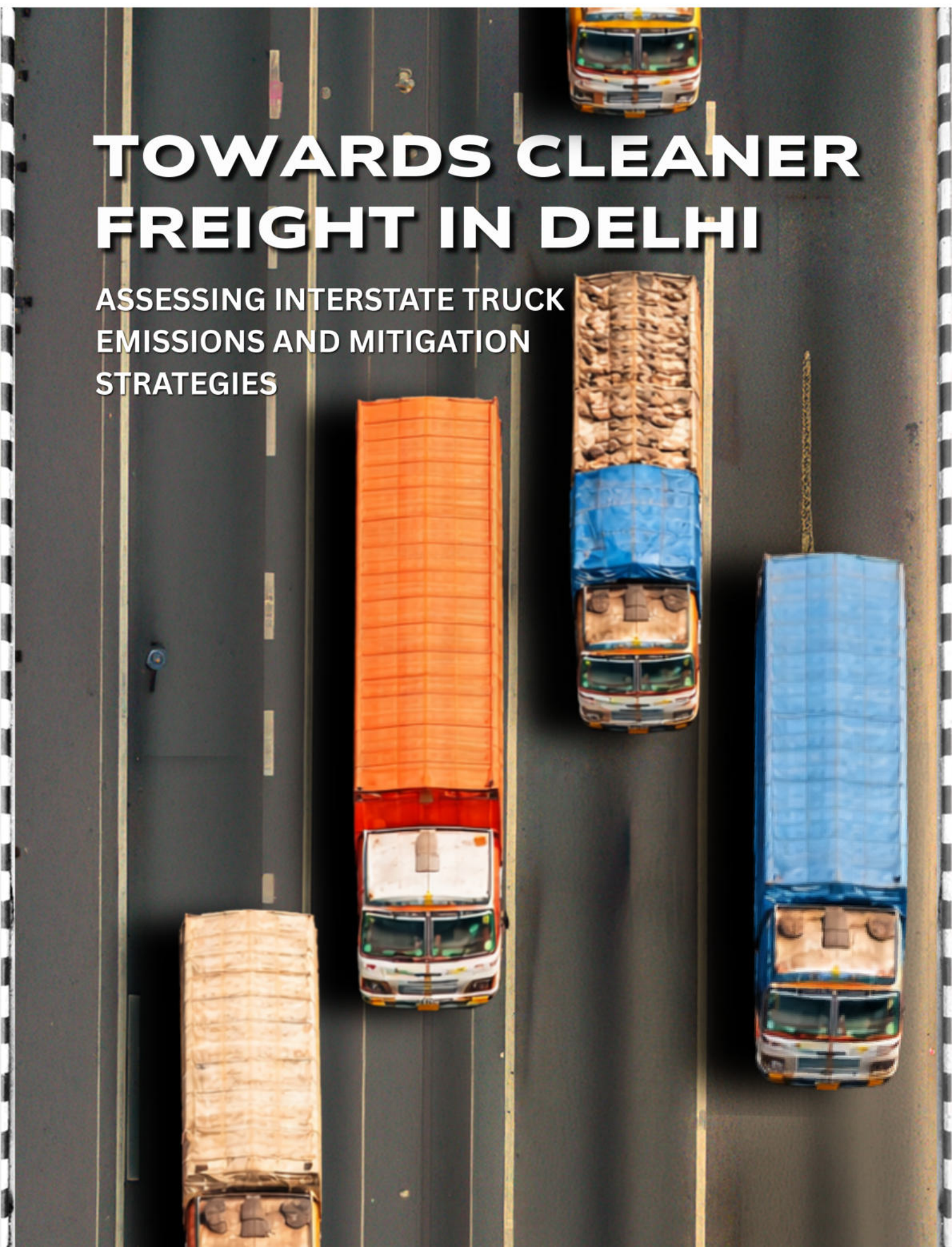


TOWARDS CLEANER FREIGHT IN DELHI

ASSESSING INTERSTATE TRUCK
EMISSIONS AND MITIGATION
STRATEGIES



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**ASSESSING INTERSTATE TRUCK EMISSIONS AND
MITIGATION STRATEGIES**

The study was jointly undertaken by **Air Pollution Action Group (A-PAG), Indian Institute of Technology Delhi (IIT Delhi)**, and **The Energy and Resources Institute (TERI)**

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Executive Summary



Air pollution in Delhi remains a persistent challenge, with the transport sector contributing approximately 18-24% of PM_{2.5} concentrations.¹ Within this, freight vehicles—particularly heavy-duty vehicles (HDVs)—account for a disproportionate share due to their diesel use, age profile, and high utilisation.

This challenge is further amplified by Delhi's role as a major logistics hub, with significant volumes of interstate truck traffic moving through the city daily. While multiple policy measures have been introduced to regulate truck emissions—including vehicle bans, environmental charges, and bypass infrastructure—limited attention has been paid to the temporal aspect of emissions, particularly at night. At the same time, the absence of reliable, granular data on interstate truck activity and real-world emissions continues to constrain effective, targeted interventions.

To address this gap, a detailed study of interstate HDVs operating in Delhi was undertaken by the **Air Pollution Action Group (A-PAG), Indian Institute of Technology Delhi (IIT Delhi), and The Energy and Resources Institute (TERI)**. The study aims to build a comprehensive, evidence-based understanding of:

1. The scale and characteristics of interstate truck movement,
2. Their real-world emissions profile, and
3. The most effective and implementable mitigation strategies.

The study integrates official toll data, on-ground traffic counts, driver surveys, and real-world emissions testing to build a comprehensive and validated understanding of interstate truck activity and emissions. These include measured data (RFID entries, surveys, and real-world VS3 emissions testing), modelled estimates (daily emissions derived from measured factors and vehicle kilometres travelled) and scenario-based projections (potential emission reductions if adoption targets are met). The analysis highlights several key insights on interstate freight operations—such as trip patterns, empty backhauls, and fleet characteristics—that are critical to understanding how emissions from this segment are generated.

Characterising Truck Profile

1. Approximately 16,900 HDVs enter Delhi each day, based on independent verification. This is around 20% higher than the approximately 13,400 daily entries captured in RFID (radio frequency identification) data, likely due to monthly-pass trucks entering without digital logging.

2. Higher presence of HDVs on the road at night, relative to passenger vehicles: Approximately 75% of interstate HDVs operate in Delhi during nighttime and early morning hours (10 pm to 7 am), whereas cars and other passenger vehicles account for only 18% of their daily volumes during this period.

3. A small set of trucks drives a disproportionate share of total traffic. Nearly 76% of recorded entries over a month are repeat entries by the same trucks, with each truck entering Delhi about 4 times per month on average. This indicates that managing trip frequency may be more effective than fleet phase-out.

¹ CAQM (2026, January). *Identification of the causes for worsening AQI in Delhi-NCR*

4. Diesel dominates fleet composition, but not trip frequency: While 80% of unique trucks are diesel, overall truck entries into Delhi are split nearly evenly between diesel and CNG. A similar pattern is observed across vehicle types—2-axle trucks, while accounting for only 45% of the fleet, contribute 60% of total entries. It appears that smaller, CNG-operated trucks undertake more frequent, short-haul trips, while larger diesel trucks are associated with less frequent, long-haul movements.

5. Pre-BS-VI trucks constitute a significant share of the fleet, despite norms conversion: Approximately 62% of trucks comply with BS-VI norms, followed by 28% BS-IV and 10% BS-III or older.

6. Truck entries are predominantly NCR-linked: 63% of trucks entering Delhi originate from states in the National Capital Region (NCR), and 77% of trucks are registered in NCR states. Effective policy interventions must operate at the NCR level, rather than being limited to Delhi alone.

7. Geographical concentration of truck entries is highly skewed: Strategic, targeted enforcement of mitigation strategies at 20 plazas has the potential to influence ~90% of truck entries, while interventions at just 4 plazas (Kundi, Rajokri, Badarpur, and Tikri) could impact over 50% of entries.

8. 92% of trucks report Delhi as their destination; only 8% report bypassing the city. Within 'bypassing' trucks, 86% originate from and 95% are destined for NCR states, suggesting that bypass traffic is not predominantly long-distance but largely consists of short, intra-NCR trips.

9. Around 51% of trucks report exiting Delhi empty, either due to Delhi being a 'consumption hub' or due to operational inefficiencies. In the case of the latter, there could be a clear opportunity for measures focused on backhaul optimisation and improved load matching.

Quantifying Emission Contribution

1. Interstate trucks emit roughly 52 kg of PM2.5, 3 tonnes of NOx, and 2.5 tonnes of CO as primary pollutants each day: This is approximately 18.9 tonnes of PM2.5, 1,095 tonnes of NOx, and 912.5 tonnes of CO annually.

2. Pre-BS-VI and diesel trucks remain the usual suspects: Pre-BS-VI trucks account for 62% of PM2.5 emissions. Diesel trucks, which represent 51% of trips, contribute 56% of PM2.5 emissions.

Total emissions from truck segments (in kilograms per day)

Truck Type	Fuel Type	PM2.5 (kg/day)				NOx (kg/day)				CO (kg/day)			
		BS-VI	BS-IV	BS-III	Total	BS-VI	BS-IV	BS-III	Total	BS-VI	BS-IV	BS-III	Total
2 Axle Trucks	Diesel	3.88	3.16	1.96	9	70.8	273.7	98.5	443.1	3.9	18	17.4	39.4
	CNG	6.96	2.92	6.55	16.43	143.9	302.5	384.4	830.8	78.9	184.5	634.6	898.1
3 Axle Trucks	Diesel	2.39	2.19	2.04	6.62	43	234.2	113.3	390.5	3.8	23.8	31.3	59
	CNG	0.36	1.02	2.01	3.39	6.8	130.6	131.8	269.3	5.8	124.3	339.9	470
4+Axle Trucks ²	Diesel	5.95	4.4	3.35	13.7	124.1	529	208.3	861.5	23.9	106.9	109.8	240.8
	CNG	0.27	0.78	1.99	3.04	6.3	104.4	142.8	253.5	10	191.4	645.9	847.3
Total		19.81	14.47	17.9	52.18	395.1	1574.5	1079.1	3048.7	126.5	649	1778.9	2554.4

² Emissions calculated as the sum of all emissions from 4-axle trucks and emissions from 5+ axle trucks, assuming that all 5+ axle trucks have the same emission factor as for 5-axle trucks.

3. While HDVs account for 23%³ of total daily transport PM2.5 emissions, their share increases to 61% during early morning and nighttime hours: Since 75% of interstate HDVs operate in Delhi during early morning and nighttime hours, it results in a much higher share of HDVs, in terms of fleet and emissions, at night, compared to cars and passenger vehicles

Proportion of nighttime PM2.5 emissions by vehicle type (all values in percentages)			
Vehicle Type	Proportion of overall emissions ⁴	Proportion of vehicles 10 pm - 7 am	Proportion of emissions 10 pm - 7 am
Motorcycle + Cars	34.6	15	17.9
Bus	7.8	19	5.1
Autorickshaw + Light Duty Vehicle (LDV)	33.9	14	16.2
<i>Heavy Duty Vehicle (HDV)</i>	23.4	75	60.5
Light Commercial Vehicle (LCV)	0.3	46	0.3
Total	100		100

³ TERI (2021). Cost effectiveness of interventions for control of air pollution in Delhi.

⁴ TERI, 2021

Strategies to Mitigate Emissions from Interstate HDVs

Based on the findings, a set of targeted interventions has been identified to reduce emissions from interstate trucks:

Strategy	Brief Overview	Target Timeline	PM2.5 Emission Reduction Potential
<i>I. Reduction in freight trips due to UCC (CNG & EV Trucking)</i>	UCCs consolidate freight at the city periphery and shift to cleaner last-mile vehicles (CNG/LEV), reducing trips, congestion, and emissions; implementation requires viable PPP models and integrated logistics systems.	By 2032	23%
<i>II. Shift to electric trucks</i>	Electrification of freight starts with high-utilisation 2-3 axle urban fleets and scales to larger trucks over time; implementation requires development of charging infrastructure, grid readiness, and financing.	By 2035	100%
<i>III. Stricter enforcement via payload sensors & ANPR</i>	Deployment of ANPR cameras and payload sensors at toll points detects overloading and delivers system-wide compliance gains. Implementation requires scaling WIM-integrated ANPR systems, enabling automated penalties, and ensuring calibration and data integration.	Ongoing	Not quantified
<i>IV. Ban on entry of pre-BS-VI trucks</i>	Restricting entry to BS-VI, CNG, and EV trucks through a LEZ to eliminate high-emitting vehicles; implementation requires strong enforcement and NCR-wide alignment.	By 2027	51%
<i>V. Reduction in no. of trips by optimising empty backhauls</i>	Reduction of empty truck trips cuts vehicle kilometres travelled, emissions and operating costs; implementation requires enabling digital freight platforms, mandating telematics integration, and developing corridor-level freight data systems.	By 2030	21%
<i>VI. Phase-out based on fitness criteria</i>	Phase out high-emitting trucks using PM/NOx-based fitness testing and OBD diagnostics to target the worst polluters in a scientifically robust, scalable way. For effective implementation, Delhi should expand ATS capacity, include PM/NOx in testing, and enable remote OBD-based compliance and enforcement.	By 2027-35	4-11%
<i>VII. Retrofitment of BS-II, BS-III & BS-IV vehicles with PM & NOx control</i>	<i>Retrofitting older trucks with emission control devices is not recommended due to unresolved cost barriers, regulatory and standardisation gaps that limit reliability and scalability.</i>	<i>Not recommended</i>	<i>11-17% in a given year</i>

Detailed implementation pathways—including timelines, cost estimates, and potential emission reduction impacts for each intervention—are provided in the full report.

Conclusion

Truck movement patterns and operational realities cut across NCR boundaries. Freight emissions in Delhi cannot be addressed through fragmented action, but need a coordinated, data-driven policy approach that aligns regulations, enforcement and incentives across jurisdictions. The evidence here offers a clear starting point. It can inform targeted interventions in Delhi, be adapted for other cities facing similar freight challenges, and be extended to under-examined segments like LCVs that play a significant role in urban emissions.



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Abbreviations

Abbreviation	Expansion
A-PAG	Air Pollution Action Group
AFMS	Automated Fitness Management System
AIS	Automotive Industry Standard
ANPR	Automatic Number Plate Recognition
ARAI	Automotive Research Association of India
ATS(s)	Automated Testing Station(s)
BAU	Business As Usual
BET(s)	Battery Electric Truck(s)
BEV(s)	Battery Electric Vehicle(s)
BS	Bharat Stage (emission norm)
CAQM	Commission for Air Quality Management
CBG	Compressed Bio-Gas
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
CSO(s)	Civil Society Organisation(s)
C-STEP	Center for Study of Science, Technology and Policy
DLC	Diagnostic Link Connector
DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter
DTC	Diagnostic Trouble Code
DTL(s)	Dedicated Truck Lane(s)
ECC	Environment Compensation Cess
ECU	Engine Control Unit

Abbreviation	Expansion
EF(s)	Emission Factor(s)
EGR	Exhaust Gas Recirculation
EME	Earth-Moving Equipment
EPE	Eastern Peripheral Expressway
EV	Electric Vehicle
FCEV	Fuel-Cell Electric Vehicle
FFV	Flex-Fuel Vehicle
GNCTD	Government of the National Capital Territory of Delhi
GPS	Global Positioning System
GRAP	Graded Response Action Plan
GST	Goods and Services Tax
GVW	Gross Vehicle Weight
HC	Hydrocarbons
HCM	Heavy Construction Machinery
HDV(s)	Heavy Duty Vehicle(s)
HGV	Heavy Goods Vehicle
HICE	Hydrogen Internal Combustion Engine
H ₂ FCEV	Hydrogen Fuel-Cell Electric Vehicle
ICCT	International Council on Clean Transportation
IIT	Indian Institute of Technology
LCV	Light Commercial Vehicle
LEV(s)	Low Emission Vehicle(s)
LEZ(s)	Low Emission Zone(s)
LMV	Light Motor Vehicle
LNG	Liquefied Natural Gas
LNT	Lean NOx Trap

Abbreviation	Expansion
LPM	Litres Per Minute
MAF	Mass Air Flow
MAP	Manifold Absolute Pressure
MAV	Multi Axle Vehicle
MCD	Municipal Corporation of Delhi
MHDV	Medium and Heavy Duty Vehicle
MIL	Malfunction Indicator Lamp
MMLP(s)	Multi-Modal Logistics Park(s)
MOUDI	Micro-Orifice Uniform Deposit Impactor
MoRTH	Ministry of Road Transport and Highways
Nano-SMPS	Nano Scanning Mobility Particle Sizer
NCR	National Capital Region
NCT	National Capital Territory
NOx	Nitrogen Oxides
OBD	On-Board Diagnostics
OEM	Original Equipment Manufacturer
OPS	Optical Particle Sizer
PEMS	Portable Emissions Monitoring System
PM	Particulate Matter
PM2.5	Particulate Matter ($\leq 2.5 \mu\text{m}$)
PPF	Partial Flow Filter
ppm	Parts Per Million
PPP	Public-Private Partnership
PUC	Pollution Under Control (certificate)
RFID	Radio Frequency Identification
RH	Relative Humidity

Abbreviation	Expansion
SCR	Selective Catalytic Reduction
SO ₂	Sulphur Dioxide
SPM	Suspended Particulate Matter
SPMA	São Paulo Metropolitan Area
TCO	Total Cost of Ownership
TERI	The Energy and Resources Institute
TRL	Technology Readiness Level
TVC	Traffic Volume Count
UCC(s)	Urban Consolidation Centre(s)
VKT	Vehicle Kilometres Travelled
VS3	Versatile Source Sampling System
WIM	Weigh-In-Motion
WPE	Western Peripheral Expressway
ZEV(s)	Zero Emission Vehicle(s)

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Foreword



Air pollution remains one of the most pressing public health challenges facing the National Capital Region (NCR). Over the past decade, governments at the central, state, and regional levels have undertaken significant efforts to address emissions across sectors. Within this broader landscape, the transport sector - particularly freight movement through heavy-duty vehicles (HDVs) - has emerged as a critical area requiring focused and data-driven intervention.

Delhi's unique geographic and economic position as a major logistics hub results in substantial volumes of interstate freight traffic crossing its borders each day. While several policy measures, such as the Environmental Compensation Charge (ECC), the Eastern and Western Peripheral Expressways, and the Graded Response Action Plan (GRAP), have been introduced to manage emissions from this segment, the absence of granular, real-world data on interstate truck activity has historically constrained the precision and effectiveness of these interventions.

In this context, the present study makes a significant and timely contribution. By combining large-scale toll data analysis, on-ground traffic assessments, driver surveys, and real-world emissions measurement using Portable Emissions Monitoring Systems (PEMS), it offers one of the most comprehensive assessments to date of interstate HDV movement and its emissions profile in Delhi.

Importantly, the study goes beyond diagnostics. It presents a structured prioritisation of mitigation strategies, evaluating each intervention against parameters such as feasibility, cost, scalability, and stakeholder acceptance. The inclusion of implementation timelines, cost estimates, and potential emissions reductions further enhances the report's value for policymakers and implementing agencies.

The findings and recommendations outlined in this report are expected to play an important role in shaping ongoing and future policy actions by the Delhi government and other stakeholders across the NCR. As we move towards more targeted and high-impact interventions, such analytical and evidence-led approaches will be essential to ensuring that regulatory efforts translate into measurable improvements in air quality.

I commend the Air Pollution Action Group (A-PAG), Indian Institute of Technology Delhi, and The Energy and Resources Institute for undertaking this rigorous and policy-relevant study. I am confident that this report will serve as an important reference for strengthening freight-related emission control strategies in Delhi and beyond.

Dr. Virinder Sharma

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Team Foreword



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Head - Strategy,
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Delhi's air quality challenge demands coordinated action across jurisdictions — and that requires a shared, credible evidence base. This study helps build that foundation.

Interstate trucks are among the most consequential and least studied contributors to Delhi's transport emissions. They cross NCR boundaries, operate largely at night, and span multiple administrative areas. Getting a credible picture required going to the roads — combining toll data, field surveys, and real-world tailpipe measurements — rather than relying on generalised estimates.

The report goes beyond diagnosis. It lays out a prioritised implementation roadmap — weighing mitigation options by feasibility, scalability, and impact — so that agencies across the NCR have something they can act on together. At A-PAG, anchoring evidence in implementable action is our reason for being. I hope this report serves that purpose.



Dr. Anju Goel

Associate Director,
TERI

Improving Delhi's air quality requires integrated strategies — grounded in science, tested against real-world conditions, and designed for how a city actually functions.

Heavy-duty trucks represent exactly the kind of challenge this demands. Their emissions profile is shaped by fuel, load, routing, and timing — factors that interact across administrative boundaries and resist simple fixes. This report brings together scientific measurements, field evidence, and stakeholder consultations to build a picture of interstate truck emissions that is both rigorous and actionable.

TERI's contribution reflects our long-standing commitment to evidence-based environmental policy, particularly in urban air quality, where the margin for imprecision is low. We hope this work strengthens the foundation available to policymakers, researchers, and implementing agencies working toward cleaner freight and healthier cities.



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A reliable emissions policy must rest on reliable measurement. Assessments of heavy-duty vehicle emissions have largely drawn on laboratory test cycles or factors developed in other contexts — this study adds real-world, India-specific evidence to that picture. Using the indigenously developed VS3 system, the team conducted on-road tailpipe measurements across the largest sample of trucks studied in any Indian research to date. Combining those real-world emission factors with actual truck activity data produced an inventory grounded in how this sector operates on Indian roads. We hope this work encourages more investment in real-world emissions monitoring, and these methods are extended to other vehicle categories and cities.

Problem Statement

The transport sector is a key driver of air pollution in Delhi, contributing between 18% and 24% to the city's PM_{2.5} concentrations⁵. In a densely populated city, this translates into widespread and continuous exposure to harmful emissions.

Within the transport sector, emissions are not evenly distributed across vehicle categories. Freight vehicles—particularly **heavy-duty vehicles (HDVs)**—account for a disproportionate share of pollution due to their diesel fuel usage, older vehicle technology, and high-mileage operations. **Note that this study classifies trucks with two or more axles as HDVs.** This trend is reflected at the India level—while medium-duty vehicles (MDVs) and HDVs account for only 3% of the total vehicle stock, they can contribute up to 53% of PM from transport nationwide⁶.

Within Delhi, HDVs contribute a moderate share to overall transport-related PM_{2.5} emissions at an aggregate level; however, this share rises sharply at night. PM_{2.5} concentrations are approximately 16%-29% higher during early morning (5 AM to 7 AM) and nighttime hours (10 PM to 5 AM), compared to daytime levels⁷. Freight movement in the city is commonly understood to be concentrated during the same hours due to regulatory restrictions, whereas passenger vehicle activity is relatively lower. The pollution impact of HDVs is further amplified at night due to atmospheric conditions: the mixing layer height is 3 to 10 times lower than during the day⁸, reducing dispersion and increasing ambient pollutant concentrations.

This challenge is further exacerbated by Delhi's porous borders and its role as a major logistics hub, resulting in substantial volumes of interstate HDVs passing through the capital each day. The Government of the National Capital Territory of Delhi (GNCTD) has implemented several interstate truck emission mitigation measures. These include banning old vehicles, imposing an environmental compensation cess (ECC) on HDVs and other goods vehicles, building the Western and Eastern Peripheral Expressways (WPE and EPE), and introducing the seasonal Graded Response Action Plans (GRAPs).

While these interventions were intended to reduce interstate truck traffic, reliable data on the volume and emission impact of this vehicle category remain limited⁹. Addressing this evidence gap requires a comprehensive understanding of the operational characteristics, traffic patterns, and emission profiles of interstate trucks operating in and around the capital.

To generate this evidence, a detailed study of interstate HDVs and their emissions in Delhi was undertaken. The study was jointly conducted by the Air Pollution Action Group (A-PAG), Indian Institute of Technology Delhi (IIT-Delhi), and The Energy and Resources Institute (TERI).

Study Objectives

The objectives of this study are threefold:

1. **Ascertain the quantum of interstate trucks entering and exiting Delhi** through comprehensive analysis of RFID-linked toll plaza data, on-ground traffic volume counts, and truck driver surveys at strategically selected toll points.
2. **Quantify their real-world emissions impact** using an indigenously designed Portable Emissions Monitoring System (PEMS) to capture tailpipe emissions profiles in real-world driving conditions.
3. **Identify and prioritise targeted emission mitigation** strategies via an evidence-driven matrix that balances technical feasibility, cost-effectiveness, stakeholder acceptance, and scalability, among other parameters.

⁵ ARAI & TERI (2018). *Source Apportionment of PM_{2.5} & PM₁₀ of Delhi NCR for Identification of Major Sources*.

⁶ NITI Aayog & RMI (2022, September). *Transforming Trucking In India: Pathways to Zero Emission Truck Deployment*.

⁷ CPCB (2025). *Continuous Ambient Air Quality Monitoring Station (CAAQMS) Data for Delhi*.

⁸ Tiwari et al (2013). *Diurnal and seasonal variations of black carbon and PM_{2.5} over New Delhi, India: Influence of meteorology*.

⁹ Unless mentioned otherwise, 'trucks' and 'heavy duty vehicles (HDVs)' will be used interchangeably.



Methodology



This study adopted a mixed-methods approach—combining primary surveys, administrative datasets, real-world emissions measurements and stakeholder consultations—to develop a comprehensive assessment of interstate HDV activity and associated emissions in Delhi.

Data Collection

We conducted a series of data collection exercises to characterise the fleet of interstate HDVs entering Delhi through its toll plazas. Three interconnected surveys were conducted in collaboration with a survey agency to collect sample-based information on fleet characteristics, operations, and movement patterns. In addition, vehicle entry data obtained from government sources were analysed as a census-level dataset, capturing the full population of vehicles entering through MCD toll plazas. The parameters estimated through these datasets were later combined with emission factors (EFs) measured using on-road, real-world emissions monitoring of HDVs to estimate the total emission load contributed by these vehicles. The process has been illustrated as a schematic diagram in Figure 2.1.

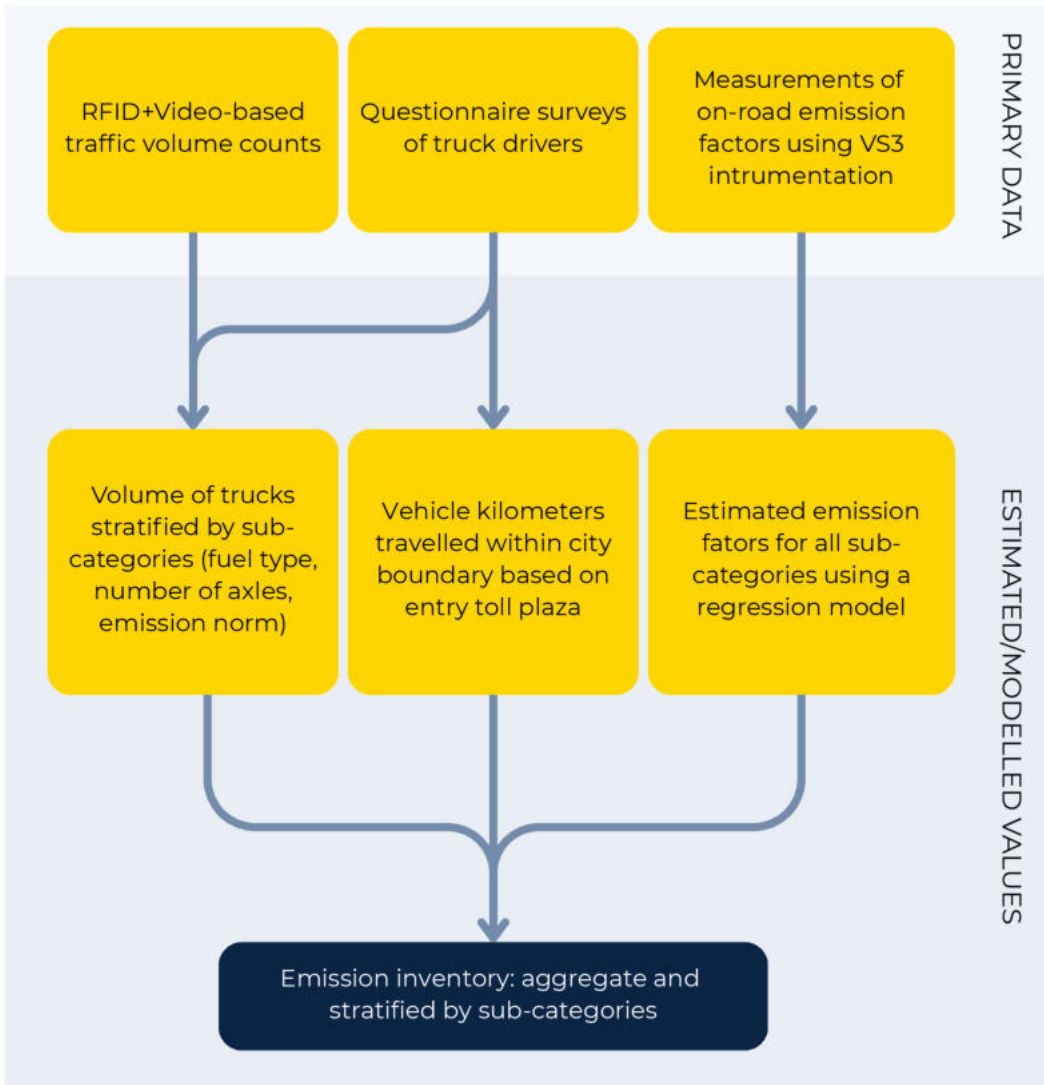


Figure 2.1 Schematic of emission inventory estimation process

Table 2.1 Overview of Data Collection

Data Collection Exercise	Objective or Purpose
RFID Data	To capture census-level data on vehicle entries, including volume, type, fuel, and temporal patterns across toll plazas
Traffic Volume Count (TVC) Survey	To measure actual traffic volumes & temporal distribution of vehicle entries at selected toll plazas
Truck Driver Survey	To collect detailed information on truck characteristics, trip patterns, and operational behaviour
Axle Load Survey	To obtain real-world vehicle weight data and check for overloading of trucks

Additional details on each survey—including details on sample size, methodology, dates, etc.—have been provided below.

I. Truck Driver Survey

Structured in-person surveys were conducted with truck drivers at **25 toll plazas**, primarily at the point of entry into Delhi. In some cases, interviews were also conducted with the drivers of vehicles exiting the city. Plazas were selected to ensure geographic representativeness across Delhi's entry and exit points and to capture a mix of major and minor plazas, providing a diverse, comprehensive view of interstate traffic patterns.

Each plaza was surveyed on a weekday (either a Friday or a Monday) and a weekend (either a Saturday or a Sunday) in the month of July 2025. The surveys took place during 11-14 July and 18-21 July 2025 and aimed to cover approximately 8-10% of trucks passing through the surveyed toll plazas. In total, **4,731 driver interviews** were completed, of which 93.5% of the responses were for the trucks entering Delhi, and a smaller share of 6.5% of the responses (n=305) were from trucks exiting.

The questionnaire captured over 20 data points, including vehicle registration number, fuel type, BS norm, origin and destination, purpose of entering or passing through Delhi, and type of goods transported, among others. The complete list of data points collected is provided in Annexure 1(A).

