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Efficient Management of Pollution in Portland Cement Industries

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Abstract

There are a number of present situations as well as forthcoming challenges that have been identified, including global warming, climate change, environmental pollution, and the depletion of fossil fuel production. Among the many different types of industries, cement plants are among the most notable zones because they are responsible for emitting fifteen percent of the global pollutions into the surroundings. Additionally, these pollutants are estimated to be 10% of the stationary admissible sources of CO_2 emissions. Several control technologies and practices are explored, including pre-combustion measures like alternative fuel usage (e.g., biomass, waste-derived fuels) to reduce carbon emissions and dependency on fossil fuels, in-process strategies, such as improving energy efficiency through preheaters and pre-calciners, and optimizing combustion processes to reduce NOx and SOx emissions end-of-pipe solutions, such as electrostatic precipitators, fabric filters, and scrubbers for particulate and gas emission control carbon capture, utilization, and storage (CCUS) as a long-term solution for CO_2 emissions. This paper describes the development of a novel method of pollution control for cement industry which minimize pollutants, policy and regulatory frameworks that promote environmental compliance and encourage the adoption of cleaner technologies. It advocates for the integration of life cycle assessment (LCA) approaches to evaluate the overall environmental impact of cement production and the development of eco-friendly cements with lower carbon footprints.

1. Introduction

Concerns about environmental pollution and global warming have arisen all over the world as a result of the expansion and mechanization of communities. When it comes to the various industries that contribute to pollution, cement developments are among the most serious zones that fall under the red class [1]. The substance that is consumed the most in both the societies is cement, which comes in second place after water. Cement is used in an extensive range of fields, including but not limited to construction, civil engineering, decorative applications, medical and dental fields. According to the statistics, a number of countries, including India, Vietnam, China, the United States of America, etc produced approximately 3,600 million metric tons of cement in the year 2021. The consumption of cement is expected to reach up to 5800 million metric tons by the year 2050, according to the predictions [2]. In the meantime, the carbon dioxide pollution that is released by these plants accounts for approximately 10–15% of the total CO2 that is released into the environment annually by the primary industries.

The extraction of limestone and various production procedures in the cement industry have detrimental effects on the environment and contribute to pollution degradation [3]. These impacts pose risks not only to the workers in the production units, but also to the residents in the surrounding areas. The air quality is a matter of significant concern. Pollution control authorities closely monitor Portland cement industries to ensure that units producing carbon monoxide emissions remain at a minimum [4]. Portland cement plants that prioritize energy and environmental concerns have significant potential for improving efficiency. The cement industry in India is characterized by low energy efficiency, primarily due to the presence of inefficient energy-intensive units, which also contribute significantly to pollution. It is crucial to achieve consistent and uninterrupted growth [5-6]. In order for cement industries to sustain large-scale production, they must coexist harmoniously with nature, minimizing their pollution levels. The cement industry is characterized by its high energy consumption. The average fuel economy of Indian cement production results in twice the amount of carbon particles per unit of production compared to advanced countries' benchmarks. Therefore, the adoption of stricter pollution control measures in the context of increasing large-scale cement production plants results in the concentration of production facilities, which in turn presents challenges in managing pollution control for these large facilities [7].

Given the increasing focus on environmental quality, it is economically advantageous for industries to effectively decrease pollution levels. To conduct an economic assessment of pollution control implementation, it is necessary to calculate the product's production cost and assign economic value to environmental externalities. This enables society to value future environmental inputs when making decisions about waste treatment and air pollution control investments. To analyze the rise in pollution control in the Portland cement industry, a concise overview of cement production in India has been provided [8].

2. Overview of Pollution and Environmental Impact

In industrial settings, the production of cement typically consists of four stages: the first stage is the extraction of raw materials, the second stage is the processing of the substances that are supplied through calcination, and the fourth stage is the grinding of clinker [9]. Mining is the primary method that is utilized in order to acquire the raw materials that are necessary for the production of cement when it comes to the acquisition of these materials [10,11]. The following are some examples of materials that are utilized as starting materials in industries such as these: limestone ($CaCO_3$), alumina (Al_2O_3), silica (SiO_2), and iron (Fe) [12,13].

