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Industrial Air pollutants and Chemical Control Strategies: Insight from NCR-Delhi and Haryana

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Abstract

The present case study evaluates government policies and implementation steps used to control pollutants from factories in NCR-Delhi and Haryana. The study integrates primary survey data (factory managers, workers, pollution officials, residents) with up-to-date secondary sources including CAQM orders, CPCB/National Clean Air Programme material, CSE industrial-assessment reports, Haryana's State Environment Plan (SEP), and recent technical studies on diesel generator emissions. The paper finds that while Delhi-NCR's interventions prioritize real-time monitoring (OCEMS), emergency responses (GRAP), and hotspot action plans, Haryana has developed a strategic State Environment Plan focused on non-CO_2 pollutants and is actively upgrading industrial monitoring but faces implementation gaps (monitoring station downtime, under-utilised NCAP funds in some districts, and persistent DG pollution). The study concludes with targeted recommendations: universal OCEMS for medium industries, outcome-based emission standards, finance for SME upgrades, stronger cross-state data integration, and community-facing transparency dashboards.

Keywords: Industrial pollution; OCEMS; GRAP; CAQM; HSPCB; NCAP; NCR-Delhi; Haryana; DG emissions; hotspot management

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Introduction

Industrial and process emissions are a persistent source of ambient $PM_{2.5}$, PM_{10}, SO_2, NO_x, VOCs and toxic effluents in North India's airshed. NCR-Delhi (which includes adjacent districts in Haryana, UP and Rajasthan) suffers chronically elevated particulate concentrations; industrial emissions from red-category factories, brick kilns, thermal plants and diesel generator (DG) sets are important contributors alongside traffic and biomass burning. A focused, questionnaire-based comparison of NCR-Delhi and Haryana helps test whether policy design differences (regional emergency authorities vs state planning) translate into different outcomes on the ground. The paper combines primary survey findings (questionnaire results) and a strengthened secondary evidence base (CAQM, CPCB, HSPCB, CSE, and technical studies) to measure policy design, monitoring, enforcement and outcomes [1-4]. The abbreviations including OCEMS (Online Continuous Emission Monitoring System), GRAP (Graded Response Action Plan), SEP (Site Environmental Plan), NCAP (National Clean Air Programme).

Although multiple technical assessments by CAQM, CPCB, HSPCB and CSE document pollution levels and sectoral source contributions for the NCR airshed, these reports largely provide emission inventories, compliance summaries and regulatory directives, but do not examine how differences in policy design, implementation pathways, institutional capacity, and on-ground enforcement actually manifest across jurisdictions within the same airshed. Existing studies also do not integrate primary, field-level evidence from industrial units to assess whether regulatory expectations translate into demonstrable behavioural change or improved compliance practices. This creates a clear research gap: the absence of comparative, ground-truth data linking policy architecture with real-world implementation outcomes across NCR-Delhi and Haryana. The present study addresses this gap by combining a structured questionnaire-based survey of industrial units with strengthened secondary evidence, enabling an empirical assessment of how regulatory design (centralised emergency authority vs. state-led planning) influences monitoring, enforcement, and compliance outcomes an area not captured in prior CAQM/CPCB/CSE assessments.

Objective of this comparative case study

The objective of this comparative case study is to empirically evaluate how differences in regulatory design and governance structures between NCR-Delhi and Haryana shape actual on-ground industrial compliance, monitoring

effectiveness, and enforcement outcomes. Specifically, the study aims to (i) compare the institutional mechanisms—such as CAQM's regional, centralised command-and-control framework versus Haryana's state-led regulatory planning; (ii) assess how these frameworks influence industry-level practices captured through primary questionnaire data; and (iii) determine whether variations in policy architecture translate into measurable differences in air-pollution management performance. This explicit comparative objective is not addressed in existing CAQM, CPCB or CSE reports, which focus on emissions and compliance status but do not link policy structures with field-level behavioural and operational outcomes.

Design of the Survey

The survey is designed to test the following hypotheses and guiding research questions:

Hypotheses

1. Differences in regulatory design (CAQM's regional authority vs. Haryana's state-led framework) leads to measurable differences in on-ground industrial compliance behaviour.
2. Industries in NCR-Delhi experience stronger monitoring intensity and enforcement pressure than industries in non-NCR districts of Haryana.
3. Firms operating under clearer, centralised directives (CAQM) demonstrate higher adoption of pollution-control technologies and cleaner fuels compared to firms under decentralised state systems.
4. Perceived regulatory certainty, inspection frequency, and penalty credibility are positively associated with better environmental management practices at the unit level.

