Green Manufacturing Research within the Indian Cement Industry

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Abstract: This abstract provides a comprehensive overview of the shifting landscape of Green Manufacturing (GM) within the Indian cement industry. It highlights a clear transition from basic environmental awareness to a sophisticated, digitally-driven sustainability model.

Here is a breakdown of the core components and findings of the research:

Evolutionary Stages of Green Manufacturing
The study categorizes into three distinct phases, showing how the industry's focus has matured:

Stage	Primary Focus
Foundational	Environmental awareness, basic performance metrics, and resource efficiency.
Integrative	Sustainability frameworks, regulatory compliance, and process-wide improvements.
Digital Transformation	IoT, AI-based optimization, real-time monitoring, and Industry 4.0 integration.

Keywords: Green Manufacturing1; Environmental Awareness2; Digitally Driven3; Sustainibility Model4; Foundational5; Integrative6; Digital Transformation7

Review of Literature and Classification

It is clear that your research is taking a structured, multi-dimensional approach by moving beyond a simple chronological review to a thematic classification. By categorizing the literature into **twelve broad categories**, you are creating a map that allows future researchers to see the "connective tissue" between operational tech, organizational culture, and legislative issues.

To help visualize how your systematic review structures this vast field, here is a summary of your methodology and the resulting classification framework.

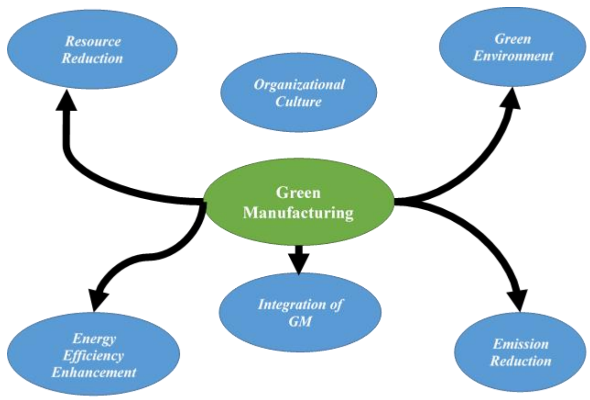

Figure 1: Green Manufacturing Process

<u>Green Manufacturing Tools</u>

GM technologies maintain customers in reducing their environmental unsafety and help them to be more profitable in a sustainable way. According to *(*Ernst *et al.* 2000*)* technologies include variety of practices involved in reduction of material waste, including recycling, substitution of less hazardous alternatives, consumption of waste internally, and remanufacturing. From the literature review of (Chung *et al.* 2010) it is found that more emphasis is given on minimizing environmental impact by reducing, reusing, remanufacturing and recycling technologies including source reduction, minimization of resource consumption, enhancing use intensity.

The functional unit (FU) choice is seen as one of the most influencing factors. Preferably this unit includes all relevant concrete aspects being its strength, durability and to some extent its workability. The major spirit of GM focus on transfer of environmentally sound technologies combined with financial services *(*Varma *et al.* 2006). The capability concept has been strongly emphasized in the strategic management literature and it is asserted that corporate business strategies should be built upon the strengths of a firm's capabilities (Chan *et al.* 2010*)*. Accordingly, to present taxonomy of green supply chain management for Taiwan manufacturing firms and examine the relationship between green supply chain and firm performance (Chen *et al.* 2011). These types of technologies have not been easily developed due to the complexities associated with these reverse supply chain processes. The various GM operational technologies issues and their references are given below:

Table 1: Topology of GMC literature highlighting operational performance issues

References	GM operational technology issues
Chung *et al.* (2010), Chan *et al.* (2011)	Deployment of a collection of resources that enables it to successfully compete against rivals
Vachon *et al*.(2006), Chen *et al.*(2011)	Environmental Performance, Pollution control technologies.
Hua *et al.* (2005), Varma*et al.* (2006)	Minimize environmental impact resource consumption
Ahmed *et al.*(2011), Tan *et al.* (2002)	Minimize resources and/or energy
Yumin Zhang et al. (1999), Dean Bartlett 2009.	Minimize heating rate in the process
Zhu *et al.* (2009), Nunes *et al*.(2010)	Reduce, reuse, remanufacturing, recycle
Tan *et al.* (2002), Mohanty *et al.* (1999)	Minimization the environment mental impact in production manufacturing processes
Bignozzi*et al.* (2011), Azzone *et al.* (1998)	Minimize Recycling process of waste raw materials

