

# Assessing Air Pollution Mitigation in Cement Production: A Case Study of Lafarge Zambia and Community Impact in Chilanga District, Zambia

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## ABSTRACT

The cement industry remains essential for infrastructure development yet generates significant air pollution with consequent health and livelihood risks for surrounding communities. Despite global decarbonisation commitments and corporate mitigation pledges, evidence from developing countries suggests persistent implementation gaps. The research gap this study addresses lies in the limited empirical examination of whether documented corporate mitigation measures translate into measurable community-level livelihood protection, particularly for informal sector workers in African cement-producing areas. This study examines the effectiveness of air pollution mitigation measures at the Lafarge Zambia cement plant in Chilanga District, focusing on impacts on vegetable vendors in adjacent Freedom Compound. A convergent mixed methods design employed a quantitative survey of 87 vegetable vendors, four focus group discussions with community members, key informant interviews with three Zambia Environmental Management Agency officials and four community leaders, and systematic analysis of institutional reports and corporate documents. Dust exposure was measured through vendor-reported frequency of visible dust deposition on produce, with cross-validation against documented complaint records and institutional inspection reports. Economic impact was operationalised as reported weekly income loss, frequency of customer rejection, price discounting necessitated by dust, and disposal of unsalable produce. Despite documented commitments including electrostatic precipitators, baghouse filters, and water spraying systems, 81.6 per cent of vendors reported daily dust deposition on produce. Economic impacts included reduced sales reported by 67.8 per cent of respondents, discounted prices for affected produce, and product spoilage requiring disposal. Regulatory oversight was perceived as ineffective, with 70.1 per cent of vendors expressing low trust in ZEMA and 80.4 per cent expressing low trust in Lafarge. These findings indicate that community-perceived dust exposure persists at levels causing measurable economic harm, despite corporate claims of mitigation functionality. The study concludes that gaps between documented mitigation commitments and observed environmental outcomes arise not from absence of technology but from implementation and enforcement deficits. Positioning these findings within the global cement sector's decarbonisation trajectory and Africa's evolving regulatory landscape, the study argues that sustainable solutions require strengthened implementation, expanded monitoring, genuine community participation, and enhanced regulatory enforcement to protect vulnerable livelihoods and advance environmental justice.

**Keywords:** Air pollution, Cement dust, Mitigation effectiveness, Regulatory compliance, Environmental justice.

## INTRODUCTION

The cement industry constitutes a fundamental pillar of modern infrastructure development, yet its environmental footprint remains substantial. Liu et al. (2025), in their comprehensive analysis of China's cement industry utilising whole process material energy flow modelling, demonstrated that the sector contributes substantially to emissions of CO<sub>2</sub> equivalent, conventional air pollutants, and atmospheric mercury, establishing it as one of the most significant industrial sources of environmental contamination globally. Their study revealed that previous accounting frameworks frequently ignored emissions from mining, transportation, power use, and

waste co processing, which collectively contributed 12.1 per cent of CO<sub>2</sub> equivalent emissions and between 4.4 and 7.7 per cent of conventional air pollutant emissions from the cement sector. This finding aligns with what Watari et al. (2022) confirmed regarding the cement sector facing the most significant challenges in achieving both climate and air quality goals simultaneously. Watari and colleagues argued that supply side technological fixes alone cannot suffice without demand side measures including material efficiency and circular economy approaches. However, Nkhama et al. (2017), in their panel study of Zambian communities, demonstrated that even basic pollution control remains elusive in many developing country contexts, suggesting a fundamental disconnect between global aspirations and local realities.