It is important to mention that after the mining stage, quarrying procedures such as blasting, drilling, handling, and excavating are carried out to acquire fine materials. Subsequently, the raw materials that have been prepared are combined and pulverized in order to obtain cement that possesses an accurate chemical composition and suitable mechanical properties. During this stage, dry, wet, and semidry methods are utilized [14].

Prior to the process of grinding the raw materials, rapid dryers that are fitted with paddles, drums, and impact technology are utilized for the purpose of drying the materials. In the wet method, water is added to the materials while they are being ground, and a pelletizing device is used to shape the materials into pellets at the end of the process [15]. In the subsequent stage, cement clinkers are produced through a chemical reaction between the raw materials. This reaction is followed by a heating process that includes pre-heating, calcining, and burning [16]. The clinker nodules that are produced as a result of the thermal process are spherical in shape and range in diameter from 0.3 to 5.0 centimeters. Finally, in order to obtain high-quality materials, a cooling process is utilized, which typically involves the circulation of air. It is important to note that a final grinding process, which is referred to as finish milling, is utilized in order to reduce the size of the particles that are obtained and to categorize them before they are utilized [17].

2.1 Air Pollution

Harmful substances in the air cause environmental contamination, which has detrimental effects on both human health and the environment. The issue of pollution control in Portland cement industries is of utmost importance given the substantial environmental consequences associated with cement manufacturing [18]. The process of cement manufacturing encompasses multiple stages that can result in the release of dust, particulate matter, greenhouse gases (such as carbon dioxide), and other harmful substances. The following are several critical strategies and technologies used for pollution control in Portland cement industries [19].

According to the aggregate load-bearing columns, the process generates a dust cloud equivalent to mass production, with an estimated annual production of approximately 500 million tons [20]. There are a total of 500,000 tons of sulfur dioxide, nitrogen oxides, and carbon monoxide that are released into the atmosphere by cement plants every year, according to the statistics. In addition, the emission of sulfur dioxide into the atmosphere is caused by the presence of sulfur in raw materials as well as the combustion of sulfur compounds in fossil fuels [21]. The production of greenhouse gases can be attributed to a variety of processes, including the heating of calcium carbonate, the preparation of limestone, and the combustion of fuels. In addition to contributing to acid rain, global warming, health problems, decreased crop productivity, and a decrease in biodiversity, the presence of these contaminants in the atmosphere also causes acid rain [22]. Fig. 1 shows the various type of sources of air pollution commonly happening in cement industry and Table 1 is summarizing previous research on the efficient management of air pollution in Portland cement industries.

Table 1 *Previous research on the efficient management of air pollution in Portland cement industries*

Pollutant	Source in Cement Production	Research Findings	Potential Solutions	Ref
CO2 (Carbon Dioxide)	Calcination of limestone, fuel combustion in kilns	Cement industry is responsible for 5-8% of global CO2 emissions.	Carbon capture and storage (CCS), use of alternative fuels (e.g., biomass), energy efficiency measures, and clinker substitution.	17,18
PM (Particulate Matter/ Dust)	Raw material handling, clinker cooling, and cement grinding	Dust emissions cause air quality issues and health hazards. Electrostatic precipitators (ESPs) and bag filters are commonly used.	Improved filtration systems (high-efficiency ESPs, baghouse filters), water spraying, and dust suppression systems.	19
NOx (Nitrogen Oxides)	Fuel combustion in cement kilns (high-temperature process)	NOx contributes to ozone formation, acid rain, and respiratory issues.	Selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), and low-NOx burners.	14,15
SOx (Sulfur Oxides)	Sulfur content in raw materials and fuels	SOx emissions contribute to acid rain and air pollution.	Use of low-sulfur fuels, lime injection in the exhaust stream, and dry/semi-dry desulfurization methods.	11,12
VOC (Volatile Organic Compounds)	Organic content in fuels and raw materials	VOCs contribute to smog formation and air quality degradation.	Combustion optimization, use of alternative fuels with lower organic content, and advanced combustion controls.	14
Heavy Metals	Raw materials and waste fuels containing trace metals	Emission of metals like mercury, lead, and cadmium can cause long-term environmental and health risks.	Activated carbon injection, improved kiln operating conditions, and alternative material sourcing.	12
Dioxins/Furans	Formation during clinker production at certain temperature ranges	Dioxins and furans are toxic and persistent in the environment, with long-term health effects.	Optimized kiln temperature control, use of clean fuels, and post-combustion gas treatment (e.g., activated carbon).	18
Ammonia (NH3)	Used in NOx control processes (SNCR)	Excess ammonia can lead to secondary air pollution (formation of PM).	Optimal dosing of ammonia and control of SNCR processes.	18
CO (Carbon Monoxide)	Incomplete combustion of fuels	CO is a result of inefficient combustion, affecting air quality and human health.	Improving kiln efficiency, optimizing combustion conditions, and using CO monitors and feedback systems.	14
Alternative Fuel Use	Introduction of waste-derived fuels like tires, plastics, and biomass	Some alternative fuels can result in increased emissions of certain pollutants (e.g., dioxins, heavy metals).	Advanced air pollution control systems, careful selection of alternative fuels, and thorough pre-processing.	12

