Educational Administration: Theory and Practice
2024, 30(5), 15968-15976
ISSN: 2148-2403
https://kuey.net/

Research Article

Green Pathways for Mini Cement Plants: Towards Sustainable Manufacturing Practices

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Citation: Rashmi Sharma, et.al (2024). Green Pathways for Mini Cement Plants: Towards Sustainable Manufacturing Practices, *Educational Administration: Theory and Practice*, 30(5) 15968-15976
Doi: 10.53555/kuey.v30i5.11217

ARTICLE INFO

ABSTRACT

Cement Industry is one of the largest industries of the world. It occupies a predominant position as a basic industry geared towards accelerating development and enhancing employment generation capacity of a region. Cement, as a basic construction commodity is extensively shaping the modern concrete environment, but it is dreadfully a massive source of carbon di-oxide to the atmosphere. The cement industry today accounts for 7 to 8 percent of global carbon emissions (IEA) and ranks next only to iron and steel industry to be the second largest industrial emitter in the world. It is therefore listed among the Red category of industries. However, the environmental impact of Mini Cement Plants (MCP) is not as gravely apprehensive as that of the large cement plants. The technology used by MCPs is appropriate to deal with the environmental exigencies of today and perfectly goes with the eco development approach of modern industrialization.

The paper aims to study the environmental responsiveness and sustainable development practices of mini cement plants of the Undivided Nagaon district (comprising of Nagaon and Hojai districts) of Assam with reference to the established norms of the government related to cement manufacturing. It adopts a structured approach to study the sustainable practices of the Mini Cement plants using available primary and secondary data sources.

Keywords: cement industry, mini cement plants, carbon emissions, sustainable practices, environmental responsiveness

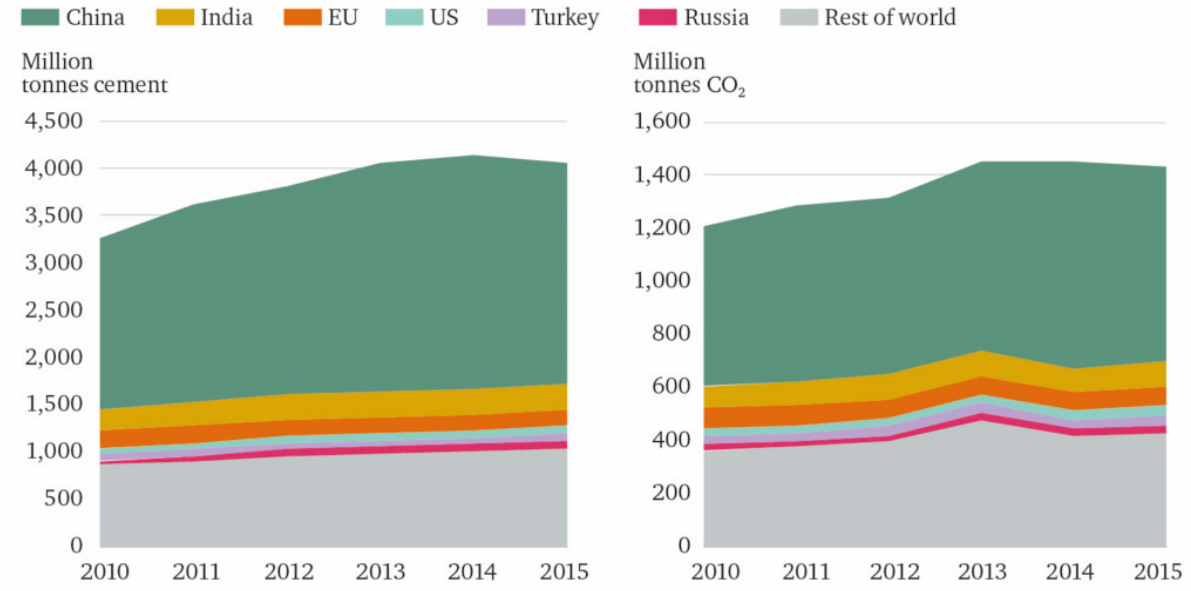
Introduction

Cement is undeniably the essence of construction and remains the most widely used man-made material in existence. With the rising demand for modern infrastructure across developing regions, cement has become the second most consumed commodity worldwide, surpassed only by water (WBCSD, 2002). Globally, close to one tonne of cement per person is produced annually, reflecting its centrality in industrial and infrastructural growth. As a core mineral-based industry, cement plays a crucial role in accelerating regional development and enhancing employment generation. In India, it is recognised among the eight core industries that significantly influence the country's industrial performance. According to the Cement Manufacturers' Association (CMA, 2018), the Indian cement industry has an installed capacity of approximately 509 million tonnes per annum (MTPA), accounting for over 8 percent of global capacity and ranking second only to China. In addition to large plants, nearly 350 mini cement plants contribute an estimated 11.10 MTPA to national capacity. Furthermore, cement production in India stood at 334 million tonnes during the financial year 2020 (IBEF, 2022).