In this paper, deployment of different GM tools insight process is discussed at length. According to (Vachon *et al.* 2006) an integrated assessment of production processes under ecological, but also under technical and economic aspects requires specific methods. According to (Nunes *et al.* 2010) for preparing an investment decision in its entirety, the concepts of Multi Criteria Decision Making (MCDM) seemed to be more suitable for eco-management combined with investment decisions than Life Cycle Assessment (LCA). In cement industry explaining GM accomplished by considering each operational element, including the supply and acquisition of upstream materials, research and development, manufacturing and packaging, marketing, promotion and education and recycling activities. According to (Azzone *et al.* 1998) green value chain refers to the lifecycle of a product beginning with the initial sourcing, through research and development (R&D) and production all the way to the final recycling of waste and product abandonment.

Table 2: Topology of GMC Tools highlighting operational performance issues:

References	GMC Tools
Nunes *et al.* (2010), Chan *et al.* (2011)	ISO 14000 series for Environmental Management Systems (EMS)
Vachon *et al.* (2006), Bartlett*et al.* 2009	Better product-based solution in Response System.
Chung *et al.* (2005), Deif *et al.*(2011)	Time-Weighted Inventory (TWI) approach
Bignozzi *et al.*(2011), Dangayach *et al.* (2001)	Leadership in Energy and Environmental Design (LEED)
Meyer *et al.*(2009), Bartlett*et al.* 2009.	Fuzzy multiple attribute method, decision making fuzzy weighting factor
Tan *et al.* (2002), Shang *et al.* (2010)	Calcium Sulfoaluminate (CSA)
Hua *et al.* (2005), Hasanbeigi *et al.*(2010)	Life Cycle Assessment (LCA)
Duxson *et al.* (2007), Mikulcic *et al.* (2010)	computational fluid dynamic (CFD), DEA models
Ali Hasanbeigi et al. (2010), Yu-Shan Chen (2011)	Determinations of total suspended particulate (TSP), fugitive dust model, FDM,
N. A. Madlool et al. (2010), Emad Benhelal et al. (2012)	Ordinary Portland cement (OPC) System

Sustainable and Eco-friendly product design part of green manufacturing:

a) Optimized processes: reducing fuel and material use and minimizing pollution by continuously increasing the efficiency of manufacturing equipment and processes.

b) Waste co-processing and energy/material recovery: using the waste and by-products of other industries as fuels and raw materials for cement manufacture, creating 'closed loops' of resource use.

c) Eco-innovation: using new knowledge and technology to make cement products increasingly resource-efficient to produce and use.

Energy Saving

Cement manufacturing comprises of various sub processes - Raw meal grinding, Preheating, Proclaiming, Clinkerization and Grinding presented in (Siddique *et al.* 2012*)*. Energy is consumed in each of these sub processes. Thermal energy constitutes 80 to 90 percent of the total energy, while the remaining is electrical energy.(Stretesky *et al.* 2009*)* have told an EMS essential to track real-time power conditions, analyze power quality and reliability, and respond quickly to alarms to avoid critical situations. It enables you to study trends and reveal energy waste or unused capacity by verifying efficiency improvements and allocating costs to buildings, departments or processes by (Vatopoulos *et al.* 2012**).**

Emission Reduction

Although there is room for improvement, certain factors inhibit the industry from attaining higher efficiencies by (Cagiao *et al.* 2010). Increasing the percentage of fly ash and blast furnace slag in blended cement up to the standards recommended by the Bureau of Indian Standards is one of the options to reduce consumption of raw material as well as energy (Chan *et al.* 2010). An energy utilization during the grinding process of clinker and gypsum can also be improved by adding polar organic compounds to the charge in the mill. It is because of their polar nature, grinding aid compounds preferentially adsorb on surface of ground materials and neutralize forces, which cause agglomeration of the newly produced cement particles by (SÖGÜT *et al.* 2012).