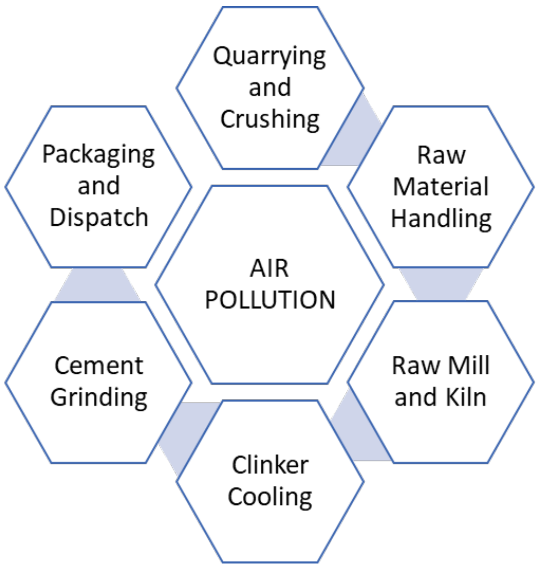

Fig. 1 *Sources of air pollution*

2.2 Noise Pollution

The production of cement involves multiple processes that generate substantial noise, making noise pollution in cement industries a significant environmental concern. The process of crushing and grinding raw materials generates significant levels of noise [23]. This equipment is generally characterized by its significant size and high power, which results in considerable noise emissions. Rotary kilns, which subject raw materials to elevated temperatures, produce incessant noise. The rotation of the kiln and its associated machinery generate this noise [24]. Large fans and blowers, used for ventilation and material handling, generate significant noise. The transportation of materials using conveyor belts and bucket elevators generates noise, especially at transfer points [25].

Extended exposure to elevated noise levels can result in auditory impairment, psychological strain, hypertension, and additional health complications for workers. Noise pollution has the potential to disturb local wildlife and impact the surrounding environment, leading to disruptions in animal behaviour and biodiversity. Proximity to residential areas may result in higher noise levels, causing discomfort and prompting residents to complain [26]. Fig. 2 shows the various type of sources of noise pollution commonly happening in cement industry and Table 2 is summarizing previous research on the efficient management of noise pollution in Portland cement industries.