Cement, as a basic construction commodity, extensively shapes the modern built environment; however, it is also a substantial source of carbon dioxide emissions. The global cement industry is recognised as one of the largest industrial contributors to CO_2 emissions. Approximately one tonne of CO_2 is released for every tonne of cement produced, with around 50 percent of emissions arising from the process of limestone decarbonation and about 40 percent from the fuel required to fire kilns (International Energy Agency [IEA], 2018). Traditional cement contains nearly 95 percent clinker, which is produced by calcination and fossil-fuel combustion at temperatures of about 1450°C, resulting in an estimated carbon footprint of 850 kg of CO_2 per tonne of cement. According to the IEA (2018), the cement sector is responsible for 7–8 percent of global

carbon emissions, ranking second only to the iron and steel industry as the largest industrial emitter. Consequently, it is classified among the "Red category" industries due to its pollution intensity. In the Indian context as well, the cement industry is identified as the third-largest energy-consuming and CO_2-emitting industrial sector in the country (Indian Institute of Petroleum [IIP], 2017).

Figure 1 Cement production and emissions from 2010 to 2015.



[Source: Analysis of Olivier et al. (2016) https://www.chathamhouse.org]

The Indian cement industry comprises of both mini and large capacity cement plants, the latter contributing almost 94% of the total cement production of the country. These large plants use the conventional Rotary Kiln technology of cement manufacturing that has extensive environmental implications. The carbon intensive fuels used in the process raise the issues of carbon emissions and concern for energy efficiency. To counter these issues, the cement manufacturing units must adopt effective measures to monitor and control the pollution level. These costs increase their average cost of production. But the environmental impact of Mini Cement Plants (MCPs) is not as gravely apprehensive as that of the large cement plants. The small-scale operations of the MCPs and the technology used are significantly mindful towards the depleting nature.
The present study sheds some light on the environmental responsiveness and sustainable development practices of mini cement plants in the districts of Nagaon and Hojai of Assam and their compliances with the established norms on emissions and environment rehabilitation.

Review of Literature

Several studies have been conducted on sustainable manufacturing practices. Although it is not possible to decarbonize technology entirely, responsible manufacturing can minimize its negative impact on ecology. **(Mahesh et al., 2023)** states that small and medium scale industries (SME) are contributing to the economy with their ecofriendly manufacturing practices, but **Behjati(2017)** argued that only 0.4 of the SMEs in our country adhere to environmental protection rules and generate around 64% of air pollution. Research on sustainability is also primarily focused on large enterprises while the sustainable performance of small-scale manufacturers is paid little attention **(Johnson et al., 2016; López-Pérez et al., 2018).** The contribution of these SMEs to national GDP is significant, but their indifference and ignorance of sustainable processes cause extensive negative impacts on the environment **(Rita et al., 2018)**. However, **Triguero et al. (2013)** reported due environmental compliances on the part of SMEs, and this is very critical for maintaining their operational efficiency and improving their financial performance too **(Wu and Pagell, 2011)**. Since cement is a major source of greenhouse gas emissions, concerns for sustainable development are scaling widely. More than 50% of emissions in cement sector arise during the phase of clinker production and hence the cement companies must focus on using alternative materials that can reduce the proportion of clinker **(Lehne and Preston, 2018)**. According to **Deb and Welling (2010)** the cement industry should set some protocols and stringent check on the sustainability efforts of the cement producers and should focus upon the more responsible use of fuel and materials that can help in reducing emissions. Dust emissions is another environmental concern from cement manufacturing that can lead to serious damage to soil, air and all plant and animal life in the effected region **(Suthar L et al., 2014). Mulgund (1992)** reported that the dust emission rate in grams per unit time in a mini cement plant is very low as compared to that of a large plant. Since the smaller plants use production processes involving lesser gas quantities, the emissions from mini cement plants are unlikely to inflict the

surroundings. Positive efforts for CO2 reduction and energy efficiency are also presumptive from the manufacturers, especially the SMEs because they are certainly related to government subsidies. **(Zhao et al., 2015)**

Research Gap

The available literature highlights the significance of sustainable manufacturing practices in today's ecologically depleting world. Prior studies also emphasize the impact of cement manufacturing on the environment. This paper deals with the unattended sustainable manufacturing practices of mini cement plants in adherence to the environmental policy and regulations of the region.