Waste Utilization

Society can manage wastes in a number of ways, depending on their physical and chemical nature, and on the economic, social, and environmental context in which they are produced by (Gustavsson *et al.* 2006). Some of these are listed below. Specific decisions will always be influenced by local circumstances such as the availability of waste treatment facilities; alternative markets for materials and the infrastructure available for safely collect manage and transport waste materials by (Kean *et al.* 2009).

Environment Protection

The cement manufacturing process a variety of calcium-containing raw materials that can include aragonite, limestone and chalk that are gathered from a quarry by (Giannopoulos *et al.* 2007). Dust generated from open sources is termed fugitive because it is not discharged to the atmosphere in a confined flow stream as usually happens with point sources **(**Chan *et al.* 2010**)**. The materials are then blended so that the desired physical and chemical properties are achieved. According to (Habert *et al.* 2010)a dry process, the moisture is typically reduced by 1% to 10% through the utilization of drum dryers or impact dryers during the grinding phase. In the wet process, water is added so that the mix becomes a pump able slurry with a moisture content in the range of 30% to 40% by (SÖGÜT*et al.* 2012).

Life Cycle Analysis

Cement is a locally produced material shipped only short distances – another environmental and energy saving plus by (Wang *et al.* 2011). Its primary components, sand and gravel or crushed stone are among the most universally available materials. According to (Moya *et al.* 2011) an LCA is based on a consistent methodology applied across all products and at all stages of their production, transport, energy use, maintenance and disposal or recycling at end of life. In (Gartner *et al*., 2004) a number of published articles espouse the sustainability of one building product over another based on a few selected metrics instead of a full life cycle assessment (LCA).

Greenhouse Effect

Global warming is generally defined as an increase in the average temperature of the earth's atmosphere, especially a sustained increase sufficient to cause climatic change. Greenhouse effect" is used to describe a scenario of how various gases cause global warming or climate change. Carbon dioxide (CO_2) and other gases exist naturally in the atmosphere. According to ***(SÖGÜT et al. 2012)*** have presented the sun's heat and create the atmosphere that sustains life on earth. Burning fossil fuels - natural gas, gasoline, coal, and oil - adds unnatural amounts of CO_2 and other gases into the air. According to (Berkel *et al.* 2007) have the potential to trap heat, raise air temperatures, and change the balance of life on earth. These gases, in the form of pollution (emissions to air) have increased 30% in the past century. It must be kept in by this (Phillips *et al. 2005)* combustible material sent to landfill degenerate into methane and CO_2 thus creating greenhouse gases anyway. Combustible materials used in cement manufacture conserve natural fuels, such as coal.

Global Warming

The earth surface is enveloped and protected from the direct effects of the rays of the sun by layers of gases in the form of the atmosphere, which is made up of the lower atmosphere called the troposphere where most of the gasses including ozone gases and vapor exist in the atmosphere by (Salgado *et al.* 2004).According to *(Ibrahim Dincer et al. 1996)*the highly developed industrialized countries of the world are always accused as the highest emitters of gasses and other substances that deplete the ozone layer than the poor and developing counties by(Tesfom *et al.* 2006)**.** Thirty five percent of the sun's radiation coming to earth is intercepted and reflected back to space by these gases, clouds and air molecules thereby protecting the earth from the direct effects of these radiations.

Climate Change

Although carbon dioxide produced by burning oil and coal is often singled out as the contributor to climate change, a number of other emissions to air (pollutants) as a result of human activities contribute to global warming by (Duxson *et al,* 2007). An Included methane (agriculture and burning natural gas), ground level ozone (car exhaust and power plants), water vapor (naturally occurring), nitrous oxide (fertilizer use and a pollutant) and chlorofluorocarbons (refrigerants and aerosol). Pound for pound, these other emissions to air have a much greater effect on global warming than CO_2 by (Williams *et al,* 1987)**.**

Environmental Implications of E-Commerce

The project is analyzing specific case studies of logistics networks, inventory and manufacturing changes and estimates the overhead cost of the Internet. Some specific issues of interest include:

Internet Infrastructure: Estimates of the electricity cost of operating the internet routers, switches and computers in 1998 range from 1% of US energy use to an unlikely 8%.