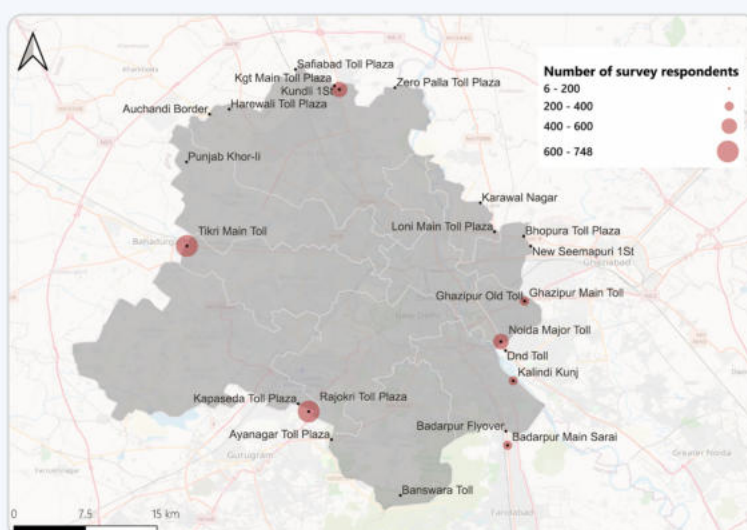


Figure 2.2. (a) Truck driver survey being conducted at Kundli 1st; (b) Toll plazas where survey was conducted

Axle Load Survey

To improve the accuracy of emissions estimation and assess freight loading patterns, axle load measurements were conducted for **152 trucks** during the truck driver survey at two toll plazas. The locations were chosen to be one major plaza (Kundli/KGT Main) and a medium plaza (Auchandi-1), accounting for 17% and 2% of total truck entries, respectively. Measurements were conducted using the Celtronic Portable Weigh Pad X-017 BA-1. This exercise was conducted primarily to obtain real-world vehicle weight data and check for overloading of trucks.



Figure 2.3. (a) and (b) Axle load survey being conducted

II. Traffic Volume Count (TVC) Survey

A traffic volume count (TVC) exercise was conducted using camera-based monitoring at **18 toll plazas**. Plazas were selected using the same criteria as for the truck driver survey, ensuring a representative mix of major and minor locations across Delhi's entry and exit points.

Two CCTV cameras were installed at each plaza to capture traffic in both directions, i.e., entering and exiting Delhi. Continuous 24-hour video footage was collected for four full days (26-27 and 29-30 September 2025) at some locations and for two days (29-30 September 2025) at others, to ensure representativeness of average weekly traffic volumes. Except for 27th September (Saturday), the rest of the days were weekdays. Data for 28 September (Sunday) was excluded, as discussions with truck drivers indicated that it may not reflect typical traffic patterns. Manual counts were obtained at 15-minute intervals from the video footage, classified by vehicle type and in both directions.

Refer to Annexures 1(A) and 1(B) for additional information on toll plazas selected and vehicle categories.

III. RFID-Linked Vehicle Entry Data

Vehicle entry data was obtained from the Municipal Corporation of Delhi (MCD), capturing Radio Frequency Identification (RFID)-based records of vehicles entering through **121 toll plazas city-wide**¹⁰. Data was shared for the following time periods:

1. April 1 to 30, 2025 (30 days)
2. July 7 to 27, 2025 (20 days)
3. September 16 to 30, 2025 (15 days)

¹⁰ This technology was adopted by the EPCA in 2019 following a 2015 NGT order to restrict the entry of diesel trucks older than 10 years. As per a document dated March 2025, Delhi reportedly hosts approximately 156 toll plazas; data for only around 120 plazas was received, as the remaining new plazas were reportedly managed either by a different vendor or still manually while a vendor was being finalised. Additionally, data from only 114 plazas was taken for analysis, as only these reported any truck entries.

April 2025 was selected for detailed analysis of truck population characteristics, as complete monthly data was available and no major festivals or policy restrictions occurred during the period. Average daily class-wise and fuel-wise vehicle entries were found to be broadly comparable across April, July, and September (refer to Annexure 1(C), providing confidence in the representativeness of the manual surveys conducted during July and September 2025.

Approximately **3.25 million vehicle entries** were captured, with each entry including the following vehicle attributes:

1. Toll plaza name
2. Unique RFID number
3. Type or category of vehicle
4. Fuel type
5. Type of pass (period or trip-based)

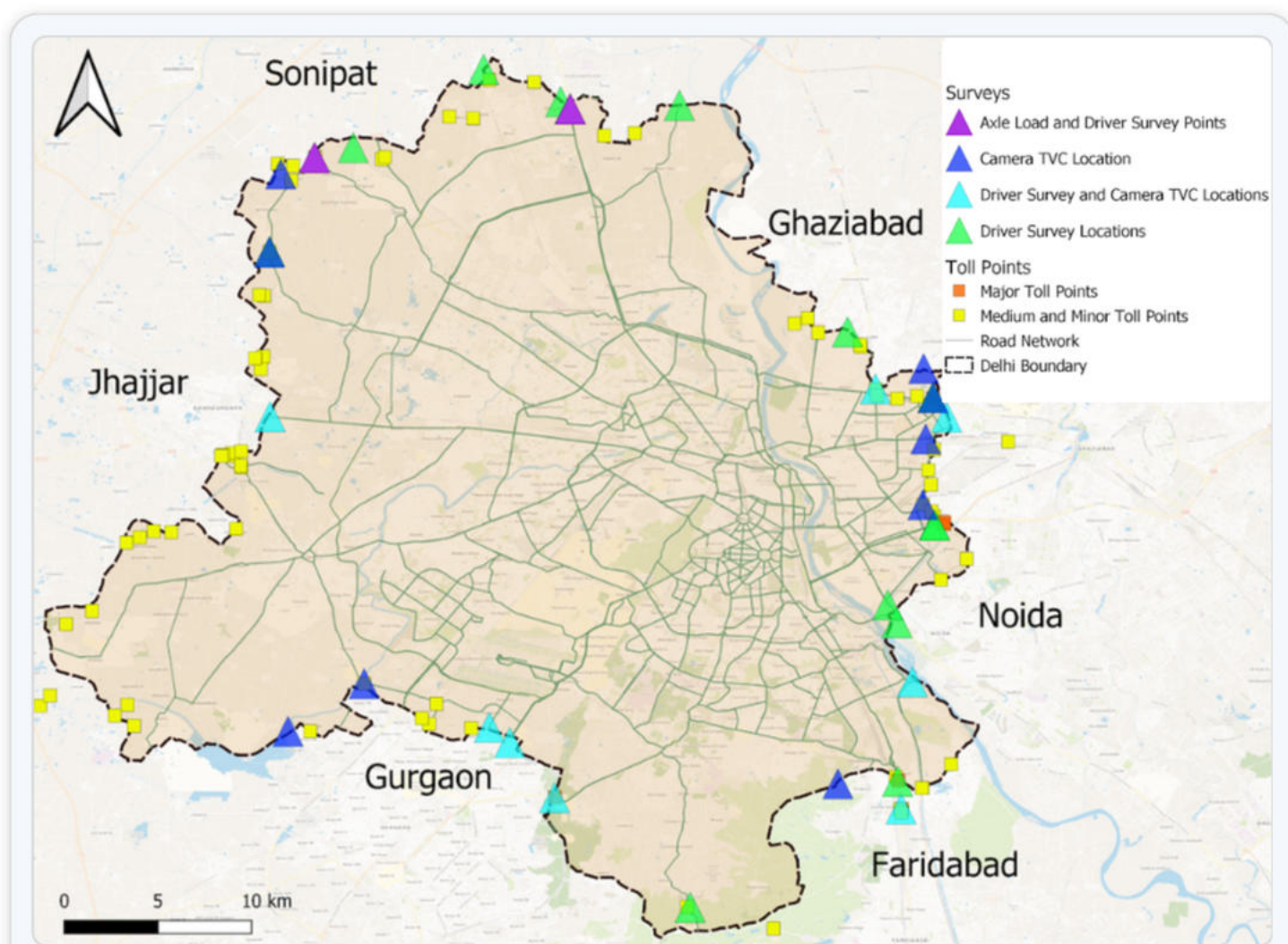


Figure 2.4. All toll plazas in RFID data and toll plazas specifically chosen for different surveys*

* Certain toll plaza locations may not be visible on the map, as they fall within the surveyed area and have therefore been incorporated into the surveyed locations.

VS3 Equipment and Emissions Measurement

I. VS3 Overview

The Versatile Source Sampling System (VS3)—an indigenously developed, multi-pollutant apparatus designed for source-specific emission characterisation—was employed for real-time tailpipe measurements during on-road vehicle operation. The system comprises a stainless steel coupler assembly having integrated ports for a heated isokinetic sampling probe, bypass line, relative humidity (RH) and temperature (Temp) sensors, a pitot tube, and a flue gas analyser.

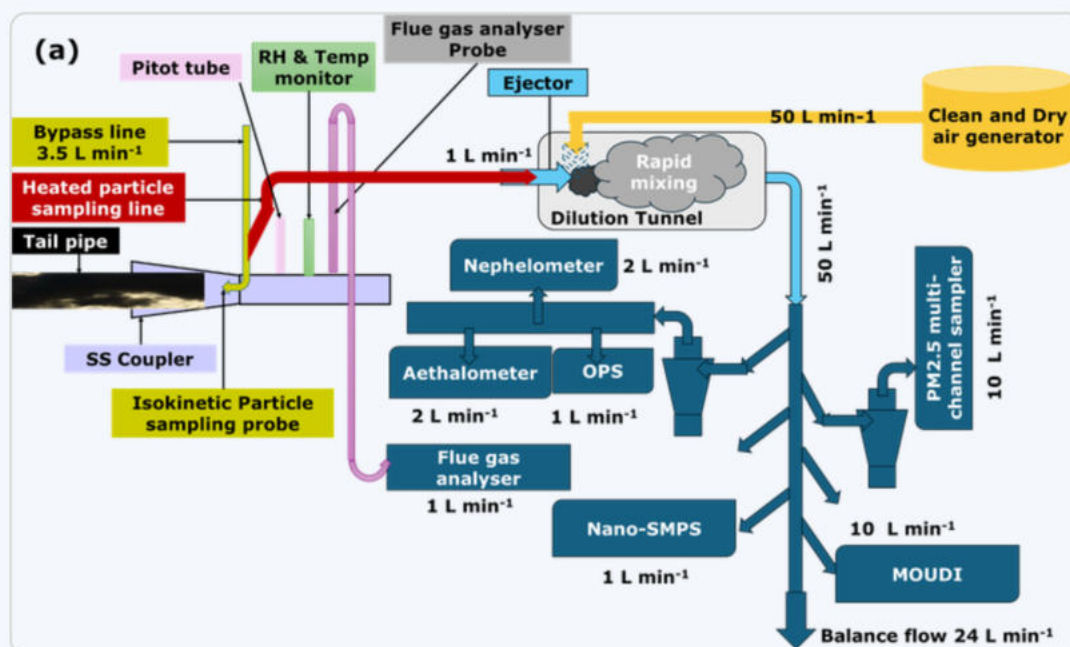


Figure 2.5. (a) Schematic of the VS3 system

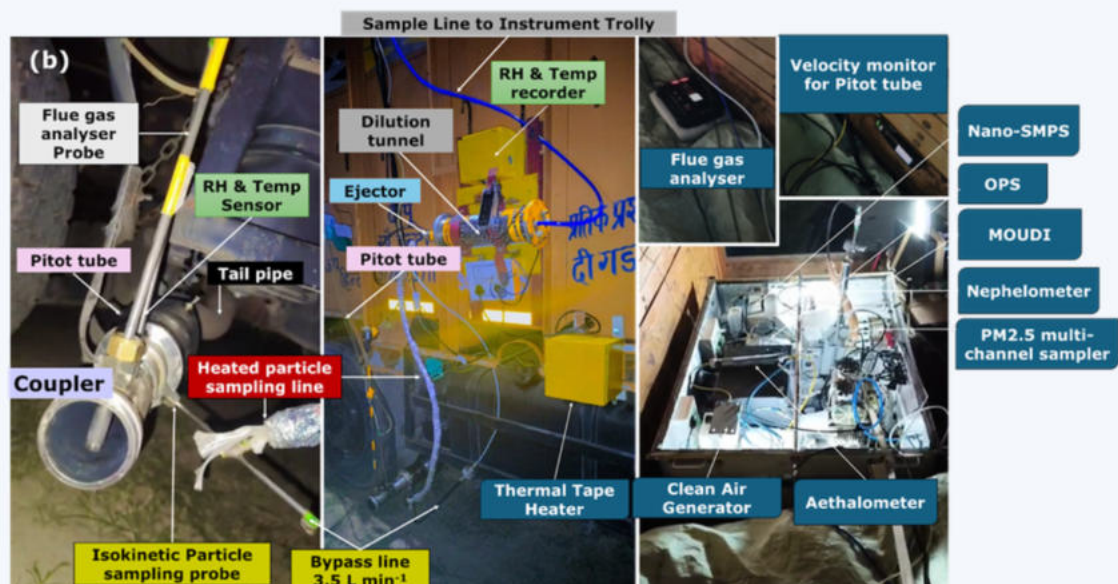


Figure 2.5.(b) Setup of the VS3 on a loaded truck

II. Exhaust Sampling and Dilution

A total flow of approximately 4.5 L min^{-1} was withdrawn from the exhaust to maintain isokinetic conditions and capture a representative exhaust sample. Of this, 1.0 L min^{-1} was passed through the heated sampling probe, while the remaining 3.5 L min^{-1} was routed through the bypass line. The flow within the heated line was sustained by an ejector that works on the pressure difference induced by dry compressed air at 50 L min^{-1} . The resulting exhaust stream (1.0 L min^{-1}) entered a dilution tunnel, where it rapidly mixed with particle-free, moisture-free, and VOC-free compressed air (50 L min^{-1}), achieving gas-to-particle partitioning within 2-3 seconds and mimicking atmospheric processes¹¹. Multiple ports positioned downstream of the tunnel enabled sample extraction for real-time and offline analyses; detailed specifications are available in Kumari et al. (2024)¹² and Jaiprakash et al. (2017)¹³.

III. Gas-Phase Measurements

The concentrations of major gaseous species (CO , CO_2 , and NO_x) and exhaust temperature were measured using a TESTO 350 flue gas analyser. The exhaust velocity was determined with a pitot tube interfaced to a TESTO 480 recorder, while RH-Temp was simultaneously recorded using a Polltech analyser during direct tailpipe sampling.

IV. Particle Sampling and Online Aerosol Measurements

The diluted aerosol stream from the dilution tunnel was directed to a stainless-steel multi-inlet manifold operating at a total flow of 51 L min^{-1} . This flow was subsequently distributed among multiple downstream sampling and measurement lines. A multi-channel $\text{PM}_{2.5}$ sampler equipped with a sharp-cut cyclone (operating at 10 L min^{-1}) collected particles with aerodynamic diameters $\leq 2.5 \mu\text{m}$ ($\text{PM}_{2.5}$) on filter substrates for subsequent chemical analyses (See Annexure 2(A) for additional details on equipment). Another port of the manifold connected with sharp-cut $\text{PM}_{2.5}$ cyclone (operating at 5 L min^{-1}) supplied flow to high-resolution instruments, including a seven-wavelength Aethalometer for black and brown carbon (2 L min^{-1}), a Nephelometer for particle scattering (2 L min^{-1}), and an Optical Particle Sizer (OPS) (1 L min^{-1}) for particle number concentration in 300 nm to $10 \mu\text{m}$ (See Annexure 2(A)).

Additional ports provided 1 L min^{-1} flow to a Nano-Scanning Mobility Particle Sizer (Nano-SMPS) for particle number concentration measurement in 10 nm to $1.0 \mu\text{m}$ size bins and 10 L min^{-1} to a 13-stage rotating type Micro-Orifice Uniform Deposit Impactor (MOUDI) for mass measurement in 10 nm to $10 \mu\text{m}$ size range (See Annexure 2(A)). In total, approximately 26 L min^{-1} of the diluted exhaust stream was sampled through the analytical instruments, while the remaining 25 L min^{-1} was vented to the atmosphere through a bypass port line. This integrated configuration enabled concurrent measurements of the size-resolved number, mass, and chemical composition of $\text{PM}_{2.5}$ under identical sampling conditions.

V. Offline PM Sampling and Chemical Analysis

The PM collected on Quartz, Teflon, and Nylosorb filters was subjected to subsequent offline analyses of organic-elemental carbon, gravimetric mass, trace elements, and water-soluble inorganic ions, respectively. The resulting chemical characterisation forms the basis for developing detailed source profiles, while emission factors for $\text{PM}_{2.5}$, its components, and associated gaseous pollutants were determined from these measurements.

¹¹ Seinfeld and Pandis (2016). *Atmospheric chemistry and physics: From air pollution to climate change*

¹² Kumari et al. (2024). *Design, evaluation, and performance of versatile source sampling system (VS3) for monitoring and characterization of aerosols from area, point and line sources*

¹³ Jaiprakash, Habib, G. (2018). *On-road assessment of light duty vehicles in Delhi city: Emission factors of CO , CO_2 and NO_x* .

VI. Field Experiment Design

To conduct field measurements, we arranged for HDVs from truck operators in Delhi and its neighbouring district. The trucks were instrumented and then operated on a pre-defined route, during the times that HDVs are allowed to be operated within Delhi. The duration of each experiment ranged from 1-2 hours.



Figure 2.6. (a) and (b) Installation of the VS3 system on a truck

VII. Truck Selection

To ensure that different vehicle norms and weight categories were appropriately represented in the study, the following sampling strategy was followed, showing the number of experiments conducted per category:

Table 2.1: Sample Distribution for VS3 Measurements ¹⁴

BS Norms	12-16t	16-30t	30-42t	Grand Total
BS-III	1	1	3	5
BS-IV	7	9	3	19
BS-VI	7	5	9	21
Grand Total	15	15	15	45

¹⁴ Vehicle loading condition (loaded vs. unloaded) was considered as a variable based on its use in existing literature, where loaded trucks are typically associated with higher emissions due to increased engine load. However, the results of this study did not indicate a significant difference in emissions between loaded and unloaded conditions (see Annexure 2(B)).

Within these categories, a mix of diesel and CNG trucks was sampled to ensure representativeness of the real truck population (refer Annexure 2(B)). While the sample adequately captures variations across BS norms and weight categories, it remains limited in representing fuel types (CNG and diesel) within each of the nine sub-categories; therefore, a regression-based approach was used to address this limitation (described later). However, to our knowledge, this is the largest sample of trucks used for on-road tailpipe emissions measurement in any Indian context.

VIII. Route and Timings

The trucks were run on pre-decided routes of an average length of 50 km, within the city, which took 1.5-2 hours, depending on road and traffic conditions. The routes were based on the volume of trucks on the road network reported by an earlier study¹⁵, and avoiding roads where movement of trucks is not allowed. The experiments were conducted during nighttime for diesel trucks and in the afternoon off-peak hours for CNG trucks, as per observed volumes and permissible hours for trucks based on fuel and size. This may limit comparability between the emission factors of CNG and diesel trucks due to different driving cycles; however, emission factors are somewhat representative of the real-world usage, since CNG trucks are predominantly used during the day.



¹⁵ Malik, et al (2021). Estimating urban freight flow using limited data: The case of Delhi, India.

Evaluation of Mitigation Strategies

In addition to the quantitative analysis of traffic activity and emissions, the study incorporated a qualitative stakeholder engagement process to identify and evaluate emission reduction strategies for interstate HDVs.

I. Literature Review & Strategy Development

A comprehensive literature review analysed peer-reviewed research, policy reports, and international case studies to identify 20-25 emission mitigation strategies for HDVs. These strategies were bucketed as follows:

1. Low- and zero-emission vehicles
2. Retrofitment
3. Regulatory interventions
4. Technology & infrastructure interventions
5. Freight & logistics optimisation

II. Expert Consultation Process

Consultations were conducted with academic researchers, civil society organisations (CSOs), industry experts, manufacturers, fleet operators, and government stakeholders. Semi-structured interviews were used to assess the technical feasibility, implementation challenges, costs, and stakeholder acceptance of each strategy.

III. Stakeholder Roundtables

Closed-door roundtables were convened to review findings from the literature review, primary surveys, and emissions measurements, and to validate preliminary strategy assessments.

IV. Final Strategy Evaluation & Emissions Assessment

Strategies were evaluated using a multi-parameter matrix considering technical feasibility, implementation complexity, cost-effectiveness, stakeholder acceptance, regulatory compatibility, and scalability. The evaluation also incorporated insights from the traffic surveys and real-world VS3 emissions measurements, ensuring that strategy prioritisation reflected observed fleet characteristics and emissions behaviour. Based on this assessment, the potential reduction in key air pollutants (PM, NOx, and CO) from selected strategies was estimated.



Survey Findings & Emissions Inventory



Truck traffic into Delhi was analysed from two perspectives: total entries and unique trucks to determine the scale and frequency of truck movements, as well as the composition and operational behaviour of the fleet. The findings draw on a combination of measured data (RFID entries, surveys, and real-world VS3 emissions testing), modelled estimates (daily emissions derived from measured factors and vehicle kilometres travelled), and scenario-based projections (potential emission reductions if adoption targets are met).

Understanding Truck Entry & Fleet Patterns

I. Total Truck Entries

An average of 13,400 truck entries into Delhi are recorded each day across 121 toll plazas, according to official RFID vehicle entry datasets. This translates to approximately 400,000 entries per month. However, daily entries could be as high as 16,900, based on our independent camera-based verification exercise. *This is critical, as it indicates toll plaza data may be underestimating the number of trucks entering the capital daily by approx. 21%.*

Potential explanation for uncaptured RFID entries: Discussions with toll operators indicate that some trucks with monthly passes may pass through without formal RFID recording, as operators can visually identify monthly-pass stickers from a distance. While this may account for only a subset of entries, no alternative explanation or evidence of faulty RFID has been identified so far.

Heavy truck entries into Delhi have declined by 7% over the past decade. CSE (2015)¹⁶ estimated approx. 18,250 daily entries of 2-axle and larger trucks, compared to approx. 13,400 daily entries in our RFID dataset (or approx. 16,900 after camera-based adjustment). The decline could likely be due to the introduction of the ECC and the commissioning of the EPE/WPE.

II. Unique Truck Entries

When analysed at the level of unique trucks rather than entries, a different pattern emerges. RFID tags serve as unique vehicle identifiers, and the dataset captures approximately 96,419 trucks over a month, with almost 12,700 unique trucks entering daily. **Nearly 76% of recorded entries are repeat entries by the same trucks, with each truck entering Delhi about 4 times per month on average.** *This indicates that a smaller fleet generates a disproportionate share of total entries and that phasing out trucks should be paired with interventions to manage trip frequency, through measures such as logistics efficiency or reducing empty return trips.*

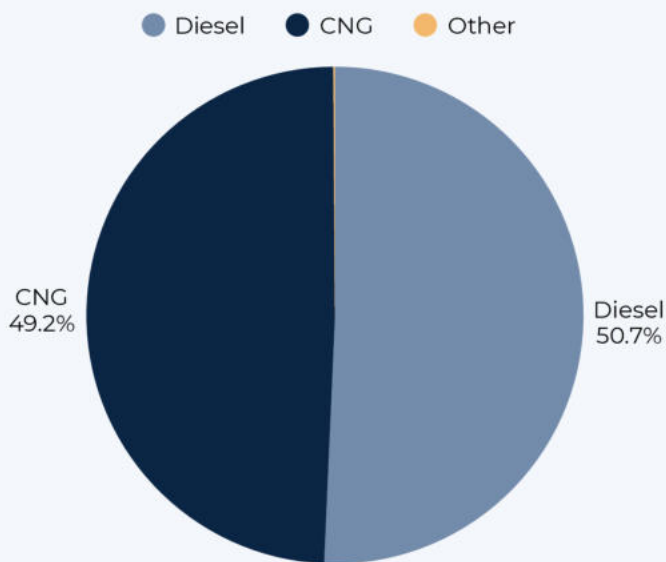
¹⁶ EPCA (2015, October). Report on strategies to reduce air pollution from trucks entering and leaving Delhi.

The dataset was analysed to examine patterns across fuel type, axle count, norms compliance, and trip frequency. Two lenses are particularly important: total truck entries and unique trucks.

III. Fuel & Axle

In terms of fleet composition, diesel trucks continue to dominate. Approximately 80% of trucks entering Delhi are diesel, while 20% are CNG; petrol and electric trucks together account for a negligible share (0.1%) (Figure 3.1). **Additionally, the fleet is skewed towards smaller vehicle categories**—2-axle trucks comprise the largest share of the fleet (45%), followed by 4+ axle trucks (~34%) and 3-axle trucks (~20%) (Figure 3.2(a)).

Fuel distribution of truck entries



Fuel distribution of unique trucks

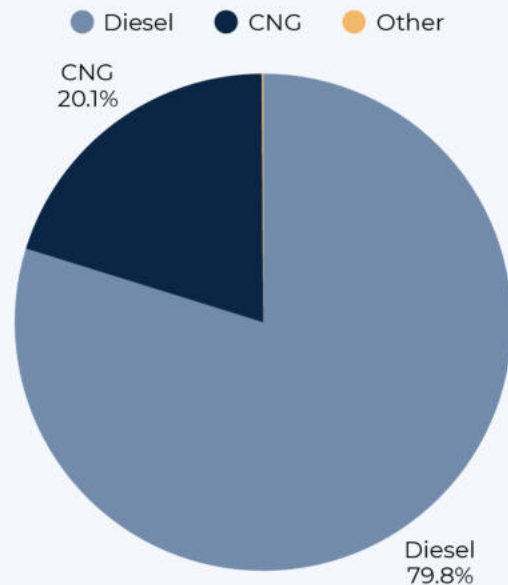


Figure 3.1. Comparing the fuel distribution of the entries (left) including repeat entries, and for the unique trucks (right) shows the high proportion of repeat trips by CNG trucks

In contrast, truck activity differs significantly. **Total entries show a near 50-50 split between diesel and CNG, indicating that CNG trucks contribute disproportionately to overall entries** (Figure 3.1). A similar pattern is observed across vehicle types—2-axle trucks, while accounting for only 45% of the fleet, contribute 60% of total entries. These trucks also represent 83% of the CNG entries (Table 3.1). Conversely, larger 3-axle and 4+ axle trucks, which are 95% diesel, contribute proportionally fewer entries (40%).

Together, it appears that smaller, CNG-operated trucks undertake more frequent, short-haul trips, while larger diesel trucks are associated with less frequent, long-haul movements.

IV. Norm-Wise Entries

Alongside these patterns, emissions generated by the fleet are determined by its compliance with vehicle emission standards. **Approximately 62% of truck entries comply with BS-VI norms, followed by 28% BS-IV and 10% BS-III or older.** Notably, entries by CNG BS-VI 2-axle trucks are most common (29%), followed by diesel 2-axle BS-VI (12%) and diesel 4+ axle BS-VI (13%), underscoring the increased employment of newer vehicles across both smaller and heavy-duty categories. *While this reflects a shift towards newer standards, a non-trivial share of older vehicles (38%) continues to contribute to emissions.*

The population distribution by axle number, fuel type and BS norms is given in Table 3.1.

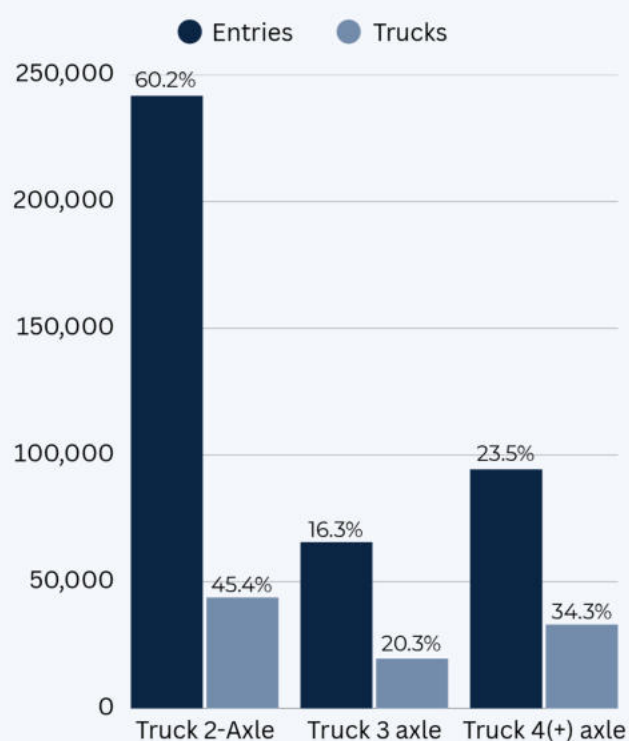


Figure 3.2(a): Fuel type distribution within each vehicle class showing 2-axle trucks making higher number of repeat entries

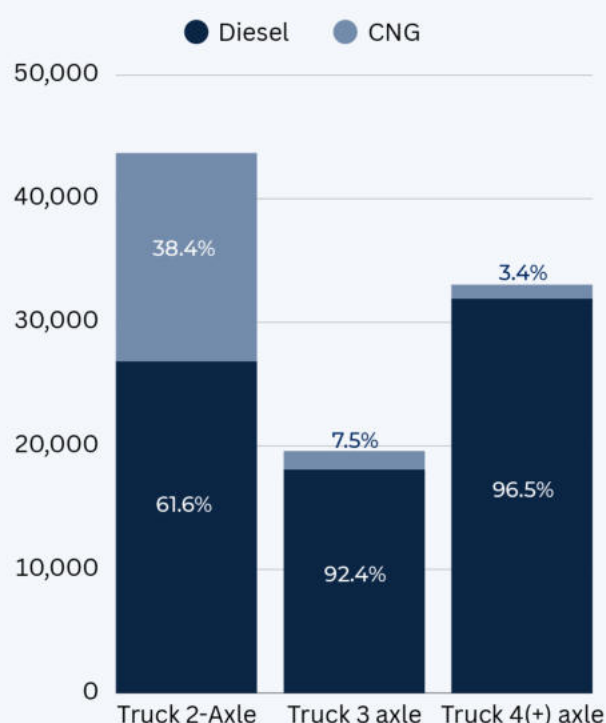


Figure 3.2(b): Number of unique trucks in truck entries split by vehicle class, where higher CNG usage is seen in the smaller-sized trucks

Table 2.2: Truck Population Composition Weighted by Number of Entries

Truck Type	Fuel Type	Proportion of total (%)		
		BS-VI	BS-IV	BS-III
2 Axle Trucks	Diesel	12.32	5.73	0.96
	CNG	29.48	7.41	4.38
3 Axle Trucks	Diesel	6.07	3.98	0.89
	CNG	1.14	2.59	1.22



V. Diurnal Patterns

There is a strong time-of-day trend, with ~80% of all truck entries occurring over a 10-hour period from 9 pm to 7 am. The highest volumes are in the 5-hour period from 11 pm to 4 am, with more than 50% of the overall day entries. Diesel entries dominate during the nighttime (Figure 3.3(a)) as compared to CNG trucks, and most (56%) of the vehicles entering during the daytime are smaller CNG trucks (Figure 3.3(b)).