Cocozza et al. (2024) evaluated an integrated biomonitoring approach in central Italy using tree rings, lichens, and beetles to assess anthropogenic impact of cement plants over three decades. Their study found trace elements of industrial origin in tree rings with maximum accumulation in 2012, while lichen transplants identified thallium and vanadium as the main elements contributing to atmospheric contamination with peaks at industrial sites. Significantly, they documented a lower number of beetle species at the industrial site, demonstrating that cement production impacts extend beyond human communities to broader ecosystem health. Martinez-Cruz, Rodriguez, and Sanchez (2023) similarly found that proximity to cement facilities in Colombia and Mexico was significantly associated with elevated rates of respiratory illness and measurable economic losses from reduced agricultural productivity. This is consistent with what Nkhama et al. (2015) discovered in their cross-sectional study of Zambian communities, where they found that respondents from Freedom Compound had significantly higher odds of experiencing eye, nasal, and sinus membrane irritations. Mungwa (2017), in his ethical investigation of the Lafarge plant, documented that dust emissions continued to adversely affect crop growth and productivity while residents suffered from respiratory tract infections, throat problems, and eye irritations. Furthermore, Chilala (2016), in his historical analysis, demonstrated that as early as 1952, the National Agricultural Research Institute at Mount Makulu discovered grave changes to soil chemistry attributed to cement dust deposition, indicating that pollution impacts have been documented for over seven decades. This historical persistence raises fundamental questions about why mitigation efforts have repeatedly failed to achieve lasting improvement.

Sub Saharan Africa presents a distinctive context for examining the environmental and social dimensions of cement production. The region is experiencing rapid urbanisation, with the United Nations Department of Economic and Social Affairs (2022) projecting that Africa's urban population will nearly triple by 2050, generating unprecedented demand for construction materials. Recent developments in environmental monitoring technology offer promising avenues for strengthening regulatory oversight. Ghana's Environmental Protection Agency launched the Ghana Online Continuous Emissions Monitoring System in 2025, representing Africa's first high tech emissions monitoring system designed to strengthen environmental quality management and tackle industrial pollution more effectively. The Ghanaian system enables real time detection of pollution incidents and verification of emission events, addressing longstanding challenges of data reliability and timeliness. Tanzania's National Environment Council has announced plans to roll out a similar system, indicating growing regional recognition of the need for enhanced monitoring capacity. However, Namiwa (2025) documented how Portland Cement Malawi Limited commenced mining operations at Chinkhumbe Hill without completing legally required compensation and relocation procedures, leaving villagers with cracked houses and damaged roofs while regulatory officials failed to act. This case illustrates the consequences when weak enforcement allows corporate interests to override legal protections for affected communities.

The compliance history of Lafarge Zambia provides important context. In 2009, the Environmental Council of Zambia, predecessor to ZEMA, took formal enforcement action against Lafarge for exceeding permissible emission limits, reducing the air emission licence validity period from twelve months to six months and requiring submission of stack emission reports every two weeks. An inspection team discovered that on 8 March 2009, the plant had emitted abnormal amounts of dust affecting surrounding buildings, motor vehicles, and plants for a distance of up to 1.6 kilometres. Subsequent years saw the company implement various pollution control upgrades, including electrostatic precipitators, bag filters, and water spraying systems. However, Mungwa (2017) found that dust emissions continued to adversely affect community wellbeing, and Nkhama et al. (2017) documented persistently elevated particulate concentrations.

The research gap that this study specifically addresses is threefold. First, while previous Zambian studies (Nkhama et al., 2015, 2017; Mungwa, 2017) documented respiratory health outcomes and general community