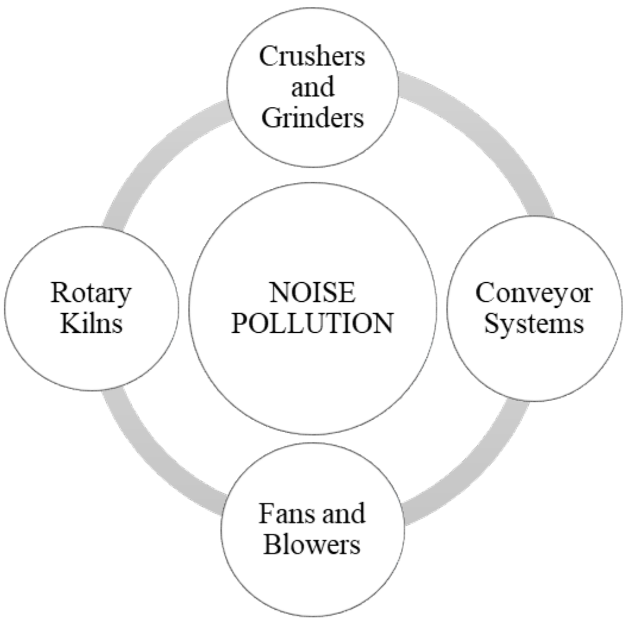

Fig. 2 *Sources of noise pollution*

Table 2 *Previous research on the efficient management of air pollution in Portland cement industries*

Noise source	Stage in cement production	Research findings	Potential solutions	Ref
Crushers	Raw material crushing	Crushers generate significant noise due to the crushing of raw materials like limestone and clay.	Installation of noise barriers, acoustic enclosures, use of vibration isolation pads.	23
Raw mills (grinding mills)	Grinding of raw materials into fine powder	Noise levels are typically high (90-100 dB) during the grinding process due to the rotating mill parts.	Use of soundproof enclosures, dampening pads, and noise insulation on the mill housing.	21
Rotary kiln	Clinker production at high temperatures	The rotating kiln can create continuous noise, especially in high-capacity cement plants.	Acoustic insulation of kiln surfaces, use of vibration isolation technology, periodic maintenance for smooth operation.	23
Fans (Preheater and Cooler)	Air circulation for cooling and preheating	High-speed fans create excessive noise levels, especially during the cooling and drying processes.	Use of sound-absorbing materials, low-noise fans, and optimizing fan speed to reduce noise emissions.	25
Cement mills	Grinding of clinker to make cement	Similar to raw mills, cement mills generate noise from the grinding process.	Soundproofing of mill rooms, use of low-noise grinding equipment, and regular equipment maintenance.	25
Conveyor systems	Transportation of raw materials, clinker, and cement	Noise from conveyor belts and chain drives is common due to material movement and mechanical parts.	Installation of noise-dampening conveyor belts, lubrication of chains, and enclosure of conveyor systems.	23
Air Compressors and Pumps	Compressed air and fluid pumping for material handling	Compressors and pumps produce significant noise due to mechanical operations.	Enclosure of compressors, use of quieter models, and proper maintenance to reduce vibration and noise.	26
Packaging and Dispatch Equipment	Final cement packaging and transportation	Noise is generated by machinery in packaging and dispatch, including filling machines and loading equipment.	Acoustic isolation of packaging areas, quieter packaging machinery, and use of noise barriers in dispatch areas.	23
Heavy equipment (loaders, trucks)	Material loading, unloading, and transportation	Heavy-duty trucks and loaders contribute to high noise levels, especially in large cement plants.	Scheduling of vehicle movement during less disruptive times, use of electric vehicles, and installing sound barriers.	24
General plant operations	All production processes combined	Overall plant noise levels can exceed 85 dB, which is harmful for workers without protection.	Implementation of comprehensive noise monitoring, provision of personal protective equipment (PPE) for workers, and noise zoning.	25

2.3 Solid Waste

Efficient management of solid waste in cement industries is an essential component of sustainable operations, given the substantial quantities of waste materials generated by these industries. Effective solid waste management can minimize environmental harm, optimize resource utilization, and foster sustainability [27].

Cement manufacturing processes produce a variety of solid wastes, including fly ash, rock spoil, and dust. Cement industries generate cement bypass dust as their primary solid waste, collecting it from the dust filter membranes' surface. The materials in question consist of pollutant particles that exhibit alkaline properties, with a pH level ranging from approximately 11 to 12. These particles, referred to as particulate matter (PM), have a diameter ranging from 1 to 10 micrometres. Meteorological conditions and the source of emissions influence the dimensions and chemical makeup of particulate matter (PM) [28]. The presence of smaller particles makes it more difficult to treat pollutants. Consequently, the primary pollutant known as PM is categorized into two groups: PM10 and PM2.5, which correspond to particles with a diameter smaller than 10 and 2.5 micrometres, respectively. The substantial concentration of this pollutant contributes to the majority of health and environmental problems [29]. Furthermore, these particles have the ability to infiltrate the respiratory system more extensively, causing detrimental effects on human well-being. The analysis reveals that the solid waste content consists of a substantial proportion of heavy metals, specifically Al_2O_3, Fe_2O_3, and MgO. These compounds have the capacity to cause damage to both living and non-living components in the environment [30].

