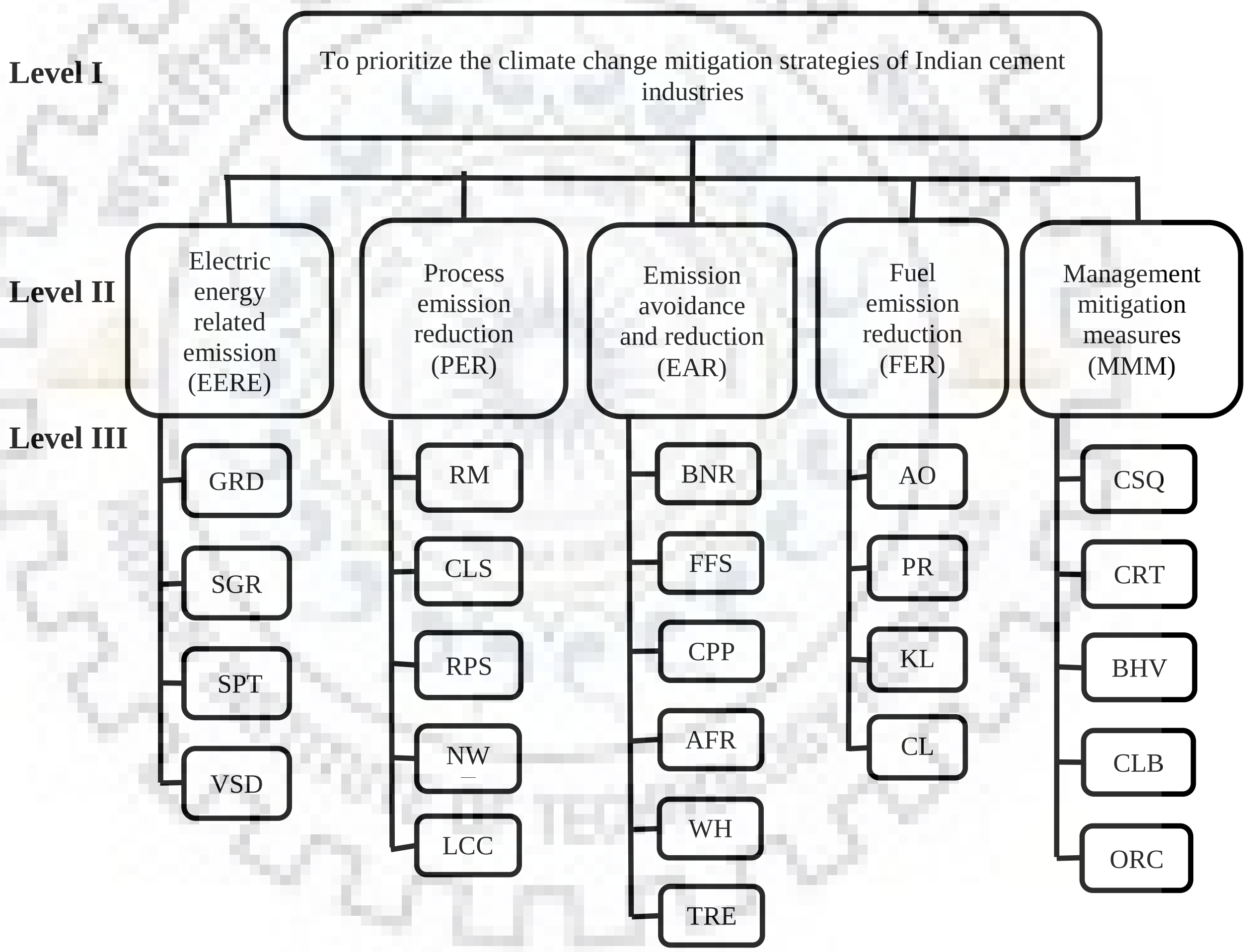

Figure 6.5: Hierarchical structure of climate change mitigation strategies of the Indian cement industry.

Table 6.3: Pair-wise evaluation matrix for the main group factors

	EERE	PER	EAR	FER	MMM
EERE	1.0000	0.1990	2.0480	0.1990	3.0840
PER	5.0251	1.0000	4.0150	0.4940	6.0290
EAR	0.4883	0.2491	1.0000	0.1990	2.0480
FER	5.0251	2.0243	5.0251	1.0000	8.0690
MMM	0.3243	0.1659	0.4883	0.1239	1.0000

Further, the computed Eigen values and Eigen vectors given as

Eigen value (maximum), λ_{max} = 5.3613, Consistency index, C.I. = 0.0903 and Consistency ratio, C.R. = 0.0814, which is less than 0.10.

Table 6.4: Pair-wise evaluation matrix of the EEREs

	GRD	SGR	SPT	VSD
GRD	1.0000	8.0690	4.0860	2.0240
SGR	0.1239	1.0000	0.1820	0.1420
SPT	0.2447	5.4945	1.0000	0.3320
VSD	0.4941	7.0423	3.0120	1.0000

Table 6.5: Pair-wise evaluation matrix of the PERs

	RMS	CLSB	RPS	NWT	LCC
RMS	1.0000	0.1980	0.1980	1.0720	2.0000
CLSB	5.0505	1.0000	1.0720	8.0820	8.0690
RPS	5.0505	0.9328	1.0000	7.0650	6.9710
NWT	09328	0.1237	0.1415	1.0000	0.6340
LCC	0.5000	0.1239	0.1435	1.5773	1.0000

Table 6.6: Pair-wise evaluation matrix of the EARs

	BNR	FFS	CPP	AFR	WHR	TRE
BNR	1.0000	3.0840	2.0240	0.5150	5.0160	1.5160
FFS	0.3243	1.0000	0.2480	0.1680	0.2550	0.1260
CPP	0.4941	4.0323	1.0000	0.4940	4.0380	1.1490
AFR	1.9417	5.9524	2.0243	1.0000	4.0380	0.4750
WHR	0.1994	3.9216	0.2476	0.2476	1.0000	0.1620
TRE	0.6596	7.9365	0.8710	2.1053	6.1728	1.0000

Table 6.7: Pair-wise evaluation matrix of the FERs

	AOP	PHR	KLN	CLR
AOP	1.0000	0.7580	0.1240	0.4610
PHR	1.3193	1.0000	0.1570	0.4750
KLN	8.0645	6.3694	1.0000	5.1440
CLR	2.1692	2.1053	0.1944	1.0000

Table 6.8: Pair-wise evaluation matrix of the MMMs

	CSQ	CRT	BHV	CLB	ORC
CSQ	1.0000	3.1040	4.1290	0.4080	0.3810
CRT	0.3222	1.0000	3.6220	0.4430	0.2420
BHV	0.2422	0.2761	1.0000	0.2300	0.1340
CLB	2.4510	2.2573	4.3478	1.0000	0.3850
ORC	2.6247	4.1322	7.4627	2.5974	1.0000

Table 6.9: Proportionate ranks and their relative importance weights of the main factors

Main factors	Ranks	Relative importance weights
FER	1	0.4761
PER	2	0.3267
EERE	3	0.1158
EAR	4	0.0814
MMM	5	0.0466

Similarly, Table 6.10 shows proportionate ranks and their relative importance weights of all the sub-factors. Furthermore, by multiplying the relative importance weight of sub-factors with their corresponding main factor importance weights, the global weights and their respective global rank of all the sub-factors are determined, as shown in Table 6.10. For all the main factors and sub-factors, the consistency ration (C.R.) is below 0.10.