Travel Mode Shifts:Air transport speeds up delivery times and shortens supply chain delays, but at significant environmental impact per ton-mile of transport.

Scale Economy Effects:E-commerce has encouraged smaller shipment sizes and shorter manufacturing production runs.

Environmental Information:E-commerce and the Internet can encourage socially conscious purchasing and consumer awareness.

Reduced Private Travel: Reduction in shopping costs is a widely anticipated impact of E-commerce. Private travel and retail store requirements can be affected.

Reduce Waste:By better matching production and consumer demands, E-commerce and the Internet can have substantial environmental benefit.

New Manufacturing Possibilities:In the long term, E-commerce and theInternet may spawn new manufacturing approaches with substantial environmental benefit.

Green Design Research Areas

Sustainable Infrastructure

Our built environment contributes significantly to environmental damages yet has not been the focus of concern or regulation. We need to consider how infrastructure systems, such as water delivery, electricity grids, telecommunications networks, or roadways, influence materials and energy consumption, waste generation, and product development.

The External Air Pollution Costs of Industrial Production

To reduce environmental damage, analysis tools such *as* Life Cycle Assessment (LCA) have been developed to better understand the total impacts of products and processes. These tools consider the effects associated with every stage in the life of a product, including raw materials extraction, component fabrication, assembly, delivery, use, and disposition.

EIO-LCA is Leontief input-output (IO) models augmented by environmental impact informationto determine the direct and total supply chain effects. The result is an assessment, rather than simply an inventory, of environmental effects. The total air pollution releases found for each commodity are combined with a range of environmental damage valuation studies to estimate the external costs of these activities. These values could be incorporated into an accounting or pricing system to show corporate decision makers or policymakers the full costs of materials, product, and process choices. Such a method could be followed by governmental agencies to adjust for environmental damage in the publication of such indices. Market-based initiatives are projected to save billions of dollars in expenditures if enacted for sulfur dioxide, nitrogen oxides, and volatile organic compounds. In addition, if new regulations were set to reduce external costs, significant improvements over current levels would result with savings in the billions of dollars.

Cleaner Products through Life Cycle Design

Life cycle inventory and cost analysis tools applied to milk packaging offer important guidelines for achieving better environmental design and management of these systems. Life cycle solid waste, energy, and costs were analyzed for seven alternative systems including single use and refillable glass bottles, single use and refillable HDPE bottles, paperboard gable-top cartons, LLDPE flexible pouches, and polycarbonate bottles on a basis of 1000 gallons of milk delivered. In addition, key performance requirements were also investigated that highlighted potential barriers and tradeoffs for environmentally preferable alternatives. Sensitivity analyses, using a life cycle inventory and cost model, indicated that material production energy, post-consumer solid waste, and empty container costs were key parameters for predicting life cycle burdens and costs. Inventory model results for life cycle solid waste and energy indicated the same rank order as results from previously published life cycle inventory studies of container systems. Refillable HDPE and polycarbonate, and the flexible pouch were identified as the most environmentally preferable with respect to life cycle energy and solid waste. The greater market penetration of these containers may be limited by performance issues such as empty container storage and handling requirements, reseal ability, and puncture resistance and deposit fees for refillables.

Waste Reduction/Pollution Prevention

Industrial ecosystem - Using the material and energy flow model of an ecosystem in an industrial system

Industrial Ecology (IE) is a concept for understanding and management of the interaction between industrial systems and natural ecosystems. The concept arises from the metaphor of the material and energy flow model of an ecosystem, in which organisms use each other’s waste material and waste energy flows through cooperation. The only external input to the system as a whole is the (infinite) solar energy. In an industrial ecosystem, the environmental burden of the system as a whole is reduced. This industrial system would develop material cycles and employ energy cascades through cooperation between the companies in the system. When successful, an industrial ecosystem substitute’s raw materials and energy that industry takes from nature with wastes and hence reduces the virgin input of the system and the waste and emission output from the system. Economic gains arise in the reduction of raw material and energy costs and waste management costs. In this study, the basic industrial ecosystem principle is understood as round put for describing recycling of matter and cascading of energy in an industrial system. The ecosystem material and energy flow model including the flows of matter, nutrients, energy and carbon is used for constructing an industrial ecosystem.