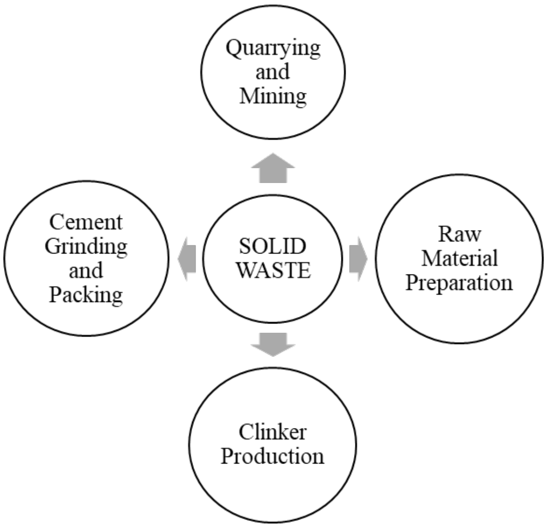

Fig. 3 *Sources of solid waste*

2.4 Waste Water

Water is utilized in a number of operations throughout the cement manufacturing process, including cooling systems and washing procedures. Non-contact sources, such as kiln bearing processes, grinding devices, thermal pipes, compressors, and finishing steps, are responsible for the majority of the water that is consumed [31]. For the purpose of effectively grinding the materials while they are in a solid state, water is utilized simultaneously. It is also essential to wash the raw materials before beginning the processing of the raw materials. During the washing process, particles of limestone and iron, in addition to suspended solids, are introduced into the water, which ultimately results in the pollution of the water. The washing water must be neutralized, the waste particles must be separated in order to remove any potentially harmful substances, and then the waste particles must be reintegrated into the production process. This is necessary in order to ensure the environmental sustainability [29]. Chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), and pH are the four primary indicators that are utilized in cement industries for the purpose of evaluating the quality of wastewater. In accordance with the criteria that have been established, the BOD/COD ratio should be lower than 1, and the COD concentration should not be higher than 250 mg/L. Consequently, lowering this ratio can be of assistance in achieving a production cycle that is more consistent with ecological sustainability. Furthermore, it is essential for the wastewater to have a pH that falls within the optimal range of 6.5 to 9, and the total suspended solids (TSS) should not exceed 100 mg/L, as per the requirements that are set forth by the standard [29]. Fig. 4 shows the various type of sources of waste water pollution commonly happening in cement industry and Table 3 is summarizing previous research on the efficient management of waste water pollution in Portland cement industries

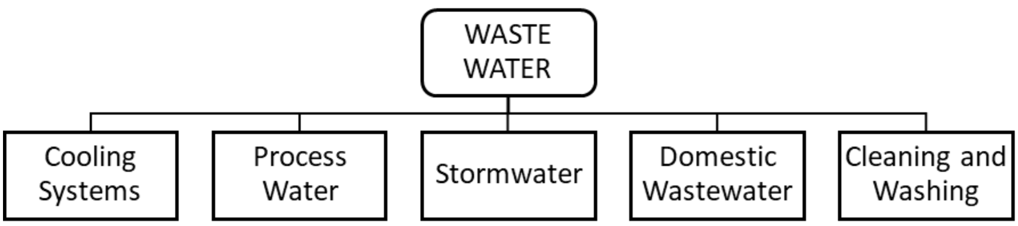

Fig. 4 *Sources of solid waste water in cement industries*

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Table 3 *Previous research on the efficient management of waste water pollution in Portland cement industries*