Hourly Truck Volume - Split by Fuel Type

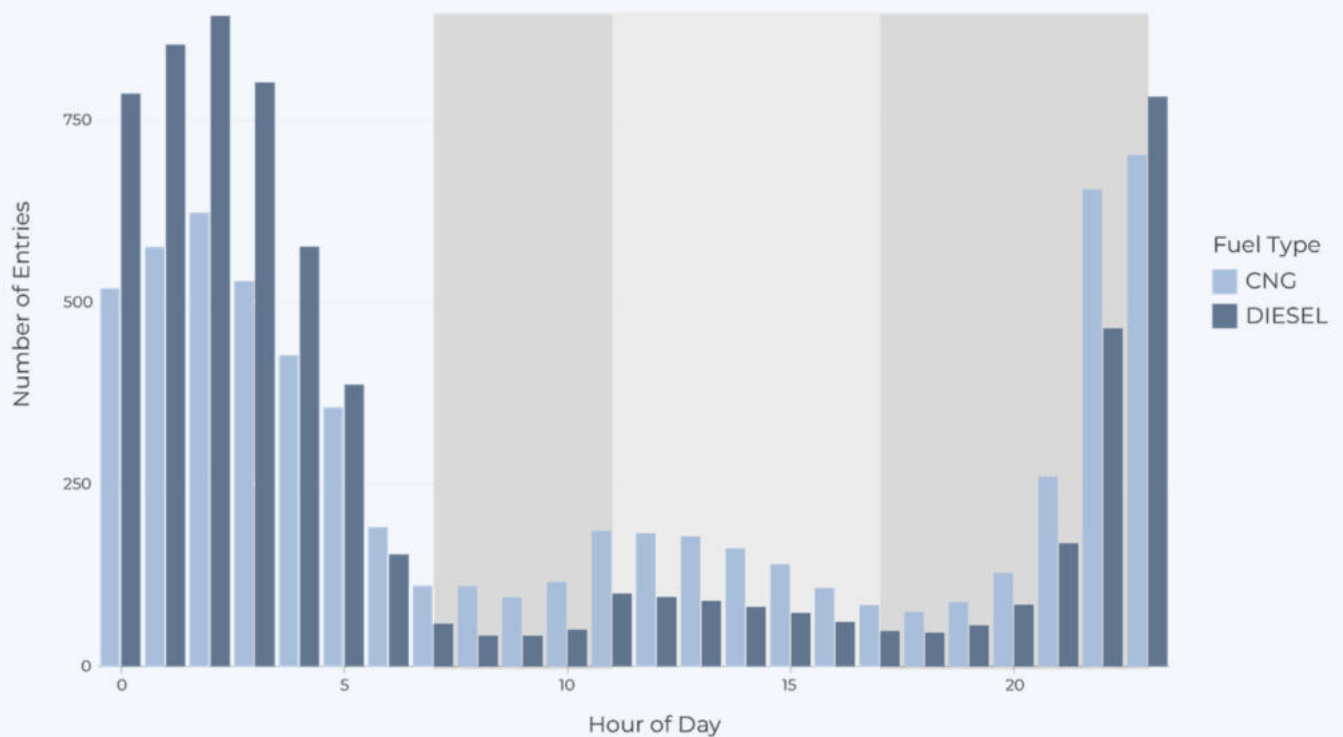


Figure 3.3(a): Average diurnal truck volume with restricted hours marked in grey, split by fuel type

Hourly Truck Volume - Split by Vehicle Type

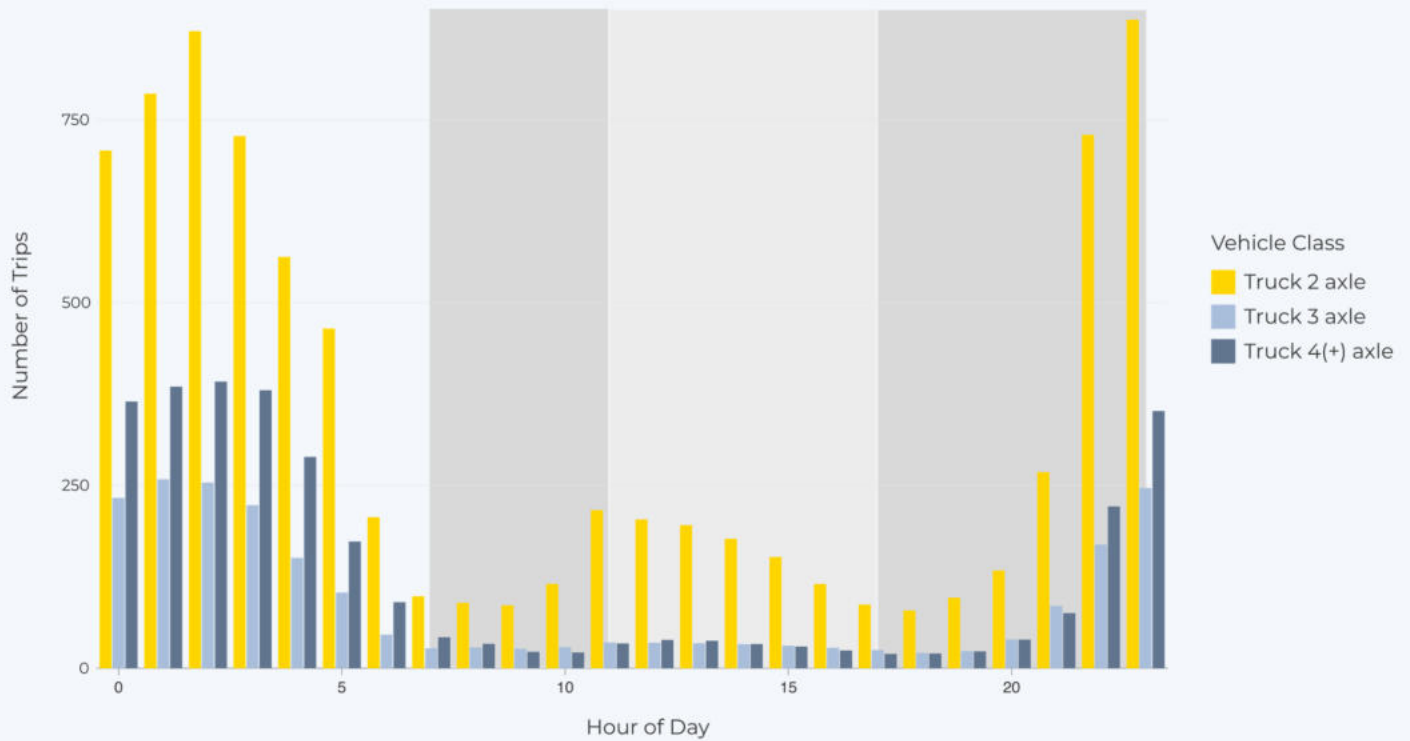
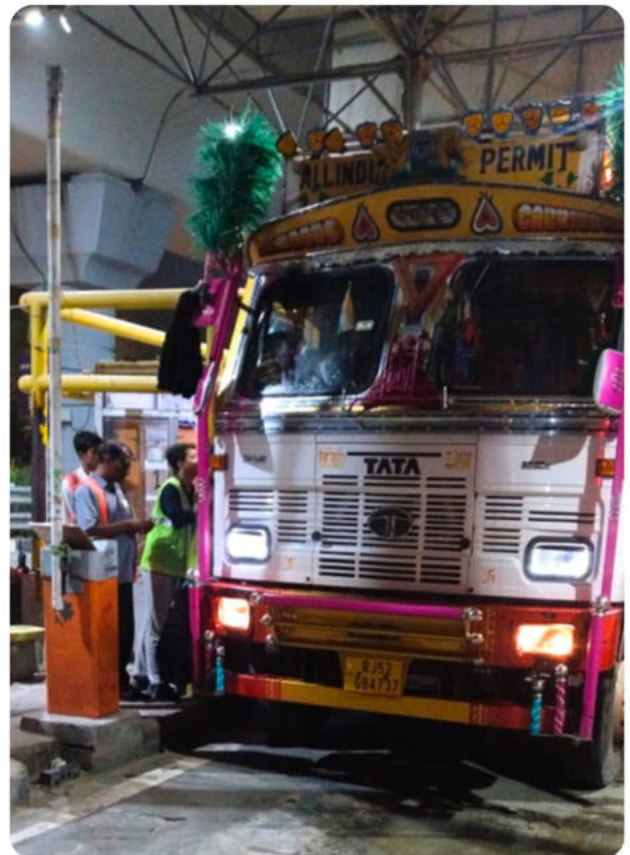


Figure 3.3(b): Average diurnal truck volume with restricted hours marked in grey, split by axle count¹⁷

Note: neither GRAP restrictions nor winter seasonality appear to materially affect overall daily HDV entries into Delhi. Comparing GRAP months (January and October-December 2025) with non-GRAP months shows total truck entries declining by only ~1.2%, with overall volumes remaining broadly stable. While 2-axle truck entries increase slightly during GRAP periods, MAV 03 and MAV 04 axle trucks decline by 5.87% and 5.20%, respectively, trends that largely offset each other.



¹⁷ Set 1 (light grey + dark grey) - full day restrictions for HDVs on 54 roads (7 am - 11 pm) and Set 2 (dark grey) - peak hour restrictions for HDVs on 29 roads (7 am - 11 am, and 5 pm - 11pm).

Understanding Operational Profile

To complement fleet composition and truck activity analysis, we surveyed truck drivers to better understand operational patterns, including origins, ownership and goods movement. We gathered and analysed over 20 variables (refer Annexure 1(A) for list of variables); detailed results are provided in Annexure 1(D). Key findings are summarised below.

I. Origin Patterns

The majority of trucks entering Delhi originate from NCR states (77%). Approximately 43% of trucks originate from Uttar Pradesh, 27% from Haryana, and 7% from Rajasthan (Figure 3.4).

Origin State Distribution

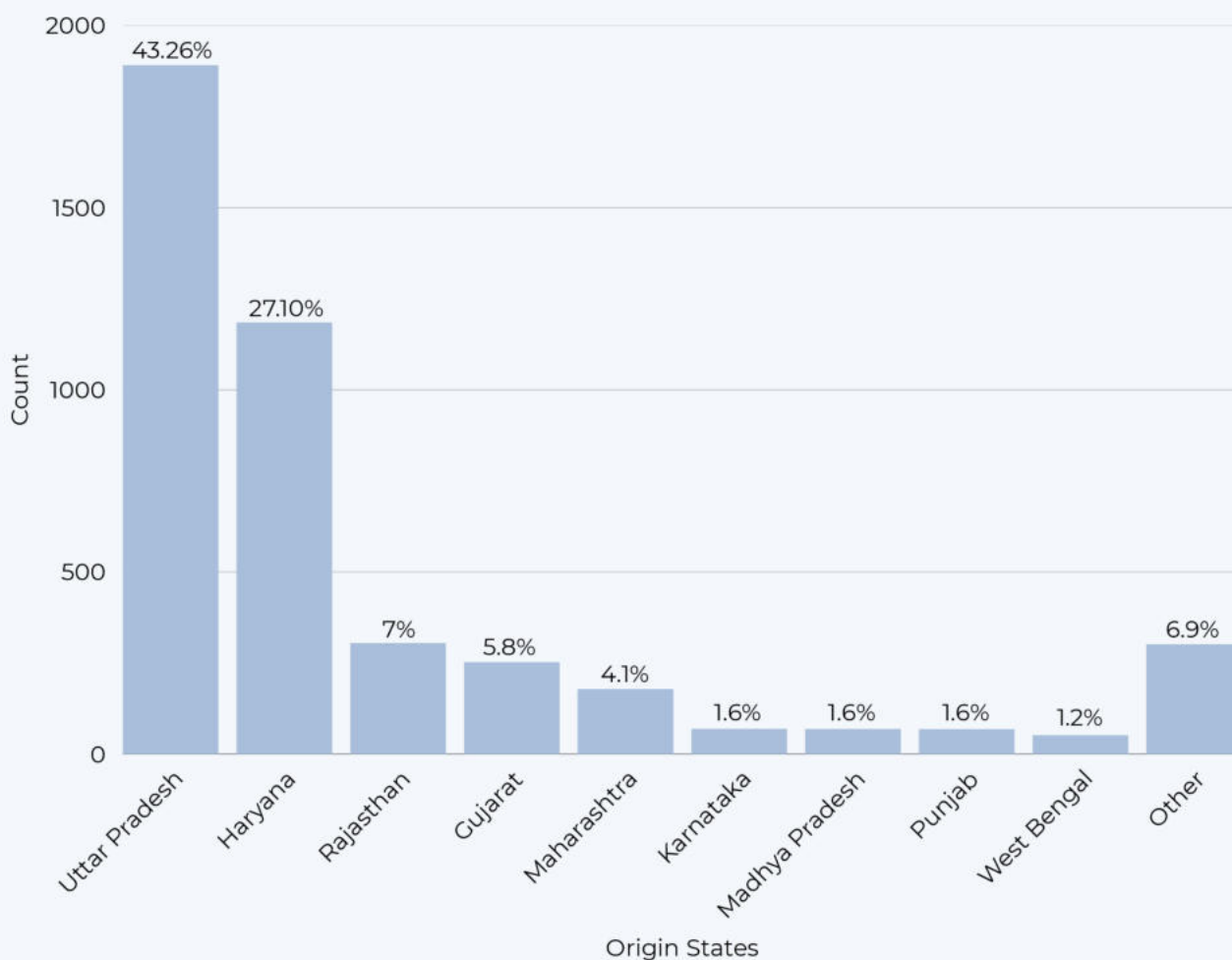


Figure 3.4: Truck entries by origin states

At the district level, entries are concentrated from adjoining NCR districts. Sonipat, Gurugram and Noida together account for approximately 66% of total truck entries into Delhi (Table 3.2). *Truck movement into Delhi is largely regional rather than long-haul, suggesting that effective policy interventions must operate at the NCR level, rather than being limited to Delhi alone.*

Table 3.2: Distribution of trucks entries by the district of entry (for top 20 toll plazas only)

Delhi District	Neighbouring District	Total Entries (%)	Unique Entries (%)	No. of Major Toll Plazas
North	Sonipat	22.8	23.2	3
South West	Gurugram	21.4	21.6	2
East	Noida	12.7	11.2	3
South East	Faridabad	12	15.6	1
South East	Noida	8.5	7.2	2
West	Jhajjar	7.7	9.4	1
Shahdara	Ghaziabad	6.1	6.8	3
South West	Jhajjar	4.2	2.3	2
North East	Ghaziabad	3.8	1.7	2
South	Gurugram	0.8	1	1

Fuel distribution also varies by origin: 60% of CNG trucks originate from Uttar Pradesh, compared to 25% of diesel trucks. This indicates that CNG trucks are more concentrated in specific regional corridors, reinforcing their role in short-haul, intra-NCR movements.

II. Entries by Toll Plaza

Geographic distribution of truck entries is highly skewed, with ~90% of trucks entering through only 20 toll plazas¹⁸.

Concentration is even more pronounced among the top locations: the 10 busiest plazas alone account for ~72% of total truck traffic. At an individual plaza level, Kundli/KGT Main handles the highest share of entries (17%), followed by Rajokri (14%), Badarpur (11%), and Tikri (7%).

Together, these four plazas account for nearly half (~50%) of all truck volumes entering Delhi. These plazas remain the most used by the trucks during the daytime as at night, with Kundli recording a fourth of the entries during the day (24%), while Rajokri has the highest entries at night (17%). *Strategic, targeted enforcement of mitigation strategies at 20 plazas has the potential to influence ~90% of truck traffic, while interventions at just 4 plazas could impact over 50%.*

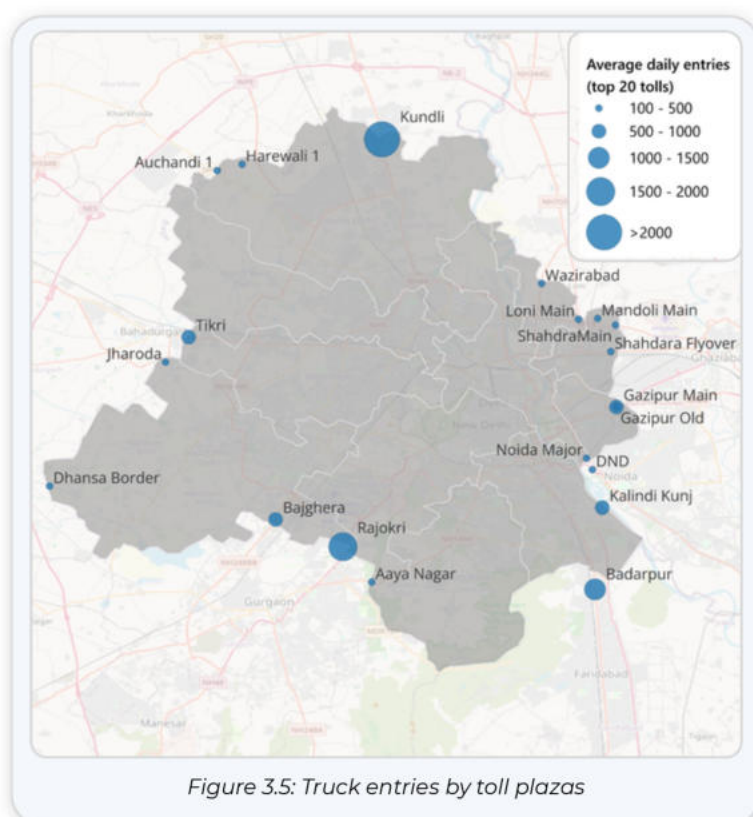


Figure 3.5: Truck entries by toll plazas

¹⁸ Note that these 20 plazas account for only 18% of all of Delhi's toll plazas that reported truck data. As mentioned previously, truck entries were reported at 114 out of Delhi's 121 toll plazas in the month of April 2025.

Table 3.3: Daily truck entries at the top 20 toll plazas

Plaza	Average daily truck entries
Kundli/KGT Main	2,222
Rajokri	1,835
Badarpur	1,430
Tikri	922
Gazipur Main	881
Bajghera	718
Kalindi Kunj	547
DND	468
NOIDA Major	355
Mandoli Main	327
Dhansa Border	306
Auchandi 1	302
Gazipur Old	277
Shahdara Flyover	268
Wazirabad	243
Loni Main	205
Harewali 1	197
Jharoda	192
Shahdara Main	143
Ayanagar	109

III. Destination Patterns

Almost all trucks (92%) report Delhi as their destination, while only 8% report bypassing the city

(Figure 3.6). Among 'bypassing' trucks, 86% originate from NCR states and 95% are destined for NCR states, indicating that these trips are largely intra-regional. Bypassing trips are also disproportionately undertaken by 2-axle CNG trucks (65%). Only 6% of 3+ axle trucks in our survey were found to be bypassing Delhi. This is a significant change from the CSE 2015 report¹⁹, which found that 40–60% of 3+ axle trucks entered Delhi while not destined for the city. Together, this suggests that bypass traffic is not predominantly long-distance through-movement, as is often assumed, but largely consists of short, intra-NCR trips²⁰.

¹⁹ Roychowdhury and Nasim (2016) *Trucks: Heavy-duty pollution and action*. Centre for Science and Environment

²⁰ However, these are survey-based estimates and should be interpreted with caution, as population-level patterns may not be fully captured.

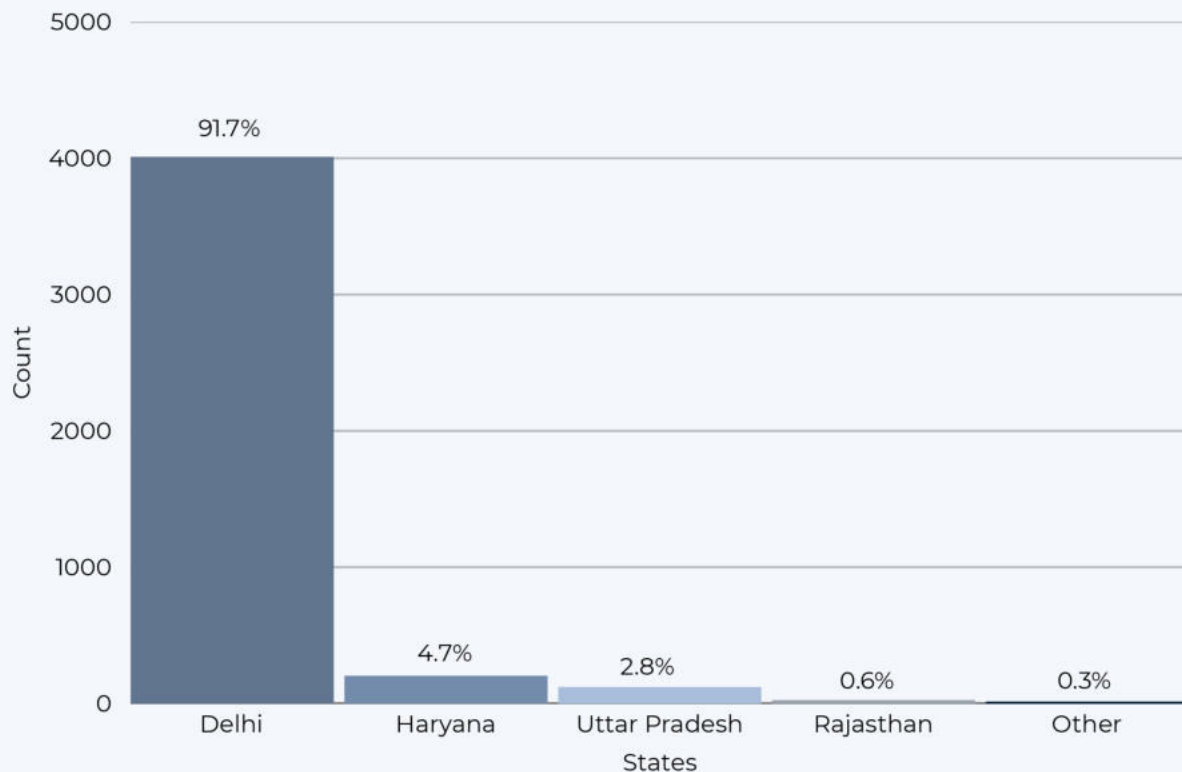


Figure 3.6: Truck entries by destination states

IV. Registration Patterns

Truck registrations are concentrated in NCR states (77%). Approximately 43% of trucks are registered in Haryana, followed by 18% in Uttar Pradesh and 16% in Rajasthan; only 9% of trucks are registered in Delhi (Figure 3.7). There is a clear disconnect between registration and origin patterns, suggesting that *policies based solely on registration (e.g., state-level restrictions) may mistarget actual traffic flows and must be supplemented with operational data.*



Figure 3.7: Truck registration by states

V. Ownership

Over 75% of trucks are company-owned. In terms of fuel share, company-owned trucks show an even CNG-diesel split, while self-owned trucks are predominantly diesel (60%) (Table 3.4). In terms of emission norms, there is no significant variation between self and company-owned trucks (Table 3.5). Differences are more evident in maintenance and operations. Company-owned trucks are better maintained, with 25% serviced at least once every three months, while only 10% of self-owned trucks report this frequency. At the same time, they exhibit higher operational inefficiencies—28% of company-owned trucks enter Delhi empty, compared to 19% of self-owned trucks.

Overall, while company-owned fleets appear relatively cleaner and better maintained, their higher share of empty trips points to inefficiencies in logistics planning and fleet utilisation. This suggests that targeted interventions—particularly among organised operators—could yield meaningful emission reductions.

Table 3.4: Percentage distribution of fuel type by type of truck ownership

Fuel Type	Company	Self
CNG	52.8	39.2
Diesel	47.2	60.8
Total	100	100

Table 3.5: Percentage distribution of emission standards by type of truck ownership

BS Norms	Company	Self
BS-III	8.9	12
BS-IV	27	28.9
BS-VI	64.1	59.1
Total	100	100

VI. Type of Goods

77% of trucks entering Delhi are loaded. Trucks carrying construction materials (26%) form the largest category, followed by industrial inputs (18%), food products (15%), and fruits and vegetables (12%); together, these account for roughly two-thirds of all trucks (Figure 3.8). Including courier items (11%) and household goods (6%), the top six categories comprise 88% of trucks. Interestingly, we found that most trucks (51%) report exiting Delhi empty²¹. This could be due to Delhi being a consumption and distribution hub, rather than a production centre, or due to operational inefficiencies. *In the case of the latter, these empty backhauls could be a source of inefficiency and emissions, highlighting a clear opportunity for measures focused on backhaul optimisation and improved load matching.*

The following four insights are particularly salient for understanding truck operations in Delhi. These findings, among others, have directly informed the design of policy and mitigation strategies:

1. The predominance of NCR-driven truck entries underscores the need for region-wide interventions, rather than Delhi-specific measures alone.
2. The high incidence of empty return trips highlights a clear and immediate opportunity for emissions reduction through backhaul optimisation and improved freight efficiency.
3. The high concentration of truck inflows at a limited number of entry points enables targeted, high-impact enforcement.
4. The dominance of company-owned fleets, along with their higher share of empty trips, suggests strong potential for efficiency and emission reduction potential through improved fleet utilisation.

²¹ As per insights from Truck Driver survey. This could be as high as 87%, based on responses from trucks surveyed on entry and asked about their return trips, where 87% indicated they would return empty. However, a lower estimate of 51% is based on a the survey of 305 trucks conducted on exit across key toll plazas (Auchandi Border, Badarpur Flyover, Kundli 1st, Sindhu Village, Zero Palla Toll Plaza, Loni Main Toll Plaza, Safiabad Toll Plaza, and Punjab Khor-II). While the exit survey provides a more accurate estimate, the 87% estimate is indicative of the potential scale of the issue.

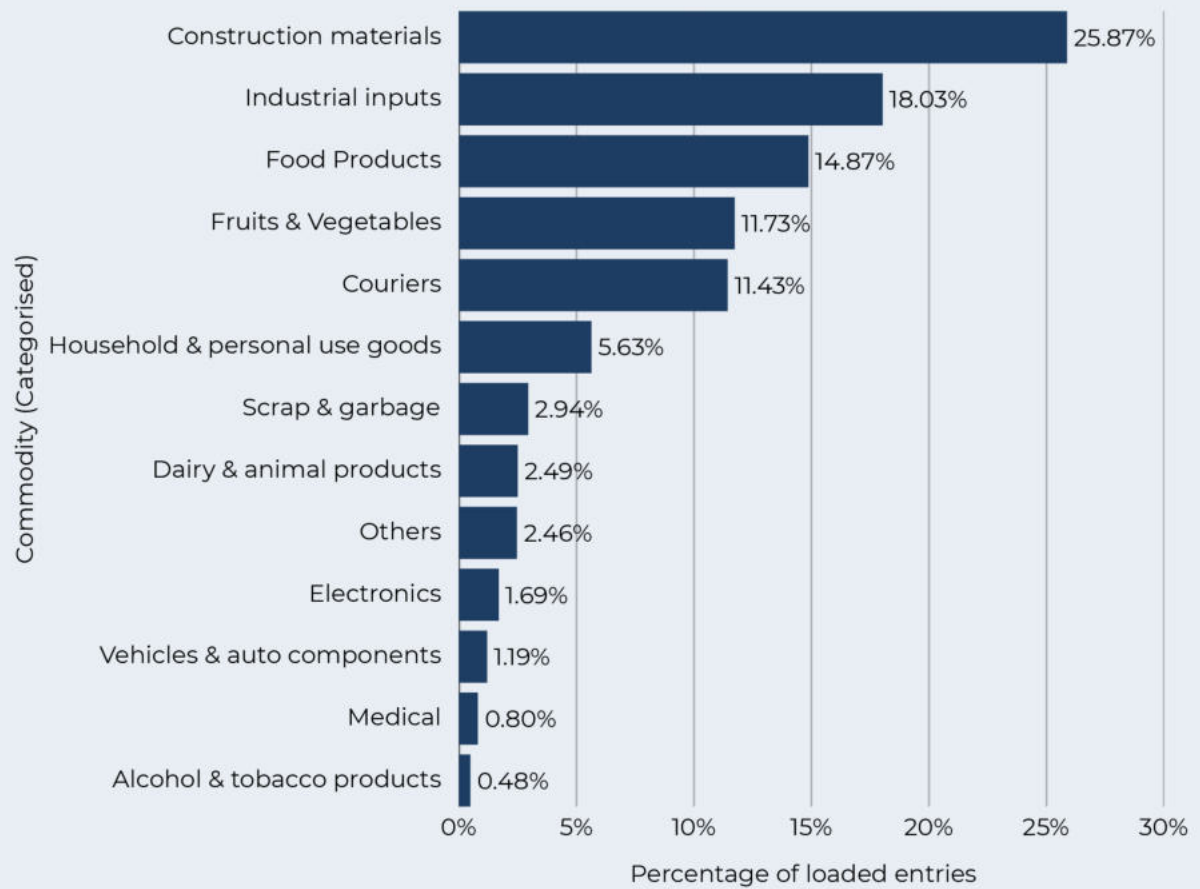


Figure 3.8: Types of goods carried by trucks

These findings have directly informed the design and prioritisation of the mitigation strategies outlined in subsequent sections of the report.

Estimating the Emission Contribution

Estimating how much pollution trucks emit per day in Delhi requires data on the number of trucks entering the city, their characteristics (e.g., age, size, and fuel type), and the corresponding emission factors, as well as the distance each truck travels within Delhi. The emissions from trucks were calculated using the following equation:

$$\text{Total Emissions (E)} = \text{Vehicle Kilometres Travelled (VKT)} \times \text{Vehicle Emission Factor (EF)}$$

Here, E is the emission of a particular pollutant, VKT is the total kilometres travelled by the total number of trucks of a given BS norm and fuel type, and EF is the emission factor for that pollutant, according to BS norm and fuel type. To estimate the average distance travelled by a truck within Delhi city, we mapped the destinations of different trucks and obtained the length of the shortest permissible route from the entry toll plaza. On average, a truck travels approximately 46.6 km per day within Delhi.