Global Carbon Dioxide Emissions from Cement Making

Carbon dioxide emissions in cement manufacturing come directly from combustion of fossil fuels and from claiming the limestone in the raw mix by (Hughes *et al.* 2005). An indirect and significantly smaller source of CO_2 is from consumption of electricity, assuming that the electricity is generated from fossil fuels. Roughly, half of the emitted CO_2 originates from combustion of the fuel and half originates from the conversion of the raw material. (Kääntee *et al.* 2004) accounted for are the CO_2 emissions attributable to mobile equipment used for mining of raw material, used for transport of raw material and cement and used on the plant site. Current emission estimates for the cement industry are based solely on the assumed clinker production and exclude emissions due to energy use. According to (Florin *et al.* 2007) emissions from energy use are included in the estimates for emissions from energy use, and not allocated to cement making.

Carbon Dioxide Emissions from Calcination

Carbon dioxide is released during the production of clinker, a component of cement, in which calcium carbonate ($CaCO_3$) is heated in a rotary kiln to induce a series of complex chemical reactions (IPCC Guidelines). Specifically, CO_2 is released as a by-product during calcination, which occurs in the upper, cooler end of the kiln, or a proclaimer, at temperatures of 600-900°C, and results in the conversion of carbonates to oxides by (Wang *et al.* 2012). They estimated the amount of clinker produced in the key countries in order to calculate process CO_2 emissions associated with clinker production. According to (Ahmaruzzaman *et al.* 2010) for the process emissions, a calcination factor of 0.136 Mt of carbon was applied to each metric ton of clinker produced. Actual clinker production data were collected for Brazil, Mexico, the United States, Canada, Germany, India, China, Japan, and Korea (29, 41–44). (Taylor*et al.* 1999) have presented divided the countries into industrialized countries and rest-of-world and into two groupings for C/Cratio-84% for industrialized countries and 87% for rest-of-world based on a weighted average of actual clinker to cement ratio data collected for key countries.

Carbon Dioxide Emissions from Fuel Use

Practically all fuel is used during pyro-processing: Fuel is burned in the kiln. The amount of CO_2 emitted during this process is influenced by the type of fuel used, coal, fuel oil, natural gas, petroleum coke, alternative fuels. According to (Vicar *et al.* 1999) have told CO_2 emission factors ($EFCO_2$) of fuels are based on emission factors defined by the Intergovernmental Panel on Climate Changed. Globally, liquid and solid fuels accounted for 76.3% of the emissions from fossil fuel burning and cement production in 2007. In *(*Krishnan *et al.*2012) have discussed for emissions from cement production have more than doubled since the mid-1970s and now represent 4.5% of global CO_2 releases from fossil-fuel burning and cement production. Gas flaring, which accounted for roughly 2% of global emissions during the 1970s, now accounts for less than 1% of global fossil-fuel releases. According to (Balaras *et al.* 2007) the direct $EFCO_2$ of waste fuels is considered zero, because the input of waste replaces an equivalent amount of fossil fuel–derived energy, and the CO_2 would probably have been released to the atmosphere without useful application of the energy content.

Carbon Dioxide Emissions from Electricity Use

Energy needs accounts for an important share of the variable cost of cement production (around 40 %). This energy requirement is split between process heat and electrical energy, the latter accounts for around 20 % of the cement energy needs by **(**Worrell *et al.* 2001). Specific electricity consumption data was reviewed for the same key industrialized and developing countries as was collected for fuel consumption data (Canada, Germany, France, Italy, Japan, Korea, Spain, Turkey, United States, Argentina, Brazil, China, Columbia, Egypt, India, Mexico, Poland, and Venezuela). By (Hauschild *et al.* 2005**)** told for all other countries and regional groupings, electricity intensity for all kilns was estimated at 0.3 GJ/t of cement for industrialized countries and 0.4 GJ/t of cement for rest-of-the-world. According to (Ernst Worrell *et al*. 2001) an IEA statistics were used to calculate the average carbon intensity of fuel inputs for public electricity generation for each country and regional grouping.