Table 6.10: Relative ranking of sub-factors of climate change mitigation strategies of the Indian cement industry

Main Factor	Relative Weights	Sub-factors	Relative Weights	Relative Rank	Global Weights	Global rank
EERE	0.1158	GRD	0.4956	1	0.0574	5
		SGR	0.0438	4	0.0051	21
		SPT	0.1503	3	0.0174	17
		VSD	0.3102	2	0.0359	8
PER	0.3267	RMS	0.0858	3	0.0280	10
		CLSB	0.4465	1	0.1459	2
		RPS	0.4106	2	0.1341	3
		NWT	0.0571	5	0.0187	15
		LCC	0.0606	4	0.0198	13
EAR	0.0814	BNR	0.2262	3	0.0184	16
		FFS	0.0376	6	0.0031	24
		CPP	0.1591	4	0.0130	19
		AFR	0.2480	2	0.0202	12
		WHR	0.0623	5	0.0051	22
		TRE	0.2668	1	0.0217	11
FER	0.4761	AOP	0.0757	4	0.0360	7
		PHR	0.0941	3	0.0448	6
		KLN	0.6673	1	0.3177	1
		CLR	0.1629	2	0.0776	4
MMM	0.0466	CSQ	0.3190	3	0.0149	18
		CRT	0.1852	4	0.0086	20
		BHV	0.0784	5	0.0037	23
		CLB	0.4174	2	0.0195	14
		ORC	0.7630	1	0.0356	9

Phase III: Determining interdependence among the identified common climate change mitigation strategies of the cement industry by DEMATEL

To establish the interrelationship between the identified common climate change mitigation strategies of cement industry regarding a causal effect relationship, same experts of respective industry were asked to assess the mitigation strategies on a scale of 0 to 4 as shown in Table 6.11. Initially, the main factors assessed.

Table 6.11: DEMATEL Linguistic scale

Score	Influence score
0	No influence on both factor
1	Very low influence of one factor over another
2	Low influence of one factor over another
3	High influence of one factor over another
4	Very high influence of one factor over another

The average matrix (a_{ij}) formulated by using Equation (3.10.4.1) by calculating the average of the reply of the experts. Further, normalized initial direct-relation matrix (D) formed by using Equation (3.10.4.2), next by using Equation (3.10.4.4) the total relation matrix (T) of the main factors is formed as shown in Table 6.12. Now the values in the ($r_i + c_j$) column are highest for the main factor FER as shown in Table 6.12, it means FER acquires high influence on the entire system in comparison to other main factors. Correspondingly, ($r_i - c_j$) column values distinguish the main factors into cause and effect groups. The main factor PER and FER is in cause group since ($r_i - c_j$) column values is positive while the main remaining factors are in effect group since ($r_i - c_j$) column values are negative. Subsequently, by averaging of the factors in the total relation matrix, the threshold value of the factors is calculated. The threshold value assists in creating a causal effect graph, making the structure well defined also filter the insignificant effects. The causal effect graph helps to interpret the structure by recognizing the influence of one factor over another.

Similarly, for all the sub-factors, the DEMATEL calculations executed Tables 6.13 to Table 6.17 represents the total relation matrices for sub-factors while Fig. 6.5 to Fig. 6.9 displays the causal effect graph for the sub-factors.

Table 6.12: Total relation matrix of the main factors

Main factors	EERE	PER	EAR	FER	MMM	Sum r_i	$r_i + c_j$	$r_i - c_j$
EERE	0.4966	0.6375	0.6725	0.7153	0.5480	3.0700	6.3111	-0.1711
PER	0.7826	0.6170	0.8612	0.9163	0.6478	3.8251	7.0313	0.6189
EAR	0.7112	0.6987	0.5710	0.8110	0.5378	3.3297	6.7254	-0.0661
FER	0.8792	0.8775	0.9056	0.7399	0.7038	4.1060	7.7049	0.5070
MMM	0.3715	0.3755	0.3854	0.4164	0.2381	1.7869	4.4624	-0.8886
Sum c_j	3.2411	3.2062	3.3957	3.5990	2.6755	Threshold value = 0.6447		

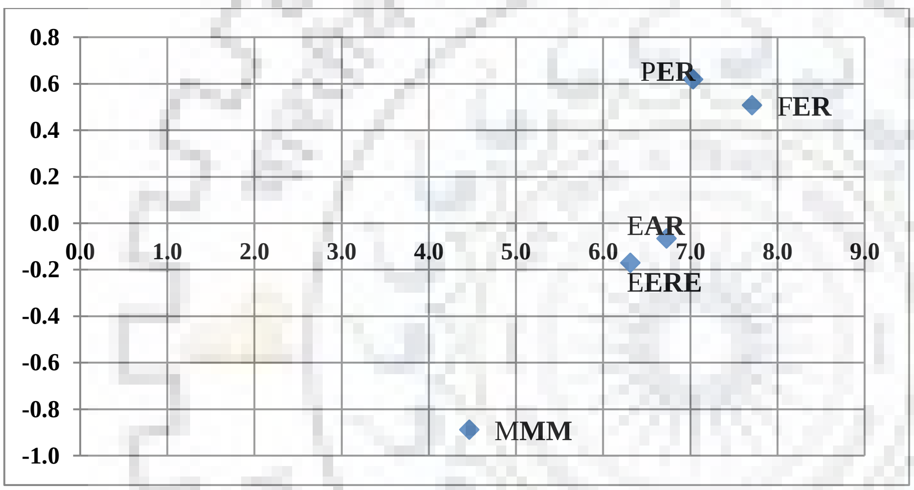

Figure 6.6: The digraph of the five main factors

Table 6.13: Total relation matrix of Electric Energy-Related Emissions (EERE)

EERE	GRD	SGR	SPT	VSD	Sum r_i	$r_i + c_j$	$r_i - c_j$
GRD	0.8578	1.0541	1.1734	1.1767	4.2621	7.6452	0.8789
SGR	0.6867	0.5184	0.6983	0.7101	2.6134	5.9489	-0.7222
SPT	0.8141	0.7062	0.6461	0.8438	3.0102	6.5850	-0.5646
VSD	1.0246	1.0568	1.0571	0.8394	3.9779	7.5479	0.4079
Sum c_j	3.3832	3.3355	3.5748	3.5700	Threshold value = 0.8664		

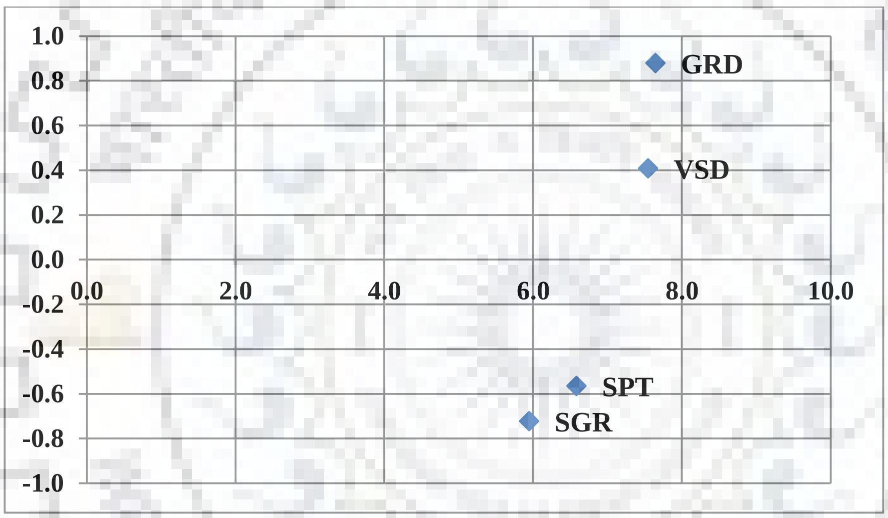

Figure 6.7: the digraph of the four sub-factors of Electric Energy-Related Emissions (EERE)

Table 6.14: Total relation matrix of Process Emission Reduction (PER)