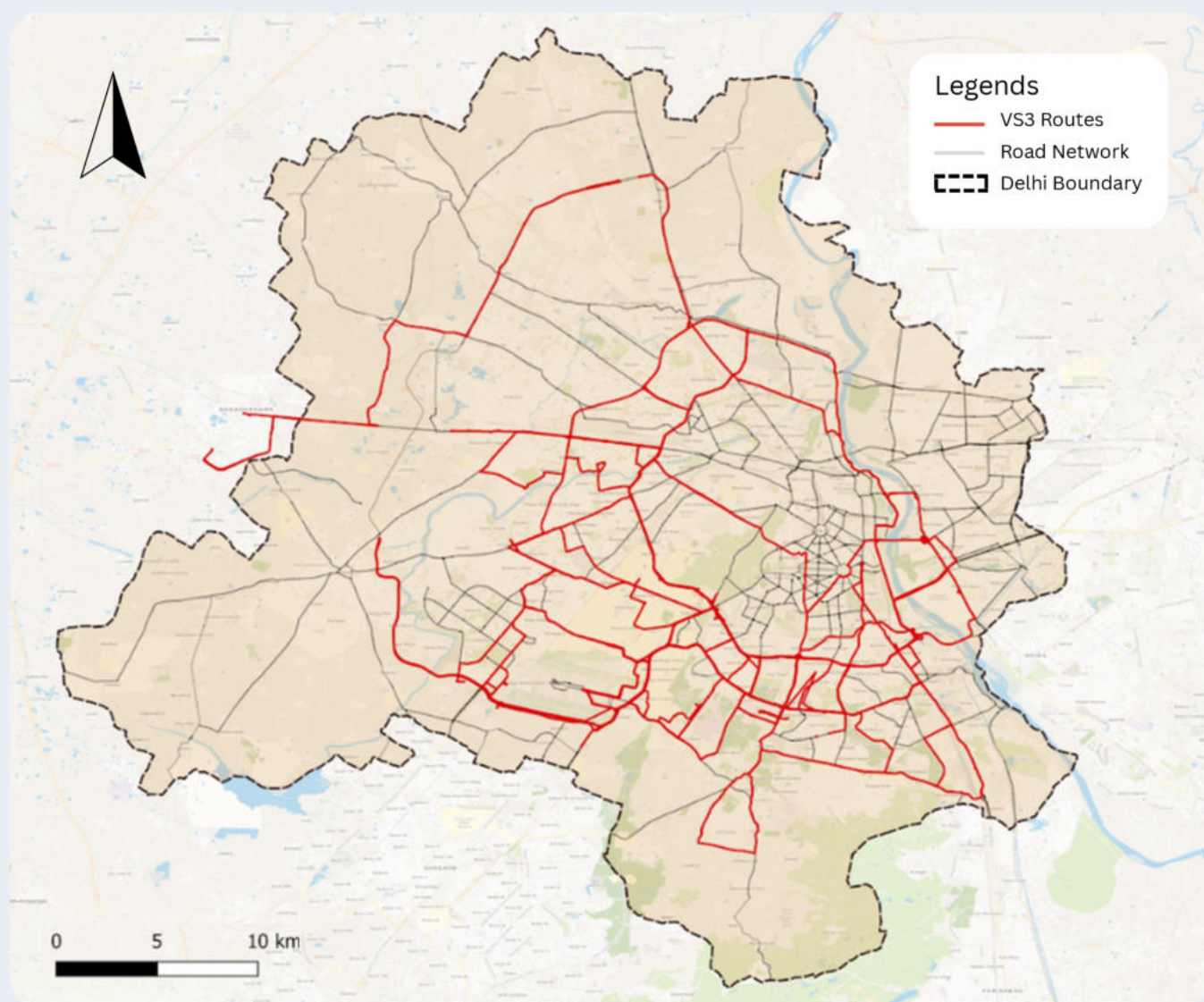


Figure 3.9: Consolidated routes from GPS mapping for VS3 experiments

Emission factors observed in the VS3 experiments (see Annexure 2(B)) were used to estimate total primary truck exhaust emissions for PM2.5, nitrogen oxides (NOx), and carbon monoxide (CO). Figure 3.9 presents the routes on which trucks were operated for on-road emission measurement. On average, BS-IV vehicles emit 1.3 times PM2.5, 7.4 times NOx, and 8.4 times CO than their BS-VI counterparts. The total average daily emissions for interstate trucks, stratified by axle type, are presented in Table 3.6. These calculations use the average number of trucks entering Delhi and the average distance travelled by each truck within the city.

The results indicate that **interstate trucks emit roughly 52 kg of PM2.5, 3 tonnes of NOx, and 2.5 tonnes of CO as primary pollutants each day.** This is approximately 18.9 tonnes of PM2.5, 1,095 tonnes of NOx, and 912.5 tonnes of CO annually. Pre-BS-VI trucks account for 62% of PM2.5, 87% of NOx, and 95% of CO emissions. Diesel trucks, which represent 51% of trips, contribute 56% of PM2.5, 56% of NOx, and 13% of CO emissions. These estimates should be treated as a pre-policy baseline against which future implementation of mitigation strategies' impacts can be assessed.

Table 3.6: Total emissions from truck segments (in kilograms per day)

Truck Type	Fuel Type	PM2.5 (kg/day)				NOx (kg/day)				CO (kg/day)			
		BS-VI	BS-IV	BS-III	Total	BS-VI	BS-IV	BS-III	Total	BS-VI	BS-IV	BS-III	Total
2 Axle Trucks	Diesel	3.88	3.16	1.96	9	70.8	273.7	98.5	443.1	3.9	18	17.4	39.4
	CNG	6.96	2.92	6.55	16.43	143.9	302.5	384.4	830.8	78.9	184.5	634.6	898.1
3 Axle Trucks	Diesel	2.39	2.19	2.04	6.62	43	234.2	113.3	390.5	3.8	23.8	31.3	59
	CNG	0.36	1.02	2.01	3.39	6.8	130.6	131.8	269.3	5.8	124.3	339.9	470
4+ Axle Trucks ²²	Diesel	5.95	4.4	3.35	13.7	124.1	529	208.3	861.5	23.9	106.9	109.8	240.8
	CNG	0.27	0.78	1.99	3.04	6.3	104.4	142.8	253.5	10	191.4	645.9	847.3
Total		19.81	14.47	17.9	52.18	395.1	1574.5	1079.1	3048.7	126.5	649	1778.9	2554.4

²² Emissions calculated as sum of all emissions from 4 axle trucks and emissions from 5+ axle trucks, assuming that all 5+ axle trucks have the same emission factor as for 5 axle trucks.

Early Morning and Nighttime Emissions

While HDVs contribute marginally during the day, their emissions share within transport increases to approximately 61% during early morning and nighttime hours.

These emissions are not evenly distributed over the day, as traffic activity varies significantly by time. Approximately 75% of interstate HDVs—for which emissions have been estimated in the study—operate in Delhi during early morning (5 am-7 am), and nighttime hours (10 pm to 5 am), whereas cars and other passenger vehicles account for only 18% of their daily volumes during this period (Table 3.7). This results in **a much higher relative presence of HDVs on the road during early morning and nighttime hours.**

Table 3.7. Proportion of early morning and nighttime emissions by vehicle type (all values in percentages)

Vehicle Type	Proportion of emissions throughout the day ²³	Proportion of vehicles (10 pm - 7 am) ²⁴	Proportion of emissions (10 pm - 7 am)
Car and Motorcycle	34.6	15	17.9
Bus	7.8	19	5.1
Autorickshaw + LDV	33.9	14	16.2
<i>HDV</i>	<i>23.4</i>	<i>75</i>	<i>60.5</i>
LCV	0.3	46	0.3
Total	100		100

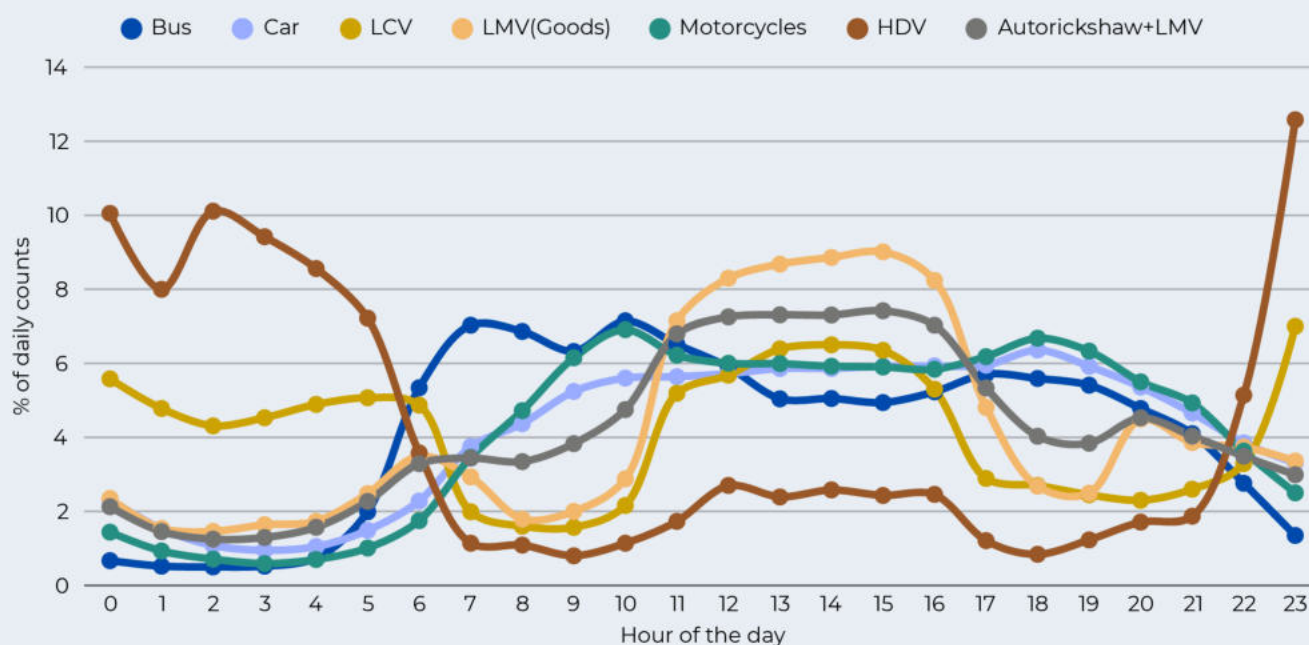


Figure 3.10. Hourly percentages of total daily traffic by vehicle type²⁵

²³ TERI, 2021

²⁴ This is based on 24-hour hourly traffic counts of 10 junctions across Delhi reported by CRRI, and corroborated by our camera-based traffic volume counts.

²⁵ This is based on 24-hour hourly traffic counts of 10 junctions across Delhi reported by CRRI, and corroborated by our camera-based traffic volume counts.

Figure 3.10 illustrates these contrasting diurnal patterns, showing that HDVs are heavily concentrated during nighttime hours, while personal vehicles are more evenly distributed across the day.

To estimate the contribution of HDVs to emissions, a recent transport emissions inventory for Delhi²⁶ was used to apportion emissions based on the temporal distribution of different vehicle types. **While HDVs account for 23% of total daily transport emissions, their share increases significantly to 61% during early morning and nighttime (Table 3.7), reflecting their disproportionate activity during these hours.**

In the early morning and nighttime hours, the impact of these emissions is further amplified by meteorological conditions—particularly the mixing layer height (MLH). In Delhi, as the wind speeds are low, the MLH heavily influences the resulting ambient concentration from emissions. During summer months, the average MLH at night time can be up to ten times higher than daytime, and during winter months, up to three times higher²⁷. This has been shown to strongly correlate with poorer air quality²⁸. Since concentrations are inversely proportional to mixing layer height, **the emission load from HDVs has a magnified impact on nighttime PM2.5 concentrations.**

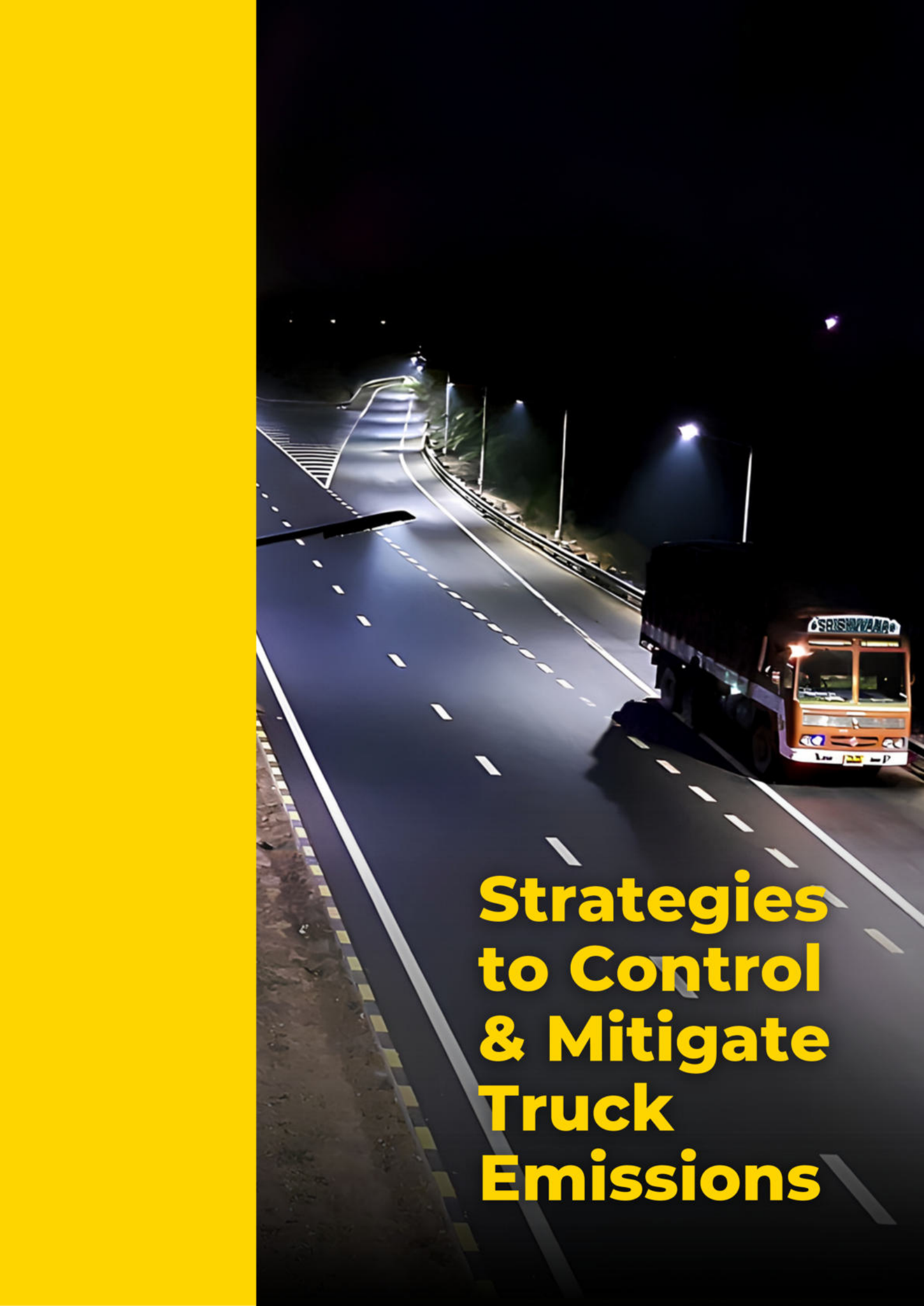
Study Limitations

- A regression model was developed to estimate emission factors across the full range of vehicle categories. This approach was adopted as not all truck configurations (age, emission norm, and vehicle weight) were covered in the VS3-based emissions measurements.
- The survey of truck drivers as well as RFID data did not capture vehicles with monthly passes, as they do not stop at the toll plazas. We have assumed that their operational and vehicular characteristics are similar to the trucks that were captured in the surveys, and they have been included in calculations for emissions.
- All the data collection, including RFID-based entry data, surveys, and camera-based traffic counts, was conducted from April to September 2025. Two policies have been implemented since then, affecting select truck categories:
 - a. **The ban on entry of pre-BS-IV diesel vehicles** would have affected approximately 3.6% of total truck entries. In the analysis, these vehicles are assumed to transition to BS-IV diesel trucks.
 - b. Following the data collection period (April to September 2025), **the Environment Compensation Charge (ECC) concessions for empty or partially loaded trucks and those carrying essential goods were discontinued.** This is expected to deter empty diesel trucks (11% of entries) and reduce trips by diesel trucks carrying essential goods (10%). As a result, some of these trips may shift towards CNG trucks, potentially reducing the share of diesel trips from 51% to around 30%. Consequently, diesel emissions may be overestimated in our current inventory.

²⁶ TERI, 2021

²⁷ Tiwari, et al, 2013

²⁸ Murthy et al (2020). Impact of mixing layer height on air quality in winter.



Strategies to Control & Mitigate Truck Emissions



Overview

As demonstrated, emissions from interstate HDVs are major contributors to PM_{2.5}, NO_x, and CO. Targeted mitigation is therefore essential, prioritising high-emitting trucks while considering local on-ground operations and logistics. Based on rigorous desk research, expert consultations, and stakeholder roundtables (see methodology in Chapter 2), a set of evidence-based strategies was identified. The complete list of nineteen strategies is provided in Annexure 3(A).

Evaluation Framework

Each of the nineteen strategies was evaluated on technical feasibility, cost-effectiveness, potential buy-in from a range of stakeholders, including drivers, manufacturers, and government, and scalability under NCAP or GRAP. Global benchmarks—such as the UK's LEZs and EU fleet electrification, among others—validated adaptations for India's context. This prioritisation has yielded recommendations for immediate, actionable implementation.

Based on this approach, seven strategies were shortlisted.

Shift to Electric Trucks

Ban on Entry of Pre-BS-VI Trucks in Delhi

Phase Out Trucks Based on Fitness Criteria

Stricter Enforcement via ANPR & Payload Sensors

Reduction in Number of Trips by Optimising Empty Backhauls

Reduction in Freight Trips Due to UCC

Retrofitment of Pre-BS-VI Trucks with PM & NO_x Control

The report first examines existing government policies and initiatives for heavy-duty vehicle emission control in Delhi-NCR, followed by lessons from global practices in countries such as China, the USA, Japan, Brazil, and Europe. This analysis highlights key gaps in implementation and scalability, which informed the selection of seven high-impact interventions.

The estimated emission reduction potential of these interventions, relevant policies, implementation status, impact assessment, and key considerations are provided in the following sections.

Existing Government Initiatives

Government agencies—e.g., MoRTH, DPCC, NGT, and MoHUA, among several others—have rolled out policies and initiatives targeting HDV emissions. The following summarises key policies and initiatives across seven main strategy categories for HDVs.²⁹

Table 4.1: Summary of government initiatives pertaining to shortlisted strategies

Strategy	Policy or Initiative	Policy / Initiative Description	Potential Impact (if implemented appropriately)	Current Status & Conditions for Success (status as on February '26)
Overall HDV Fleet	Policy (India)	Bharat Stage VI (BS-VI) HDV Standards (2016): Nationwide tailpipe PM and NOx standards for new HDVs with DPF/SCR systems and OBD compliance ³⁰	High	Fully implemented for new vehicles; dependent on in-use compliance & durability enforcement
	Initiative (India)	CNG/LNG Promotion for HDVs (2018-2025): Expansion of gas-based freight vehicles via fuel availability and fiscal incentives	Moderate	Gradual adoption in select corridors; constrained by fuel infrastructure & economics
	Policy (India)	Vehicle Scrappage Policy (Commercial Vehicles) (2021): Incentivised scrapping of old, polluting trucks with OEM discounts and deregistration mandates ³¹	Moderate-to-high	Operational but uneven uptake; dependent on incentive adequacy & enforcement stringency
	Policy (India)	Roadmap toward BS-VII / tighter in-use conformity (under discussion): Proposed tightening of real-world emission testing, durability factors, and conformity of production ^{32 33}	High	Policy under development; effectiveness dependent on real-world enforcement architecture
Reduction in Freight Trips Due to UCC	Initiative	Digital Load Consolidation & Emission Tracking (2025): Standardised digital tracking to eliminate redundant freight movement ³⁴	Moderate	Minimal implementation; dependent on data integration and industry participation

²⁹ Note that this summary focuses on policies that apply nationally or to Delhi-NCR only; state-specific policies outside these geographies are not included.

³⁰ PIB (2017, March 30). Bharat Stage-VI norms.

³¹ PIB (2021, March 18). Road Transport & Highways Minister, Shri Nitin Gadkari announces vehicle scrapping policy.

³² PIB. (2025a, January 17). MoRTH organise two-day workshop in Delhi to deliberate issues, solutions and further steps to be taken to help drive transformation in India's road transport sector.

³³ Down To Earth. (2025, September 11). Centre to roll out BSVII to tackle air pollution, expand scrappage; eyes seamless EV charging.

³⁴ PIB (2025b, September 8). Union Minister of Commerce and Industry launches Logistics Data Bank (LDB) 2.0 to boost India's digital trade and export competitiveness.

Table 4.1: Summary of government initiatives pertaining to shortlisted strategies

Strategy	Policy or Initiative	Policy / Initiative Description	Potential Impact (if implemented appropriately)	Current Status & Conditions for Success (status as on February '26)
Shift to Electric Trucks	Policy (India)	PM E-DRIVE (2024): ₹10,900 Cr support for EV adoption, including HDVs ³⁵	High	Nascent pilot phase; full scale deployment dependent on charging infrastructure & procurement scale
	Policy (DL)	Delhi EV Policy (2026): Subsidies outlined for goods vehicles (i.e. LGVs) among delivery fleet operators ³⁶	Moderate-to-low	Mandates & subsidies for HDVs needed; there remains scope to define subsidies & charging infrastructure guidelines for e-HDVs
Retrofitment of Pre-BS-VI Trucks with PM & NOx Control	Policy (India)	G.S.R. 625(E) (2022): Permits BS-IV diesel trucks to convert to CNG/LPG via certified retrofit kits ³⁷	Moderate	Legally permitted; limited air quality gains due to absence of standards for advanced after-treatment
	Initiative (India)	Delhi BS-IV to VI Retrofit Challenge (2025): Financial incentive for scalable OEM-grade emission retrofit solutions ³⁸	High	Pilot-stage initiative; scalability and commercial viability yet to be demonstrated.
Phase Out Trucks Based on Fitness Criteria	Policy (DL-NCR)	NGT Diesel >10-Year Ban (Order 95/2014): Age-based deregistration of older diesel vehicles under CMVR Rules ³⁹	High	Enforcement currently suspended; effectiveness contingent on legal and administrative revival.
	Policy (DL-NCR)	Recommendation by the Supreme Court to Deregister Vehicles based on Performance: Court-recommended shift from age-based to emission-performance-based removal ⁴⁰	High	Implementation underway; dependent on robust OBD and testing integration

³⁵ PIB (2025c, February 11). PM E-DRIVE scheme for electric vehicle adoption.

³⁶ GNCTD (2026, April 11). Delhi electric vehicle policy, 2026-2030 (Draft).

³⁷ MoRTH (2022, August 11). Notification regarding use of CNG and LPG kits in Bharat Stage-VI vehicles. Government of India.

³⁸ The Economic Times. (2025, July 23). Delhi to throw ₹50 lakh innovation challenge to retrofit BS-IV trucks.

³⁹ NGT (2023). Compilation of orders of Hon'ble Supreme Court of India and NGT submitted by applicant in M.A. 112 of 2023 in O.A. 21 of 2014

⁴⁰ CAQM (2025a), Amendment to Direction No. 89 under Section 12

Table 4.1: Summary of government initiatives pertaining to shortlisted strategies

Strategy	Policy or Initiative	Policy / Initiative Description	Potential Impact (if implemented appropriately)	Current Status & Conditions for Success (status as on February '26)
Phase Out Trucks Based on Fitness Criteria	Initiative (India)	Automated Testing Stations (ATS) Expansion (2024): Nationwide expansion of automated fitness testing with digital integration ⁴¹	Moderate-to-high	Infrastructure scaling in progress; effectiveness dependent on enforcement consistency.
Ban on Entry of Pre-BS-VI Trucks in Delhi	Policy (DL-NCR & some Indian cities)	GRAP Stage III/IV Entry Restrictions (2017 onwards): Seasonal prohibition of pre-BS-VI trucks entering Delhi during high AQI periods ⁴²	High, in the short-term; ineffective in the long-term	Episodically enforced; limited structural effect outside activation periods
Stricter Enforcement via ANPR & Payload Sensors	Policy (India)	MoRTH ATS & OBD Mandate (2024): OBD-II, ANPR, integrated with VAHAN for e-challan enforcement ^{43 44}	High	Nationwide rollout active; dependent on data integrity and enforcement follow-through.
Reduction in No. of Trips by Optimising Empty Backhauls	Initiative (India)	Gati Shakti National Master Plan (2021): Integrated infrastructure planning for freight corridors to optimise logistics and reduce empty trips ⁴⁵	High	Implementation ongoing; dependent on inter-agency coordination and infrastructure execution

Conclusion

India and Delhi-NCR have rolled out ambitious HDV emission policies across standards, fleet modernisation, enforcement, and freight operations. However, most initiatives remain at an early stage, requiring scaling, real-world testing, and coordinated enforcement to deliver measurable emission reductions. Against this backdrop, it is valuable to examine global HDV emission practices, which highlight regulatory approaches, technology adoption, and logistics strategies that can inform the next phase of India's clean freight transition.

⁴¹ MoRTH (2024). Vehicle fitness testing at automated testing stations (ATS): Guidelines for vehicle owners

⁴² CAQM (2025). Graded Response Action Plan (GRAP) schedule for NCR.

⁴³ MoRTH, 2024

⁴⁴ PIB (2025, April 18). Clarification on launch of satellite-based tolling system from 1st May 2025.

⁴⁵ PIB (2024, October 12). PM Gati Shakti: Transforming India's infrastructure and logistics sector

Learning from Global Evidence: Key Enablers of Successful Emission Reduction Strategies

The following is a review of global truck emission reduction strategies, focusing on key implementation enablers and learnings for Delhi-NCR. Detailed country-specific initiatives and outcomes from China, the USA, Japan, Brazil, the UK, and Norway are provided in Annexure 3(B).

1. Clear, Enforceable Emission Standards

All jurisdictions established unambiguous emission limits or access restrictions for heavy-duty vehicles (e.g., China-VI⁴⁶, Euro VI⁴⁷, PROCONVE⁴⁸) and backed them with robust enforcement mechanisms, including in-use testing, remote monitoring, roadside inspections, and legal penalties. Regulatory certainty reduced compliance delays and accelerated investment by manufacturers and fleet operators.

Learning for Delhi-NCR:

Transition from episodic emergency measures to permanent, enforceable in-use emission and access standards for trucks, supported by predictable penalties and continuous monitoring.

2. Economic Incentives Aligned with Total Cost of Ownership

Successful countries (especially China) reduced the cost disadvantage of clean trucks through capital subsidies, operating incentives⁴⁹, and differential taxation, ensuring that zero- or low-emission trucks are price-competitive over their full lifecycle. Incentives were designed to influence daily operating decisions, not only the upfront vehicle purchase.

Learning for Delhi-NCR:

Prioritise operating-cost incentives (e.g., toll exemptions, access privileges, fuel pricing reforms) so that clean trucks are economically preferable to diesel alternatives in regular use.

3. Urban-Focused Controls with Local Authority

Truck emission policies in the U.K. were implemented first in high-density urban areas, where the potential for emission impact/reduction is the highest. National governments provided legal authority and funding, while cities enforced low- or zero-emission zones, access charges, or outright bans on high-polluting trucks⁵⁰.

Learning for Delhi-NCR:

Grant NCR cities clear statutory authority to implement truck-specific low- and zero-emission zones, particularly around logistics hubs, industrial clusters, and high-exposure corridors.

⁴⁶ ICCT (2018, July 20). *China's Stage VI emission standard for heavy-duty vehicles (final rule)*

⁴⁷ ICCT (2016, July 1). A technical summary of Euro 6/VI vehicle emission standards

⁴⁸ ICCT (2019, February 27). Brazil PROCONVE P-8 emission standards.

⁴⁹ Smart Freight Centre (2023, August). China zero emission freight status report 2022.

⁵⁰ UK Government. (2023, January 30). Driving in a clean air zone. GOV.UK.

To begin with, Delhi should prioritise charging infrastructure along routes connected to the top 5 freight entry points - Kundli, Rajokri, Badarpur, Gazipur Main, and Tikri, which together account for 52% of 2- and 3-axle truck traffic entering the city. Charging infrastructure should be concentrated at existing truck halt locations such as logistics hubs, dhabas, etc.

4. Lifecycle Accountability for Vehicles, Fuels, and Operators

Effective systems ensured accountability beyond vehicle registration, covering real-world vehicle emissions, fuel quality, and operator behaviour. Measures included manufacturer recalls (USA⁵¹), fuel adulteration enforcement (Japan⁵²), remote emissions reporting (China⁵³), and anti-idling rules⁵⁴.

Learning for Delhi-NCR:

Adopt a lifecycle compliance framework combining in-use emission monitoring, strict fuel-quality enforcement, and operator-level penalties for non-compliance.

5. Public Investment to De-Risk Early Adoption

Governments (e.g., in the U.K.) played a catalytic role by funding⁵⁵ infrastructure, pilot projects, and early fleet deployments, reducing risk for operators and enabling market scale-up. These investments preceded or accompanied tighter regulations.

Learning for Delhi-NCR:

Deploy targeted public funding for urban freight electrification pilots, charging hubs, and scrappage-linked replacement, focusing initially on high-utilisation truck segments.

Overall Implication for Delhi-NCR:

International experience demonstrates that sustained reductions in truck emissions require integrated policy design, combining regulatory certainty, economic alignment, urban governance, lifecycle enforcement, and strategic public investment. Fragmented or short-term measures are unlikely to deliver durable air-quality gains.

⁵¹ ICCT (August, 2013). *Survey of best practices in emission control of in-use heavy-duty diesel vehicles.*

⁵² ICCT, 2013

⁵³ ICCT, 2018

⁵⁴ ICCT, 2013

⁵⁵ Department for Transport, UK Government (2022, May 12). *£200 million boost to rollout of hundreds more zero-emission HGVs*

Strategy 1: Shift to Electric Trucks

Our Point-of-View:

Transitioning the freight fleet towards battery electric trucks is **feasible & recommended** in Delhi, but should be strategically phased, beginning with 2- and 3- axle trucks engaged in short-haul, high-utilisation operations. E-trucks eliminate 100% of tailpipe emissions (PM, NOx, CO₂), making them a critical solution. However, large-scale deployment is constrained by high upfront costs (₹220-270 lakh for 28-42 tonne trucks vs. ₹42-49 lakh for diesel⁵⁶), limited range (100-350 km⁵⁷), sparse charging infrastructure (1:400⁵⁸ EV to public charger ratio) and grid readiness challenges. These barriers are particularly significant for heavier, long-haul trucks, making 2- and 3-axle trucks the most viable near-term segment for electrification. Accelerating adoption will require targeted financing support, especially for small and informal fleet operators facing high upfront costs and limited access to credit. Deployment should also align with the PM E-DRIVE Scheme and National Logistics Policy to support electrification, charging infrastructure expansion and more efficient freight movement. For effective implementation, Delhi should adopt the following phased roadmap:

- **Phase 1 (within 12 months):** Expand corridor charging infrastructure along high-volume freight corridors and establish financing mechanisms for fleet operators, targeting ~10% electrification of 2- & 3-axle trucks.
- **Phase 2 (within 3 years):** Continue to scale deployment across short-haul trucks, expand charging networks, and strengthen grid capacity
- **Phase 3 (Post-2030):** Expand electrification of heavier long-haul truck segments as battery technology matures, costs decline and charging ecosystems strengthen across Delhi-NCR.

I. Introduction & Context⁵⁹

Battery electric trucks eliminate tailpipe emissions entirely (zero PM, NOx, CO₂ at point of use) by using electric motors powered by rechargeable batteries. Major Indian models include: Tata Ultra T.7 EV (8 tonnes, ~100 km range, ₹15-17 lakh)⁶⁰, Ashok Leyland Boss 1218 HB EV (12 tonnes, 300-350 km, ₹25-26 lakh)⁶¹, and Ashok Leyland AVTR 55T EV (55 tonnes, 180 km, ~₹1.25 crore)⁶².

II. Trucks Targeted

In the short term, this intervention primarily targets 2-axle and 3-axle trucks for electrification that constitute about 76% of the total truck entries⁶³. They contribute 68% to PM_{2.5}, 63% to NOx, and 57% to CO emissions from inter-state trucks. In the long term, this intervention will target the full fleet.