Key Research Questions

How do industries in NCR-Delhi and Haryana perceive the stringency, clarity and consistency of air-quality regulations?

1. Do monitoring and inspection practices differ across the two regulatory settings, and how do firms respond to these differences?
2. Are enforcement actions (notices, penalties, closures) viewed as credible and fair by industrial units in both regions?
3. What operational changes—technology upgrades, fuel switching, record-keeping have industries undertaken, and do these changes vary between NCR-Delhi and Haryana?
4. How do institutional factors (policy design, governance structure, coordination mechanisms) translate into actual environmental outcomes at the unit level?

Context: Policy Instruments & Recent Developments (Key Facts)

Below are the most relevant recent developments and policy tools; these are the factual backbone used later in analysis. The Commission for Air Quality Management (CAQM) reports that 3,551 industrial units in the NCR have been identified for OCEMS installation and operationalization, and a dedicated OCEMS cell has been set up to track stack emissions in real time[1]. CAQM's GRAP orders remain the operational emergency framework specific orders and stage-wise activations for Delhi-NCR are published and updated frequently to respond to deteriorating AQI conditions [2]. The Government of NCT of Delhi has identified 13 industrial/urban hotspots (e.g., Narela, Bawana, Wazirpur, Okhla, Mayapuri) for targeted industrial emission control [3]. Haryana launched a State Environment Plan (SEP, 2025) with a unique emphasis on non-CO_2 pollutants (short-lived climate pollutants and PM sources), and accompanying technical work (TERI / IGSD / state partnership) [4]. A technical study (CSTEP) estimated that diesel generator sets emitted >1,121 tonnes of $PM_{2.5}$ in 2022 in Haryana signaling an underappreciated industrial/residential source of localized PM [5]. A newspaper analysis shows Faridabad under-spent NCAP allocations (used ~40% of allocated funds) and invested little in industrial emissions (most funds went to dust control). This highlights implementation and priority-setting gaps at city level [6].

The government briefings or newspaper-style summaries will be substantially rewritten to reflect analytical, scholarly interpretation rather than descriptive reporting. Instead of reproducing policy announcements or summarising official documents, the revision will synthesise regulatory information critically, link each policy element directly to the study's research questions and conceptual framework, avoid narrative reporting of government actions unless analytically necessary, and emphasise comparative analysis, theory-driven interpretation, and empirical insights from

the survey data. This restructuring will ensure that the manuscript maintains an academic tone and focuses on original analysis rather than descriptive restatement of official sources.

Methodology: Questionnaire Design & Sample

Questionnaire design

We improved the original instrument to probe policy awareness, monitoring practice, enforcement experience, fuel & technology choices, DG usage, and NCAP/SEP familiarity. The questionnaire included 30 closed items across Awareness, Monitoring & Tech, Enforcement, Finance & Incentives, Community Impact, 12 open-ended items for qualitative comments (barriers, suggestions).

Sampling & respondents

Total respondents: N = 320 (expanded from original plan to increase statistical power). The Delhi NCR (N = 180): respondents from industrial hotspots (Narela 40; Bawana 30; Mayapuri 30; Okhla 40; other 40). The Haryana (N = 140): respondents from Faridabad 40; Panipat 35; Gurugram 30; Sonipat 35.

Stakeholder mix: Factory managers (110), Pollution board / municipal inspectors (40), Workers (80), Local residents / community leaders (90).

Justification for Sample Distribution

The sample size distribution (e.g., 40 from Narela, 30 from Bawana, etc.) will be justified based on Cluster size and density, Sectoral concentration and Access feasibility and permissions. Narela and Bawana are among the largest planned industrial areas in NCR, with thousands of units; hence they were allocated proportionally larger samples. The Clusters with higher proportions of red and orange-category industries were prioritised. The Field access, willingness of units to participate, and availability of cluster association support influenced feasible sample allocation. The Data collection period for Field survey is from August to October 2025.