PER	RMS	CLSB	RPS	NWT	LCC	Sum r_i	$r_i + c_j$	$r_i - c_j$
RMS	0.4162	0.5212	0.5536	0.5580	0.6378	2.6868	5.1639	0.2097
CLSB	0.6852	0.4101	0.6992	0.6948	0.7453	3.2347	5.2820	1.1873
RPS	0.3973	0.3374	0.2659	0.3441	0.3565	1.7012	4.2212	-0.8188
NWT	0.3946	0.3170	0.4052	0.2810	0.4402	1.8379	4.3085	-0.6326
LCC	0.5839	0.4616	0.5961	0.5927	0.4254	2.6596	5.2647	0.0545
Sum c_j	2.4771	2.0473	2.5200	2.4706	2.6051	Threshold value = 0.4848		

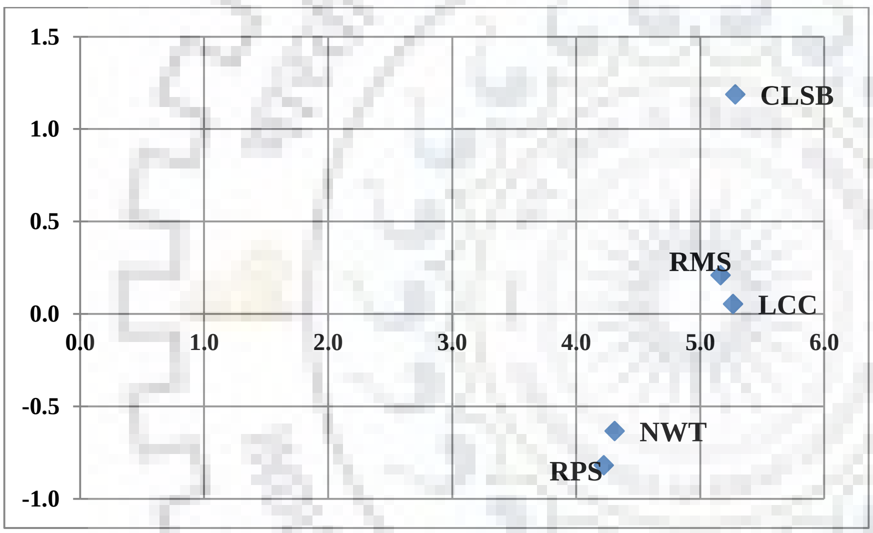

Figure 6.8: The digraph of the five sub-factors of Process Emission Reduction (PER)

Table 6.15: Total relation matrix of Emission Avoidance and Reduction (EAR)

EAR	BNR	FFS	CPP	AFR	WHR	TRE	Sum r_i	$r_i + c_j$	$r_i - c_j$
BNR	0.2925	0.4288	0.3938	0.5166	0.4445	0.4223	2.4986	4.7416	0.2556
FFS	0.3426	0.2225	0.3113	0.3842	0.3076	0.3078	1.8758	4.1667	-0.4150
CPP	0.3077	0.3182	0.2674	0.3955	0.4005	0.3854	2.0748	4.5398	-0.3903
AFR	0.5224	0.4967	0.5639	0.4206	0.5232	0.5579	3.0848	5.7249	0.4447
WHR	0.2719	0.2727	0.3393	0.3048	0.2240	0.3261	1.7388	4.2237	-0.7461
TRE	0.5058	0.5519	0.5893	0.6185	0.5852	0.4007	3.2514	5.6516	0.8512
Sum c_j	2.2430	2.2909	2.4650	2.6401	2.4849	2.4002	Threshold value = 0.4034		

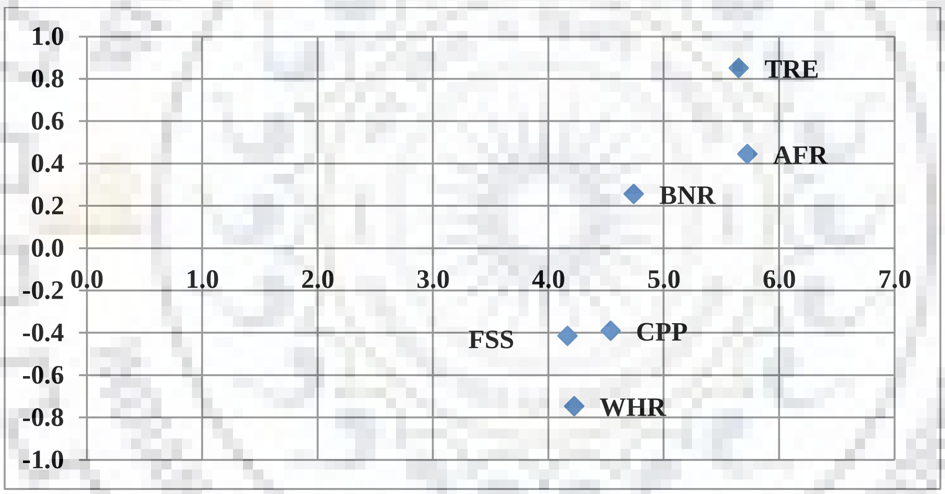

Figure 6.9: The digraph of the six sub-factors of Emission Avoidance and Reduction (EAR)

Table 6.16: Total relation matrix of Fuel Emission Reduction (FER)

FER	AOP	PHR	KLN	CLR	Sum r_i	$r_i + c_j$	$r_i - c_j$
AOP	1.1310	1.3750	1.4994	1.4416	5.4471	10.0135	0.8807
PHR	1.0757	0.9273	1.2159	1.1417	4.3606	9.0439	-0.3227
KLN	1.4273	1.4222	1.2538	1.4609	5.5642	10.5268	0.6016
CLR	0.9323	0.9588	0.9934	0.8136	3.6981	8.5559	-1.1596
Sum c_j	4.5664	4.6833	4.9626	4.8578	Threshold value = 1.1919		

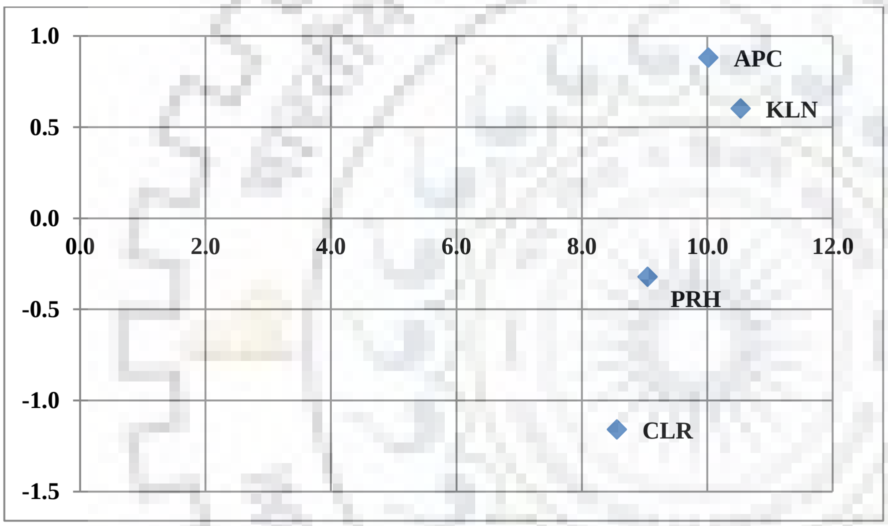

Figure 6.10: The digraph of the four sub-factors of Fuel Emission Reduction (FER)

Table 6.17: Total relation matrix of Management Mitigation Measures (MMM)