⁵⁶ ICCT (2024). Total cost of ownership parity between battery electric trucks and diesel trucks in India.

⁵⁷ ICCT, 2024

⁵⁸ The Times of India (2025) India's EV charging infra undergoing an upgrade

⁵⁹ Note that, unless cited otherwise, all inputs in this strategy note are from stakeholder consultations.

⁶⁰ Tractor Junction. (n.d.). Tata Ultra T.7 electric truck. Retrieved April 10, 2026, from <https://trucks.tractorjunction.com/en/tata-truck/ultra-t7-electric>

⁶¹ TrucksFloor. (n.d.). Ashok Leyland Boss 1218 HB EV truck. Retrieved April 10, 2026, from <https://trucksfloor.com/en/ashok-leyland-truck/boss-1218-hb-ev>

⁶² TrucksFloor. (n.d.). Ashok Leyland AVTR 55T EV truck. Retrieved April 10, 2026, from <https://trucksfloor.com/en/ashok-leyland-truck/avtr-55t-ev>

⁶³ As per insights from our RFID & TVC analysis



III. Emission Reduction Potential⁶⁴

Emission reduction estimates are calculated relative to a 2025 Business-as-Usual (BAU) baseline scenario.

Target (Cumulative)	Timeframe	Percentage Reduction w.r.t. BAU			
		PM2.5	CO	NOx	CO2
10%	2027	14	19	20	4
15%	2028	15	25	23	4
30%	2030	23	44	57	13
50%	2032	39	62	68	30
100%	2035	100	100	100	100

Begin electrification of 2-axle trucks in the short term, and gradually transition 3 & 4+ axle trucks in the long term.

⁶⁴ Estimates are from our emission reduction modelling. See Annexure 3(F) for more information

IV. Cost⁶⁵

Component	Cost Estimate
2 axle electric truck	40-70 lakh per vehicle
3 axle electric truck	70 lakh-₹1.2 crore per vehicle
4+ axle electric truck	₹1.2-2.0 crore per vehicle
Charging infrastructure (depot-based)	₹5-20 crore per depot
Fast-charging corridor infrastructure	₹10-30 crore per corridor
Grid strengthening and upgrades	Project-dependent
Battery replacement	~₹3-13 lakh per truck (depending on size)
Payback period	~3-5 years for high-utilisation segments; longer (5-7+ years) for heavy-duty trucks

V. Infrastructure Requirements

Successful transition to electric trucks requires:

1. Development of charging infrastructure at fleet operator depots and key logistics clusters
2. Deployment of fast-charging stations along the freight corridor
3. Strengthening of electric grid capacity

⁶⁵ Cost estimates are indicative and based on our analysis

VI. TRL in India⁶⁶

Segment	TRL (India)	Evidence
Battery & Electric Drivetrain	TRL 8-9	Proven and commercially available; multiple Indian OEMs offering models.
DC Fast Charging	TRL 8-9	Deployed on select expressways; high-capacity systems under standardization
Depot Charging Infrastructure	TRL 7-8	Operational for organized fleets; highway infrastructure sparse
Grid Integration & Smart Charging	TRL 5-6	Local grids unprepared for megawatt-scale loads; V2G in pilot stages.
System Integration for Short-Haul Urban Fleets	TRL 7-8	Viable for captive fleets; multiple successful pilots with e-commerce and logistics operators.

VII. Key Advantages:

The following advantages have been identified, based on stakeholder consultations and secondary research:

- 1. Zero Tailpipe Emissions:** E-trucks eliminate 100% of tailpipe PM, NOx, CO2, and VOCs, while reducing overall lifecycle GHG emissions by 63% relative to diesel.⁶⁷
- 2. Significantly Lower Operating Costs:** Operational costs are up to 47% lower than diesel (₹6-8/km), with operational savings of ~₹18/km in regional haul applications⁶⁸. For high-utilization fleets (200+ km/day), OpEx savings offset high upfront costs within 6-8 years with subsidies.⁶⁹
- 3. Policy Support & Regulatory Momentum:** Strong government push via PM E-DRIVE (₹500 crore subsidies for 5,500 trucks)⁷⁰, road tax waivers, and net-zero commitments.

VIII. Potential Challenges:

The following challenges have been identified, based on stakeholder consultations and secondary research:

- 1. High Upfront Costs & Limited Financing:** E-trucks cost 50-70% more than diesel (₹80-115 lakh vs. ₹38-55 lakh for HDVs). Without subsidies, payback exceeds 10 years. Traditional financiers are hesitant due to battery risks, asset depreciation, and weak residual value predictability⁷¹.

⁶⁶ TRL levels are based on our analysis, informed by multiple reference frameworks.

⁶⁷ ICCT (2023). Battery electric trucks emit 63% less GHG emissions than diesel.

⁶⁸ NITI Aayog & RMI, 2022

⁶⁹ ICCT, 2024

⁷⁰ Ministry of Heavy Industries. (2025, July 10). Notification S.O. 3081(E): Phased manufacturing programme (PMP) for electric trucks (N2 and N3 categories)

⁷¹ ICCT, 2024

2. **Limited Range & Payload Trade-offs:** Current models offer 100-350 km range, unsuitable for long-haul (diesel: 700-1,200 km). Batteries reduce payload capacity by 15-20%, impacting freight economics⁷².
3. **Sparse Charging Infrastructure & Grid Readiness:** EVs to public charger ratio (1:400) inadequate⁷³ corridor-scale infrastructure absent. Depot charging requires megawatt-scale grid upgrades unavailable at most logistics hubs⁷⁴.
4. **Adoption Barriers for Small & Informal Operators:** High capital requirements, limited digital access, and lack of financing options make e-truck adoption particularly difficult for small fleet owners⁷⁵.

⁷² ICCT, 2024

⁷³ The Times of India. (2025, January 18). India's EV charging infra undergoing an upgrade

⁷⁴ Observer Research Foundation. (2025). Charging Infrastructure: The Missing Link in India's EVs Transition

⁷⁵ ICCT, 2024

Strategy 2:

Ban on Entry of Pre-BS-VI Trucks

Our Point-of-View:

Restricting the entry of pre-BS-VI trucks into Delhi through a Low Emission Zone (LEZ) is **feasible** and **recommended**. A permanent, norms-based LEZ—limiting access to BS-VI trucks, electric trucks, or other low-emission trucks (i.e. hydrogen, LNG, etc.)—enables predictable, year-round emission reductions and offers a more sustained reduction alternative to episodic measures such as GRAP. This strategy is technically mature and policy-feasible, supported by existing enforcement systems such as ANPR and integrated vehicle databases. However, isolated implementation risks diversion of traffic and emissions to surrounding districts and an uneven cost burden on smaller and informal operators. Therefore, LEZs must be combined with regional coordination for sustained impact, phased timelines, and financing support. Additionally, alignment with national initiatives such as the National Logistics Policy and PM Gati Shakti can help minimise supply-chain disruptions and enable coordinated regional freight and infrastructure planning in Delhi. For effective implementation, Delhi should adopt the following phased roadmap:

- **Phase 1 (within 12 months):** Establish ANPR-enabled enforcement systems at major freight entry points, define vehicle eligibility criteria and integrate compliance systems with the VAHAN database.
- **Phase 2 (within 3 years):** Strengthen inter-agency coordination and pilot coordinated compliance mechanisms with neighbouring NCR districts to minimise traffic diversion and enforcement gaps.
- **Phase 3 (Post-2030):** Expand LEZ implementation across NCR.

I. Introduction & Context⁷⁶

Low Emission Zones (LEZs) are geographically defined regulatory areas where entry of vehicles not meeting specified emission standards is restricted or penalised. It is a permanent restriction that yields sustained air quality benefits over time, as opposed to one-off spikes. This gives residents and businesses clarity to plan transitions and re-routing.

II. Trucks Targeted

LEZs will target all pre-BS-VI trucks, which comprise 38% of truck entries⁷⁷. Presently, these vehicles collectively contribute an estimated ~62% of PM_{2.5} emissions, ~87% of NO_x emissions, and ~95% of CO emissions originating from inter-state trucks. On average, BS-IV diesel trucks emit 1.5 times PM_{2.5}, 8.4 times NO_x, and 9.4 times CO emitted by their BS-VI counterparts⁷⁸.

⁷⁶ Note that, unless cited otherwise, all inputs in this strategy note are from stakeholder consultations.

⁷⁷ As per insights from our RFID & TVC analysis.

⁷⁸ As per insights from our VS3 / PEMS analysis & modeling. Additionally, emissions from BS-III diesel trucks are even higher, at 6 times PM_{2.5}, 18 times NO_x, and 55 times CO, relative to BS-VI. Further, pre-BS-VI CNG trucks are comparatively polluting to their diesel counterparts (BS 4 CNG:diesel emission ratios: PM_{2.5}: 0.74 times, NO_x: 0.85 times, CO: 8 times). However, this finding is based on a small sample (n=3) and non-comparable testing conditions (day-time CNG measurements vs night-time diesel measurements under different traffic conditions); results should therefore be considered indicative.

III. Emission Reduction Potential⁷⁹

Emission reduction estimates are calculated relative to a 2025 Business-as-Usual (BAU) baseline scenario. Note that, in this report, emissions modeling has been done assuming Delhi-specific entry restrictions.

Target	Timeframe	Percentage Reduction w.r.t. BAU			
		PM2.5	CO	NOx	CO2
100%	2027	51	94	83	48

IV. Costs⁸⁰

Component	Cost Estimate
ANPR system deployment (per entry corridor)	₹5-10 crore
City-wide ANPR infrastructure	₹100-250 crore
Central IT system and VAHAN integration	₹10-25 crore
Annual O&M and monitoring	~10-15% of capital cost

IV. Infrastructure Requirement

1. Identification and notification of LEZ boundaries and clearly defined vehicle eligibility criteria
2. Deployment of ANPR-based enforcement systems across all entry points and major freight corridors
3. Integration with the VAHAN database for vehicle verification and compliance checks
4. Establishment of real-time violation detection and automated penalty enforcement mechanisms

V. TRL in India

Segment	TRL (India)	Evidence
ANPR-based enforcement systems	TRL 8-9	Widely deployed across toll plazas and traffic systems
Vehicle database integration (VAHAN)	TRL 8-9	Widely deployed, mature and operational
City-wide LEZ system (incl. regional enforcement, logistics planning etc)	TRL 5-6	Limited implementation; policy-ready

⁷⁹ Estimates are from our emission reduction modelling. See Annexure 3(F) for more information

⁸⁰ Cost estimates are based on our analysis and are indicative.

VI. Key Advantage

The following challenges have been identified, based on stakeholder consultations and secondary research:

1. **Targeted & Hyperlocal:** LEZs restrict older, high-emitting vehicles from core zones, which is linked to improved local air quality in multiple studies⁸¹.
2. **Regulatory Certainty for Operators:** Evaluations of LEZs show that when emission standards are clearly defined and enforced over time, operators can plan their shifts toward cleaner technologies⁸².
3. **Accelerated fleet modernisation:** LEZs incentivise the transition to BS-VI, EVs, and cleaner fuels⁸³.
4. **Scalable and flexible:** LEZ restrictions can be gradually tightened or expanded, enabling policy adaptation.

VII. Potential Challenges

The following challenges have been identified, based on stakeholder consultations and secondary research:

1. **Traffic & Emissions Displacement:** LEZ can shift truck traffic and emissions to peripheral areas, leading to congestion and localised pollution outside the zone⁸⁴.
2. **Equity & Affordability Risks:** If LEZs are implemented without phased timelines, financing support, or scrappage incentives, compliance costs could disproportionately burden small and informal truck operators⁸⁵.
3. **Need for Inter-State Coordination:** Effective LEZ implementation requires alignment and coordination between state governments & institutions, which could be challenging⁸⁶.
4. **Enforcement & Compliance Demands:** Effective LEZ implementation depends on robust enforcement technology (e.g., ANPR cameras) and administrative capacity. Without these, compliance may be uneven⁸⁷.

⁸¹ Greater London Authority. (2024, July 25). London-wide ultra low emission zone: Six month report

⁸² Kang et al., (2024). Benefits of diesel emission regulations: Evidence from the world's largest low emission zone.

⁸³ Greater London Authority, 2024

⁸⁴ Moral-Carcedo (2024) J. Dissuasive effect of low emission zones on traffic: the case of Madrid Central.

⁸⁵ Ma et al. (2025) Access restrictions in urban logistics: a systematic review of policy effectiveness and sustainability. *Futur Bus J* 11, 259

⁸⁶ Moral-Carcedo, 2024

⁸⁷ WRI (2025). Low-emission zones: A blueprint for Delhi's urban transformation.

Strategy 3:

Phase out Trucks based on Fitness Criteria

Our Point-of-View:

Phase-out of in-use trucks based on scientific, emissions-based fitness criteria is **feasible** and **recommended** for Delhi. Current PUC testing is insufficient: it does not capture PM2.5 and NOx and instead relies on weak proxy indicators (e.g., smoke opacity) that do not reliably reflect real-world emissions. Notably, Delhi has also relied on age-based bans (diesel > 10 years & petrol > 15 years), which similarly do not indicate actual emissions performance⁸⁸. Delhi should identify and remove high-emitting trucks based on actual emissions (rather than age or other weak proxies) in a scientifically robust, cost-effective and scalable manner. To this end, we recommend the expansion of Automated Testing Stations (ATSs), the deployment of PM and NOx measurement equipment at ATS, and the integration of On-Board Diagnostics (OBD) systems. Alignment with national ATS rollout efforts can support scalable implementation. For effective implementation, Delhi must:

- Deploy certified PM2.5 and NOx testing equipment across all operational ATSs in Delhi under standardised testing procedures.
- Accelerate the establishment of ATSs to enable city-wide coverage.
- Mandate comprehensive remote transfer of OBD diagnostics for BS-VI trucks to enforcement authorities, including installation of telematics systems.
- Notify regulations prohibiting tampering with or disabling of emission-control systems, including restrictions on the sale and promotion of defeat devices and bypass products.

Since this intervention is a sweeping ban, it does not require enforcement in phases.

I. Introduction & Context⁸⁹

Vehicle fitness testing is the periodic inspection of in-use vehicles for emission, safety, and operational compliance, with non-compliant vehicles deemed unfit and automatically deregistered. Testing is conducted at Automated Testing Stations (ATSs) that are standardised, machine-based inspection facilities integrated with the AFMS and the larger VAHAN database⁹⁰. Using observations from field visits to ATS facilities and secondary research, we identified three critical gaps and recommendations:

⁸⁸ The New Indian Express. (2025, August 12). SC halts coercive action against owners of old vehicles in Delhi-NCR; to re-examine 2018 ban.

⁸⁹ Note that, unless cited otherwise, all inputs in this strategy note are from stakeholder consultations.

⁹⁰ MoRTH, 2024

Reliance on weak proxies for emissions enforcement:

Even at ATSs, PUC tests remain the primary compliance tool that fails to measure PM2.5 and NOx, relying instead on outdated proxies like Hartridge Smoke Units (HSU) that poorly capture real emissions, especially in newer engines⁹¹. Instead, high-emitting trucks could be identified based on actual emissions (rather than age or other proxies) in a scientifically robust, cost-effective, and scalable manner.

Our Recommendation:

Expand fitness criteria to include PM2.5 and NOx.

Underutilisation of On-Board Diagnostics (OBD) Systems:

Despite being mandated for BS-VI vehicles, OBD systems are minimally used for emissions enforcement, primarily limited to MIL checks before PUC testing at ATS⁹². There is no mechanism for remote or real-time access by enforcement agencies, as is widely done in China⁹³ (see Annexure-3(C) for more information on OBD Diagnostics).

Our Recommendation:

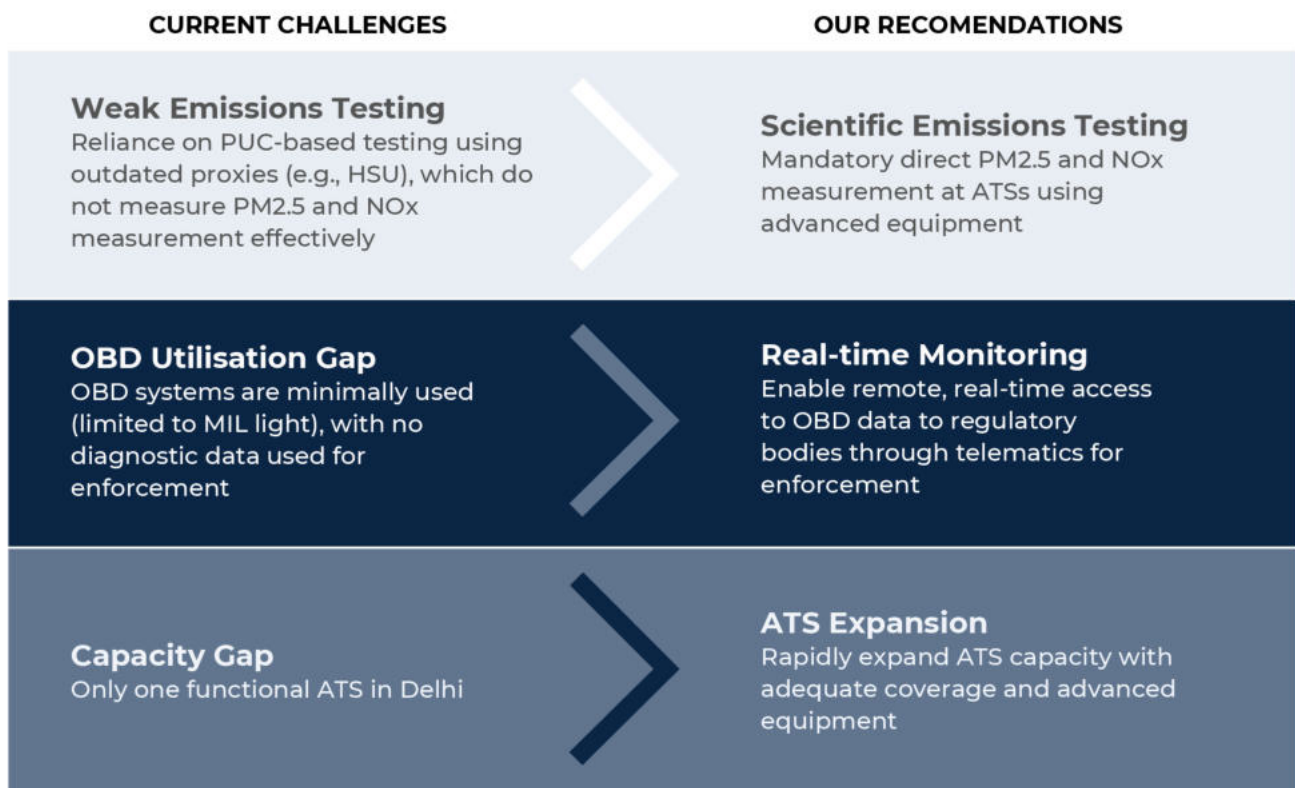
Enable real-time integration of OBD data into enforcement systems and mandate telematics devices to allow continuous, remote monitoring of high-emitting vehicles. Further, MoRTH should establish formal protocols and legal rules governing the remote transfer of real-time OBD data and anti-tampering safeguards for emissions-control systems.

Insufficient ATS Capacity:

From 1 April 2025, fitness testing for all commercial vehicles is mandated exclusively at ATSs. However, stakeholders report that ATS capacity is insufficient to meet current demand, with the VAHAN portal reporting only one functional station in Delhi⁹⁴.

Our Recommendation:

Rapidly scale ATS capacity with new infrastructure and PM2.5/NOx testing equipment. MoRTH should establish protocols for standardised PM2.5 and NOx testing at ATSs.



⁹¹ TERI (2016). *Improving inspection and maintenance system for in-use vehicles in India*. ⁹² Ministry of Road Transport and Highways. *Vehicle fitness testing at automated testing stations (ATS): Guidelines for vehicle owners*.

⁹³ MoRTH (2024). *Vehicle fitness testing at automated testing stations (ATS): Guidelines for vehicle owners*

⁹⁴ ICCT, 2018

⁹⁴ PIB (2025, December 30). *Year End Review 2025: Ministry of Road Transport & Highways, Government of India*.

II. Trucks Targeted⁹⁵

Expanded testing for PM2.5 and NOx applies across the full fleet. OBD-based diagnostics are most immediately applicable to BS-VI-compliant trucks, which comprise approximately 62.4% of trucks entering Delhi.

III. Emission Reduction Potential⁹⁶

Emission reduction estimates are calculated relative to a 2025 Business-as-Usual (BAU) baseline scenario.

Target (Year-wise)	Timeframe	Percentage Reduction w.r.t. BAU			
		PM2.5	CO	NOx	CO2
15%	2027	8	1	3	7
20%	2028	11	2	4	11
10%	2030	8	1	5	7
5% ⁹⁷	2032-2035	4	2	5	8

IV. Costs⁹⁸

Component	Cost Estimate
Automated Testing Station (ATS) setup	₹1-3 crore per station
OBD diagnostic scanners at ATS	₹50 lakh-₹1 crore per station
OBD telematics (per truck for remote data transfer)	5,000-₹15,000 per truck
OBD data management	₹10-30 crore for city-level deployment,
Equipment for measurement of PM 2.5 & NOx	₹1-5 crore per station
Central database integration (VAHAN linkage)	₹5-10 crore
Annual O&M of Inspection and compliance system	~10-15% of capital cost
City-wide ANPR infrastructure	₹100-250 crore

⁹⁵ As per insights from our RFID & TVC analysis.

⁹⁶ Estimates are from our emission reduction modelling. See Annexure 3(F) for more information

⁹⁷ For fitness testing, the targets are year-wise, & assume that a larger share of older, highly polluting trucks are phased out in the initial years. Over time, as awareness, compliance, & system capacity improve, the rate of phaseout is expected to stabilise.

⁹⁸ Cost estimates are indicative and based on our analysis.

V. Infrastructure Requirements

Establishment of ATSs, OBD integration & fitness criteria expansion requires:

1. ATS setup requires a structured site with enough space for testing lanes and segregated zones. Each lane must be equipped with certified machinery for all fitness and emission tests as per the guidelines
2. OBD integration requires diagnostic scanners for reading full DTC logs at ATS, telematics devices in each truck for remote data transfer to authorities, & a centralized data management system to aggregate and support enforcement based on OBD data.
3. Deployment of PM_{2.5} & NO_x measurement equipment at ATSs under standardised testing conditions
4. Upgraded and standardised testing checklists and protocols to operationalise the use of OBD data and emissions measurement equipment.
5. City-wide ANPR infrastructure to enable real-time identification and automated challaning of non-compliant vehicles

VI. TRL in India⁹⁹

Segment	TRL (India)	Evidence
Automated Testing Stations (ATS)	TRL 8-9	Established under national regulations
OBD hardware (vehicle-level)	TRL 7-8	Mandated and deployed across all BS-VI vehicles.
OBD systems for in-use enforcement	TRL 5-6	Absence of a data-sharing & telematics mandate
PM _{2.5} & NO _x measurement	TRL 7-8	Technologically mature and widely used in ambient monitoring; integration into vehicle inspection is limited in India.

VII. Key Advantages

1. **Scientifically grounded compliance:** Inclusion of PM_{2.5} and NO_x in fitness criteria ensures that only high-emitting trucks are phased out, not well-maintained older vehicles.
2. **Scalable, telematics-enabled surveillance:** With OBD mandated in BS-VI vehicles, emissions monitoring can scale rapidly and waive or defer physical inspections for clean vehicles¹⁰⁰.
3. **Standardised testing:** Through automated equipment, ATS reduces manipulation and improves transparency.
4. **Road safety co-benefits:** Systematic removal of structurally unfit vehicles reduces accident risk.

VIII. Potential Challenges

1. **Stakeholder resistance:** Operators of older, non-compliant vehicles may resist expanded fitness criteria and ATS rollout due to concerns over livelihood disruption, particularly among small and informal fleet owners.
2. **High capital expenditure and land barriers:** Cost and space requirements limit rapid ATS expansion
3. **OBD tampering risks:** ECU reprogramming, sensor emulators, and removal of systems like DPF and SCR can mask faults and prevent detection. Additionally, India lacks regulations restricting defeat devices¹⁰¹.

⁹⁹ TRL levels are based on our analysis, informed by multiple reference frameworks.

¹⁰⁰ Centre for Science and Environment. (2020). Strategy for inspection of on-road BS-VI vehicles: New challenges (Policy brief).

¹⁰¹ CSE, 2020

Strategy 4:

Stricter Enforcement via Payload Sensors & ANPR Cameras

Our Point-of-View:

Strengthening freight compliance by deploying payload sensors, with AI-enabled ANPR cameras, is **feasible & recommended** for Delhi. While these systems need proper calibration for each vehicle type and regular checks to ensure accuracy, they can enable real-time identification of overloaded trucks, which are associated with higher emissions, significant safety risks, and higher accident rates¹⁰². Scalable deployment will require interoperable digital enforcement systems, reliable sensor infrastructure, and minimisation of compliance burdens for smaller transport operators. Integration with broader freight digitalisation initiatives can further strengthen enforcement efficiency and data coordination. For effective implementation, Delhi should adopt the following phased roadmap:

- **Phase 1 (within 12 months):** Deploy weigh-in-motion (WIM) systems and AI-enabled ANPR cameras at major freight entry points, integrate with VAHAN databases and operationalise automated identification of overloaded trucks entering Delhi.
- **Phase 2 (within 3 years):** Expand real-time payload-based enforcement across all freight corridors
- **Phase 3 (Post-2030):** Scale up automated inter-state enforcement systems across Delhi-NCR.

I. Introduction & Context

Overloading of trucks increases their engine load, leading to higher fuel consumption and associated emissions¹⁰³. Additionally, they pose severe safety and infrastructure risks, including higher accident rates, making effective payload monitoring essential for enforcement and risk mitigation¹⁰⁴. Payload sensors measure truck cargo weight in real-time using devices installed at weigh-in-motion (WIM) points. These sensors detect physical changes such as pressure, displacement, strain, or vibrations to determine vehicle load. When integrated with ANPR systems, payload data enables identification of overloaded vehicles.

However, while national highways and some toll plazas have WIM systems installed, our stakeholder inputs suggest that MCD toll plazas in Delhi do not have functional payload monitoring infrastructure. This means that overloaded trucks can enter Delhi without any payload-based compliance checks. Therefore, we recommend implementing an integrated enforcement system that captures vehicle registration in real time, links payload data to the VAHAN database, and enables comprehensive checks on overloading & triggering penalties automatically without manual intervention.

¹⁰² The Times of India. (2025, November 10). Truck with lawlessness: Overloading leads 28% jump in offences on road.

¹⁰³ Wahyudi et al. (2014) Effect of overloading freight vehicles on increased carbon emissions.

¹⁰⁴ The Times of India, 2025

II. Trucks Targeted

Payload sensing is most effective for overloaded trucks, which can be up to 56% of loaded trucks¹⁰⁵.

III. Emission Reduction Potential

This has not been modelled as it is an additive measure and direct emission impact is challenging to estimate.

IV. Costs¹⁰⁶

Component	Cost Estimate
ANPR with payload sensors	₹40 - ₹80 lakh per checkpoint

V. Infrastructure Requirements

1. Installation of payload sensors at weigh-in-motion (WIM) points to measure the weight of the vehicle and cargo
2. Installation of AI-enabled cameras at WIM-equipped toll plazas
3. Model-specific sensor calibration facilities and periodic verification systems are also required to manage accuracy.
4. Centralized data platform to correlate vehicle ID, load data, and emission profiles.

VI. TRL in India¹⁰⁷

Segment	TRL (India)	Evidence
AI-enabled ANPR systems	TRL 8-9	Widely deployed in tolling and enforcement
Payload monitoring (WIM systems)	TRL 7-8	Installed at select toll plazas
Payload sensors for emissions enforcement	TRL 6-7	Application for emissions-based enforcement is at concept stage

VII. Key Advantages

The following advantages have been identified, based on stakeholder consultations and secondary research:

¹⁰⁵ As per insights from our Axle-load survey.

¹⁰⁶ Cost estimates are indicative and based on our analysis.

¹⁰⁷ TRL levels are based on our analysis, informed by multiple reference frameworks.

1. **Automated enforcement reduces manual intervention:** Real-time identification of overloaded vehicles enables immediate enforcement action (fines, redirections) without physical inspection.
2. **Multi-parameter compliance monitoring:** Integration with ANPR enables simultaneous enforcement of weight limits, emission standards, insurance validity, and ELV status, creating a comprehensive vehicle compliance platform.

VIII. Potential Challenges

The following challenges have been identified, based on stakeholder consultations and secondary research¹⁰⁸:

1. **Accuracy variability across truck models:** Different suspension systems, chassis designs, road surface quality, etc., can cause payload sensors to measure variably, which requires model-specific calibrations and frequent verification.
2. **Calibration drift and maintenance requirements:** Payload sensors experience drift over time and mechanical wear degrades accuracy, necessitating regular recalibration and replacement.
3. **Privacy and data security concerns:** Continuous vehicle monitoring raises issues around tracking without consent, data misuse, and vulnerability to security breaches.

¹⁰⁸ Parliamentary Standing Committee on Transport, Tourism and Culture. (2023, March). Three hundred forty-second report (Report No. 342). Rajya Sabha Secretariat.

Strategy 5:

Reduction in Trip Numbers by Optimising Empty Backhauls

Our Point-of-View:

Empty truck optimisation is **feasible & recommended** for Delhi. Empty truck movements account for ~23% of trucks entering Delhi and ~51% of outbound trips. These movements lead to unnecessary fuel consumption, higher emissions, and increased congestion, but optimisation platforms can substantially reduce these inefficiencies through improved backhaul utilisation, with global evidence showing CO₂ reductions of up to 34%. However, effective deployment in Delhi remains constrained by ecosystem gaps. These include: absence of any operational MMLPs inside Delhi, inadequate parking/consolidation infrastructure, regulatory time-bound restrictions that limit HDV flexibility, and sector fragmentation (75% of truck operators own <5 trucks). Scaling freight optimisation systems will require widespread adoption of digital freight-matching platforms, real-time GPS and telematics integration, development of freight flow databases and targeted support to improve participation by small and informal fleet operators. Alignment with the National Logistics Policy, PM Gati Shakti, and Logistics Data Bank (LDB) systems can further support corridor planning and backhaul matching. For effective implementation, Delhi should adopt the following phased roadmap:

- **Phase 1 (within 12 months):** Develop freight flow databases, establish data-sharing frameworks, identify high-frequency freight corridors, and promote adoption of telematics and digital freight-matching platforms.
- **Phase 2 (within 3 years):** Pilot freight optimisation and digital backhaul matching across major freight corridors and flexible cargo segments, while encouraging participation from small and informal fleet operators.
- **Phase 3 (Post 2030):** Scale-up integrated freight optimisation systems across Delhi-NCR through wider deployment of digital freight platforms and multimodal logistics infrastructure.

I. Introduction & Context¹⁰⁹

Empty truck movements occur when a truck completes a delivery and returns with no cargo. These inefficiencies result in increased vehicle kilometres travelled (VKT), leading to higher fuel consumption, emissions and added congestion on freight corridors. At the national level, up to 40% of truck kilometres involve empty backhauls, a persistent inefficiency in freight logistics¹¹⁰. These are typically due to poor coordination between shippers and transporters, information asymmetry in freight demand, and limited adoption of digital logistics platforms. Addressing this gap is therefore critical to reducing both environmental and operational costs.