Total Carbon Dioxide Emissions from Cement Production

CO_2 emissions estimate (in million metric tons of carbon) by key cement-producing countries and regions of the countries shown, China accounts for by far the largest share of total emissions (33.0%), followed by the United States (6.2%), India (5.1%), Japan (5.1%), and Korea (3.7%) by (Lenzen *et al.* 2009). According to (Worrell *et al.* 2009) the top 10 cement-producing countries in 1994 accounted for 63% of global carbon emissions from cement production for that year. Regionally, after China, the largest emitting regions are Europe (11.5%), OECD-Pacific (9.3%), and Asian countries excluding China (9.3%), and the Middle East (8.4%). In (Ernst Worrell *et al*. 2000) have told the world average primary energy intensity was 4.8 GJ/t, with the most energy-intensive regions being Eastern Europe and the former Soviet Union (5.5 GJ/t), North America (5.4 GJ/t), and the Middle East (5.1 GJ/t). The average world carbon intensity of carbon emissions in cement production is 222 kg of C/t of cement. According to (Karstensen *et al.* 2008) China is the largest emitter, the most carbon intensive cement region in terms of carbon emissions per tonne of cement produced is India (253 kgC/t), followed by North America (242 kgC/t), and then China(240 kgC/t).

Reduction of Carbon Dioxide Emissions

Energy Efficiency Improvement

Benchmarking is a commonly used term that generally means comparing a defined characteristic of one facility to other facilities or other "benchmarks" by (Moya *et al.* 2011). It has been estimated that 5% of global carbon dioxide emissions originates from cement production. Approximately 60% of the CO_2 production is due to the calcimine process with the remaining 40% originating from fuel combustion. In according to (Giannopoulos *et al.* 2007) cement industry is an energy-intensive industry where the thermal energy consumption accounts for around 80% of the primary energy; the remaining 20% is in the form of electrical energy. The EU Heads of State and Government set a series of climate change and energy targets to be met by 2020, namely target: at least 20% reduction of greenhouse gas emissions below 1990 levels, 20% energy consumption to come from renewable resources and 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency in (Wang *et al.* 2011).

Replacing High-Carbon Fuels with Low-Carbon Fuels

In (Martin *et al.*1999), the use of wastes as alternative fuel decreases the dependency on fossil fuels, reduces the production cost of the cement and decreases the CO_2 emissions. In this value decreases from around 882 kg of CO_2 pertonne of clinker in 2002 to around 849 kg of CO_2 per ton of clinker in 2030 by (G. Habert *et al*. 2010). This reduction is only 3.7% compared to the decrease of 11% obtained in the weighted-average thermal energy consumption per ton of clinker (D. Giannopoulos *et al*. 2007).

Leticia *et al.* (1998) studied Energy use and CO_2 emissions in Mexican cement industry analyzed for the period 1982-1994. From 1982-1994 energy use in Mexican cement industry increased by 10.8% and CO_2 emissions related to both energy use and the industrial process increased by 40%. During this period, it was found that the energy intensity dropped significantly. This was due to modernization of existing plant, increased production of blended cement and the use of alternative fuels. It was also found that preheating system and automatic control at several process results in more efficient energy use. They noted that the operation of modern kiln with long residence time and high temperature ensured low emissions also.

Worrell *et al.* (2000) performed an in-depth analysis of the US cement industry, identifying carbon dioxide savings, cost-effective energy efficiency measures and potential between 1970 and 1997. They gave the energy efficiency improvement and carbon dioxide emissions reductions in the production of cement in the US cement industry. Such large amounts of energy saving need to improve the energy efficiency of combination process. Any success in this direction, improving machine design and choosing optimal operating and environmental conditions could possibly lead to the development of new approaches toward energy saving in cement production.