MMM	CSQ	CRT	BHV	CLB	ORC	Sum r_i	$r_i + c_j$	$r_i - c_j$
CSQ	0.3150	0.4263	0.3317	0.4605	0.4660	1.9994	2.7048	-0.4875
CRT	0.4757	0.3412	0.3601	0.5042	0.5616	2.2428	4.6183	-0.1328
BHV	0.3072	0.2841	0.1816	0.3709	0.3184	1.4624	3.4356	-0.5109
CLB	0.6836	0.6467	0.5167	0.5002	0.7300	3.0773	5.6609	0.4936
ORC	0.7054	0.6773	0.5831	0.7479	0.5311	3.2448	5.8519	0.6376
Sum c_j	2.4869	2.3756	1.9733	2.5836	2.6072	Threshold value = 0.4811		

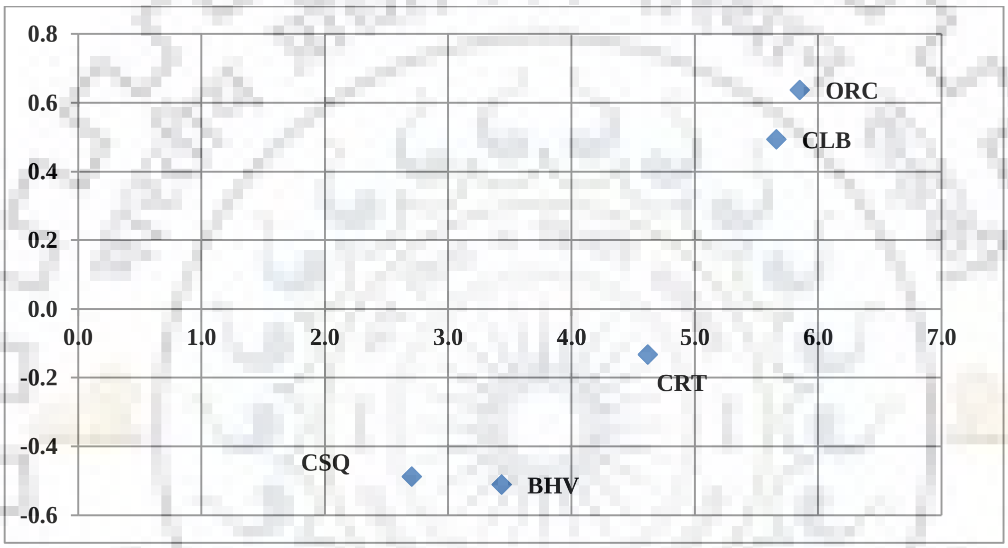

Figure 6.11: The digraph of the five sub-factors of Management Mitigation Measures (MMM)

6.3 Results and discussions

According to the finding of this research work, among the main factor, Fuel Emission reduction (FER) obtain the highest priority as it holds the first rank (Table 6.9). Also, FER is fitted to cause group, since (r_i-c_j) score is positive, equal to 0.5070 (Table 6.12) hence on the main remaining factors it has remarkable domination. Consequently, for the Indian cement industry, it is revealed that the FER is a decisive factor in reducing a significant amount of thermal energy consumption and GHGEs, thus FER improving environmental performance. The four sub-factors associated with these main factors are organized as per their relative rank, given as KLN > CLR > PRH >AOP. KLN is at the top position in the global ranking column also in relative importance weights of a sub-factors column of FER (Table 6.10) and demonstrated as the most significant climate change mitigation strategy for the Indian cement industry. The results are in conformance with the recent studies (Matar and Elshurafa, 2017) wherein they found process emission minimized by investing in the more efficient kiln. Furthermore, the positive value of (r_i-c_j) score, mitigation strategy KLN and AOP is belonging to the cause group, and PRH and CLR belong to effect group as per Table 6.16 and Fig. 6.8. Thus, in cause group factors focus must need on the high-priority basis since an efficient kiln is the heart of the cement production process which consumes less energy (Gao et al., 2016) and consequently, the effect group factors recognize the objective of the study.

Process emission reduction (PER) among main factors gets the second priority and is considered as notable GHGEs reduction measure since about 50% of total emission from cement industry comes directly from process emission which is unavoidable (Shanks et al., 2019). PER is also a top place among cause group main factors, as shown in Fig.6.4. It means it can be a considerable contributing factor, which has a huge potential to reduce GHGEs from the cement industry. The relative importance order of five sub-factors are Clinker substitution (CLSB) > Reduce production and sales (RPS) > Raw material substitution (RMS) > Low carbon cement (LCC)>Newer technologies (NWT). Clinker substitution (CLSB) and Reduce production and sales (RPS) are key mitigation strategies, which play a vital role in reducing GHGEs from the Indian cement industry. Shwekat and Wu, (2018) found that by clinker substitution financial saving, energy saving, GHG reduction, raw material consumption reduction are significant. As these mitigation strategies are ranked at the second and third position in global rank as per Table 6.10 also CLSB, RMS and LCC find their place in cause group factors as shown in Fig. 6.6, which indicates that they have remarkable influence over the remain sub-factors which are being in the effect group factors, namely RPS and NWT. Furthermore, all these mitigation strategies perform a crucial part to avoid process emission and foster sustainable cement manufacturing.

Another main factor, Electric energy-related emission reduction (EERE) has a third relative rank among the main factors. It is placed in the effect group, as shown in Fig.6.4. The relative ranking of four sub-factors are Grinding (GRD) > Variable speed drive (VSD) > Separator (SPT) > Separate grinding (SGR). Grinding (GRD) and Variable speed drive (VSD) are fifth and eighth position as per global ranking as per Table 6.10. Moreover, mitigation strategy GRD and VSD are in the cause group, require more focus (Schneider, 2015; Madlool et al., 2013) and have a substantial influence on the effect group sub-factors as shown in Fig. 6.5.
Emission avoidance and reduction (EAR) among main factors acquired the fourth priority and had a significant GHGEs reduction potential along with great reduction potential of thermal

energy consumption in the manufacturing of cement as per Table 6.9. Further, seeing the cause-effect graph it placed in effect group factors. This factor has a great ability to replace a significant amount of fossil fuel by alternate fuel and substitute fossil fuel with low carbon fuel (Georgiopoulou and Lyberatos, 2018). This factor also has a huge potential of using waste heat for drying of raw material and for producing power through mechanisms of waste heat recovery (Naeimi et al., 2019). It also avoids the transmission and distribution loss, reduces the dependence of national grid power by captive power generation, uses the fuel in kiln more efficiently by using a modern burner (Carrasco et al., 2019) and transport the clinker, cement, coal and other raw material more effectively and efficiently hence this main factor requires great attention. This main factor categorized in six sub-factors and their relative importance rank are Transport efficiency (TRE) > Alternate fuel and raw material (AFR) > Modern Burner (BNR) > Captive power generation (CPP) > Waste heat recovery (WHR) > Fossil fuel substitution (FFS). Among the above six sub-factors, TRE, AFR, and BNR fall under the cause group, whereas CPP, FFS, and WHR come under the effect group, as shown in Fig. 6.7.

Management mitigation measures (MMM) another main factor placed is the last position as per relative importance weight of main factors, as shown in Table 6.9. The relative importance rank of five sub-factors of management mitigation measures are Change in organization culture (ORC) > Networking/Collaboration (CLB) > Carbon sequestration (CSQ) > Carbon trading (CRT) > Consumer behavior change (BHV) as per Table 6.10. The mitigation strategies ORC and CLB are placed in the cause group, means they have significant impacts on the CRT, CSQ, and BHV sub-factors, which occurs in the effect group, as shown in Fig. 6.9.