¹⁰⁹ Note that, unless cited otherwise, all inputs in this strategy note are from stakeholder consultations.

¹¹⁰ NITI Aayog. (2021, June). Fast-tracking freight in India: A roadmap for clean and cost-effective goods transport.

II. Trucks Targeted:

Empty backhaul optimisation targets trucks entering and exiting Delhi without cargo. These account for 23% of trucks entering the city and 51% of those exiting¹¹¹. The measure should apply across all goods categories, including perishables, with exemptions permitted only where operationally infeasible.

III. Emission Reduction Potential¹¹²

Emission reduction estimates are calculated relative to a 2025 Business-as-Usual (BAU) baseline scenario.

Target (Cumulative)	Timeframe	Percentage Reduction w.r.t. BAU 2025			
		PM2.5	CO	NOx	CO2
20%	2027	15	22	22	7
30%	2018	17	28	26	8
50%	2030	21	45	55	15

IV. Costs¹¹³

Component	Cost Estimate
Digital freight platforms / marketplaces	₹5-20 crore (platform development & scaling)
GPS & telematics systems	₹10,000-₹50,000 per vehicle
Data integration and analytics systems	₹5-15 crore
Operations & maintenance	~10-15% annually

V. Infrastructure Requirement

1. Construction of Multi-Modal Logistics Parks (MMLPs) that provide warehousing, cold storage, container terminals, parking, repair zones, and administrative services all in one location
2. Creation of dedicated parking & consolidation hubs for trucks to drop goods and quickly pick up return cargo from nearby locations.
3. Development of digital freight matching platforms that are integrated with GPS tracking and telematics.
4. Establishment of data-sharing frameworks across stakeholders
5. Corridor-level logistics planning and coordination mechanisms

¹¹² Estimates are from our emission reduction modelling. See Annexure 3(F) for more information

¹¹³ Cost estimates are indicative and based on our analysis

VI. TRL in India¹¹⁴

Segment	TRL (India)	Evidence
GPS tracking and telematics	TRL 8-9	Widely deployed in commercial fleets
Digital freight platforms	TRL 7-8	Rapid growth in logistics marketplaces
Freight data analytics	TRL 7-8	Increasing adoption in organized logistics
Integrated corridor coordination systems	TRL 6-7	Early-stage implementation

VII. Key Advantages

The following advantages have been identified, based on stakeholder consultations and secondary research:

- Emissions Impact:** Truck optimisation has shown a ~34% drop in CO₂ emissions¹¹⁵. AI-enabled optimisation has demonstrated savings of 760 T of CO₂ annually through better load efficiency¹¹⁶. With 51% of trucks leaving Delhi empty, optimisation can quickly reduce VKT and fuel use.
- Lower Logistics Costs:** Optimising truck usage cuts overall OpEx and reduces vehicle kilometers traveled (VKT), leading to lower fuel consumption and emissions.
- Scalable with Policy Support:** Aligns with PM Gati Shakti, National Digital Freight Exchange, and urban freight hub initiatives, enabling rapid deployment once infrastructure gaps are addressed.

VIII. Potential Challenges

The following challenges have been identified, based on stakeholder consultations and secondary research:

- Regulatory Constraints:** Time-bound MHDV entry and movement rules limit scheduling flexibility.
- Limited Digital Adoption:** ~75% of the freight market comprises small fleet operators (<5 trucks)¹¹⁷. Many of them rely on brokers instead of digital platforms, which limits their adoption and reduces the effectiveness of the intervention.
- Stakeholder Coordination & Data Transparency:** Reluctance to share data across competing operators makes coordination complex.
- Cargo-Specific Limits:** Certain commodities that require specialised vehicles (milk, hazardous goods) reduce feasible return-load matching; early focus on flexible cargo can mitigate this.

¹¹⁴ TRL levels are based on our analysis, informed by multiple reference frameworks.

¹¹⁵ Valdi et al (2020). Environmental impact of bundling transport deliveries using SUMO: Analysis of a cooperative approach in Austria.

¹¹⁶ Toyoda Gosei Co., Ltd. (2025). Moving toward efficient logistics: Efforts to improve truck loading efficiency.

¹¹⁷ Redseer Strategy Consultants. (2024, December 12). Unlocking growth in India's fragmented trucking sector.

Strategy 6:

Urban Freight Optimisation through UCCs with Cleaner Trucking (CNG & LEV)

Our Point-of-View:

Urban Freight Optimisation through the establishment of Urban Consolidation Centres (UCCs) combined with the deployment of last-mile cleaner trucking (CNG and LEVs) is **feasible & recommended** in Delhi-NCR. By consolidating shipments at city peripheries and reducing redundant trips, UCCs significantly lower vehicle kilometres travelled (VKT), while cleaner vehicles ensure substantial reduction in tailpipe emissions within urban areas. However, their deployment is constrained by: high CapEx/OpEx from double-handling costs, land acquisition challenges and dependence on government subsidies. Most UCCs are financially unsustainable without sustained public funding. Therefore, scalable implementation will require public-private partnerships, shared logistics infrastructure and targeted support for smaller freight operators. Alignment with the National Logistics Policy and PM Gati Shakti can help identify strategic freight corridors, improve warehousing efficiency and support India's goal of reducing logistics costs from ~13–14% of GDP to global benchmarks (~8–9%) by 2030. For effective implementation, Delhi should adopt the following phased roadmap:

- **Phase 1 (within 12 months):** Identify strategic UCC locations near major freight entry points, establish PPP and governance frameworks, deploy digital freight coordination systems, and pilot UCC operations with electric and CNG last-mile freight fleets.
- **Phase 2 (within 3 years):** Expand UCC operations across priority freight corridors, scale cleaner freight fleets, and integrate warehousing, consolidation, and freight scheduling systems.
- **Phase 3 (Post 2032):** Scale up an integrated UCC network across Delhi-NCR

I. Introduction & Context¹¹⁸

An Urban Consolidation Centre (UCC) is a logistics facility located in or near a city where goods from different suppliers are collected, sorted, and combined into full truckloads for consolidated delivery to final destinations. This approach helps reduce the number of freight trips into city centers and enables the use of smaller, cleaner vehicles for last-mile delivery.

¹¹⁸ Note that, unless cited otherwise, all inputs in this strategy note are from stakeholder consultations.

II. Trucks Targeted

Implementation of UCCs can begin with trucks entering urban areas that transport non-perishable commodities, which account for 54%¹¹⁹ of trucks entering Delhi. Over time, as logistics systems and cold-chain integration mature, UCCs can be progressively scaled to accommodate a broader range of goods wherever feasible.

To begin with, UCC deployment can start near points, handling predominantly non-perishable goods. These are Sindhu Village, Kundli 1st, Kalindi Kunj, Kapashera, and Auchandi Border¹²⁰.

III. Emission Reduction Potential¹²¹

Emission reduction estimates are calculated relative to a 2025 Business-as-Usual (BAU) baseline scenario.

Strategy	Target Scenario (Cumulative)	Timeframe	Percentage Reduction w.r.t. BAU 2025			
			PM2.5	CO	NOx	CO2
UCC with electric trucking	15%	2027	20	26	26	12
	30%	2028	31	41	39	24
	60%	2030	58	70	76	54
	100%	2032	100	100	100	100
UCC with CNG & electric trucking	15%	2027	10	12	18	2
	30%	2028	12	15	24	5
	60%	2030	15	20	46	12
	100%	2032	23	21	50	22

IV. Costs¹²²

Component	Cost Estimate
UCC infrastructure (land + warehousing + logistics systems)	₹50-150 crore per centre (location dependent)
Charging / refuelling infrastructure (EV/CNG)	₹5-20 crore per facility
Digital freight management systems	₹5-15 crore
Fleet transition (CNG / LEV vehicles)	Vehicle-dependent (₹10 lakh - ₹1+ crore per vehicle)

¹¹⁹ As per insights from the Truck Driver survey. Categories of goods considered non-perishable include: construction materials, industrial inputs, parcels, household and personal use goods, scrap & garbage, electronics, vehicles & auto components and alcohol and tobacco products.

¹²⁰ As per insights from our Truck Driver analysis.

¹²¹ Estimates are from our emission reduction modelling. See Annexure 3(F) for more information

¹²² Cost estimates are indicative and based on our analysis

V. Infrastructure Requirement

1. Development of UCCs at strategic city peripheries to ensure efficient consolidation
2. Establishment of warehousing, loading/unloading bays, sorting & parking, facilities to ensure smooth goods transfer between large trucks and smaller last-mile delivery vehicles.
3. Deployment of EV charging and CNG refuelling infrastructure
4. Implementation of digital logistics coordination systems, including IoT sensors, telematics & transport & warehouse management systems (TMS, WMS)
5. Integration with urban transport planning and zoning frameworks

VI. TRL in India¹²³

Segment	TRL (India)	Evidence
Warehousing and logistics infrastructure	TRL 8-9	Widely deployed across freight networks
Digital Infrastructure (WMS, TMS, IoT)	TRL 7-8	Commercially available and operational
Integrated UCC systems	TRL 6-7	Limited pilot implementations

VII. Key Advantage

The following advantages have been identified, based on stakeholder consultations and secondary research:

1. **Lower Emissions:** UCCs reduce freight emissions by minimising the number of truck trips, optimising delivery routes, and promoting the use of LEVs that reduce emissions¹²⁴.
2. **Reduced congestion:** By combining multiple deliveries into a single trip, UCCs reduce traffic congestion¹²⁵.
3. **Improved Logistics Efficiency:** UCCs enhance logistics performance by increasing vehicle load factors and optimising delivery schedules, resulting in faster, more cost-effective last-mile operations¹²⁶.

VII. Potential Challenges

The following challenges have been identified, based on stakeholder consultations and secondary research:

1. **Lack of Financial Viability:** Most UCCs struggle to sustain operations due to:
 - a. High CapEx & OpEx (land, warehouses, tech, staff, fleets).
 - b. Extra expenses due to double handling of goods & low transport cost savings for shippers¹²⁷.
 - c. Dependence on government subsidies, without which UCCs can collapse.

¹²³ TRL levels are based on our analysis, informed by multiple reference frameworks.

¹²⁴ Shakti Sustainable Energy Foundation & IIT Madras (2020) Development and evaluation of freight consolidation strategies.

¹²⁵ Shakti Sustainable Energy Foundation & IIT Madras, 2020

¹²⁶ Logistics Division & RMI (2021, July). Enhancing urban freight systems: A handbook of measures on performance improvement.

¹²⁷ Shakti Sustainable Energy Foundation & IIT Madras, 2020

2. **Low Stakeholder Participation:** Retailers, logistics firms, and shippers are often unwilling to participate in UCCs due to fears of higher costs, delivery delays, and reduced control over their operations.
3. **Operational Complexity:** Running UCCs demands skilled staff, real-time logistics systems, and precise coordination due to the diversity of goods to be handled.
4. **Volume-Dependent Viability:** UCCs require consistently high freight volumes and broad stakeholder participation to remain economically viable¹²⁸.

Strategy 7:

Retrofitment of BS-II, BS-III & BS-IV vehicles with PM & NOx Control

Our Point-of-View:

Retrofitment of in-use diesel & CNG trucks is **feasible** in Delhi-NCR. It is considered as an interim strategy to curb air pollution from the existing aging fleet. However, based on extensive stakeholder inputs and current market conditions, deployment is **not recommended** due to poor cost-effectiveness and regulatory and market-readiness gaps that need to be addressed. Any targeted retrofit deployment will require robust financing support, certified technology ecosystems, and clear regulatory frameworks to improve operator confidence and reduce compliance uncertainty. Transition support mechanisms will be particularly important for small operators that may be unable to absorb retrofit costs independently. However, should Delhi choose to pursue retrofitment as a targeted, interim intervention, the city must:

- **Phase 1:** Develop MoRTH-led regulatory standards, certification protocols, and engine-family-specific retrofit guidelines, while establishing accredited retrofit centres and compliance monitoring frameworks.
- **Phase 2:** Pilot retrofit deployment for selected high-utilisation fleets and vehicle categories, alongside integration with VAHAN, OBD diagnostics, and periodic emissions monitoring systems.
- **Phase 3:** Consider targeted scale-up only where retrofit technologies demonstrate technical reliability, emissions reduction effectiveness, regulatory compliance, and economic viability.

I. Introduction & Context¹²⁹

'After-treatment systems' refer to devices or technologies used in ICE vehicles to reduce harmful exhaust emissions e.g., PM, NOx and CO before they are released into the atmosphere. These systems improve air quality, offering alternatives that are cost-effective (compared to solutions such as scrappage) or shorter-term (compared to solutions such as electrification) (see Annexure-3(D) for aftertreatment technologies).

II. Trucks Targeted

Retrofitment is most relevant for pre-BS-VI diesel and CNG trucks, which comprise ~38% of the trucks entering Delhi¹³⁰. These trucks contribute 56% to PM_{2.5} and NOx, and 13% to CO emissions¹³¹. Emission reduction estimates are calculated relative to a 2025 Business-as-Usual (BAU) baseline scenario.

¹²⁹ Note that, unless cited otherwise, all inputs in this strategy note are from stakeholder consultations.

¹³⁰ As per insights from our RFID & TVC analysis

¹³¹ As per insights from our VS3 / PEMS analysis & modeling

III. Emission Reduction Potential¹³²

Target ¹³³	Timeframe	Percentage Reduction w.r.t. BAU			
		PM2.5	CO	NOx	CO2
DPF for all BS-IV Diesel Trucks	Strategy not recommended, % reduction for 1 year is provided for indicative purposes only	17	0	0	0
SCR for all CNG Trucks		0	0	9	0
DOC + PPF on pre-BS-VI trucks		11	0	0	0

IV. Costs¹³⁴

Retrofit Technology	Applicable Vehicles	Cost (₹ per vehicle)
DPF for all BS-IV Diesel Trucks	BS-IV	1.5-2.5 lakh
SCR for all CNG Trucks	CNG	2-4 lakh
DoC + PPF on pre-BS-VI trucks	Pre-BS-VI	0.8-1.5 lakh

V. Infrastructure Requirement

1. Certification and regulatory approval systems for retrofit technologies and technology suppliers.
2. Development of accredited retrofit installation centres and trained technical service providers.
3. Strengthening of vehicle fitness testing infrastructure to ensure retrofit eligibility and compliance.
4. Integration with digital monitoring systems such as VAHAN, OBD-based diagnostics, and ANPR-enabled enforcement systems.
5. Establishment of performance monitoring and periodic inspection mechanisms to ensure continued emission reduction effectiveness.

VI. TRL in India¹³⁵

Segment	TRL (India)	Evidence
DPF	TRL 8-9	Widely used in global programmes; pilots in India
SCR-based NOx control	TRL 6-7	Technically established; limited deployment in India
DoC + PPF systems	TRL 8-9	Widely used in emission-compliant vehicles

¹³² Estimates are from our emission reduction modelling. See Annexure 3(F) for more information

¹³³ Technologies mentioned refer to Diesel Particulate Filters (DPFs), Selective Catalytic Reductors (SCRs), Diesel Oxidation Catalysts (DOCs) & Partial Flow Filter (PPF).

¹³⁴ Cost estimates are indicative and based on our analysis.

¹³⁵ TRL levels are based on our analysis, informed by multiple reference frameworks.

VII. Key Advantages

The following advantages of retrofitment have been identified, based on stakeholder consultations and secondary research:

1. **High, rapid PM reduction:** Global programmes show >90% PM reduction (up to ~97% particle number), achievable within 6-12 months, far faster than fleet turnover timelines (10-15 years)¹³⁶.
2. **Extends vehicle life and enables phased transition:** Extends vehicle life by 5-10 years, avoiding premature scrappage while allowing phased adoption of cleaner technologies.

VIII. Potential Challenges

The following challenges with retrofitment have been identified, based on stakeholder consultations and secondary research:

1. **Not a cost-effective alternative to new procurement:** While retrofit costs are lower upfront (~10-15% of a new truck), the effective cost of ownership can be high, limiting viability, especially for small and medium operators.
2. **Technical complexity and lack of standardisation:** Multiple engine variants and families require separate retrofit testing and calibration, and the lack of standardisation discourages uptake.
3. **Regulatory and monitoring gaps:** The absence of clear MoRTH standards and the lack of VAHAN integration for retrofitted vehicles limit compliance tracking and create legal uncertainty for operators.
4. **Infrastructure constraints:** Limited AdBlue availability and absence of accredited retrofit workshops constrain scale-up.
5. **Insurance and warranty barriers:** OEM warranty voiding and lack of insurance recognition create financial and adoption barriers.

¹³⁶ ICCT (2017, June). Diesel retrofit technologies and experience for on-road and off-road engines.

Additional Recommendation:

Modal Shift Pilot via Delhi Metro and Orbital Rail Corridor

In addition to the strategies outlined above, we recommend piloting opportunities for modal shift. Rail-based freight offers significantly lower per-tonne-km emissions, reduces congestion at urban entry points, and supports the National Rail Plan's target of increasing rail's freight share from ~27% to 45% by 2030¹³⁷.

In this context, as of May 2026, the government has proposed a 135-km Orbital Rail Corridor, or "Mega Ring Rail" project, around Delhi-NCR. Planned along the Eastern and Western Peripheral Expressways, the semi-high-speed rail network aims to connect major satellite cities and logistics hubs across Haryana and Uttar Pradesh without routing traffic through central Delhi. The corridor is expected to support both passenger and freight movement, reduce congestion on Delhi's roads and railway network, improve regional connectivity, and strengthen logistics efficiency and economic integration across the NCR¹³⁸.

At the urban scale, Delhi's extensive metro network—already operational, electrified, and well distributed across the city—presents a complementary opportunity to leverage existing public infrastructure for freight movement during off-peak hours. Accordingly, we recommend exploring a DMRC-led pilot for metro-based freight movement in Delhi to assess its operational feasibility, logistics requirements, and potential emissions and congestion benefits.

Recommended Pilot:

We recommend piloting an off-peak/night-time freight movement initiative on the Delhi Metro network, in partnership with the Delhi Metro Rail Corporation (DMRC)¹³⁹. Under this model, non-perishable freight would be moved via metro during non-passenger hours from designated origin stations to destination stations near major freight consumption zones. From metro stations, cleaner end-mile fleets (electric LCVs, CNG vehicles, LEVs) would handle final delivery to consignees, addressing the end-mile connectivity gap.

Operational Next Steps:

In order to implement this strategy, we believe the following main steps need to be undertaken:

1. **Feasibility Assessment with DMRC:** Study on load tolerances, station access, off-peak operational windows, freight handling design, and modifications required to rolling stock and station infrastructure.
2. **Station Selection:** Shortlist 1-2 priority metro routes and stations based on freight demand. According to our truck driver survey, the following 7 destinations emerged as the top freight destinations in Delhi, together accounting for over 35% of surveyed trips entering Delhi. We have mapped the nearby metro connectivity to identify potential sites for a phased freight pilot.

¹³⁷ PIB (2022, December 21). National Rail Plan aims to increase share of freight traffic from current percentage of 27 to 45 by 2030.

¹³⁸ The Times of India. (2026, May 12). Orbital rail set to meet rapid rail corridor at Duhai.

¹³⁹ Notably, DMRC and Blue Dart have already signed an MoU to pilot urban logistics services using metro trains during non-peak hours in Delhi-NCR, and this recommendation could further reinforce and expand such efforts.

Destination	Nearest Metro Station
Azadpur	Azadpur
Mundka	Mundka
Alipur	Samaypur Badli / Haiderpur Badli Mor
Narela	Samaypur Badli (proposed metro in Narela))
Okhla	Okhla NSIC / Govindpuri / Jasola
Sanjay Gandhi Transport Nagar	Samaypur Badli
Bawana	Rithala

Emission Reduction Potential

Building on these lessons and gaps in Delhi-NCR, the seven shortlisted interventions were assessed for emission reduction potential, considering local fleet characteristics, operational patterns, and enforcement feasibility. Estimated using VS3-derived emission factors, they demonstrate the high-impact nature of these measures.

Table 4.2: Emission reduction potential of shortlisted strategies ¹⁴⁰

Strategy		Timeframe	Percentage reduction w.r.t. BAU 2025			
			PM2.5	CO	NOx	CO2
Reduction in Freight Trips due to UCC (EV trucking)	15%	2027	20	26	26	12
	30%	2028	31	41	39	24
	60%	2030	58	70	76	54
	100%	2032	100	100	100	100
Reduction in Freight Trips due to UCC (CNG & EV trucking)	15%	2027	10	12	18	2
	30%	2028	12	15	24	5
	60%	2030	15	20	46	12
	100%	2032	23	21	50	22
Shift to Electric Trucks	10%	2027	14	19	20	4
	15%	2028	15	25	23	4
	30%	2030	23	44	57	13
	50%	2032	39	62	68	30
	100%	2035	100	100	100	100
Ban on Entry of Pre-BS-VI Trucks (LEZ)	100%	2027	51	94	83	48
Reduction in Trips via Empty Backhaul Optimisation	20%	2027	15	22	22	7
	30%	2028	17	28	26	8
	50%	2030	21	45	55	15

¹⁴⁰ Estimates are from our emission reduction modelling. See Annexure 3(F) for more information

Strategy Evaluation Matrix

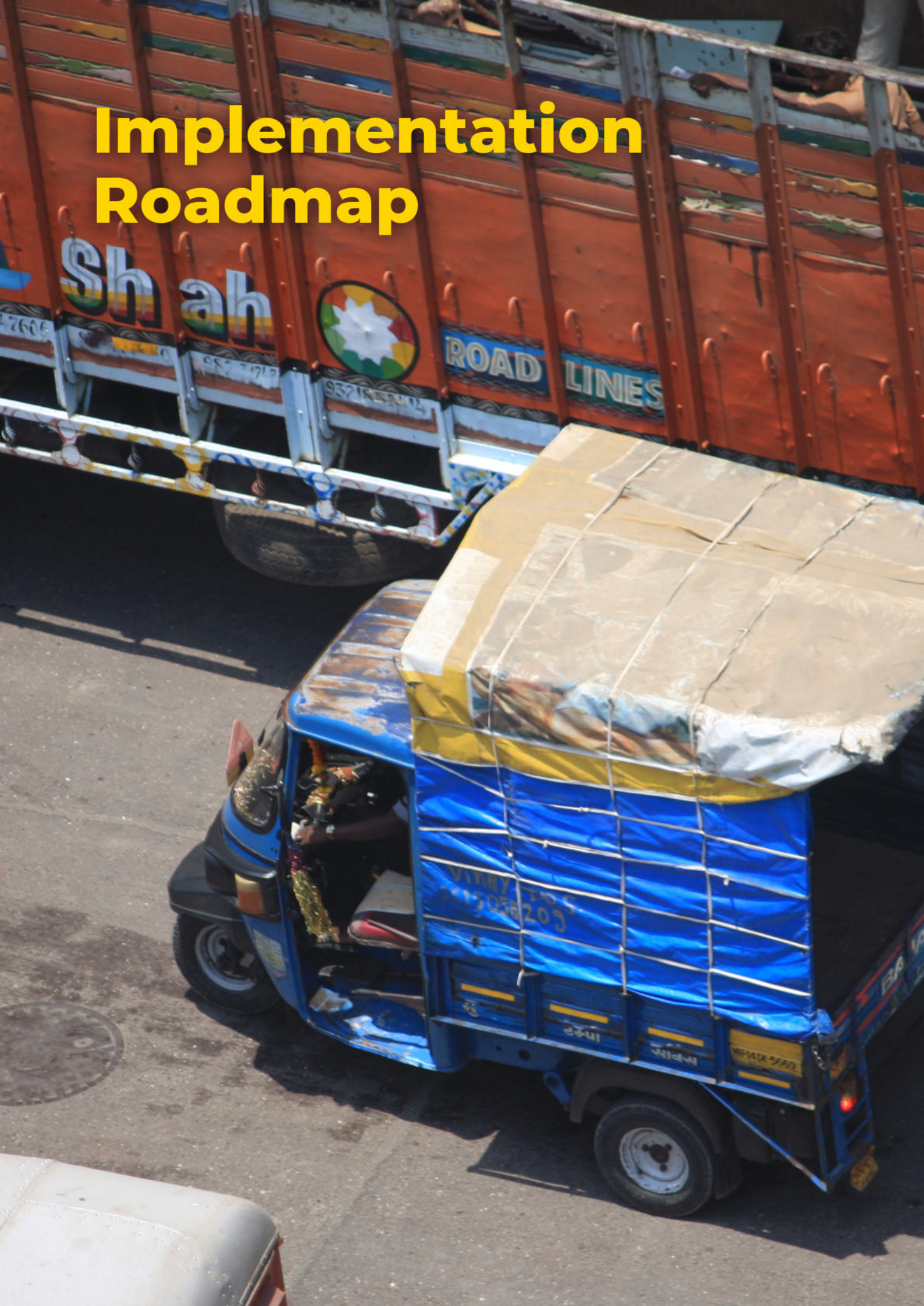
Following the assessment of emission reduction potential, the next section presents a strategy evaluation matrix to support decision-making on implementation pathways. This matrix complements the quantitative estimates by comparing each intervention across key dimensions, including feasibility (policy and technical) and costs.

Strategy	Targets	Trucks Targeted	Timeframe	Policy Feasibility	Technical Feasibility	Costs (For Owner)	Costs (For Players Other Than Owner)	PM2.5 Reduction Potential	Relevant Stakeholders (Government)	Relevant Stakeholders (Non-Government)
I. Reduction in freight trips due to UCC (EV & CNG)	15%	Trucks carrying non-perishable goods	2027	High	High for short-haul; moderate for long-haul	₹10 lakh - ₹1+ crore per vehicle for fleet transition (CNG / LEV vehicles)	₹50-150 crore per centre for UCC infrastructure ₹5-20 crore per facility for charging / refuelling infrastructure (EV/CNG) ₹5-15 crore for digital freight management systems	10%	MoRTH, Transport Dept, Traffic Police, CAQM	Logistics Operators, Fleet Operators, OEM
	30%		2028					12%		
	60%	account for up to 54% of entries into Delhi; this scope is expected to expand over time to include perishable goods as well	2030					15%		
	100%		2032					23%		
II. Shift to zero-emissions trucks (e-trucks)	10%	Begin with electrification of 2-axle and 3-axle trucks, which are 76% of the trucks entries, later, scale to all trucks	2027	High	High for short-haul operations; moderate for long-haul	40 - 70 lakh per 2 axle truck 70 lakh - ₹1.2 crore per 3 axle truck ₹1.2 - 2.0 crore per 4+ axle truck ₹3 - 13 lakh per truck for battery replacement ~3 to 5 years payback period	₹5-20 crore per depot for charging infrastructure (depot-based) ₹10-30 crore per corridor for fast-charging corridor infrastructure Project dependent costs for grid strengthening and upgrades	14%	MoRTH, GNCTD, CAQM, DISCOMs, Traffic Police	OEMs, fleet operators, CPOs, logistics companies
	15%		2028					15%		
	30%		2030					23%		
	50%		2032					39%		
	100%		2035					100%		

Strategy	Targets	Trucks Targeted	Timeframe	Policy Feasibility	Technical Feasibility	Costs (For Owner)	Costs (For Players Other Than Owner)	PM2.5 Reduction Potential	Relevant Stakeholders (Government)	Relevant Stakeholders (Non-Government)
III. Stricter enforcement via payload sensors & ANPR cameras	Applicable for entire fleet	Overloaded trucks, which could be up to 56% of loaded trucks	Ongoing	Medium	Medium		₹40 - ₹80 lakh per checkpoint for ANPR with payload sensors	Challenging to calculate direct impact	MORTH, Transport Dept (Delhi), Traffic Police, CPCB, CAQM, NIC	ATS Operators, OEM
IV. Ban on entry of pre-BS-VI trucks in Delhi (entry of BS-VI, & electric only in Low Emission Zone)	100%	All pre-BS-VI diesel, 38% of the truck entries	2027	High	Medium	70 lakh - 1.2 crore per electric heavy-duty truck, ₹20-50 lakh per truck	₹5-10 crore per corridor for ANPR system deployment ₹100-250 crore for city-wide ANPR infrastructure ₹10-25 crore for central IT system and VAHAN integration 10-15% annual O&M cost	51%	Transport Dept (Delhi), Traffic Police, MoRTH, CPCB/DPCC, CAQM	Fleet operators
V. Reduction in no. of trips by optimising empty backhauls	20%	Trucks entering and exiting Delhi without cargo; - 23% of trucks entering the city and 51% of those exiting.	2027	High	High	High	₹5-20 crore for digital freight platforms / marketplaces ₹5-15 crore for Data integration and analytics systems ~10-15% annually for operations and maintenance	15%	MoRTH, NITI Aayog, Transport Dept (Delhi), CAQM	Fleet operators
	30%		2028					17%		
	50%		2030					21%		

Strategy	Targets	Trucks Targeted	Timeframe	Policy Feasibility	Technical Feasibility	Costs (For Owner)	Costs (For Players Other Than Owner)	PM2.5 Reduction Potential	Relevant Stakeholders (Government)	Relevant Stakeholders (Non-Government)
VI. Phase out based on fitness criteria	15%	Fitness testing applies to the full fleet. OBD is applicable to BS-VI trucks, which are 62.4% of trucks entering Delhi.	2027	Medium	High	₹20-40 lakh for purchase of new truck 5000-15000 per truck for OBD Telematics device	₹1-3 crore per ATS for setup ₹50 lakh-₹1 crore per station for OBD diagnostic scanners at ATS ₹1-5 crore per station for equipment for measurement of PM 2.5 & NOx ₹10-30 crore per city for OBD data management ₹5-10 crore for central database management ~10-15% of capital cost for annual O&M of system	8%	Transport Dept (Delhi), MoRTH, Traffic Police, CPCB/DPCC, CAQM	Fleet operators
	20%		2028					11%		
	10%		2030					8%		
	5%		2032 and 2035					4%		
VII. Retrofitment of BS-II, BS-III & BS-IV vehicles with PM & NOx Control	DPF on BS-IV	Pre-BS-VI diesel and CNG trucks, ~38% of the trucks entering Delhi	2027	Low	Medium	1.5 - 2.5 lakh per vehicle		17%	Transport Department, Traffic Police, MoRTH, CAQM, DPCC, ARAI	Fleet operators
	SCR on CNG					2-4 lakh per vehicle		0%		
	DoC+PPF on pre-BS-VI					0.8-1.5 lakh per vehicle		11%		

Implementation Roadmap



his roadmap operationalises the modelled emissions reduction pathways into a time-bound implementation plan, outlining how strategies can be sequenced, combined, and scaled. The strategies assessed in the roadmap should not be viewed as standalone interventions, but as part of integrated implementation pathways for reducing freight emissions in Delhi-NCR.

All reductions are measured against a 2025 baseline. It is structured around two packages of strategies:

- EV-led transition with complementary measures, combining freight electrification with targeted operational efficiencies; and
- Optimised freight transition with complementary measures, focusing on system-level efficiency improvements.

More on the methodology used to calculate these can be found in Annexure 3(E).