Source of wastewater	Stage in cement production	Research findings	Potential solutions	Ref.
Cooling water	Cooling systems in kilns, clinker coolers, compressors	Wastewater from cooling systems can become contaminated with heat and suspended solids.	Recycling cooling water in closed-loop systems, using dry cooling methods, and implementing heat recovery systems.	31
Stormwater runoff	Plant areas, raw material storage, and transportation zones	Stormwater can pick up contaminants like dust, oils, and particulate matter, leading to potential water pollution.	Installation of stormwater treatment units (sedimentation basins, filtration systems) and proper drainage design.	31
Quenching water	Clinker cooling (wet quenching)	Quenching water contains high levels of suspended solids, mainly dust and fine clinker particles.	Use of sedimentation and filtration units to remove solids, and recirculation of treated quenching water.	29
Process water	Grinding, raw material slurry preparation (wet process plants)	Process water is often contaminated with raw material fines, dissolved minerals, and chemicals from the production process.	Implementation of filtration and sedimentation techniques, and water reuse in the production cycle.	29
Boiler blowdown water	Boilers for steam generation (if used)	Boiler blowdown can contain chemicals, dissolved solids, and high temperatures, contributing to thermal and chemical pollution.	Use of blowdown recovery systems, chemical treatment, and reusing blowdown water for other plant processes.	29
Equipment washing	Cleaning of plant equipment and vehicles	Wash water can carry oils, grease, and particulate matter, causing environmental pollution if untreated.	Use of oil-water separators, sedimentation systems, and recycling of wash water after treatment.	28
Laboratory wastewater	Chemical labs (quality control and testing)	Wastewater from laboratories may contain chemical reagents, acids, and heavy metals used in material testing.	Proper neutralization and chemical treatment before discharge, or reuse in plant processes after treatment.	22
Sanitary wastewater	Employee facilities (toilets, kitchens, etc.)	Sanitary wastewater may be generated in large quantities, especially in large cement plants.	On-site wastewater treatment systems (e.g., septic tanks, small sewage treatment plants), or discharge to municipal systems.	31
Slurry wastewater (wet process)	Wet process plants generate wastewater from slurry preparation	Wet process plants produce large volumes of water containing suspended solids and chemical additives.	Transition to dry or semi-dry process to reduce water use, filtration, and recycling of slurry water.	31
Dust suppression water	Dust control during material handling and storage	Water used for dust suppression can pick up cement dust and other particulate matter, contributing to wastewater generation.	Use of dry dust suppression methods (e.g., bag filters), or recycling water with filtration to remove dust.	29

3. Control of Pollution in Cement Plant

The process of making cement entails manipulating raw materials and finely pulverized clinker. Efficient methods for controlling dust include employing baghouse filters, electrostatic precipitators (ESPs), and implementing dust suppression techniques at transfer points and storage areas. Fabric filters (baghouses) and ESPs capture particulate matter during the kiln and grinding processes. These technologies aid in mitigating atmospheric emissions. High-temperature combustion processes in cement kilns produce nitrogen oxides (NOx). Methods for managing NOx emissions encompass selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR) systems. Sulfur oxides (SOx) emissions are regulated by utilizing low-sulfur fuels, such as natural gas, and by implementing flue gas desulfurization (FGD) systems [12]. The cement production process is a significant contributor to the release of carbon dioxide (CO_2) into the atmosphere. The calcination of limestone and the combustion of fuels are the primary causes. Methods to decrease CO2 emissions encompass the utilization of alternative fuels and raw materials, enhancing energy efficiency, and investigating carbon capture and storage (CCS) technologies [28,32].

Implementing energy efficiency enhancements and waste heat recovery systems can enhance energy-intensive operations involved in cement manufacturing, such as grinding and kiln processes. Water is needed by cement plants for cooling and mitigating dust. Implementing effective water management practices and utilizing advanced technologies can significantly decrease water usage and mitigate environmental harm. The ongoing research and development efforts are dedicated to the advancement of sustainable methods and technologies for cement production, with the aim of reducing environmental impacts. Regulatory requirements and standards force the cement industry worldwide to adopt pollution control measures [22].