6.4 Chapter summary

This chapter presents a robust MCDM method for prioritizing the various option of climate change mitigation strategies of the cement industry. Total twenty-four emission reduction strategies have been identified. Then integrated approach using AHP- DEMATEL is applied to get final rank. AHP is applied to get the relative weights of the climate change mitigation strategies, and DEMATEL is applied to analyze the relationship of the casual interaction among these mitigation strategies. The result exhibits that KLN is at the top position in the global ranking column also in relative importance weights of a sub-factors column of FER for climate change mitigation strategies adoption. Furthermore, mitigation strategy KLN and AOP are belonging to the cause group, and PRH and CLR belong to effect group. Thus, in cause group factors focus must need on a high-priority basis, and consequently, the effect group factors recognize the objective of the study. The findings of this chapter would help manage the various emission reduction strategies to the effective implementation of mitigation practices but also enable in enhancing the ecological-economic gains.

Chapter 7

Research summary and Contributions, Conclusions, Implications, Limitations, and Future scope

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Preview

This chapter summarizes the work carried out in the research. The key findings and major outcomes of the results have also been discussed. The unique contributions, theoretical and practical implications of the study are also highlighted so that academicians and practitioners can utilize the implications of the present research work. Lastly, the limitations and future scope of the study have been presented.

7.1 Introduction

In the today's era of globalization, competitiveness and rapid industrialization, there is a need to reduce GHGEs across the supply chain of cement industry more efficiently and effectively across the world to mitigate the global and noble problem of climate change. Cement is the most produced and consumed product on earth after water; it is a fundamental requirement of modern society, it is also the primary building material and used extensively in infrastructure development, industrial sector, urban housing, and employment generation. The primacy of the cement industry would continue as all over the world cement remains paramount for the infrastructure development and near the future, no other material would possibly substitute it (IMY, 2017a). Sustainable development is an essential concept for the organization in the 21st century, and that could be managed by implementing low carbon operations in its supply chain (IPCC, 2014a). Moreover, owing to rising customer requirements, fast-changing technologies, shorter product lifecycle, and increasing waste, there has been a great emphasis on sustainability, to maintain the availability of resources for the long run. An efficient carbon management program can support the companies to make effective utilization of resources and retain equilibrium between the environment and the economy.

However, the successful implementation of low carbon practices involves several factors, which are useful in decision making such as management and analysis of various mitigation measures, their diving factors and barriers to climate change mitigation strategies implementation.

The cement industry is the most emission-intensive industry, and it is currently under pressure to reduce GHGEs. However, the cement industry is giving their best efforts to adopt green practices to reduce GHGEs along with gaining a competitive advantage over other, create a green corporate image and sustain in the long run (Maddalena et al., 2018). But, while implementing climate change mitigation strategies, the cement industry faces a variety of barriers (Gao et al., 2016). Thus, this research focuses on identifying and understanding the climate change mitigation measures adoption barriers and its solutions to overcome these barriers in the Indian cement industry. Based on the past research and inputs received from the experts, various significant barriers related to emission reduction strategies adoption were identified. To overcome these identified emission reduction barriers, set of solutions has been proposed in this study. The research work also suggests an integrated Fuzzy AHP- Fuzzy TOPSIS based model propose the solutions to overcome these barriers. The results of this study would be beneficial for the cement industry to become efficient in carbon management practices. Then, we seek to evaluate the drivers to climate change mitigation strategies of the Indian cement industry. In the present study, a model is projected by applying the AHP and ISM techniques to assess the common drivers to climate change mitigation strategies of the cement industry. The AHP technique help in establishing the priorities of the drivers to climate change mitigation strategies, while ISM technique forms the relationships among them. Finally, this research focuses on identifying and understanding of various climate change mitigation strategies in the cement manufacturing industry through literature review and experts opinion. These identified mitigation strategies of the cement manufacturing industry were then assessed through integrated AHP-DEMATEL method. The AHP technique help in establishing the priorities of the climate change mitigation strategies, while the DEMATEL technique forms the causal relationships among them. The main purpose of this study was to provide a better understanding of developing and managing GHGEs in the most effective and competent way.

The next section of this chapter presents the research summary, which covers details on contributions made in this research work. It is followed by the research implications, limitations of the research work, and scope for further study.

7.2 Summary and Contributions

A summary and contributions made in this research work are given as follows:

Chapter 1

This chapter presents the basic background and an outlook of the cement industry. It focuses on the importance of mitigation measures adopted in the cement industry and discussed various emission reduction measures in the cement industry. It also discussed the basic definitions of climate change, mitigation, adaptation and the need for the drivers and barriers to implementing climate change mitigation strategies in the cement industry. It also covers the motivation of the study and organization of the thesis.

Chapter 2

This chapter provided an in-depth and exhaustive review of the literature on climate change mitigation strategies of the cement industry. It presented the overview of the cement manufacturing process and overview of the Indian cement industry. An extensive review of literature on drivers and barriers to climate change mitigation strategies of the cement industry is also presented in this chapter. The solutions to overcome these barriers are also discussed. After that, an extensive review of past studies on climate change mitigation measures was done. Through an extensive review of the literature, various gaps have been identified. The identification of these gaps have led to the formulation of research objectives for this thesis, and four research objectives were formulated based on the literature review and identified gaps.

Chapter 3

This chapter presents the research approach followed for the accomplishment of the research objectives. A conceptual framework and developing a model is proposed for overcoming barriers, drivers and various climate change mitigation strategies of the cement industry, involved a detailed discussion about various steps of five MCDM techniques namely - AHP, Fuzzy AHP, Fuzzy TOPSIS, ISM, and DEMATEL. The data collection methods and procedures, sample design, target populations, data analysis and interpreting of the information have also been discussed.

Chapter 4

In this chapter, a comprehensive framework has been developed which identify barriers and solutions to overcome these barriers. From the framework, five main factors of barriers, twenty-six sub-factors of barriers and fourteen barrier overcoming solutions were identified. The FAHP analysis is employed to rank the barriers to climate change mitigation strategies. FAHP analysis results showed that Government policy and regulation barriers (GB) as the most dominating barriers followed by Organizational and managerial barriers (OB) and Economics and time frame barriers (EB). Further, to rank barrier overcoming solutions, FTOPSIS analysis was used. The result of FTOPSIS analysis showed that provision of Clear and environmental supportive government policies and directions (S3) is ranked first among solutions followed by top management commitment to emission reduction (S2) and Building environmental collaboration and partnerships within and across the industrial sector at a different level (S7). Indian cement organizations can build their green image by working on these solutions.

Chapter 5

In this chapter, a model is projected by applying the AHP and ISM techniques to assess the common drivers of climate change mitigation strategies of the cement industry. According to the study outcomes, there are thirty drivers related to climate change mitigation strategies practices. Ranks of the driving factors based on their driving power depicted in MICMAC analysis indicate that Litigation risk (BR3), Health issue (SP4), Physical threat to assets and supply chain disruption (BR4), Demand for low carbon Products (MP2), Media and NGOs attention (MP4), Local public or societal pressure (SP3), Demand from customers in environmental protection requirements (SP5), High penalty for environmental pollution (GR5), Cut in subsidies and increased taxes on fossil fuels (BR1) and Fluctuating raw material prices (BR2) are the key independent factors having major driving power but weak dependence also they take the lower levels in the ISM model. As per AHP analysis, these driving factors have 1st, 3rd, 2nd, 4th, 6th, 7th, 5th, 11th, 8^{th,} and 10th respective global ranks. Thus, the drivers should be considered for implementing climate change mitigation strategies among Indian cement industries. Litigation risk (BR3), Health issue (SP4) and Physical threat to assets and supply chain disruption (BR4) become the key driving factors as they have the highest driving power in the final reachability matrix. They assume the top position in MICMAC and at the bottom level in the ISM model. Factors like, Generate stream of revenue from low carbon product (BO2), Emission and Cost reduction through material substitution and operational improvement (IF4 and IF3), Improving risk management (IF2), Enhanced brand image and corporate reputation (MP3), Earn through emission reduction certification (BO1), Opportunity to modify product and process (BO5) and Investment opportunity (BO4) have been found as dependent drivers in MICMAC analysis. These driving factors have weak driving power but possess a strong dependence on others, and they assume the upper levels in the ISM model. Thus they are influenced by other driving factors. It is recommended that the Indian cement industry should critically investigate and recognize such factors as they have a strong dependence on other factors while implementing climate change mitigation strategies. As per AHP analysis, these dependent drivers possess 26th, 30th, 29th, 25th, 22nd, 23rd, 16^{th,} and 12th global ranks.