Scenario 1:

Description	Alternative Scenarios	PM2.5 Reduction Potential from Inter-State Trucks (% reduction w.r.t 2025 baseline, modelled for target milestones)									
		2027	2028	2029	2030	2031	2032	2033	2034	2035	
EV-Led Transition with Complementary Measures	Alternate Scenario 1	Total Emission Reduction (%)	34%	49%	78%	100%					
		Total Trucks	19,169	20,415	24,660	27,970	33,786				
		Shift to zero-emissions trucks (e-trucks)									
		Target Achievement (%)	100%								
		Emission Reduction (%)	51%	0%	0%	0%	0%			0%	
		Truck Targetted	All pre BS-VI: 5,689	All pre BS-VI: 0	All pre BS-VI: 0	All pre BS-VI: 0	All pre BS-VI: 0			All pre BS-VI: 0	
	Reduction in freight trips due to UCC	Target Achievement (%)	15%	20%	Ongoing progress	10%	Ongoing progress	5%	Ongoing progress	Ongoing progress	5%
		Emission Reduction (%)	9%	13%		8%		5%			6%
		Truck Targetted	All BS-VI: 2,022	All BS-VI: 2956		All BS-VI: 2,192		All BS-VI: 1,268			All BS-VI: 1,592
		Target Achievement (%)	15%	30%	Ongoing progress	60%	Ongoing progress	100%	Assumes 100% target achievement are maintained through 2035		
		Emission Reduction (%)	4%	9%		23%		44%			54%
	Reduction in no. of trips by empty backhauls	Truck Targetted	All Diesel BS-VI: 880	All Diesel BS-VI: 1807		All Diesel BS-VI: 6,711		All Diesel BS-VI: 13,392		All Diesel BS-VI: 1,6177	

Scenario 2:

Description	Alternative Scenarios	PM2.5 Reduction Potential from Inter-State Trucks (% reduction w.r.t 2025 baseline, modelled for target milestones)									
		2027	2028	2029	2030	2031	2032	2033	2034	2035	
Optimised Freight Transition with Complementary Measures	Alternate Scenario 2	Total Emission Reduction (%)	65%	24%	44%	61%	75%				
		Total Trucks	19,169	14,779	21,915	25,357	31,832				
	Ban on entry of pre-BS-VI trucks in Delhi via a Low Emission Zone (entry of BS-VI & electric)	Target Achievement (%)	100%	Assumes 100% target achievement is maintained through 2035							
		Emission Reduction (%)	51%	0%		0%		0%		0%	
		Truck Targetted	All pre BS-VI: 5,689	All pre BS-VI: 0		All pre BS-VI: 0		All pre BS-VI: 0		All pre BS-VI: 0	
	Phase-out based on fitness criteria	Target Achievement (%)	15%	20%	Ongoing progress	10%	Ongoing progress	5%	Ongoing progress	Ongoing progress	5%
		Emission Reduction (%)	9%	13%		8%		5%		6%	
		Truck Targetted	All BS-VI: 2,022	All BS-VI: 2956		All BS-VI: 2,192		All BS-VI: 1,268		All BS-VI: 1,592	
	Reduction in freight trips due to UCC (start with non-perishables; later, scale to all)	Target Achievement (%)	15%	30%	Ongoing progress	60%	Ongoing progress	100%	Assumes 100% target achievement are maintained through 2035		
		Emission Reduction (%)	4%	9%		23%		44%		54%	
		Truck Targetted	All Diesel BS-VI: 880	All Diesel BS-VI: 1807		All Diesel BS-VI: 6,711		All Diesel BS-VI: 13,392		All Diesel BS-VI: 1,6177	
	Reduction in no. of trips by optimising empty backhauls (apply across all goods, including perishables; exempt where infeasible)	Target Achievement (%)	20%	30%	Ongoing progress	50%	Assumes 50% target is maintained				
		Emission Reduction (%)	5%	7%		13%		12%		15%	
		Truck Targetted	All trucks	All trucks		All trucks		All trucks		All trucks	

In addition to regulatory and infrastructure measures, successful implementation of the roadmap will require strong stakeholder engagement, capacity building and behavioural transition across the ecosystem. Training and awareness programmes for fleet operators, drivers, logistics stakeholders, and enforcement agencies will be critical to support adoption of cleaner technologies, freight optimisation practices, and digital compliance systems.

Monitoring, Reporting and Verification (MRV) Framework

To ensure effective implementation of the roadmap, Delhi-NCR should establish a Monitoring, Reporting, and Verification (MRV) framework to track the progress of emissions-reduction measures over time. Key indicators should include, but are not limited to:

- Number and share of electric freight trucks deployed (by axle category)
- Number and share of freight trips reduced through UCCs and backhaul optimisation
- Share of freight vehicles operating through cleaner last-mile systems
- Number and share of high-emitting trucks identified through RSDs, ATSS, and OBD-based systems
- Compliance rates under LEZ and payload enforcement systems
- Deployment of charging infrastructure, UCC facilities, and digital freight platforms
- Estimated PM2.5 and NOx emission reductions relative to the 2025 baseline

Progress should be reviewed annually using integrated databases such as VAHAN, AFMS, ANPR systems, telematics platforms, freight management systems, and corridor-level monitoring data. Periodic review of targets and implementation performance will help refine strategy sequencing, strengthen enforcement, and support adaptive policy implementation across Delhi-NCR.



**Conclusion &
Way Forward**



The findings from this study point to a clear need for coordinated policy action across Delhi and the wider NCR. Freight movement patterns, vehicle origins, and operational dynamics extend beyond administrative boundaries, making isolated interventions less effective. A harmonised approach—across state governments, city agencies, and national authorities—will be essential to ensure consistency in regulations, enforcement, and outcomes. In this context, coordination is not optional; it is central to achieving meaningful and sustained emission reductions.

The analysis also suggests that the insights generated for Delhi are relevant for other cities facing similar challenges related to freight movement and air quality. While extending this work is beyond the scope of the current study, there is potential for future efforts to build on these findings:

- **Identification of cities for similar interventions:** Post-project, an assessment can be undertaken to identify cities where such interventions may be applicable, along with key contextual differences that would need to be addressed.
- **Integration into policy frameworks:** Study insights can be adapted for other geographies and submitted to relevant authorities to inform air quality and transport policies, ensuring that interventions are grounded in real-world data.
- **Scope to profile other freight vehicles:** In addition, while the focus of this study has been on interstate heavy-duty vehicles, a notable number of light commercial vehicles (LCVs) were also observed in the dataset. Approximately 50,000 LCVs enter Delhi daily, according to RFID data; these are vehicles between 3.5 and 12 tonnes. Given their role in urban freight movement, a similar profiling of this segment could provide useful insights into operational patterns and emissions and help inform more comprehensive policy design.

Going forward, targeted interventions—supported by data and implemented through coordinated institutional mechanisms—can play a critical role in reducing freight-related emissions. The evidence presented here provides a starting point for such efforts, with scope for further refinement and application across geographies.

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Annexure 1(A)

Study Area & List of Data Points Captured

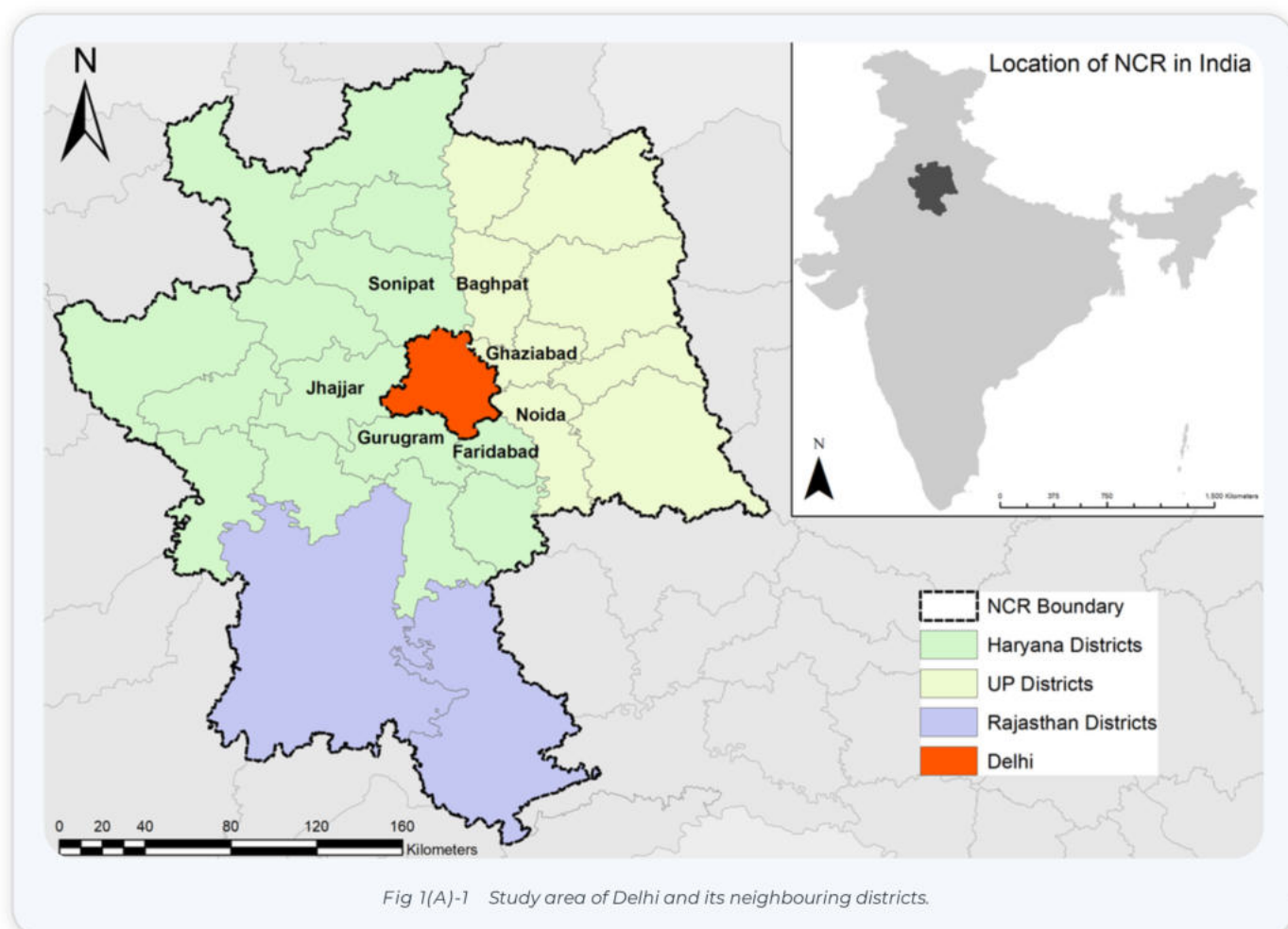


Table 1(A)-1 • Complete list of data points captured

Data Point	Format or Example(s) of Data Inputted
Data points captured in RFID data	
1. Toll Plaza Name	Kundli, Rajokri, Ayanagar
2. Date & Timestamp at Entry	dd/mm/yyyy & hh:mm:ss
3. Unique RFID Number	25-digit hexadecimal number
4. Type or Category of Vehicle	2-Axle, 3-Axle
5. Fuel Type	Diesel, CNG, Petrol, EV
6. Pass Type	Periodic, Trip-Based
Data points captured in truck driver surveys	
1. Toll Plaza Name	Kundli, Rajokri, Ayanagar
2. Direction of Entry	Gurugram to Delhi, Sonipat to Delhi
3. Time of Day	Day, Night

Data Point	Format or Example(s) of Data Inputted
4. Vehicle Type	2-Axle, 3-Axle
5. Truck Registration Number	RJ14GQ11XX, HR38AD42XX
6. Origin	Nashik, Bhiwadi
7. Destination	Delhi
8. Frequency of Visits to Delhi	Daily, Weekly, Monthly, Occasionally
9. Number of Trips	Once Daily, Twice Monthly
10. Commodity Type on Entry	Parcels, Vegetables, Dairy Products
11. Commodity Type on Exit	Parcels, Construction Equipment
12. Load	37 tonnes, 45 tonnes
13. Daily Distance Travelled	130 kilometres, 170 kilometres
14. Ownership	Self, Company
15. Registration Year	2016, 2024
16. BS Norms	BS-VI, BS-IV
17. Manufacturer & Model	Ashok Leyland 2820, Tata 1912
18. Fuel Type	Diesel, CNG, Petrol, EV
19. Maintenance Frequency	Monthly, Bimonthly, Quarterly
20. Age	9 years, 15 years
Data points captured in axle-load survey	
1. Type or Category of Vehicle	2-Axle, 3-Axle
2. Reported weight	Weight in tonnes
3. Measured weight (via axle load measuring instrument)	Weight in tonnes
Data points captured in camera-based traffic volume count (TVC)	
1. Toll Plaza Name	Kundli, Rajokri, Ayanagar
2. Direction of Entry / Exit	Vehicle Entering or Exiting
3. Date & Timestamp at Entry	dd/mm/yyyy & hh:mm:ss
4. Type or Category of Vehicle	2 Axle Truck, 3 Axle Truck

Annexure 1(B)

List of Toll Plazas Surveyed

Table 1(B)-1: Complete list of data points captured

S. No.	Plaza Name	Census Data	Sample Data		
		RFID Data	TVC Survey	Truck Driver Survey	Axle Load Survey
1	Kapashera Main	Yes	Yes	Yes	–
2	Ayanagar	Yes	Yes	Yes	–
3	Old Bijwasha	Yes	–	–	–
4	New Bijwasan	Yes	–	–	–
5	Palam Vihar	Yes	–	–	–
6	Bajghera	Yes	Yes	–	–
7	Jhatikara	Yes	Yes	–	–
8	Nanakheri	Yes	–	–	–
9	Mandi More	No	–	–	–
10	Banswara	Yes	–	Yes	–
11	Kapashera Bypass	Yes	–	–	–
12	Bajghera Bypass	Yes	–	–	–
13	Palam Bypass	Yes	–	–	–
14	Kapashera CNG	Yes	–	–	–
15	Rajokri	Yes	Yes	Yes	–
16	B 150-Shani Mandir	No	–	–	–
17	Bajghera 3rd	No	–	–	–
18	Nanakheri-II	No	–	–	–
19	Nanakheri-III	No	–	–	–
20	Badarpur Main Sarai	Yes	Yes	Yes	–
21	Badarpur Flyover	Yes	–	Yes	–
22	Tuglakabad	Yes	Yes	–	–
23	Pul Prahaladpur	Yes	–	–	–
24	Suraj Kund	Yes	–	–	–
25	Kalindi kunj	Yes	Yes	Yes	–

S. No.	Plaza Name	Census Data	Sample Data		
		RFID Data	TVC Survey	Truck Driver Survey	Axle Load Survey
26	Jaitpur	Yes	—	—	—
27	Jaitpur-II	Yes	—	—	—
28	Jaitpur-III	Yes	—	—	—
29	Jaitpur-IV	Yes	—	—	—
30	Ballabgarh	No	—	—	—
31	Sector-37	Yes	—	—	—
32	Sector-37 (II)	Yes	—	—	—
33	Sector-37 (III)	Yes	—	—	—
34	Sector-37 (IV)	Yes	—	—	—
35	Sector-37 (V)	Yes	—	—	—
36	Lakkadpura	Yes	—	—	—
37	Durga Builder/Jaitpur-V	No	—	—	—
38	Kalindi Kunj Machine/Jaitpur-VI	No	—	—	—
39	Mithapur (NH Road)	No	—	—	—
40	Tikri Main	Yes	Yes	Yes	—
41	Jharoda	Yes	—	—	—
42	Jharoda II	Yes	—	—	—
43	Dhansa Border	Yes	—	—	—
44	Darola Border	Yes	—	—	—
45	Darola Border-II	Yes	—	—	—
46	Nizampur (I)	Yes	—	—	—
47	Nizampur (II)	Yes	—	—	—
48	Bakkargarh	Yes	—	—	—
49	Badshah Galimpur	Yes	—	—	—
50	Badshah Galimpur-II	Yes	—	—	—
51	Badshah Galimpur-III	No	—	—	—
52	Surakhpur	Yes	—	—	—
53	Dewar Khana	Yes	—	—	—
54	Dewar Khana-II	Yes	—	—	—

S. No.	Plaza Name	Census Data	Sample Data		
		RFID Data	TVC Survey	Truck Driver Survey	Axle Load Survey
55	Mundela kalan	Yes	–	–	–
56	Mundela kalan-II	Yes	–	–	–
57	Mundela kalan-III	No	–	–	–
58	kair Naka	Yes	–	–	–
59	kair Naka-II	Yes	–	–	–
60	Chor naka	Yes	–	–	–
61	Ishapur	Yes	–	–	–
62	Ishapur-II	Yes	–	–	–
63	Darola Border-III	No	–	–	–
64	Dhansa 2nd	No	–	–	–
65	Jharodha III	No	–	–	–
66	Jharodha IV	No	–	–	–
67	Jharodha V	No	–	–	–
68	Jharodha VI (Exit)	No	–	–	–
69	Jharodha VII (Flyover)	No	–	–	–
70	Manjari	No	–	–	–
71	Nizampur-III	No	–	–	–
72	Sainik School	Yes	–	–	–
73	Shahdara Main	Yes	–	–	–
74	Shahdara Flyover	Yes	Yes	Yes	–
75	Shahdara (II)	No	–	–	–
76	Mandoli Main	Yes	Yes	Yes	–
77	Mandoli II	Yes	–	–	–
78	Loni Main	Yes	Yes	Yes	–
79	Loni II	Yes	–	–	–
80	New Seemapuri-I	Yes	Yes	Yes	–
81	New Seemapuri-II	Yes	–	–	–
82	New Seemapuri-III	Yes	–	–	–
83	Chander nagar	Yes	–	–	–

S. No.	Plaza Name	Census Data	Sample Data		
		RFID Data	TVC Survey	Truck Driver Survey	Axle Load Survey
84	Surya Nagar	Yes	–	–	–
85	Karawal nagar-II	Yes	–	–	–
86	Indrapuri-III	Yes	–	–	–
87	Dharamkata-II	Yes	–	–	–
88	Sewadham-II	Yes	–	–	–
89	Mandoli More	No	–	–	–
90	Sonia Vihar	Yes	–	–	–
91	Ramprashth	Yes	–	–	–
92	Wazirabad	Yes	–	Yes	–
93	Indrapuri	Yes	–	–	–
94	Johripur-I	Yes	–	–	–
95	Johripur-II	Yes	–	–	–
96	Sewa Dham	Yes	–	–	–
97	Karawal Nagar	Yes	–	–	–
98	Dharam Kata	Yes	–	–	–
99	Indrapuri-II	No	–	–	–
100	Shahdara-III	No	–	–	–
101	Jhilmil	No	–	–	–
102	Ramprashth-II	No	–	–	–
103	KGT Main	Yes	–	Yes	Yes
104	Jounti-I	Yes	–	–	–
105	Jounti-II	Yes	–	–	–
106	Punjabkhor	Yes	Yes	–	–
107	Punjabkhor-II	Yes	–	Yes	–
108	Kutubgarh-I	Yes	–	–	–
109	Kutubgarh-II	Yes	–	–	–
110	Kutubgarh-III	Yes	–	–	–
111	Mangeshpur	Yes	–	–	–
112	Auchandi-I	Yes	–	Yes	Yes

S. No.	Plaza Name	Census Data	Sample Data		
		RFID Data	TVC Survey	Truck Driver Survey	Axle Load Survey
113	Auchandi-II	Yes	–	–	–
114	Harewali	Yes	–	Yes	–
115	Lampur	Yes	–	–	–
116	Bankner	Yes	–	–	–
117	Safiabad	Yes	–	Yes	–
118	Saboli Road	Yes	–	–	–
119	TT Post	Yes	–	–	–
120	Kundli-I	Yes	Yes	Yes	–
121	Kundli-II	Yes	–	–	–
122	Singhu School	Yes	–	–	–
123	Singhu Village	Yes	–	Yes	–
124	Janti Khurdh	Yes	–	–	–
125	Zero Palla	Yes	–	Yes	–
126	Tajpur	Yes	–	–	–
127	Auchandi-III	No	–	–	–
128	Harewali-II	No	–	–	–
129	Harewali-III (NH Road)	No	–	–	–
130	KGT Main (CNG Point)	Yes	–	–	–
131	Kundli-III	No	–	–	–
132	Mangeshpur II	No	–	–	–
133	Mangeshpur-III	No	–	–	–
134	Gazipur Main	Yes	–	Yes	–
135	Gazipur old	Yes	–	Yes	–
136	Mohan Nagar	Yes	–	–	–
137	New Kondli	Yes	–	–	–
138	Old Kondli	Yes	–	–	–
139	Vasundhara-I	Yes	–	–	–
140	Vasundhara-II	Yes	–	–	–
141	Ashok Nagar-I	Yes	–	–	–

S. No.	Plaza Name	Census Data	Sample Data		
		RFID Data	TVC Survey	Truck Driver Survey	Axle Load Survey
142	Ashok Nagar-II	Yes	—	—	—
143	Between-I	Yes	—	—	—
144	Between-II	Yes	—	—	—
145	Sabji Mandi	Yes	—	—	—
146	Sabji Mandi-II	Yes	—	—	—
147	Nagarjun	Yes	—	—	—
148	Nehar Naka	Yes	—	—	—
149	Nehar Naka-II	Yes	—	—	—
150	Nehar Naka-III	Yes	—	—	—
151	Mayur Vihar-3	No	—	—	—
152	Noida Major	Yes	—	Yes	—
153	Mayur Vihar CNG	No	—	—	—
154	C .R.P.F	Yes	—	—	—
155	DND Flyway	Yes	—	Yes	—
156	EDM Mall	No	Yes	—	—
157	Mungeshpur	Yes	Yes	—	—
158	Seva Dham*	Yes	Yes	—	—

Please note that plazas 1 to 156 are provided in the official MCD list; plazas 157 and 158 were identified by our survey vendor & may be going by other names in the official MCD list.

Annexure 1(C)

RFID Data — Detailed Methodology & Insights

RFID Data Overview

We have primarily characterised truck entry patterns into Delhi using datasets received from the Municipal Corporation of Delhi (MCD). RFID data was shared for three time periods—(i) April 1 to 30, 2025, (i) July 7 to 27, 2025, and (iii) September 16 to 30, 2025. **April 2025 was selected** for detailed analysis of truck population characteristics, as it provided complete monthly data and did not coincide with major festivals or policy restrictions. Average daily class-wise and fuel-wise vehicle entries were found to be broadly comparable across April, July, and September (see Table X), providing confidence in the representativeness of the manual surveys conducted during July and September 2025.

Table 1(C)-1 · Average daily entries compared for the three months for which RFID data was collected

Truck Type	April		July		September	
	CNG	Diesel	CNG	Diesel	CNG	Diesel
2 Axle Truck	5,435	2,617	4,891	2,445	6,083	2,472
3 Axle Truck	693	1,492	618	1,335	810	1,421
4+ Axle Truck	463	2,679	475	2,327	596	2,567
Total Entries	13,379		12,091		13,949	

All commercial vehicles entering through MCD toll plazas are charged based on their assigned vehicle category under defined tax brackets. For trucks, these charges vary by axle count, as outlined in Table 1(C)-1.¹⁴¹

Table 1(C)-2 · Toll taxes levied on different types of vehicles at MCD toll plazas (as of May 2026)

Vehicle type	Entry per visit (₹)	Monthly pass (₹)	ECC for non-CNG Vehicles (₹)*
Taxi, tempo (3-wheeler) and such types of other commercial vehicles	100	3,000	NIL
Tata 407 and such types of vehicles (light duty vehicles, etc.)	100	3,000	1,400
Bus	200	6,000	NIL
Tata 709, Canter, Nissan and such types of other commercial vehicles	200	6,000	1,400
6-wheeled truck (2 axle truck)	400	12,000	1,400
10-wheeled truck (3 axle truck)	800	24,000	2,600
14+ wheeled truck (4+ axle truck)	2,000	60,000	2,600

** In addition to routine toll payment, an Environment Compensation Charge (ECC) is also levied on diesel and petrol vehicles, based on their axle count. At the time of data collection, the ECC was halved for empty or partially laden vehicles. However, this reduction has since been removed by a Supreme Court order dated 26 September 2025.¹⁴²*

The RFID dataset captures individual vehicle entry data through 121 toll plazas along the city border. Please note:

1. As per an MCD document dated March 2025, **Delhi has 156 toll plazas** (refer Annexure 1(B) for complete list). However, **we received data for only 121 plazas**, as the remaining, newly added plazas were reportedly either managed by a different vendor or operating manually while a vendor was being finalised.
2. Of these, **data from 114 plazas was used for analysis**. Based on our field visits, the remaining 7 plazas either did not record truck movement or had their data aggregated with nearby, typically larger toll plazas for operational convenience.

In April 2025, **33,59,865 commercial vehicle entries** were recorded. Each entry included the following attributes: (i) timestamp, (ii) toll plaza name, (iii) fuel type, (iv) vehicle class, (v) unique RFID tag, and (vi) RFID tag type. The distribution of entries by vehicle class is presented in Table 1(C)-2. An 'MAV' or 'multi axle vehicle' typically refers to vehicles with multiple axles, including trucks and possibly a small number of special purpose vehicles (e.g. cranes and other construction equipment). For our analysis, we have assumed all MAVs to be trucks and renamed them as '3 axle truck' and '4+ axle truck'. Collectively, 2 axle trucks, 3 axle trucks, and 4+ axle trucks are referred to as 'trucks' or 'heavy duty vehicles' throughout the report.

Table 1(C)-3 · Vehicle distribution as per RFID data

Vehicle class	Number of vehicles	Percent vehicles
Car / 3-wheeler	13,03,863	39
Light motor vehicle (LMV)	11,70,148	35
Light commercial vehicle (LCV)	3,06,582	9
2 axle truck	2,41,680	7
Bus	1,77,640	5
4+ axle truck	94,336	3
3 axle truck	65,616	2
Total	33,59,865	100

I. Truck Entries (Unique & Repeat)

A total of 4,01,632 truck entries were recorded in April 2025 across 114 toll plazas, averaging 13,388 entries per day. This accounted for approximately 12% of all commercial vehicle entries.

Using RFID tag numbers, we identified 96,420 unique trucks that contributed to the 4,01,632 entries. In other words, a truck enters 4.2 times through one of the toll plazas on average in a month. The average number of repeat entries stratified by different categories of trucks are presented in Table 1(C)-3. We found that smaller trucks are likely to enter Delhi multiple times; for instance, on average, 2-axle trucks enter Delhi 5.5 times monthly, whereas 4+ axle trucks enter Delhi only 2.9 times monthly.

Table 1(C)-4 · Unique trucks and repeated entries by vehicle class

Vehicle class	Unique vehicles (per month)	Average entries (per month)	Repeat trips (%)
2 axle truck	43,727	5.53	82%
3 axle truck	19,612	3.35	70%
4+ axle truck	33,081	2.85	65%

Table 1(C)-4 shows the frequency distribution of the number of entries per month. The distribution shows that approximately 37% of all trucks enter only once a month, 42% enter 2 to 5 times, and the remaining 20% enter more than 5 times a month.

Table 1(C)-5 · Proportion of unique trucks classified by their number of repeat trips

Number of monthly entries	Number of unique RFID tags	Percentage share
1 entries	36,103	37.4
2-5 entries	40,678	42.2
6-10 entries	10,001	10.4
10+ entries	9,637	10

II. Axle & Fuel

Approx. 50% of all truck entries are made by CNG trucks, but their share among unique trucks is only 20%. Conversely, 50% of truck entries are made by diesel trucks, but their share among unique trucks is significantly higher at 80% (refer Table 1(C)-5). In other words, a CNG truck on average makes 10 trips into Delhi per month, while its diesel counterpart makes only 3 trips.

Table 1(C)-6 · Truck entry frequency by fuel type

Fuel type	Entries	Truck entries	Average trips per truck
CNG	197721 (49.2%)	19402 (20.1%)	10
Diesel	203630 (50.7%)	76921 (79.8%)	3
Petrol	281 (0.1%)	96 (0.1%)	3

Figure 1(C)-1 presents the percentage distribution of all truck entries and unique trucks, stratified by number of axles. In this figure, the percentages by number of entries and by unique trucks each sum to 100 percent. **While 2-axle CNG trucks comprise 60% of all entries, their share among unique vehicles is 45%. In contrast, while trucks with 4 axles or more comprise 24% of all entries, their share in all unique trucks is 34%.**

Figure 1(C)-2 presents the distribution of fuel type among unique and repeat entry trucks, stratified by number of axles. **Nearly 38% of all unique 2-axle trucks are CNG, while this share is 7.5% for 3-axle trucks and only 3% for 4+ axle trucks**, indicating a strong preference for CNG among smaller trucks.

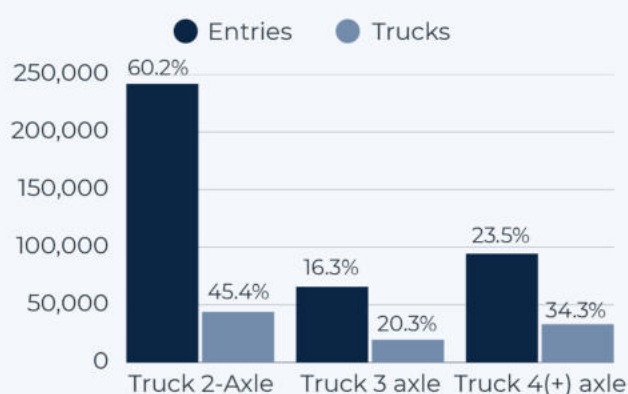


Fig 1(C)-1 Share of unique trucks versus truck entries, by axle count.

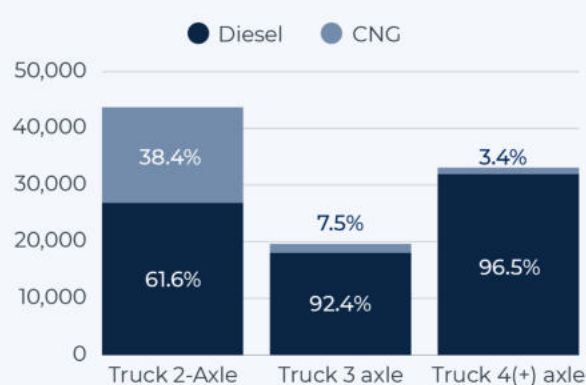


Fig 1(C)-2 Fuel type distribution, by unique trucks' axle count.

III. Temporal Characteristics of Entries

No large variations between days of the week are observed; however, there are variations when analysing truck entry by hour. From Monday through Friday, the average daily number of truck entries is 13,500. On Saturdays with 14,078 entries per day, there is a 4% increase compared to an average weekday, and on Sundays with 11,782 entries, there is a 13% reduction compared to an average weekday (refer Figure 1(C)-3).