Rehan *et al.* (2005) discussed climate change, the current and proposed actions for mitigating its effects, and the implications of such actions for the cement industries. They examined emerging policy instruments such as environmental taxes and financial incentives in the form of grants, subsidies, and/or tax credits for taking action to protect the environment. They also discussed the traditional methods like CO_2 captured and CO_2 sink in order to reduce greenhouse gas emissions. They suggested that the Government needs to increase R&D investments in commercializing new kiln types, development of economic and effective complementary products for concrete made with blended cements, and improvements in construction practices. Such measures are likely to prove valuable in reducing GHG emissions of the cement industry.

Shammakh *et al.* (2008) discussed the effective control strategies to mitigate emissions in cement plant. They developed a mathematical programming model to determine the best cost effective strategy to minimize CO_2 emissions from cement plant. Efficiency improvement measures were found to be effective options to meet emissions reduction targets up to 10%. The model recommended that fuel switching and carbon capture needed to be implemented to achieve more than 10% emissions reduction.

Van *et al.* (2009) studied an overview of the emissions from Australian cement sector including both the emissions from the chemical process itself, as well as the associated emissions from energy use within those processes. He mentioned two benefits of CO_2 capture and storage in the cement industries over power generation. Firstly, cement kilns produce much more concentrated stream of CO_2 (up to 31%) compared to power stations (12 to 14%), hence lower cost is required to achieve the desired volume of CO_2 for storage. Secondly, cement kilns have exhaust gas temperatures of approximately 200°C or above and this heat can be used to recover the solvent used in the capture process. The use of this heat from a cement plant does not impact the production of cement. But in power generation station, low pressure steam needs to be diverted from the turbines resulting in less electricity being produced.

Binding of CO_2 in concrete

Taking into consideration the emissions of CO_2 in cement industry another aspect needs to be considered as well by (Youjuan Wang *et al*. 2011). From the produced cement by the cement plants concrete is manufactured, which in natural conditions binds CO_2 from the atmosphere (Berkel *et al.* 2007). In this way, to some extent, the product of cement plant indirectly causes emissions reduction. Polish cement industry reduced significantly the emissions factor per ton of cement in the period of 1988–2008 by 28%. In 1988 by (Giannopoulos *et al.* 2007), the factor amounted to 0.879 tonnes CO-$_2$/tonnes of cement and 1.1 tonnes CO_2/tonnes of clinker, respectively 0.631 tonnes CO_2/tonnes of cement and 0.865 tonnesCO_2/tonnes of clinker.

Carbon Dioxide Removal

According to the World Business Council for Sustainable Development, "Concrete is the most widely used material on earth apart from water, with nearly three tons used annually for each man, woman, and a child by (Wang *et al.* 2011). Carbon dioxide emissions from a cement plant are divided into two source categories: combustion and calcination. Combustion accounts for approximately 40% and calcination 60% of the total CO_2 emissions from a cement manufacturing facility. In (Gartner *et al.,* 2004) have generated CO_2 emissions are related to fuel use. The CO_2 emissions due to calcination are formed when the raw materials are heated to over 2500°F and CO_2 is liberated from the decomposed limestone. As it carbonates and reabsorbs by (Giannopoulos *et al.* 2007) the CO_2 released during calcination. Calcination is a necessary key to cement production. Therefore, the focus of reductions in CO_2 emissions during cement manufacturing is on energy use.

Forecasting Models

Sanjib *et al.* (1992) developed a system dynamics model to study the long-term dynamic behaviour of the Indian oil and gas exploration/ exploitation industry for the period 1965-2005. The dynamics of finite and non-renewable fossil fuel resources were portrayed in the model and were linked with the financial sector. The credibility of the model has been enhanced through model validation. Model-generated projections were compared to the projections made by the industry and the Indian government and thereby found satisfactory in both trend and values. The effect of important variables on the model has been studied in order to choose alternative policies. The expected behaviour of the model has been analyzed under a standard run and under changed conditions. Perhaps the most striking revelation of the study was that oil production will start declining after attaining a peak of 39.5 million tonnes during 1994-96.