Chapter 6

This chapter was aimed to assess various common climate change mitigation strategies of the cement industry. This objective applied combined AHP-DEMATEL approach to evaluating the various climate change mitigation strategies in the Indian cement industry. As per AHP analysis, Fuel emission reduction (FER) and Process emission reduction (PER) are the two decisive main factors. Besides, Kiln (KLN), Clinker substitution (CLBS), Reduce production and sales of emission-intensive cement (RPS), Efficient cooler (CLR) and Grinding (GRD) is top five significant sub-factors for effective reducing of GHGEs. While, the DEMATEL technique initiated the cause and effect relationship between the factors, gives long-term improvement options. The two critical main factors, Process emission reduction (PER) and Fuel emission reduction (FER) are categorized under cause group and their tendency to affect all the main factors hence, it would be more important to concentrate on cause group factors in order to reduce efficiently and effectively the GHGEs from the Indian cement industry. On the contrary, the effect groups factors are well affected by factors of cause group, hence contribute significantly towards the achievement of GHGEs reduction objective.

7.3 Implications of the study

The outcomes of the present study may provide theoretical as well as a practical contribution to the low carbon supply chain literature. The focus of this research was to implement efficient emission reduction practices. The outcomes of the study will assist the managers/practitioners in adopting successful low carbon operations and other decisions related to emission reduction and sustainability. The key implications of this study are given, as follows:

- This study has significant contributions for carbon management for the entire worldwide cement industry, as this study followed analysis, including barriers and its overcoming solutions from a global context. Also, this study includes managerial implications for the Indian cement industry, as the identification of the fundamental barriers and its solution based on experts' view from the Indian cement industry. The result of the analysis is beneficial for the worldwide cement industry interested in the adoption of GHGEs reduction strategies. This work categorized barriers and its overcoming solutions for carbon reduction and explored the priority of these obstacles and their solution. This study can also help the management to resources optimization during the emission reduction process. This research exposed the most compatible barrier for emission reduction in the Indian cement industry: The absence of economic incentive policies (GB2). Without any economic policies, it is very difficult to motivate the cement industry to reduce GHGEs. The second barrier in the priority list is Uncertainty and lack of government policies and regulations (GB4). The Government of India policies for the cement industry to reduce the emissions are uncertain and present regulation is not sufficient to stimulate the cement industry for innovation of lower carbon technologies and processes. Emission mitigation relatively low priority, other priority for capital investment (OB1) is the third barrier faced by the Indian cement industry. The Indian cement industry has the other priority for investment capital like enhance the capacity of production, market expansion, etc. Next significant barrier is Mitigation measures often incur an additional capital cost (EB1). The Indian cement industry is resisting to opt efficient emission reduction technologies because of high capital cost also the rate of return of capital cost is not very attractive.

- Apart from the prioritization of barriers to emission reduction, this study takes a step further to identify solutions, which can help overcome these barriers. From these overcome solutions of barriers, management of cement industry can benefit, as they can work towards removing these barriers in their respective industry. There are fourteen solutions identified through literature review and experts' opinion. To evaluate these solutions, Fuzzy TOPSIS is used. Provision of well-defined and environmental supportive government policies and directions (S3) is rank first among all fourteen solutions. The Government of India has many policies for the cement industry, to adopt green practices and carry out innovations, but sometimes policies are not favorable to industry, and sometimes managers are unaware of benefits of these policies. Therefore, management should avail the benefits of government policies and management should give their insights to the government for some amendment of unfavorable policies. Similarly, a score of other solutions are suggested, and management can practically try to implement these solutions on priority to save the environment like creating awareness and conduct some motivational programmer among the employee and to the society about low carbon products and environment issue.

- The present work reveals how the driving factors assist in implementing climate change mitigation strategies in the Indian cement industry and at the same time how these driving factors are prioritized and interrelated with the help of hybrid AHP and ISM methodologies. This study reveals six main factors and thirty sub-factors from large cement organizations. All these driving factors are beneficial for the management of cement organizations to effectively implementing climate change mitigation strategies. Thus, reduce the GHGEs along with the production of low carbon and economical cement, conserving minerals and natural resources, and reducing waste as well. Further, it will improvise the Indian cement organizations overall performance, affects the competitiveness in the global market and built an image of the green business. This study exposed the most compatible driver for emission reduction in the Indian cement industry: Litigation risk because of high emission profile of industry (BR3), Health issue (SP4), Physical threat (BR4) and Demand for low carbon product (MP2). These highly prioritized drivers are useful in improving tactical or operational performance while, on the other hand, the drives classified as driving power and dependence are useful in improving strategic performance. Besides, strategic results can be achieved by continually improving the linkage driving factors such as, New market opportunity (BO3), Greenmarket competitive pressure (MP1), CSR and ethical responsibility (IF6), Investor demand (SP1), Environmental awareness of employee (IF5), Supplier engagement (SP2), Top management involvement (IF1), Technological change and innovation (BR5), SEBI business responsibility report (GR2), Energy conservation act 2001 (GR3), PAT Scheme (GR4) and Environmental regulation compliance (GR1). Finally, this is the benchmark study to rank drivers to climate change mitigation strategies adoption. The results of this research model may provide fruitful insights for managers related to the designing effective framework and flexible decision strategies for the implementation of low carbon practices in an environmentally friendly way and roadmap to subsequently achieve the goal of economic and social sustainability based on the novel AHP-ISM results in the Indian Cement Industry

- From GHGEs reduction perspective, this study reveals five main factors and twenty-four sub-factors from large cement organizations. In addition to the economic basis, cement organization is pressurized to compete on an environmental basis also. Thus to sustain their organization on the environmental front, cement organizations need to be aware of various GHGEs reduction strategies. Climate change mitigation strategies can accomplish the objective of economic as well as environmental competitiveness. The present research study is an attempt to enumerate various common factors of mitigation strategies related to GHGEs reduction for cement organizations. Based on intensive literature and discussion with experts, five main factors viz. Electric energy emission reduction (EERE), Process emission reduction (PER), Emission avoidance and reduction (EAR), Fuel emission reduction (FER) and Management mitigation measures (MMM)were identified. All these factors are beneficial for the management of cement organizations to effectively reduce the GHGEs along with the production of low carbon and economical cement, which in turn can achieve their objective of becoming an organization complying with regulations set by the government and built an image of the green business. Management of cement organizations is often facing the environmental regulations imposed by the government to reduce the GHGEs. This study presents a novel framework for climate change mitigation strategies of the cement manufacturing industry. Integrated AHP and DEMATEL methodologies have been used for mitigating climate change. AHP is the most consistent technique to calculate relative weights and relative ranks of each factor and sub-factors. The result exhibits that Kiln System (KLN) is at the top position in the global ranking column also in relative importance weights of a sub-factors column of FER for climate change mitigation strategies adoption.

- Furthermore, mitigation strategy Kiln System (KLN) and Automation, optimization and process control (AOP) are belonging to the cause group, and Pre-heater (PRH) and Efficient cooler (CLR) belong to effect group. Thus, in cause group factors focus must need on a high-priority basis, and consequently, the effect group factors recognize the objective of the study. The findings of this chapter would help manage the various emission reduction strategies to the effective implementation of mitigation practices but also enable in enhancing the ecological-economic gains.