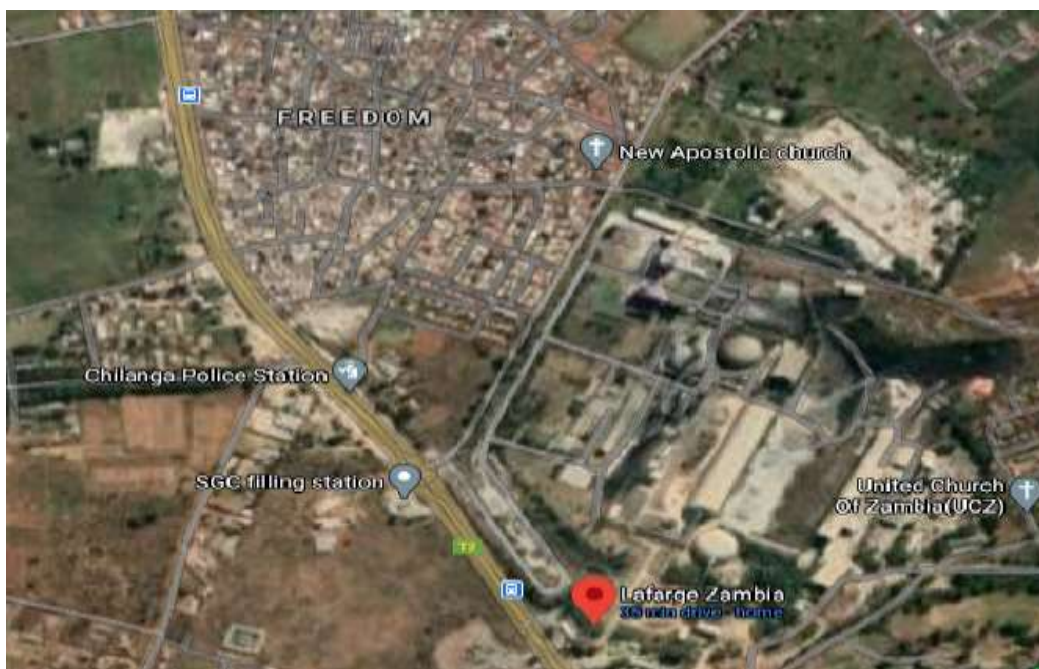
complaints, none have systematically quantified livelihood-specific economic impacts on informal food vendors who constitute a distinct and highly exposed occupational subgroup. Second, existing literature has not empirically examined the relationship between documented corporate mitigation investments and community-perceived outcomes at the household economic level. Third, no previous study has benchmarked Zambia's regulatory enforcement performance against emerging African innovations such as Ghana's continuous emissions monitoring system or Zimbabwe's conditional compliance certification framework. This study addresses these gaps by examining the effectiveness of air pollution mitigation measures implemented by Lafarge Zambia PLC, with specific focus on vegetable vendors in Freedom Compound, guided by four objectives: to assess the technical effectiveness of dust mitigation measures; to evaluate regulatory compliance monitoring by ZEMA; to document community perceptions of pollution impacts on livelihoods; and to identify barriers to effective mitigation positioned within global decarbonisation trends and regional regulatory innovations.

## METHODOLOGY

### Study Area

The study was conducted in Freedom Compound and surrounding areas adjacent to the Lafarge cement factory in Chilanga District, Lusaka Province, Zambia. Chilanga is located approximately 20 kilometres south of Lusaka's central business district. Freedom Compound is an informal, densely populated settlement situated immediately adjacent to the plant boundary, lying within the established pollution fallout zone of cement dust emissions. Prevailing wind patterns result in regular transport of particulate emissions towards residential areas, particularly during dry season conditions when atmospheric stability and low rainfall reduce natural removal of particulates. The local economy in Freedom Compound is dominated by informal sector activities, with vegetable vending representing a particularly important livelihood. Based on community mapping exercises and key informant consultations, the estimated population of active vegetable vendors in the study area was approximately 140 individuals. Figure 1 below shows the site where the study took place. It shows the location of the unplanned settlement (Freedom Compound) lying closely to Lafarge Cement Factory.

**Figure 1 Location Map of Lafarge Zambia PLC**



Source: Google maps (2020)

### Research Design and Sampling

The study adopted a convergent mixed methods design, integrating structured questionnaires, semi structured interviews, focus group discussions, and document review. This design was selected as appropriate for capturing

both the scope of impacts across the vendor population and depth of understanding regarding lived experiences and institutional dynamics. For vegetable vendors, simple random sampling was employed from a comprehensive list of active vendors compiled through market visits and community consultation, achieving responses from 87 vendors representing approximately 62 per cent of the estimated population. For key informants, purposive sampling ensured inclusion of individuals with specific knowledge and institutional positions, including three ZEMA officials, four community leaders, and one Lafarge environmental manager. Four focus group discussions were conducted, each comprising six to eight participants, stratified to include men and women separately to facilitate open discussion of gender differentiated impacts.

Data collection occurred over four weeks in May and June 2019. Questionnaires covered demographic characteristics, vending activities, exposure patterns, economic impacts, and perceptions of corporate responsibility and regulatory effectiveness. Regarding variable measurement: dust exposure frequency was operationalised using a five-point Likert-type scale (never, occasionally, several times per week, daily, multiple times daily), with daily deposition defined as visible dust settlement on produce surfaces at least once per 24-hour period. Economic impact measurement triangulated three indicators: (i) self-reported weekly income loss calculated as difference between expected and actual earnings attributed to dust-related customer rejection; (ii) frequency of price discounting necessitated by visible dust; and (iii) reported disposal volume of unsalable produce measured categorically (none, minimal, moderate, substantial). These perceptual measures were cross-referenced where possible with documented complaint records from ZEMA and Lafarge community relations logs, though independent environmental monitoring data (e.g., continuous particulate matter readings) were not accessible to the researcher. Interviews explored institutional perspectives on pollution mitigation, regulatory compliance, and community engagement. Focus group discussions examined collective experiences of dust pollution, perceptions of changes over time, and views on appropriate solutions. Document review included the Environmental Management Act, environmental impact statements, emission monitoring reports, corporate sustainability reports, and previous research studies.