Rationale of the study

The modern concept of development has taken a shift towards eco-development where emphasis is laid upon structuring industrialization by environment friendly measures. The small-scale manufacturing units are suitable for achieving the twin objectives of industrial and sustainable development. The Mini cement plants (MCPs) deliver a wide range of socio-economic benefits that include intensification of regional development, enhancement of employment opportunities, and best possible use of locally available capital, resources, technology, labour etc. The dry process for cement manufacturing adopted by the mini cement plants is energy-saving and complies with the environmental protection policies.

The researcher has not come across any study that encompasses the significance of MCPs in promoting sustainable development of Northeast India. This study is influenced by the need to fill over this gap and conduct a comprehensive study on various sustainable practices of the MCPs in the region.

Qualitative data on environmental practices have been analyzed to evaluate the responsiveness of mini cement plants towards sustainability. The study adopts a structured approach to study the sustainable practices of the Mini Cement plants using available primary and secondary data sources.

Areas of focus included:

- Emission reduction practices.
- Use of alternative and low-emission raw materials.
- Energy-efficient technologies.
- Waste management techniques.
- Eco-friendly packaging and green marketing initiatives.

Objectives of the Study

The present study aims at studying the environmental responsiveness and sustainable development practices of mini cement plants and how they contribute towards the attainment of green manufacturing practices.

Area of the Study

The area of research is the districts of Nagaon and Hojai (together we refer to them as Undivided Nagaon) in the state of Assam. It is one of the largest districts of Assam. On 15 August 2016, the three tehsils of Nagaon district, namely Hojai, Doboka and Lanka were carved out to form the Hojai district. The region is noted for its vast cement market and flourishing construction sector. Therefore, several major as well as mini cement plants have been operating in and around the area. At present, 2 out of 6 large-scale and 5 out of 12 mini cement plants of the state are located in the Nagaon-Hojai districts.

Research Design

The study is descriptive and analytical in nature. It is based on a multi-case study approach conducted among five Mini Cement plants of the study area. It uses information from direct observation, structured questionnaires along with secondary data for the analysis.

Sample Size of the Study

The sample of the study comprises of the five Mini Cement Plants operating in Nagaon and Hojai districts in the period between 2011-2020.

Sources of Data

To collect primary data, a semi-structured questionnaire was administered to the management and staff of the selected mini cement plants. The questionnaire covered various aspects such as demographic details, production methods, environmental measures taken, regulations and compliances thereof. Responses were collected through physical visits to the plants.

Secondary data were obtained from:

- Annual reports of the selected plants (2010–2020)
- CMIE and IBEF publications

• Industry-specific articles and government publications

Analysis of the Sustainable Practices of Investigated Mini Cement Plants

Table 1. List of Mini Cement Plants of Nagaon-Hojai districts

Sl. No.	Name of the Company	Brand Name	Location	Year of Establishment	Capacity (in TPD)	Investment (in ₹ lakh)	Technology
1	RJ Cement Industries	RJ Cement	Doboka, Hojai	2005	200	225	VSK
2	Bulland Cement Pvt. Ltd	Prithvi Cement	Lanka, Hojai	2006	186	210	VSK
3	Dragon Cement Industries Pvt. Ltd.	National Cement	Doboka, Hojai	2009	220	200	Grinding Unit
4	KD Cements	Suraksha Cement	Amoni, Nagaon	2010	250	250	Grinding Unit
5	Aditi Industries	Atibal Cement	Kaliabor, Nagaon	2012	300	200	Grinding Unit

[Source: Industrial reports 2020]