Analytical approach

The Analytical approach includes Descriptive statistics (mean, SD), Two-sample t tests to compare mean responses between Delhi and Haryana, Thematic coding for open-ended responses, and Triangulation against secondary data (CAQM OCEMS roll-out, CAQM GRAP orders, HSPCB SEP, CSE & CPCB hotspot analyses).

Results (Selected Quantitative Findings)

Awareness & Policy Familiarity

Indicator	Delhi (mean ± SD)	Haryana (mean ± SD)	p-value
Awareness of emission standards	4.3 ± 0.6	3.6 ± 0.8	<0.001
Knowledge of OCEMS requirement	4.1 ± 0.7	3.4 ± 0.9	<0.001
Awareness of GRAP triggers	4.0 ± 0.8	3.2 ± 1.0	<0.001

Interpretation

Delhi respondents were significantly more aware of regulatory instruments (OCEMS, GRAP, consent conditions) which aligns with active CAQM/DPCC communication and OCEMS identification in NCR [1].

Monitoring & Compliance

Indicator	Delhi	Haryana
Proportion of firms reporting installed CEMS/OCEMS	62%	37%
Firms reporting third-party audits in last 12 months	48%	29%
Respondents reporting at least one govt inspection last 6 months	58%	35%

Triangulation

CAQM has identified 3,551 industrial units for OCEMS in NCR; our field results align with partial installations and operationalization in Delhi clusters but lower coverage in Haryana clusters especially outside Gurugram and Faridabad urban limits [1].

DG Use & Localized Emissions

The DG Use & Localized Emissions includes the average number of industrial DG hours per day (winter). Delhi clusters mean 3.2 hours; Haryana clusters mean 4.6 hours (higher reliance in Haryana for backup and process continuity). The CSTEP study indicates DGs in Haryana contributed ~1.1 Gg (1,121 tonnes) $PM_{2.5}$ in 2022, concentrated in several districts including Panipat, Bhiwani and Gurugram; our survey confirmed persistent DG use in Haryana manufacturing zones [5]. The NCAP Funds & Local Investment (Faridabad example) includes Local officials in Faridabad reported suboptimal NCAP expenditure patterns: ~40% of allocated funds used, with <1% earmarked to address direct industrial emissions per local reporting consistent with press analyses [6].

Qualitative Findings (Themes from Open-Ended Responses)

1. **Cost & Finance Barrier:** SMEs in Panipat/Faridabad repeatedly cited capital costs for ESPs, bag filters, or fuel switching as the primary obstacle. Many requested low-interest loan schemes.
2. **Monitoring Trust Deficit:** Several respondents (across both regions) suspected tampering or manipulation of OCEMS/CEMS data if only industry-operated without third-party validation.
3. **Capacity & Skilled O&M:** Industry managers reported lack of trained staff to operate & maintain ETPs/ETPs/OCEMS, creating performance gaps even when equipment is nominally present.
4. **Interagency confusion:** Local managers reported overlapping inspections from multiple agencies (DPCC/HSPCB/municipal), causing compliance fatigue and uncertainty over reporting formats.
5. **Community access to data:** Residents requested public dashboards showing factory stack emissions and enforcement actions.

Delhi-NCR's CAQM-led approach (OCEMS cell, GRAP implementation, hotspot lists) has raised awareness and inspection frequency in Delhi clusters; the 3,551-unit OCEMS identification demonstrates scale and an institutional push for real-time monitoring. Nevertheless, installation and data reliability remain work in progress [1, 2].

Haryana's strategic advantage SEP and non-CO_2 focus but execution challenges

Haryana's SEP (2025) provides a strong strategic direction on non-CO_2 pollutants and seeks to integrate industrial policy with SLCP and PM pathways. However, the state faces pragmatic problems: CAAQMS maintenance lapses and DG emissions remain stubborn sources, and some monitoring stations were reported non-functional at times undermining data continuity and enforcement [4, 7].

DG sets: a serious local contributor (policy blindspot)

The technical estimate of >1,121 tonnes $PM_{2.5}$ from DGs in Haryana (2022) underlines a policy blind spot: DGs are a distributed, hard-to-regulate source across industrial and residential premises. Addressing DG pollution requires targeted programs (replacement, scrappage, fuel switching, solar + storage incentives) [5].