## Data Analysis

Quantitative data from vendor questionnaires were analysed using descriptive and inferential statistics. Frequencies and percentages summarised demographic characteristics, exposure patterns, economic impacts, and trust perceptions. Cross tabulation with chi square tests examined associations between demographic variables and reported impacts. Statistical significance was set at  $p$  less than 0.05. Qualitative data from interviews and focus group discussions were analysed using thematic analysis, following Braun and Clarke's framework of familiarisation, coding, theme development, and refinement. Triangulation across data sources strengthened validity, with quantitative findings contextualised and illuminated by qualitative insights. Ethical approval was obtained from the University of Lusaka Research Ethics Committee (Approval No. UNILUS/REC/2019/017) and the Zambia National Health Research Authority (Approval No. ZNHRA/2019/042). All participants provided written informed consent, with confidentiality protected through anonymisation and secure data storage. The study was conducted in accordance with the Declaration of Helsinki.

## RESULTS

### Demographic Characteristics of Respondents

The study achieved responses from 87 vegetable vendors. Female vendors predominated at 72.4 per cent ( $n=63$ ), consistent with broader patterns in Zambian informal food trading where women constitute the majority of market traders. Male vendors comprised 27.6 per cent ( $n=24$ ). The age distribution showed concentration in economically active years, with 39.1 per cent ( $n=34$ ) aged 31 to 40 years, 25.3 per cent ( $n=22$ ) aged 41 to 50 years, 21.8 per cent ( $n=19$ ) aged 21 to 30 years, and 13.8 per cent ( $n=12$ ) aged 51 to 64 years. Education levels were relatively low, with 16.1 per cent ( $n=14$ ) having no formal schooling, 47.1 per cent ( $n=41$ ) having completed primary education, 33.3 per cent ( $n=29$ ) having secondary education, and only 3.4 per cent ( $n=3$ ) having tertiary education. Regarding years of vending, 12.6 per cent ( $n=11$ ) had vended for less than two years, 33.3 per cent ( $n=29$ ) for two to five years, 35.6 per cent ( $n=31$ ) for six to ten years, and 18.4 per cent ( $n=16$ ) for more than ten years. Length of residence in Freedom Compound showed 14.9 per cent ( $n=13$ ) residing less than five years, 32.2 per cent ( $n=28$ ) for five to ten years, 35.6 per cent ( $n=31$ ) for eleven to twenty years, and 17.2

per cent (n=15) for more than twenty years. Chi square analysis revealed no significant association between education level and likelihood of reporting dust impacts ( $\chi^2 = 4.23$ ,  $df = 3$ ,  $p = 0.237$ ), suggesting that dust exposure affects vendors regardless of educational background.

**Table 1 Demographic characteristics of vegetable vendor respondents (n=87)**

Characteristic	Category	Frequency (n)	Percentage (%)	Cumulative (%)
Sex	Female	63	72.4	72.4
	Male	24	27.6	100.0
Age group	21-30 years	19	21.8	21.8
	31-40 years	34	39.1	60.9
	41-50 years	22	25.3	86.2
	51-64 years	12	13.8	100.0
Education level	No formal schooling	14	16.1	16.1
	Primary education	41	47.1	63.2
	Secondary education	29	33.3	96.5
	Tertiary education	3	3.4	100.0
Years vending	Less than 2 years	11	12.6	12.6
	2-5 years	29	33.3	45.9
	6-10 years	31	35.6	81.5
	More than 10 years	16	18.4	100.0
Length of residence	Less than 5 years	13	14.9	14.9
	5-10 years	28	32.2	47.1
	11-20 years	31	35.6	82.7
	More than 20 years	15	17.2	100.0

Source: Author's computation based on survey data (2020)