The first mini cement plant of Nagaon- Hojai district (then Undivided Nagaon) was RJ Cement Private Limited that was established in 2005. The following years saw a surge in the number of MCPs in the area. The list included National Cement, Mahabali Cement, Prithvi Cement, Suraksha Cement, Atibal Cement, Buland Cement, Delta cement, Gold cement etc. but by 2015, only 5 out of them could be found sustaining.
Of the five MCPs under study, RJ Cement Industries and Bulland Cement Pvt Ltd. are undergoing operations under VSK Technology and produce clinker on their own before grinding into cement. This step known as Pyroprocessing is the heart of the cement manufacturing process, where raw materials undergo chemical transformations to form clinker. The environmental impact of mini cement plants based on Controlled Rotary Intermittent Vertical Shaft Kiln (CRI-VSK) technology are not as gravely apprehensive as that of the large cement plants. In particular, the VSK technology used in the dry process is known for its low fuel consumption and economical use thus making it preferable for small-scale production. As we know, the process of clinker production involves majority of greenhouse emissions, the sustainability practices of these two plants are quite different from the other three plants that are basically grinding units, procuring clinker from outside sources to be ground into cement. Before commissioning, these plants conducted a Rapid Environmental Impact Assessment (REIA) and prepared an Environmental Management Plan (EMP) to comply with the environmental policy of the government.

Objectives of the REI Assessment

- Establish the baseline environmental and socioeconomic conditions of the project site and surroundings.
- Determine compliance requirements for environmental approvals.
- Assess environmental, socioeconomic, and health impacts from the project.
- Recommend preventive and mitigative measures to manage adverse impacts.
- Integrate measures for monitoring and corrective actions.
- Identify and mitigate residual and cumulative impacts.

The ensuing narrative gives an organized summary of the existing air pollution control measures implemented at the Mini Cement Plants under study across various plant sections.

Table 2. Pollution Control Measures at the Mini Cement Plants under Study

Section	Area / Equipment	Pollution Control Measures	Dust Generation (Typical Range)
1. Crushing Section	Hammer Crusher	Hammer crusher used to crush limestone; cyclone with dust collector provided. Collected dust transferred via covered conveyor belt to storage bunkers to prevent escape into air.	5–15 gm/Nm³
2. Raw Material Storage	a) Belt Conveyors	Fully enclosed in hoods to prevent dust release.	—
	b) Vibratory Feeders	Equipped with electronic magnetic vibratory feeders at bunker outlets to suppress dust during discharge.	—
	c) Roller Mills	Cyclone-type dust collectors installed to minimize dust during operation.	—
3. Air Lift and Blending Section	a) Air Lift & Bucket Elevator	Dedicated cyclones with dust collectors installed to control dust emissions.	—
	b) Blending & Storage Silos	Dust linked to air lift dust collector system; bag filters cum dust collectors installed at the top of each silo.	—
4. Kiln Section	a) Air Lift & Bucket	Separate cyclone with dust collector provided for	—

	Elevator	this section.	
	b) Stacks / Chimneys	Each kiln has individual chimneys (~100 ft high); emissions within CPCB/SPCB standards.	≤250 mg/Nm³
	c) Chain Conveyor	Common cyclone with dust collector for conveyors; conveyors fully enclosed in hoods to reduce dust.	≤250 mg/Nm³
5. Clinker and Gypsum Storage	a) Conveyors & Silos	Clinker stored in silos/domes; bucket conveyors fully covered; bag filters cum dust collectors installed.	—
	b) Hopper Feeders	Electronic magnetic vibratory feeders installed at hopper outlets to control discharge dust.	—
6. Cement Mill Section	Cement Mills, Screw Conveyor & Bucket Elevator	Common cyclone with dust collector connected to mills; linked to screw conveyor and bucket elevator to ensure dust recirculation and collection.	150–250 g/Nm³
7. Storage and Packing of Cement	a) Air Lift & Bucket Elevator	Completely enclosed and connected to a common cyclone; dust from cement transfer conveyed to silos through collector.	20–40 g/Nm³
	b) Cement Silo Dust Control	Individual bulk silos equipped with bag filters cum dust collectors to reduce emissions during storage.	—

Thus, the MCPs make extensive use of cyclones, bag filters, and enclosures across all material handling points. They ensure Multiple dedicated systems per section to prevent dust escape. Enclosed conveyors and hoods are used extensively to prevent airborne dust, and electronic vibratory feeders are used to suppress emissions during discharge. All these are undertaken to keep the emissions well below permissible standards through efficient filtration and process design. Moreover, all diesel and gasoline-powered vehicles and construction equipment are regularly maintained to minimize exhaust emissions and ensure efficient operation. The unauthorized dumping of waste oil or other hazardous materials is strictly prohibited, and all waste is disposed of at approved landfill or disposal sites, in compliance with local regulations.