- The major objective of this study was to develop a framework for emission reduction measures, technology and innovation implementation in emission and energy-intensive cement industry. The result of the whole process can be very beneficial for the managers as well as practitioners. They can make use of different qualitative techniques to accumulate the solutions for the problems faced at their end, and they can also formulate strategies to overcome problems according to these profiles. The managers can work on developing technical know-how, providing adequate training to staff on environmental thinking and management, recruit staff who possess skills like low carbon manufacturing and green marketing, allocate financial and human capital for carrying out green R&D, accumulating green resources like latest production machinery, latest technology, trained human capital, energy efficient materials etc. for low carbon manufacturing and building strong relationship with other industry, universities and research institutes for effective low carbon technology development and low carbon innovation implementation/adoption at their end.

7.4 Limitations of the research work

This study has its limitations, mentioned below:

- The results of this study mainly depend upon the skills, experience, knowledge, and expertise of the decision group and decision-making process, which may vary because of human bias.
- Due to the unavailability of sufficient data and research literature on emission reduction strategies in the Indian context, a case study based approach has been used. The data and its analysis are typically based on the cement manufacturing industry in the southern,

central, western part of India. Therefore, the generalization of results may not be extended in the context of industries of different types, regions, sizes, etc.

- In this work, a fuzzy AHP-Fuzzy TOPSIS approach has been utilized to overcome the barriers to climate change mitigation measures adoption. This study has identified twenty-six barriers and fourteen solutions to overcome these identified climate change mitigation measures adoption barriers in business. Other barriers (if any) may be identified and classified. Similarly, other solutions to overcome barriers to implement climate change mitigation measures practices (if any) may be identified and classified.
- Thirty driving factors under six categories are considered based on the extensive relevant review and discussion with experts are widespread but still limited. Further, the study can explore more drivers. In the current research work, the AHP-ISM methodology has been developed as an interrelationship model. This methodology has its limitation, and the model is extremely reliant upon the verdict of the proficient panel.
- There are twenty-four climate change mitigation strategies of the cement industry in the Indian context identified, and these twenty-four strategies are categorized under five main factors, some more strategies have not been revealed and categorized. The combined AHP-DEMATEL model is dependent on the judgments of experts only.
- There are other several limitations of the case study; research needs to be taken care off. It includes time consumption, difficulty in data collection, incorrect interpretation of the facts, etc. Thus, secondary/numerical data have been used in this research wherever required.
- There may be bias in the low, high and most likely estimates of an expert which affects the relevance of membership function. In future, a fine tuning method may be adopted to update the membership function based on the feedback.

7.5 Chapter summary

This chapter provides comprehensive details of the research work undertaken in this study. It contains the summary and research contributions, implications for the academician and management professionals, findings of the study, limitations of the present work, and scope for the future study. The details of the management and analysis of various climate change mitigation strategies, their drivers and barriers suggested in the study is based on various MCDM techniques, such as AHP, DEMATEL, ISM, fuzzy AHP, and fuzzy TOPSIS.

AHP is a useful and widespread method for solving choice and ranking problems. Practical limitation of AHP is that a high number of alternatives imply a large number of comparisons. ISM produces a graphical representation of the original problem situation that can be communicated more effectively to others. However, in this method, we can only consider limited number of variables in the development of ISM model. In the TOPSIS, a scalar value that accounts for both the best and worst alternatives simultaneously. DEMATEL is advantageous in revealing the relationships among factors and prioritizing the criteria based on the type of relationships and severity of their effects on each other criteria but it is unable to deal with uncertain situations, lack of information and conflict resolution among experts.

The application of these decision-making methods will enable management and strategic group of Indian cement manufacturing organizations to implement climate change mitigation strategies, their drivers, barriers and overcome mitigation adoption solutions by prioritizing on a priority basis. Besides, professionals and managers may modify the framework by incorporating several other mitigation strategies, drivers, barriers and solutions/strategies. The present study is useful to both theoretical and practical domains in the field of carbon management. This study suggested that ecological concerns are getting attention in India, and the cement-manufacturing industry is under huge pressure to implement a greener or more environmentally friendly sustainable business culture. While many industries have already started working in this direction and rests are also equipping to manage these issues. Emission management has become a significant research subject among researchers and practitioners. However, still, there is a solid requirement to make proper plans to enhance cognizance about low carbon management practices and their benefits among the public and industrial sector. Government and Industrial sector both need to emphasize more on these poorly addressed areas of carbon management to ensure sustainable development. Finally, this research work will help managers/practitioners to manage the emission reduction practices efficiently while achieving sustainability in business.

7.6 Conclusions

The cement industry is the most emission-intensive. It is currently under pressure to reduce GHGEs. The cement industry is giving their best efforts to adopt climate change mitigation strategies to reduce GHGEs. However, while implementing these strategies, it faces a variety of barriers. Thus, this research focuses on identifying and understanding the barriers and drivers to climate change mitigation measures and to overcome these barriers for Indian cement industry.

- To overcome the barriers to emission reduction, the current research work suggests an integrated Fuzzy AHP- Fuzzy TOPSIS model. The analysis suggests that *provision of well-defined and environmental supportive government policies and directions (S3)* is the best solution to overcome the barriers.
- The present study also seeks to evaluate the drivers to climate change mitigation strategies by proposing a model using the AHP and ISM techniques. The *litigation risk because of high emission profile of the company* (BR3) is found to be the ace driver.
- Finally, various climate change mitigation strategies are identified and assessed using integrated AHP-DEMATEL methodology. Adopting *PH-PC kiln (KLN)* is found to be the best among the identified mitigation strategies.

7.7 Future scope

As discussed in the last section, every study has its limitations. These limitations may be considered as opportunities for future research work. This research work is based on the literature review, Fuzzy AHP-Fuzzy TOPSIS approach, AHP-ISM technique, and AHP-DEMATEL method. The following are some directions suggested for future research based on this work:

- All the organizations taken in this study were from India, and so, future work may be conducted in the context of other developing/developed countries to compare the results with this research work.
- Complexity in the selection of other climate change mitigation strategies, their drivers and barriers might be a challenge from a future research perspective.
- The proposed integrated models may be extended to various other emissions-intensive sectors, for example, paper and pulp, iron and steel, chemical and petrochemicals, aluminum, etc. that seeks to implement an effective emission reduction measures adoption. However, the expert’s judgment may vary with industry type and their priorities.

- Future work may be conducted by inculcating more climate change mitigation strategies, their drivers, their barriers and solutions to overcome these barriers.
- This study can be extended to explore and compare emission reduction practices by using other approaches such as Analytic Network Process, Best Worst Method, Interpretive Ranking Process, MAUT, VIKOR, PROMETHEE, SMART, ELECTRE and Rough set theory either by utilizing a single or integrated approach to analyze various mitigation measures, their drivers, their barriers and the solutions to overcome these barriers.
- In the present research work, data collection through the questionnaire is limited to only ten cement industry of India, for future work data collection from some more cement industry can also do, and the finding can be compared to present study.
- In the future, we can validate this model structure, with structural equation modelling (SEM). It is important to note here that ISM was useful in developing the initial model, whereas SEM was useful to test the developed model statistically.