The predominance of female vendors reveals the gendered dimension of pollution vulnerability. Women bear a disproportionate burden of environmental harm through their primary role in informal food trading, facing compounded vulnerabilities from industrial pollution due to their dual responsibilities for income generation and household wellbeing. The concentration of vendors in economically active age groups indicates that pollution affects individuals during prime working years when livelihood contributions to household welfare are most

critical. Low educational attainment constrains vendors' capacity to access formal complaint mechanisms or engage with regulatory processes, explaining the low rate of formal complaints (9.2 per cent) and creating power asymmetries in interactions with corporate and regulatory officials. The substantial proportion of vendors with over ten years of vending experience provides exceptional temporal depth to community observations. These experienced vendors possess longitudinal knowledge of pollution patterns spanning multiple management regimes, representing an undervalued knowledge system for environmental monitoring. The finding that 52.8 per cent of vendors have resided in Freedom Compound for more than ten years establishes them as long term witnesses to environmental change.

### Implementation of Mitigation Measures and Community Perceptions

Document review confirmed that Lafarge Zambia has formally committed to a range of mitigation measures, including electrostatic precipitators on kiln exhaust stacks, baghouse filters at multiple process points, fog cannons and water spraying systems at material transfer points, enclosed material handling, road watering programmes, vegetative screening, and an ISO 14001 certified environmental management system. Despite these documented commitments, community members consistently reported that dust pollution remains a visible and persistent problem.

While the findings presented above derive primarily from vendor perceptions, triangulation with institutional documents revealed partial convergence. Lafarge Zambia's internal emission monitoring reports (referenced in ZEMA inspection records from 2017–2019) indicated compliance with stack emission limits, yet these documents did not capture fugitive dust emissions from material handling, road transport, or stockpiles - sources consistently identified in focus group discussions as responsible for the visible dust affecting produce. No continuous ambient air quality monitoring data from Freedom Compound itself were available from either ZEMA or Lafarge, meaning that community perceptions constitute the only systematically collected longitudinal evidence of ground-level impacts within the residential and vending zone. The frequency of dust impacts was striking, with 81.6 per cent (n=71) of vendors reporting daily dust settlement on their produce. A further 12.6 per cent (n=11) reported dust settlement several times per week, while only 5.7 per cent (n=5) reported occasional deposition. No respondents reported never experiencing dust deposition. Seasonal variation was evident, with 94.3 per cent (n=82) reporting that dust problems worsen during the dry season months from May to October. Table 2 below illustrates these findings.

**Table 2 Community perceptions of mitigation measure effectiveness (n=87)**

Mitigation Measure	Aware of Measure (%)	Believe Measure is Effective (%)	Have Observed Improvement (%)	95% Confidence Interval (Effectiveness)
Electrostatic precipitators	23.0	9.2	4.6	3.2-15.2
Baghouse filters	18.4	6.9	3.4	1.8-12.0
Fog cannons and water sprays	67.8	18.4	11.5	10.1-26.7
Enclosed material handling	12.6	4.6	2.3	0.9-9.6
Road watering and sweeping	74.7	21.8	13.8	12.4-31.2
Vegetative screening	56.3	13.8	8.0	6.5-21.1

Mitigation Measure	Aware of Measure (%)	Believe Measure is Effective (%)	Have Observed Improvement (%)	95% Confidence Interval (Effectiveness)
Complaint mechanisms	41.4	5.7	2.3	1.2-10.3
Environmental management system	8.0	2.3	1.1	0.1-6.5

Source: Author's computation based on survey data (2020)

While awareness of visible measures such as road watering (74.7 per cent) and fog cannons (67.8 per cent) was relatively high, perceived effectiveness was low across all measures. The gap between corporate investment and community observation is evident, with no measure achieving even 25 per cent perceived effectiveness. This discordance suggests either that technical measures are inadequately maintained, that fugitive emission pathways circumvent them, or that community thresholds for acceptable dust levels differ from regulatory benchmarks.

### Economic Impacts on Vending Livelihoods

Economic consequences of dust pollution were substantial and multi-dimensional. Lost sales due to customer rejection were reported by 67.8 per cent (n=59) of vendors. Reduced prices for affected produce were reported by 48.3 per cent (n=42). Disposal of unsalable produce was reported by 35.6 per cent (n=31). Customers commented on dust regularly according to 78.2 per cent (n=68) of respondents. A minority of vendors, 20.7 per cent (n=18), had changed their vending location specifically due to dust problems. Investment in protective covers was reported by 83.9 per cent (n=73), representing the most common coping strategy. The mean estimated weekly income loss reported by affected vendors was ZMW 87.50 (approximately USD 5.80 at 2019 exchange rates), representing a substantial proportion of typical daily earnings from vending.