In the process of cement manufacturing, most of the emissions result from the calcination reaction due to burning of clinker at high temperature. Of the two major types of cement produced namely, OPC and PPC; the former requires a minimum 95% clinker in cement manufacturing while the minimum cement requirement in PPC cement is 60%. The Mini Cement plants manufacture PPC cement, which due to less concentration of clinker, is less expensive and more environment friendly as compared to OPC. Also, the MCPs use supplementary cementitious materials like fly ash, slag and natural pozzolans such as rice husk ash, to reduce the amount of clinker per ton of cement output. The use of these materials in cement production also contributes notably towards environment protection. These waste products are hazardous to the environment and are difficult to dispose of; by using them in the cement manufacturing process, the units take a leap towards production of greener cement.

Alongside, the plants are also responsible for Green Belt Development & Environmental Management around the premises. Demonstrating their commitment to sustainable practices, they plant trees like Eucalyptus, Neem etc. that help to arrest escaping dust particles and act as natural barriers. They also help diminish sound pollution from machinery and operations.

Impact on Water Environment

Based on the REIA reports of the plants, a summary of the impact of cement manufacturing on both surface water and groundwater within the impact zone of the cement plants has been prepared, particularly with respect to wastewater from existing industrial activities.

The cement units of RJ Cement and National Cement are in close proximity to Jamuna River near NH -54, Suraksha Cement plant is located near Diju River and the rest two plants of Prithvi Cement and Atibal Cement also have several ponds alongside to provide water necessary for their industrial activities. The water requirement for the plant is estimated at 100 cubic meters per day, The primary water consumption is for cooling purposes and domestic use. The manufacturing process itself does not generate any industrial effluents.

One of the key features of the plants is the commitment not to discharge any effluent outside the site. Instead, all the plants operate a closed-loop water recycling system, where all water used within the facility is recycled and reused.

The area has a naturally high water table with sufficient rainfall. A survey was conducted in the villages within a 5 km radius of the plant sites and it revealed that the majority of households primarily depend upon tube wells and hand pumps for their daily usage. Additionally, some households have open ring wells and dug wells, with ponds used for both drinking water and fish farming.

To meet the water requirements of the cement plant as well as the domestic water needs of the facility, water is sourced from tube wells and on-site bore wells. Suraksha Cement and National Cement have installed dedicated water treatment plants, with water being drawn from deep tube wells. All the plants have proper

drainage systems to handle stormwater runoff and prevent soil or surface water contamination. To promote groundwater recharge, rainwater harvesting is also done. Besides, the sanitary waste is directed to septic tanks followed by soak pits.
It is noteworthy that the wastewater generated from the cement production process is minimal, and no wastewater is discharged to external sources. This proactive approach helps to avoid any potential health hazards in the surrounding areas. Moreover, fisheries and aquatic biodiversity, including flora and fauna, are also not reported to be affected by the plants' operations.

Impact on Air Quality

The investigated mini cement plants do not feature large industrial stacks; instead, have only process vents that are connected to dust collection systems, which recycle the collected dust back into the production process. The limited stacks in kiln are at suitable heights as recommended by the Central Pollution Control Board (CPCB). The CPCB and the SPCB have fixed stringent emission standards for particulate matter that varies from 400 mg/Nm^3 for plants with capacity less than 200 TPD to 250mg/Nm^3 for plants with capacity more than 200 TPD. The emissions from all the investigated plants range from average 190 mg/Nm^3 to 230 mg/Nm^3.

Air Pollution from Generator (DG) Set

The operation of a generator set used for power backups cause air pollution, emitting pollutants such as particulate matter (PM), oxides of sulfur (SOx) and nitrogen (NOx), carbon monoxide (CO), carbon dioxide (CO2), and hydrogen in significant amount. But the manufacturing units studied here do not use generators frequently at the site and, therefore, emissions from these sources have minimal impact on ambient air quality.

Impact of Vehicular Emissions

The degree of vehicular emissions due to the plants is generally marginal, with an estimated 40-50 trucks per day in traffic. The impact on air quality from these emissions is limited to a short distance from the plant and is anticipated to be insignificant. The roads leading to the plant site are mostly tar roads, and therefore, result in minimal fugitive emissions.
Though the plants try to keep the pollution levels within the prescribed limits during production, mitigative measures are duly implemented to ensure that emissions remain within acceptable limits.