Finance, clusters and SMEs

SMEs constitute the majority of polluting units in Haryana clusters (Panipat, Faridabad). They respond to capital constraints and need pooled financing (CETP upgrades, shared OCEMS, cluster modernization). The Faridabad NCAP fund-use example shows misaligned priorities can reduce industry-focused investment [6].

Governance & transparency

Our survey and triangulated sources indicate a demand for third-party audits, transparent dashboards, public disclosure of OCEMS/CEMS data and clear interagency reporting pathways (e.g., a central NCR command portal). These steps would increase trust and compliance.

Policy Recommendations (Targeted & Evidence-Linked)

1. **Scale & Mandate OCEMS/CEMS:** Make OCEMS mandatory for all medium and large industrial units across NCR and priority districts in Haryana; ensure central aggregation and public dashboards. (Supported by CAQM OCEMS push and field survey showing higher compliance where monitoring is mandated) [1].

2. **Third-party verification & tamper-proof data:** Mandate independent periodic audits of OCEMS/CEMS and integrate tamper-detection features; publicize audit summaries. (Addresses trust deficits from survey) [8].
3. **DG set mitigation strategy:** Launch a state-level DG mitigation program in Haryana: targeted scrappage, incentives for gas/solar backup, and retrofit norms for large industrial DGs. This responds to quantified DG PM emissions reported by CSTEP and field confirmation [5].
4. **Cluster modernization finance:** Create a state/NCR pooled finance instrument (low-interest loans, grants) to help SMEs invest in APCDs and access shared CETPs. (Motivated by SME cost barrier theme) [6].
5. **Outcome-based standards & flexible tech choices:** For industrial clusters introduce performance thresholds (emission concentration limits) rather than prescriptive equipment lists, allowing cost-effective technology choices while ensuring outcomes. (Survey showed managers prefer flexibility) [9].
6. **Maintenance & uptime of monitoring networks:** Prioritize maintenance contracts for CAAQMS in Haryana and NCR to avoid outages (evidence: reports of non-functional stations) [7].
7. **Public dashboards & grievance redress:** Publish OCEMS/CEMS and inspection results in real time to foster community oversight and faster enforcement. (Respondent community demand) [8].

Core aspects of policy effectiveness

The study compares four core aspects of policy effectiveness across NCR-Delhi and Haryana:

1. Policy Design and Institutional Architecture: The Centralised, emergency-response-oriented governance under CAQM versus state-level regulatory planning under HSPCB and line departments. It reflects clarity of responsibilities, coordination mechanisms, and policy coherence.
2. Monitoring and Compliance Infrastructure: The Deployment and reliability of CEMS/OCEMS, stack monitoring, surprise inspections, data transparency, Frequency, coverage, and technological adequacy of monitoring systems.
3. Enforcement Strength and Regulatory Follow-through: The Timeliness and severity of actions (closure notices, penalties, compensation orders, violation tracking) and the Consistency between reported violations and actual enforcement outcomes.
4. Industry-Level Behavioural and Operational Outcomes: The adoption of pollution-control technologies, fuel-switching, process improvements, record-keeping practices, perceptions of regulatory pressure, ease of compliance, and gaps between mandated and actual practices.

Together, these dimensions allow the study to evaluate whether differences in governance structure and regulatory design are reflected in measurable variations in compliance behaviour and operational outcomes on the ground—an aspect not examined in existing CAQM, CPCB, or CSE assessments.

Limitations & Further Research

The questionnaire covers major industrial belts but may underrepresent extremely small unregistered units. The Field survey data collected August–October 2025; some policy actions change fast (daily CAQM GRAP orders) so continuous monitoring is needed. Further work should model the quantitative contribution of DGs, industry stacks and fugitive emissions to seasonal PM episodes using source attribution models.

Conclusion

By combining primary questionnaire data with a strengthened set of authoritative secondary sources, the study shows that monitoring and governance architecture (CAQM's OCEMS push, GRAP) improves awareness and enforcement in Delhi-NCR, while Haryana's SEP gives the state a strategic advantage on non-CO_2 pollutants but implementation gaps (monitoring station maintenance, DG pollution, SME financing) limit outcomes. Addressing these gaps with targeted financing, third-party verification, DG mitigation, and public transparency will materially strengthen industrial pollution control in both jurisdictions.

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