**Table 3 Economic impacts and coping strategies (n=87)**

Impact or Strategy	Frequency (n)	Percentage (%)	95% Confidence Interval
<b>Impacts</b>			
Dust settles on vegetables daily	71	81.6	72.5-88.7
Customers comment on dust regularly	68	78.2	68.5-86.1
Lost sales due to customer rejection	59	67.8	57.4-77.3
Reduced prices for affected produce	42	48.3	37.6-59.0
Disposal of unsalable produce	31	35.6	25.7-46.6
Changed vending location due to dust	18	20.7	12.8-30.8
<b>Coping Strategies</b>			
Invested in protective covers	73	83.9	75.0-90.6

Impact or Strategy	Frequency (n)	Percentage (%)	95% Confidence Interval
Shaking off dust from produce	67	77.0	67.5-85.0
Washing produce before sale	41	47.1	36.4-57.9
Discounting prices for dusty produce	42	48.3	37.6-59.0
Formal complaints to authorities	8	9.2	4.1-17.3

Source: Author's computation based on survey data (2020)

The high prevalence of daily dust deposition (81.6 per cent) and consequent sales losses (67.8 per cent) demonstrates the pervasive nature of economic disruption. The contrast between widespread adoption of individual coping strategies and the rarity of formal complaints (9.2 per cent) reflects low institutional trust.

### Trust in Institutions

Trust ratings for Lafarge Zambia were very low or low among 80.4 per cent (n=70) of respondents. Specifically, 47.1 per cent (n=41) expressed very low trust and 33.3 per cent (n=29) expressed low trust, while only 13.8 per cent (n=12) expressed moderate trust and 5.7 per cent (n=5) expressed high or very high trust. For ZEMA, 70.1 per cent (n=61) expressed very low or low trust, comprising 31.0 per cent (n=27) very low and 39.1 per cent (n=34) low. Moderate trust in ZEMA was expressed by 20.7 per cent (n=18), while 9.2 per cent (n=8) expressed high or very high trust. Local government received somewhat higher ratings, with 21.8 per cent (n=19) very low trust, 35.6 per cent (n=31) low trust, 27.6 per cent (n=24) moderate trust, and 14.9 per cent (n=13) high or very high trust. Traditional leaders were the most trusted institution, with only 9.2 per cent (n=8) expressing very low trust, 19.5 per cent (n=17) low trust, 33.3 per cent (n=29) moderate trust, and 38.1 per cent (n=33) high or very high trust. Table 4 below summarises these results.

**Table 4 Community trust in institutions (vendor perceptions, n=87)**

Institution	Very Low Trust n (%)	Low Trust n (%)	Moderate Trust n (%)	High Trust n (%)	Very High Trust n (%)	Mean Trust Score (1-5)
Lafarge Zambia	41 (47.1)	29 (33.3)	12 (13.8)	4 (4.6)	1 (1.1)	1.80
ZEMA	27 (31.0)	34 (39.1)	18 (20.7)	6 (6.9)	2 (2.3)	2.10
Local government	19 (21.8)	31 (35.6)	24 (27.6)	9 (10.3)	4 (4.6)	2.40
Traditional leaders	8 (9.2)	17 (19.5)	29 (33.3)	21 (24.1)	12 (13.8)	3.14

Source: Author's computation based on survey data (2020)

Mean trust scores (calculated on a scale where 1 equals very low trust and 5 equals very high trust) show a clear hierarchy: traditional leaders (3.14) command the highest trust, followed by local government (2.40), ZEMA (2.10), and Lafarge Zambia (1.80).