Land Environment

The impact of operational activities of investigated MCPs on land quality is also minimal. None of the plants has disturbed any prime agricultural land for their operations. The plants do not generate sludge or hazardous waste requiring disposal, thus minimizing land pollution. Proper waste management, soil conservation, and erosion control strategies of the plants help preserve land characteristics and support long-term ecological sustainability.

Noise Environment

The primary sources of noise at the site are generators and compressors. These machineries are enclosed with acoustic insulation to significantly reduce emitted sound levels, thereby minimizing their impact on the surrounding environment. Besides, transportation vehicles also contribute to the levels of noise pollution in the area. The noise most significantly affects the workers within the cement plant. Hence, protective measures like Personal Protective Equipment (PPE) such as earmuffs or ear plugs are provided to reduce noise exposure risks. To mitigate the level of noise pollution, the plants adopt strategies like scheduling of high-noise operations during daytime, installing noise dampeners and acoustic enclosures at major sources etc.

Green Belt Development

The MCPs investigated in the research recognize the importance of maintaining greenery both within and around the plant premises. With the intent to create a green environment around, they are undertaking systematic and scientifically planned green belt development activities for effective pollution control. To ensure the effectiveness and sustainability of the green belt, plant species are selected based on the considerations like the plants should be fast-growing and evergreen, having thick canopy cover to trap dust and reduce air pollutants. Also, the choice of vegetation includes indigenous species, suited to the local climate and ecosystem and resistant to specific air pollutants emitted from industries. Examples of such trees are eucalyptus, neem etc. The units also undertake social forestry and community plantation programs for environment conservation.
All these measures help to create a functional green barrier that not only enhances the plant's visual appeal but also acts as a natural sink for air pollutants, contributing to environmental sustainability and community well-being. Furthermore, the Green belts further reduce noise levels by over 50%.
Along with this, the cement plants also pursue regular environmental monitoring to ensure that the activities remain within environmental compliance and minimizes adverse impacts.

Observations from the study

The study provides a firm ground for the contribution of the Mini Cement plants towards sustainability. Irrespective of their size and scale of operations, these MCPs are inclined towards their environmental and social sustainability performances. They are committed to eco-friendly industrial development of the region and adhere to all State and Central Pollution Control Board regulations. The environmental policies related to chimney heights, stack emissions, filters and effective maintenance practices are duly complied with. The units are set up in areas where environmental impact should be low and hence there is not much adverse impact on natural vegetation or species diversity in the area. The Green Belt Development & Environmental Management plans of the plants add to their sustainable practices.

Recommendations

1. The CPCB recommends formation of a Safety and Environmental Cell to oversee the monitoring of environmental and safety-related activities at the plants. These monitoring activities will help ensure that the plants operate in an environmentally responsible manner and that any potential environmental impacts are promptly addressed.
2. The increased use of alternative fuels, such as waste or biomass, could further reduce the carbon footprint of the cement plant, making the operation more sustainable.
3. To promote sustainability in practices, the manufacturing units can use environmentally friendly transport options like CNG/LNG or e-vehicles. This will considerably address the issue of vehicular emissions. Also, efforts must be taken to reduce dependence on road transport through shifting to railways or waterways.

Conclusion

Sustainable manufacturing is what is critically needed to conserve the degrading environment without compromising with the industrial development. The opinion of the local population regarding the cement plants has been gathered through surveys conducted in nearby villages. It is encouraging to note that, overall, 80% of the surveyed households expressed a positive outlook towards the mini cement plants. They believe that the plants have offered employment opportunities for the local youth, contributing to the region's economic development. They appreciate the plants' contribution to the development of infrastructure, such as improved road connectivity, healthcare, and educational facilities in the region. However, the local community also emphasizes the need for stringent measures to minimize environmental pollution associated with the plants. While they are in favour of industrial development, the residents are keen on ensuring that any pollution generated by the plants is controlled using modern machinery and effective pollution control technologies.

According to the current status of global economy, technological change is required to endure the problems of pollution, unemployment and regional imbalances. The technology used by MCPs is appropriate to deal with these exigencies and perfectly goes with the eco development approach of modern industrialization.

Limitations of the Study

This study is a limited investigation conducted in a specific state of India and focusing on only five mini cement plants of the area, which may affect generalizability.

Scope for future study

The paper focuses only on the sustainable manufacturing practices of Mini cement plants. It therefore leaves scope for analysis of the financial performance and viable existence of the mini cement plants vis-à-vis the large manufacturing units amidst the surging competition.

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