The use of alternative raw materials, such as fly ash, slag, and pozzolans, can decrease the clinker production per metric ton of cement. This approach not only preserves natural resources, but also reduces energy consumption and greenhouse gas emissions associated with cement production. Effective waste management, which includes the proper handling of hazardous wastes and by-products from other industries, can significantly reduce environmental consequences. Certain waste materials can serve as alternative fuels or raw materials in cement kilns, thereby promoting the principles of circular economy. It is crucial to continuously monitor emissions and ensure compliance with environmental regulations. Cement plants frequently adopt comprehensive environmental management systems to ensure compliance with emission limits and operational standards [16].

It is crucial to actively involve local communities and stakeholders in order to address concerns pertaining to air quality, noise, and other environmental impacts. Openness in disclosing environmental performance fosters confidence and responsibility. The focus of current cement technology research and innovation is on developing cleaner and more sustainable production methods. This encompasses progress in technologies aimed at reducing clinker production, capturing and utilizing carbon, and creating cements with low carbon emissions or carbon neutrality [32].

The Cement Sustainability Initiative (CSI) by the World Business Council for Sustainable Development (WBCSD) is an international effort that aims to promote the implementation of best practices and sustainability principles in the cement industry. Complying with internationally recognized standards and certifications, such as ISO 14001 for managing environmental systems, facilitates ongoing enhancements in pollution control and sustainability endeavours. Performing lifecycle assessments (LCAs) enables the evaluation of the environmental consequences of cement production throughout its entire lifespan. This comprehensive approach takes into account not only emissions during the manufacturing process but also the effects related to the extraction of raw materials, transportation, the use phase, and the disposal or recycling at the end of the product's life cycle [29].

The cement industry is actively looking for ways to achieve carbon neutrality and develop low-carbon cements. Calcined clays, limestone calcined clay cement (LC3), and other supplementary cementitious materials (SCMs) have the potential to reduce CO2 emissions per ton of cement produced [19].

With the growing severity of climate change effects, cement manufacturers are progressively incorporating climate adaptation strategies into their operations. This encompasses the development of strategies to prepare for and respond to severe weather conditions, the implementation of measures to address water scarcity, and the integration of assessments of climate-related risks into business plans. The process of cement production necessitates significant water consumption for cooling and dust control. By implementing water conservation measures, recycling process water, and adopting closed-loop systems, it is possible to minimize water consumption and mitigate the environmental impacts on water resources [18].

Table 4 shows previous research on the efficient management of pollution control using alternative raw material in Portland cement industries. The studies show that the use of alternative raw materials can significantly reduce environmental pollution in Portland cement industries, primarily by lowering CO2 emissions, reducing reliance on fossil fuels, and recycling industrial and agricultural by-products. However, the effectiveness depends on the type and processing of the alternative materials, as well as the existing infrastructure in the cement plants.

Table 4 *Previous research on the efficient management of pollution control using alternative raw material in Portland cement industries*

Alternative Raw Material	Pollution Reduction	Key Findings	Ref
Fly Ash	Reduced CO2 emissions by 20%	Fly ash replacement lowered energy consumption in clinker production.	29
Blast Furnace Slag	Reduced SOx and NOx emissions	Use of slag reduced clinker demand, lowering overall emissions.	31
Sewage Sludge	Reduced particulate matter	Sewage sludge was used as an alternative fuel, reducing reliance on fossil fuels.	30
Recycled Construction Waste	Reduction in CO2 and NOx emissions	Use of construction waste led to less limestone processing and lower temperatures.	31
Agricultural Waste (Rice Husk Ash)	CO2 emissions lowered by 15%	Agricultural waste by-products were effective as pozzolanic materials.	29

4. Economic Analysis

The paper aimed to analyse the economy by utilizing data to calculate energy values required by the facility and comparing the cost structures between the private and public sectors. Subsequently, the air emission module developed in the METU environmental and occupational health application is utilized to assess the impacts of air emissions and determine any negative values. The determination of these values involves multiplying ongoing costs by specific energy values and air emission costs. The basis for determining fossil energy use related to CO_2 emissions in the vicinity was established. Subsequently, further investigation is conducted in various fields such as transportation, tourism, and associated matters (such as electric line systems and regional ecological studies) following an analysis of the environmental costs and benefits to impact the choice of location, and potential solutions are deliberated [3,7].