## DISCUSSION

The findings of this study reveal systematic gaps between documented mitigation commitments and actual environmental outcomes when benchmarked against evolving international standards. Liu et al. (2025) declared that previous accounting frameworks significantly underestimated total emissions by excluding mining, transportation, and waste co processing stages. This has been confirmed by Coccozza et al. (2024) in their integrated biomonitoring study, which demonstrated that cement plant impacts extend far beyond stack emissions to affect entire ecosystems through cumulative deposition pathways. The persistent dust complaints in Freedom Compound reflect precisely the monitoring blind spots that Liu et al. (2025) identified in conventional regulatory oversight. Furthermore, Chilala (2016) documented that soil chemistry changes attributable to cement dust were first recorded in 1952, indicating that regulatory frameworks have failed for over seven decades to address impacts that were scientifically documented decades ago. This historical persistence suggests that the problem is not primarily technical but institutional and political.

Martinez-Cruz et al. (2023) submitted that proximity to cement facilities in Colombia and Mexico was significantly associated with elevated rates of respiratory illness and economic losses from reduced agricultural productivity. This has been corroborated by Nkhama et al. (2017) in the Zambian context, who demonstrated elevated PM concentrations and respiratory symptoms in Freedom Compound residents through objective monitoring. The current study extends these findings by documenting the specific livelihood impacts on vegetable vendors, revealing economic pathways through which pollution harms vulnerable populations. The finding that 81.6 per cent of vendors experience daily dust deposition aligns with what Mungwa (2017) documented regarding persistent community complaints, suggesting that despite corporate investments in mitigation technology, observable environmental outcomes have not improved for affected residents. The finding that 67.8 per cent of vendors report lost sales due to customer rejection indicates that pollution imposes economic costs through market mechanisms, not merely through health expenditure pathways. This economic dimension has been largely absent from regulatory impact assessments and corporate reporting.

Ghana's launch of the Online Continuous Emissions Monitoring System in 2025 represents a significant regulatory innovation that addresses what the Global Cement and Concrete Association (2025) identified as critical gaps in data reliability and timeliness. The Ghanaian system enables real time detection of pollution incidents and verification of emission events, addressing what Watari et al. (2022) identified as the need for integrated monitoring approaches that capture both point source and fugitive emissions. Zambia's regulatory performance falls short of these emerging regional standards. While the 2009 ECZ enforcement action demonstrated that regulatory authorities can take meaningful action when violations are documented, the subsequent lack of visible enforcement has undermined deterrent effect and community confidence. This is consistent with what Namiwa (2025) documented in Malawi, where regulatory failure allowed operations to proceed without adequate environmental assessment or community compensation. The Zimbabwean approach, documented in the Environmental Management Agency (2024) compliance certificate for the Magunje cement project, offers a contrasting model with time limited certificates, explicit performance conditions, and clear suspension provisions.

The evidence from this study linking conclusions to specific data points is as follows: the conclusion that regulatory monitoring has not translated into effective pollution control rests on three empirical pillars (i) 81.6 per cent daily dust deposition despite documented ZEMA inspection visits; (ii) the absence of continuous ambient monitoring data from Freedom Compound itself; and (iii) the historical pattern whereby enforcement action in 2009 (licence reduction) produced no sustained improvement detectable by community respondents seven decades after first documented impacts (Chilala, 2016). The conclusion regarding eroded community trust derives directly from Table 4, where 70.1 per cent expressed low or very low trust in ZEMA and 80.4 per cent in Lafarge, with mean trust scores of 2.10 and 1.80 respectively on a five-point scale. The conclusion regarding economic impacts is anchored in Table 3, showing 67.8 per cent lost sales and mean weekly income loss of ZMW 87.50 among affected vendors. This economic dimension has been largely absent from regulatory impact assessments and corporate reporting.

The African Commission's Resolution ACHPR/Res.605 (African Commission on Human and Peoples' Rights, 2024) reaffirming the mandate of its Working Group on Extractive Industries provides a continental framework

for addressing the accountability deficits documented in this study. The resolution explicitly recalls Articles 21 and 24 of the African Charter on the rights of peoples to freely dispose of their natural resources and to a generally satisfactory environment. This finding aligns with what Kunz, Hein, and Sobirin (2023) documented in the Kendeng Mountains case, where the Sedelur Sikep indigenous community successfully challenged cement factory construction by asserting their rights under international law and questioning procedural aspects of the permit process. Kunz et al. (2023) argued that environmental justice requires not only procedural participation but epistemic justice, challenging the dominant forms of knowledge production that exclude local and indigenous perspectives. Similar epistemic justice concerns arise in Chilanga, where community observations of persistent dust over decades are systematically devalued relative to corporate monitoring data that may not capture fugitive emissions or cumulative impacts. The low trust in ZEMA (70.1 per cent expressing low or very low trust) and Lafarge (80.4 per cent) reflects this systematic devaluation of community knowledge. The high trust in traditional leaders (38.1 per cent high or very high trust) suggests that culturally legitimate institutions could play a greater role in environmental governance if appropriately empowered.