Similarly, gas production will start falling after reaching a peak of 25.1 billion cubic meters during 1997-99. They concluded that in order to face the difficult situation in India, alternate policies must be adopted. This will mitigate the oil crisis to some extent in the short term, but will be unable to contain growing demand and the consequent imports in the long run.

Choucri *et al.* (1990) conducted a detailed simulation analysis to study Egypt's oil industry as a near-typical, non-OPEC, oil-producing developing country. This model was used to explore implications of alternative scenarios for government policies (which affect Egypt's domestic consumptions directly), world oil prices (which influence earnings from export), and geological parameters (which affect the condition of resources and reserves) on patterns of production, exports, and earnings. The model effectively distinguished foreign oil companies and government agents as well as oil-producing regions which disaggregated geologically, to represent the characteristics of oil production; moreover, it made a distinction between domestic consumptions and exports as well as the domestic and international prices. The model had three exogenous variables including export and subsidized domestic prices, discovery and development prices, and initial levels of reserves and undiscovered oil.

Anand *et al.* (2005) used system dynamic approach for estimating the methane emissions from rice fields in India till the year 2020. Mitigation options studied for curtailing the methane emissions include rice production management, use of low methane emitting varieties of rice, water management and fertilizer amendment. They concluded that improved high yielding rice varieties together with efficient cultivation techniques will certainly contribute to the curtailment of the methane emission fluxes.

Discussions

It is clear that the research is taking a structured, multi-dimensional approach by moving beyond a simple chronological review to a thematic classification. By categorizing the literature into twelve broad categories, a map is created that allows future researchers to see the "connective tissue" between operational tech, organizational culture, and legislative issues.

To help visualize how your systematic review structures this vast field, here is a summary of your methodology and the resulting classification framework.

The 12-Category Classification Framework

By organizing the literature into these specific buckets, you are effectively solving the "predicament perspective"—allowing practitioners to see how, for example, *legislation* interacts with *economic aspects*.

Table 3: The 12 – Category Classification Framework

Category Cluster	Specific Categories Included
Strategy & Foundation	Importance, Elements of GM, Approaches/Strategies

Category Cluster	Specific Categories Included
Operational & Tech	Operational Technologies, Tools, Trends/Cases
Human & Cultural	Organizational Culture, Integrating GM with Quality Efforts
Contextual Factors	Legislation Issues, Economic Aspects, Industry/Country Specific Practices
Evaluation	Measurement & Performance Metrics

Methodological Approach

The study emphasizes a transition from general observation to specific, categorized analysis:

- **Database Selection:** Synthesis of leading journals and high-impact publications
- **Gap Identification:** Highlighting the lack of geographical-comparative studies, which serves as a justification for our specific focus on the Indian context versus global trends.
- **Perspective Building:** Utilizing previous findings not just as citations, but as "hints" to frame the current research within a "proper perspective."

Conclusions

Key Insights from the Literature Synthesis

- **Contextual Relevance:** You've noted that while factors influencing performance are well-documented, **systematic comparisons based on geography** remain a significant research void.
- **Interconnectivity:** The inclusion of "Quality Efforts" (such as Lean or Six Sigma) alongside Green Manufacturing suggests an emerging trend of "Lean-Green" integration.
- **Actionable Intelligence:** This classification doesn't just archive data; it simplifies the complexity of GM for easier application in industrial settings. Green, or sustainable, manufacturing is defined as a method to "develop technologies to transform materials without emission of greenhouse gases, use of non-renewable or toxic materials or generation of waste" *(*Zhu *et al.,* 2009*)*. The term "green", often used interchangeably with "environmentally-safe", comes from ideology that was originally developed by the Green Party, a political party in Australia in the early 1970's, whose political agenda quickly spread around the world. Life cycle assessment (LCA) is rapidly emerging as a useful environmental management tool worldwide for many process industries including cement manufacturing. According to *(*Pardo *et al.,* 2011*)* LCA study for cement sector was carried out in 2005-06 for the first time. Green Manufacturing - The concept and its applications are carried out in the current manufacturing scenario at the global level.

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