The correlation between the measured gases and the annual financial flow of industrial facilities does not guarantee a direct relationship with the deposition of carbon monoxide, carbon dioxide, sulfur dioxide, and similar emissions on soil and snow, which can impact the environment as well as human health and well-being. Interpretation and quantification of results are done using literature values. This exclusively impacts the sector as a source of income and as a significant environmental necessity. When analyzing the economy, it is recommended to regulate and plan it within a comprehensive framework in order to restore the operations of the sector that contribute significantly to the environmental issue, in conjunction with public policies [9,12].

Performing life cycle cost analysis (LCCA) in conjunction with environmental assessments enables cement manufacturers to make well-informed choices that strike a balance between economic viability and environmental and social consequences. This comprehensive approach takes into account the complete cost of owning a product, which includes the initial investment, ongoing operational expenses, maintenance costs, and considerations for the product's end-of-life. Additionally, it assesses the environmental advantages and impacts throughout the entire lifespan of cement products [21].

By adopting the principles of the circular economy, we can transform waste and by-products from various industries into valuable resources for cement production. By using alternative raw materials and fuels obtained from industrial residues, construction and demolition waste, and agricultural by-products, we can decrease our dependence on new materials, preserve natural resources, and minimize the environmental consequences of waste disposal [18].

Implementing adaptive management techniques requires meticulous monitoring of environmental impacts, assessing potential hazards, and adjusting approaches in response to changing regulatory requirements, market dynamics, and climatic conditions. Facilitating innovation via pilot projects, collaborative research collaborations, and technological incubation accelerates the development and application of cutting-edge solutions for pollution control and sustainable growth in the cement sector [33].

5. Conclusion

Pollution control in Portland cement industries requires a comprehensive strategy that includes technological innovations, adherence to regulations, efficient use of resources, and active involvement of stakeholders. Sustained endeavours are crucial to alleviate environmental consequences and advance sustainable progress in the worldwide cement industry. To achieve effective pollution control in Portland cement industries, a comprehensive approach is necessary. This approach should include integrating technological innovation, regulatory frameworks, stakeholder engagement, and sustainable business practices. Consistent enhancement and cooperation throughout the sector are crucial to minimize ecological consequences and support worldwide sustainability objectives. Through the integration of these strategies and initiatives, the cement industry can make progress towards achieving sustainable development goals, reduce environmental impacts, and play a role in constructing a resilient and low-carbon future by integrating these strategies and initiatives. Collaboration among stakeholders, regulatory support, and technological innovation play crucial roles in attaining long-term sustainability in Portland cement industries.

It is possible that increased energy recovery and efficiency could result in a significant overall environmental advantage in terms of respiratory inorganics, global warming, and non-renewable energy. Through the implementation of modernized production methods and the promotion of dry rotary kiln cement production technology as an alternative to shaft kiln cement production technology, the cement industry can effectively reduce the overall impact that it has on the environment. It is also strongly recommended that the distance and mode of transportation be optimized, that the consumption of limestone be reduced, that air pollution control systems be implemented, and that cement export be prioritized. The findings of this study will make a contribution to the improvement of the life cycle inventory database among cement industry professionals. Furthermore, they will supply policymakers with the necessary scientific information for estimating the environmental impacts that the national cement industry has on the environment. Furthermore, the decision-making processes that are involved in the establishment, reconstruction, expansion, or technological transformation of cement industries will be supported by these results.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

Halima Khalid Al-Shukaili: ***Investigation, Writing - review and editing****, Reyan Abdullah Ba Abood:* ***Literature Review, Data administration, review and editing*** *Abdul Rahman Al Murazza:* ***Literature Review, Data administration, review and editing****, Saikat Banerjee:* ***Conceptualization, Project administration, Supervision, Methodology, Investigation, Writing - original draft, and Writing - review and editing****.*

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