The United Nations Industrial Development Organization (2025) emphasised that successful cement sector decarbonisation in emerging markets and developing economies requires adaptation to local conditions, stakeholder priorities, and development trajectories. This has been confirmed by Liu et al. (2025), who demonstrated that synergistic mitigation of pollutants and CO<sub>2</sub> is achievable through whole process accounting and integrated control strategies. However, while global industry leadership accelerates decarbonisation through carbon capture technologies and alternative fuels, basic dust control remains inadequate in Chilanga after seven decades of operation. This disparity reflects what Watari et al. (2022) identified as the need for both supply side and demand side measures, but even basic supply side controls remain elusive in contexts where regulatory enforcement is weak and community voice is marginalised. The economic impacts documented in this study reveal the vulnerability of informal sector workers to environmental degradation. Chen (2020) emphasised that informal sector workers typically lack access to formal employment protections, health insurance, or compensation mechanisms, making them more susceptible to environmental shocks. This pattern is confirmed, with vegetable vendors lacking any form of compensation for pollution related losses and expressing low confidence in formal complaint mechanisms. The finding that only 9.2 per cent of vendors have ever made formal complaints reflects not apathy but rational assessment of institutional responsiveness.

## CONCLUSION AND RECOMMENDATIONS

### Conclusion

This study assessed air pollution mitigation effectiveness at the Lafarge Zambia cement plant, focusing on vegetable vendors in Freedom Compound. Five key conclusions emerge. First, a significant and persistent gap exists between documented mitigation commitments and actual environmental outcomes, with visible dust deposition continuing despite corporate investment in pollution control technologies. Second, regulatory compliance monitoring by ZEMA has not translated into effective pollution control when compared with emerging regional innovations in Ghana, Zimbabwe, and Tanzania. Third, community trust in both corporate and regulatory institutions has been significantly eroded, with over 80 per cent of vendors expressing low trust in Lafarge and 70 per cent low trust in ZEMA, reflecting cumulative decades of unaddressed complaints. Fourth, the economic impacts of pollution on vulnerable livelihoods are substantial, with 81.6 per cent of vendors experiencing daily dust deposition and consequent income losses through reduced sales, price discounts, and product spoilage. Fifth, Zambia's obligations under international law, including the African Charter on Human and Peoples' Rights, require enhanced protection for affected communities, yet implementation gaps suggest these obligations are not being met. The primary obstacles to effective mitigation are not technical but institutional and political, requiring strengthened implementation, robust enforcement, and genuine community participation to achieve environmental justice.

### Recommendations

Lafarge Zambia should conduct comprehensive pollution control reviews using whole process accounting methodologies, adopt publicly accessible continuous emissions monitoring systems, and ensure genuine community participation including women vendors.

ZEMA should strengthen inspection capacity through continuous emissions monitoring, expand ambient air quality monitoring in surrounding communities, and establish transparent complaint mechanisms with timely feedback. Specifically, the Zambia Environmental Management Agency (ZEMA) should, within its mandate under the Environmental Management Act No. 12 of 2011, require Lafarge Zambia to install and maintain a publicly accessible continuous particulate monitor at the Freedom Compound community boundary, with real-time data streaming to a public dashboard. ZEMA should also conduct quarterly community feedback meetings where monitoring data are reviewed alongside documented complaints, thereby operationalising the principle of procedural environmental justice.

Central government should strengthen the Environmental Impact Assessment follow up framework, allocate adequate resources to ZEMA, and ensure implementation of Zambia's obligations under the African Charter through engagement with the African Commission's Working Group on Extractive Industries.

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## Declarations

Ethics approval and consent to participate: Ethical approval was obtained from the University of Lusaka Research Ethics Committee (Approval No. UNILUS/REC/2019/017) and the Zambia National Health Research Authority (Approval No. ZNHRA/2019/042). All participants provided written informed consent prior to data collection. The study was conducted in accordance with the Declaration of Helsinki.

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