Appendix A: Sample questionnaire to overcome barriers to climate change mitigation strategies of the Indian cement industry

Table A.4.1: A pairwise comparison matrix of the main factors of barriers to climate change mitigation strategies of the Indian cement industry

Main Factors	Economic and Time frame barriers (EB)	Market Barriers (MB)	Organizational and Managerial Barriers (OB)	Government policy and Regulations barriers (GB)	Technology and information barriers (TB)
Economic and Time frame barriers (EB)	1				
Market Barriers (MB)	------	1			
Organizational and Managerial Barriers (OB)	------	------	1		
Government policy and Regulations barriers (GB)	------	------	------	1	
Technology and information barriers (TB)	------	------	------	------	1

Scale - 1/EI: Both factors are **Equally Important**, **3/WI):** One factor **Weakly Important** over other, **5/(SMI):** One factor **Strongly More Important** over other, **7/(VSI):** One factor **Very Strongly Important** over other, **9/(EMI):** One factor **Extremely More Important** over other, **2,4,6,8: An Intermediate value** between two adjacent judgments.

Table A.4.2: Linguistic scale evaluation matrix for the solutions with the Economic and Time Frame Barriers (EBs)

Code	Solutions	Mitigation measures often incur additional and high capital cost (EB1)	Difficulty in accessing financial capital (EB2)	No incentive built in budgetary systems (EB3)	Poor financial performance of emission mitigation measures (EB4)	Longer project development time, longer payback period (EB5)
S1	Establishment of financial resources, capabilities and contingency plans for mitigation measures					
S2	Top management commitment and incorporation of climate change mitigation measures in corporate strategies					
S3	Provision of well-defined and environmental supportive government policies and directions					
S4	Awareness and education of the customers and society about low carbon products and benefits of emission reduction					
S5	Conduct seminar, motivational programs and arranging funds for supply chain partners to build their commitment about emission reduction					
S6	Multiple supplier policies based on environment criteria					
S7	Building environmental collaboration and partnerships within and across the industrial sector at a different level					

S8	**Training and education of employee to increase their competency regarding climate change mitigation**					
S9	**To develop and upgrade on state-of-the-art- technology being used in the specific sectors for implementation of emission reduction target.**					
S10	**R & D facilities in collaboration between industries, educational institutes, and the Government**					
S11	**Implementation of policies for the use of alternate substituting material and waste as a fuel including biomass**					
S12	**The government should implement "Pollutants have to pay" Principle**					
S13	**The government should enhance the workforce for monitoring pollution prevention and reduction activities**					
S14	**Govt. should create a healthy environment for Carbon market/emission trading systems**					

Scale- VP: Very Poor solution, **P**: Poor solution, **M**: Medium solution, **G**: Good solution, **VG**: Very Good solution

Appendix A: Sample questionnaire for Analyze drivers to climate change mitigation strategies of the Indian cement industry

Table A.5.1.: A pairwise comparison matrix of the Main factors of climate change mitigation strategies of the Indian cement industry

	Business Risk (BR)	**Role of Government Regulations and Policies (GR)**	**Internal (IF)**	**Market Pressure (MP)**	**Stakeholder Engagement / Pressure (SP)**	**Business Opportunity (BO)**
Business Risk (BR)	1					
Role of Government Regulations and Policies (GR)	------	1				
Internal (IF)	------	------	1			
Market Pressure (MP)	------	------	------	1		
Stakeholder Engagement / Pressure (SP)	------	------	------	------	1	
Business Opportunity (BO)	------	------	------	------	------	1

Scale **- 1:** Both factors are **equally important**, **3:** One factor **moderately important** over other, **5:** One factor **strongly important** over other, **7:** One factor **very strongly important** over other, **9:** One factor **extremely more important** over other, **2,4,6,8: an Intermediate value** between two adjacent judgments.

Table A.5.2: Structural self-interaction matrix (SSIM)

	BO5	BO4	BO3	BO2	BO1	SP5	SP4	SP3	SP2	SP1	MP4	MP3	MP2	MP1	IF6	IF5	IF4	IF3	IF2	IF1	GR5	GR4	GR3	GR2	GE1	BR5	BE4	BR3	BR2
BR1																													
Br2																													
BR3																													
BR4																													
BR5																													
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MP4																													
SP1																													
SP2																													
SP3																													
SP4																													
SP5																													
BO1																													
BO2																													
BO3																													
BO4																													

Scale- V: Variable i will help achieve variable j; **A:** Variable j will help achieve variable i; **X:** Variable i and j will help achieve each other; and **O:** Variables i and j are unrelated

Appendix A: Sample questionnaire for evaluating climate change mitigation strategies of the Indian cement industry

Table A.6.1.: A pairwise comparison matrix of the major factors of climate change mitigation strategies of the Indian cement industry

Main Factors	Electric energy-related emissions (EERE)	Process emission reduction (PER)	Emission avoidance and reduction (EAR)	Fuel emission reduction (FER)	Management mitigation measures (MMM)
Electric energy related emissions (EERE)	1				
Process emission reduction (PER)	------	1			
Emission avoidance and reduction (EAR)	------	------	1		
Fuel emission reduction (FER)	------	------	------	1	
Management mitigation measures (MMM)	------	------	------	------	1

Scale - 1: Both factors are **equally important**, **3:** One factor **moderately important** over other, **5:** One factor **strongly important** over other, **7:** One factor **very strongly important** over other, **9:** One factor **extremely more important** over other, **2,4,6,8: an Intermediate value** between two adjacent judgments.

Table A.6.2.: Evaluation of the influence relationship among the five factors of climate change mitigation strategies of the Indian cement industry

Main Factors	**Electric energy-related emissions (EERE)**	**Process emission reduction (PER)**	**Emission avoidance and reduction (EAR)**	**Fuel emission reduction (FER)**	**Management mitigation measures (MMM)**
Electric energy-related emissions (EERE)	0				
Process emission reduction (PER)		0			
Emission avoidance and reduction (EAR)			0		
Fuel emission reduction (FER)				0	
Management mitigation measures (MMM)					0

Scale - 0: Both factors mutually have **no influence**, **1:** One factor have **very low influence** over other, **2:** One factor have **low influence** over other, **3:** One factor has **high influence** over other, **4:** One factor has **very high influence** over other

Appendix B **Cover letter**

Date: May 30, 2017

Subject: Survey on **"An assessment of climate change mitigation strategies of the Indian cement industry"**

Dear Sir,

I, Sachin Balsara, am working as a doctoral student in the Department of Mechanical and Industrial Engineering, Indian Institute of Technology, Roorkee, Uttarakhand, India. I am pursuing my doctoral research work in the area of 'Low Carbon Supply Chain'. As a part of my doctoral research, I am conducting a survey on my topic "An assessment of climate change mitigation strategies of the Indian cement industry". The objective of the research is to investigate the factors affecting the climate change mitigation strategies in material processing (Cement) industry of India. Your feedback in this regard will be a significant input to the study.

I would be grateful if you could spare some of your precious time to answer the questionnaire. The objective of the survey is purely research and academic, therefore, all the responses will be kept strictly confidential and will be used for academic work.

I am aware that you have a busy schedule of work but I do hope that you would be able to spare some time to help me in the fulfillment of this study.

Sincerely yours,

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- Balsara S, Jain P.K. and Ramesh A. (2019) An integrated approach using AHP and DEMATEL for evaluating climate change mitigation strategies of Indian cement manufacturing industry. Environmental pollution, 252, 863-878. DOI: 10.1016/j.envpol.2019.05.059

- Balsara S, Jain P.K. and Ramesh A. (2018) Analyzing drivers of climate change mitigation strategies of Indian cement manufacturing industries (under review) Journal of Cleaner Production

- Balsara S, Jain P.K. and Ramesh A. (2018) A framework to overcome barriers to climate change mitigation strategies in Indian cement manufacturing industries under fuzzy environment (under review) Environmental Science and Pollution Research (Springer)

- Balsara S, Jain P.K. and Ramesh A. (2018) Analyzing Enablers of emission reduction strategies of cement manufacturing industries of India under fuzzy environment in 7th International and 28th All India Manufacturing Technology, Design and Research Conference 2018 (AIMTDR) at Anna University, Chennai during 13th-15th December 2018.