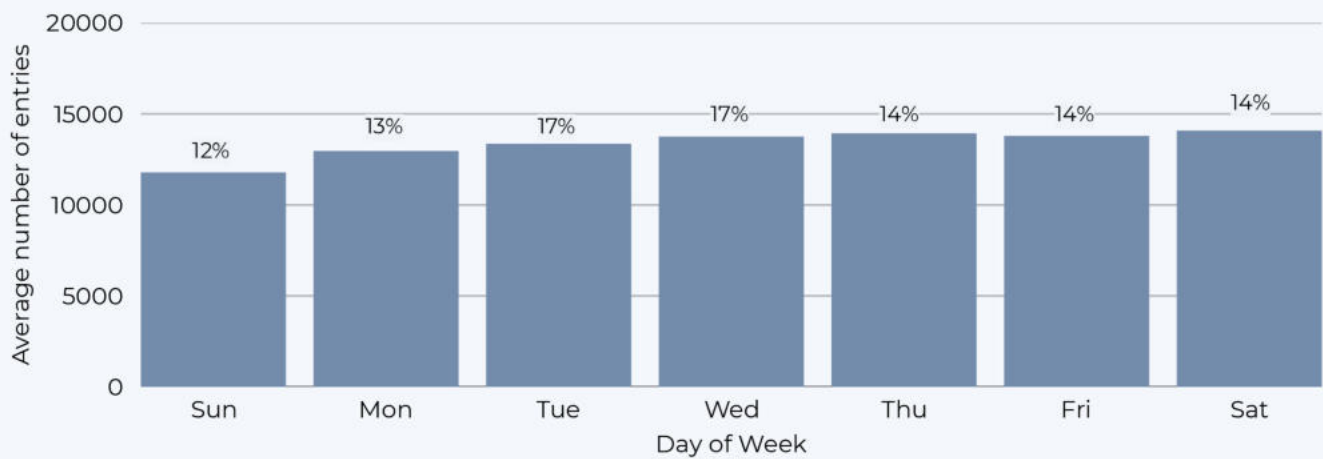


Figure 1(C)-3: Average truck volume by day of week

The diurnal distribution of the number of truck entries is shown in Figure 1(C)-4. There is a **strong time-of-day trend, with ~80% of all truck entries occurring over a 10-hour period from 9 pm to 7 am**. The highest volumes are in the 5-hour period from 11 pm to 4 am, with **more than 50% of the overall day entries**. This is an effect of the policies¹⁴³ prohibiting heavy and medium goods vehicle movement on 54 major and minor roads in the city between 7 am to 11 pm.

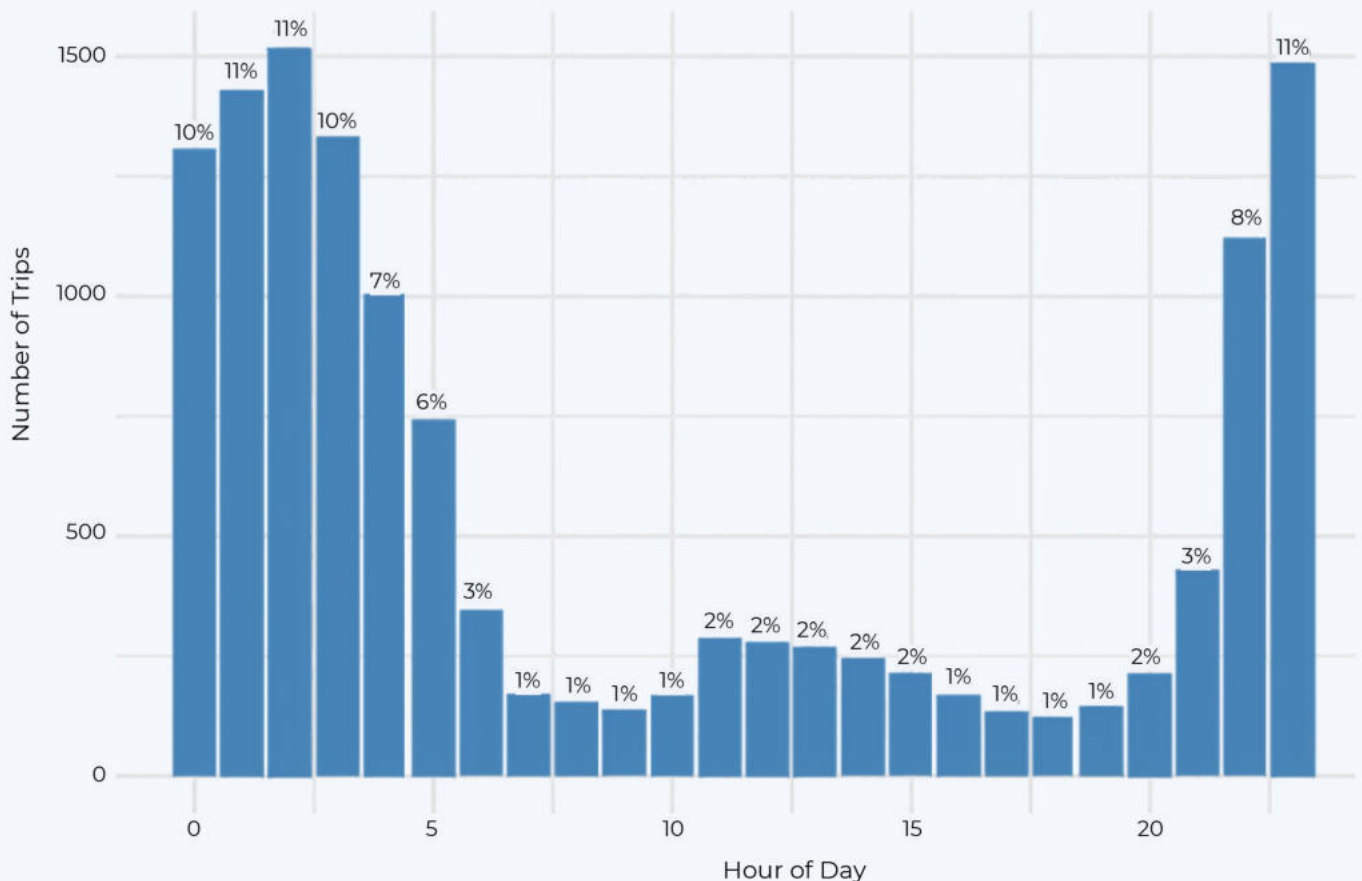


FIG 1(C)-4 Average hourly truck volume (daily average) and percent distribution.

Truck entry is permitted during non-peak hours (11 am to 5 pm) on certain roads, which likely explains the daytime patterns observed in Figure 1(C)-5 (diurnal truck traffic by fuel) and Figure 1(C)-6 (diurnal truck traffic by axle count). These **trends are similar, with a higher share of 2-axle trucks during this period**, possibly due to heavier personal vehicle traffic discouraging larger trucks. The **higher proportion of CNG trucks** also suggests a prevalence of short-haul trips. Overall, about 56% of entries **between 11 am and 5 pm were 2-axle CNG trucks**.

Hourly Truck Volume - Split by Fuel Type

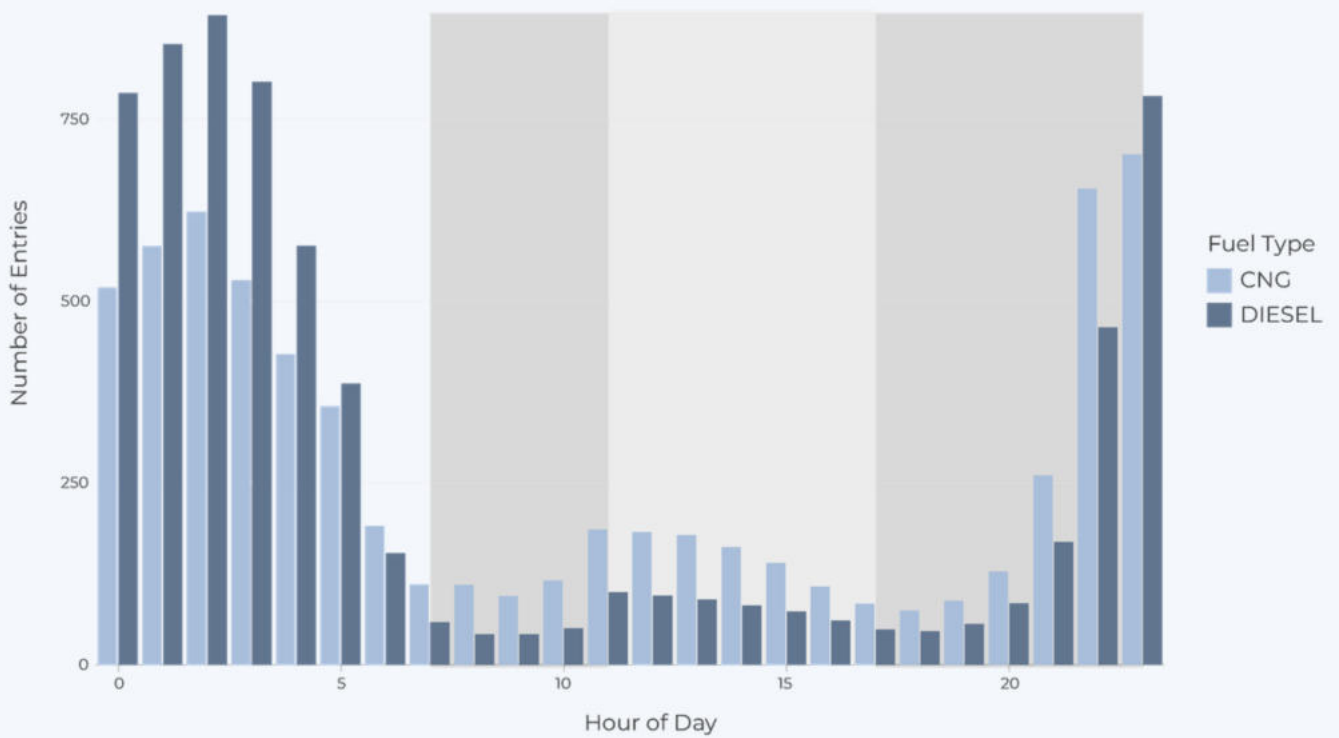


Figure I(C)-5: Average diurnal truck volume with restricted hours marked in grey, split by fuel type

Hourly Truck Volume - Split by Vehicle Type

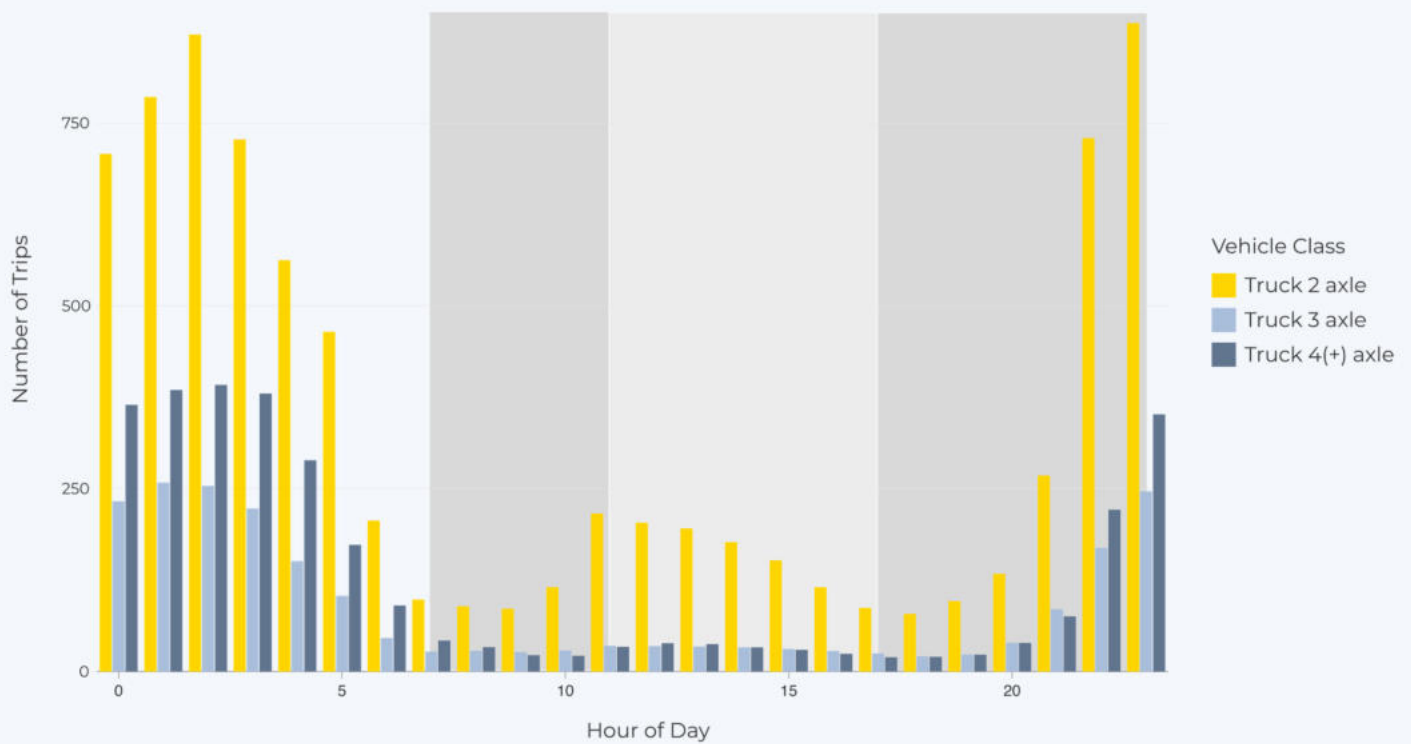


Figure I(C)-6: Average diurnal truck volume with restricted hours marked in grey, split by axle count¹⁴⁴

¹⁴⁴ Set 1 (light grey + dark grey) - full day restrictions for HDVs on 54 roads (7 am - 11 pm) and Set 2 (dark grey) - peak hour restrictions for HDVs on 29 roads (7 am - 11 am, and 5 pm - 11pm)

IV. Spatial Characteristics of Entries

As mentioned previously, truck entries were reported at 114 out of 121 toll plazas in April 2025. Kundli recorded the highest share (17%), followed by Rajokri (14%), Badarpur (11%), and Tikri (7%). As is evident, the distribution of truck volumes across these plazas is highly skewed. The **four listed plazas accounted for approximately 50% of all truck entries** into the city; the **top 10 plazas received 72% of truck entries**, and the **top 20 plazas (accounting for only 18% of all toll plazas along Delhi's borders) received 90% of total truck traffic entering Delhi** (Figure 1(C)-7). These plazas remain the most used by the trucks during the daytime, as at night, with Kundli recording a fourth of the entries during the day (24%), while Rajokri has the highest entries at night (17%).

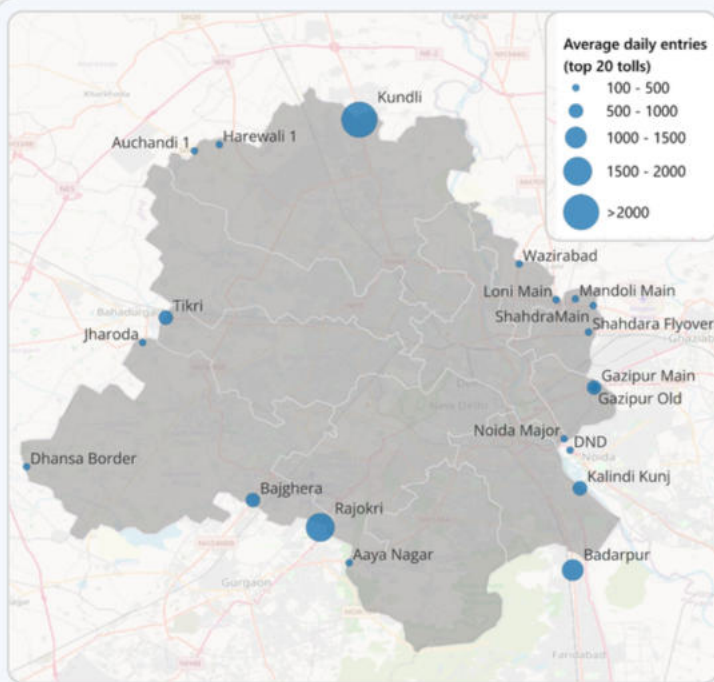


Figure 1(C)-7: Top 20 toll plazas in terms of truck entries

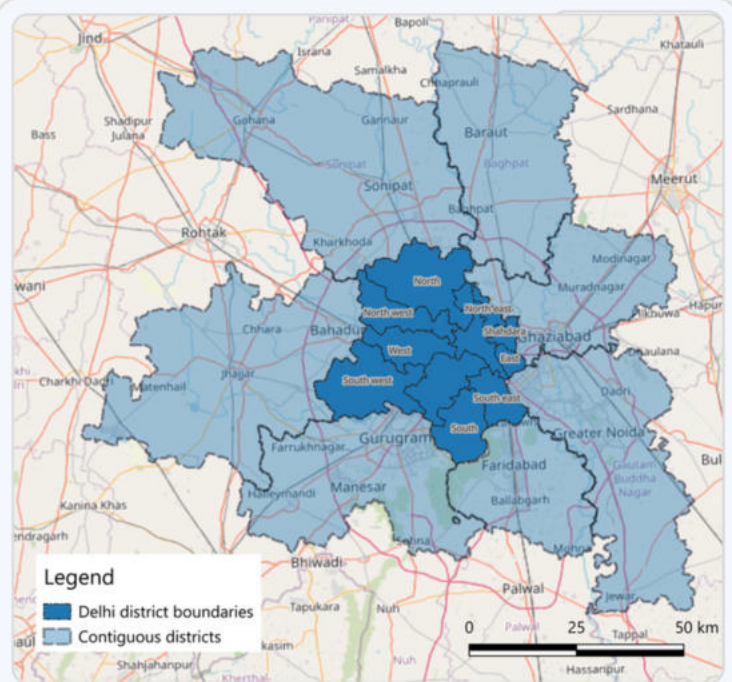


Figure 1(C)-8: Delhi and NCR districts adjacent to Delhi

Toll plazas were classified by the Delhi district in which they are located, as well as the bordering districts they serve (see Figure 1(C)-8). Significant variation is observed across plazas in terms of truck characteristics (axle count and fuel type) and time of entry. **At the 20 major toll plazas, 48% of truck entries are CNG vehicles. This share varies widely—ranging from 36% to 94% across Delhi districts and from 26% to 73% across neighbouring NCR districts** (see Figure 1(C)-9 and Figure 1(C)-10).

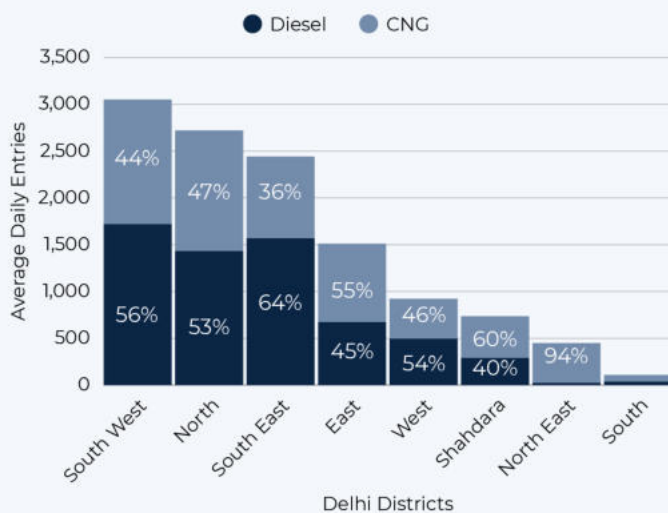


Figure 1(C)-9: Distribution of truck entry by fuel type at each Delhi district

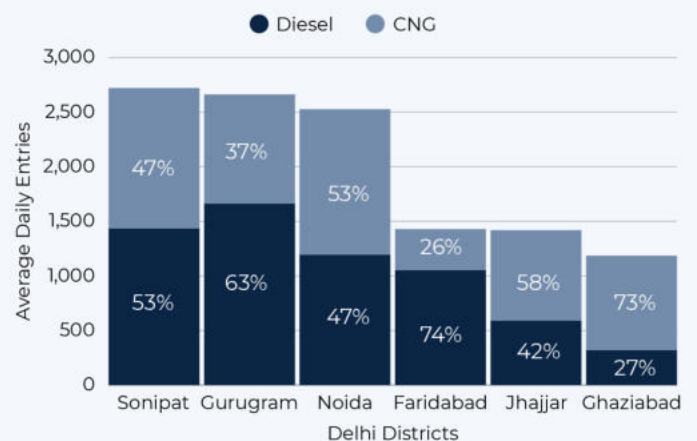


Figure 1(C)-10: Distribution of truck entry by fuel type at Delhi's bordering districts

As expected, the distribution of **fuel type at toll plazas is strongly related to the distribution of trucks by axle type**. For instance, at major toll plazas along the Ghaziabad border—where the share of CNG vehicles is high—most trucks are 2-axle vehicles (see Figure 1(C)-12).

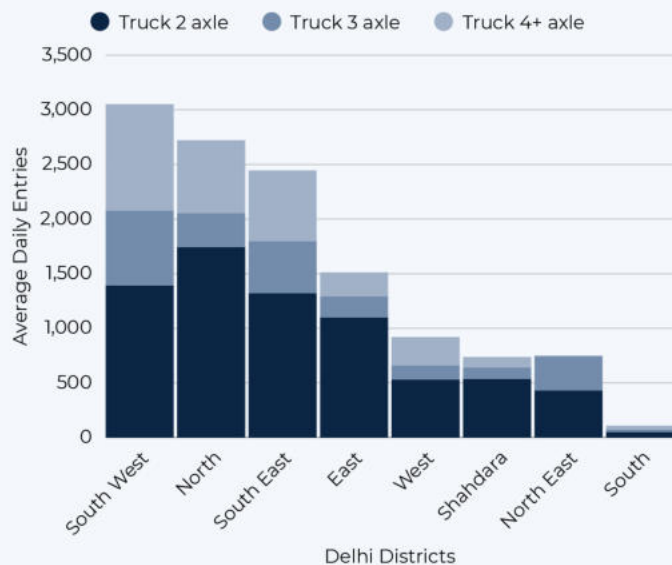


Figure 1(C)-11: Distribution of truck entry by vehicle class at each Delhi district

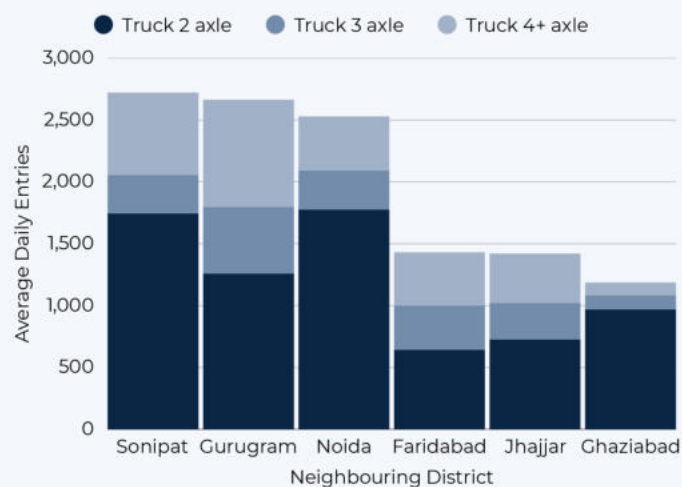


Figure 1(C)-12: Distribution of truck entry by vehicle class at Delhi's bordering districts

In terms of diurnal patterns, some toll plazas in the southern and eastern districts have a large majority (75% or more) of their truck entries at night time from 11 pm to 7 am, while some have close to half of their entries during the day (Figure 1(C)-13). This is as expected per the truck entry regulations.

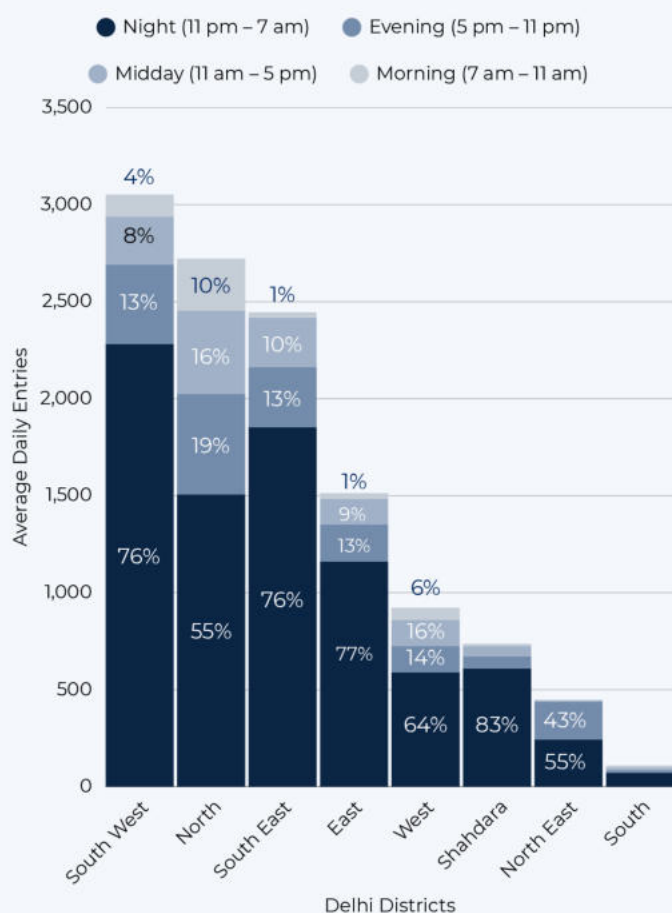


Figure 1(C)-13: Distribution of truck entry by time-of-day at each Delhi district

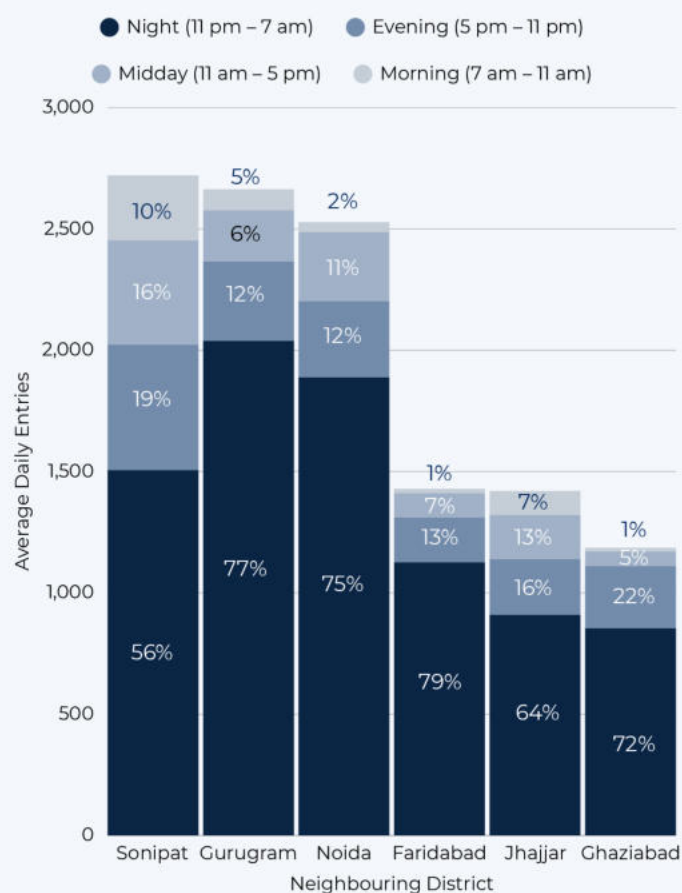


Figure 1(C)-14: Distribution of truck entry by time-of-day at Delhi's bordering districts

Annexure 1(D)

Traffic Volume Count (TVC) Survey — Detailed Methodology & Insights

A traffic volume count (TVC) exercise was conducted using video-based monitoring at **18 toll plazas**.¹⁴⁵ Plazas were selected using the same criteria as for the truck driver survey, ensuring a representative mix of major and minor locations across Delhi’s entry and exit points. The following toll plazas were selected (note: names of ‘major’ plazas have been italicised & data for plazas marked with an (*) has only been collected for 2 days):

- | | |
|---------------------|-------------------------|
| 1. Kundli | 10. Loni Main* |
| 2. Rajokri | 11. Kapashera |
| 3. Badarpur | 12. Tuglakabad |
| 4. Tikri | 13. Jhatikara |
| 5. Bajghera | 14. Mungeshpur toll |
| 6. Kalindi Kunj | 15. Plaza EDM Mall |
| 7. Ayanagar | 16. Seva Dham* |
| 8. Shahdara Flyover | 17. Punjab Khor |
| 9. Mandoli Main | 18. Seemapuri 1st Toll* |

Two CCTV cameras were installed at each plaza to capture traffic in both directions, i.e. entering and exiting Delhi. Continuous 24-hour video footage was recorded for four days (i.e. 26, 27, 29 and 30 September 2025) with real-time data transmission to remote servers. Survey personnel stationed nearby ensured equipment maintenance and operational continuity. Traffic was classified at 15-minute intervals into the following vehicle categories:

- | | |
|-----------------|---|
| 1. 4 Tyre LCV | 8. 7+ Axle Truck |
| 2. 6 Tyre LCV | 9. Car / Jeep / Van / Taxi |
| 3. 2 Axle Truck | 10. Auto |
| 4. 3 Axle Truck | 11. Bus |
| 5. 4 Axle Truck | 12. Goods Auto / Mini LCV |
| 6. 5 Axle Truck | 13. Heavy Construction Machinery (HCM) / Earth-Moving Equipment (EME) |
| 7. 6 Axle Truck | |

Approximately **3.25 million vehicle entries** were captured through this exercise.

A comparison of camera traffic volume count (TVC) exercise with corresponding aggregates from the RFID dataset (for the same dates and toll plazas) shows higher truck volumes in the camera data. Field investigations indicate that these discrepancies are primarily due to trucks with monthly passes, which are not stopped at toll plazas and therefore not recorded in the RFID system. The proportion of such unrecorded trucks was estimated by vehicle class, and used to derive an adjusted average daily count (see Table 1(B)-1). This corrected count forms the basis for estimating the total emissions load from interstate heavy goods vehicles.

Table 1(B)-1 • Updated daily counts for trucks via camera TVC

Category	Proportion of trucks not in RFID	Average daily truck count in RFID	Updated average daily truck count
2 axle truck	25%	8,056	10,070
3 axle truck	37%	2 ,187	2 ,996
4(+) axle truck	24%	3,145	3,900
Overall	-	13, 388	16,966

Source: Data collected from the Traffic Volume Count (TVC) exercise conducted by the Ministry of Road Transport and Highways, Government of India, September 2025.

Annexure 1(E)

Truck Driver Survey — Detailed Methodology & Insights

We present results from questionnaire-based surveys of truck drivers conducted across 25 toll plazas (refer Annexure 1(B)). The surveys were carried out between 11-14 July and 18-21 July 2025, covering both daytime (11 am-5 pm) and nighttime (11 pm-7 am) periods. The survey aimed to cover approximately 8-10% of trucks passing through these plazas. In total, **4,731 driver interviews were completed, of which 4,426 correspond to trucks entering Delhi and 305 to trucks exiting**. Unless specified otherwise, all the results are for the trucks entering Delhi. The datapoints collected through the survey are detailed in Annexure 1(A). Invalid entries have been removed before presentation of each result.

Data extrapolation & analysis methodology

To extrapolate survey findings to the full population of trucks, we apply post-stratification weights to align the survey sample with the distribution observed in the RFID dataset. Two variables are common across both datasets—fuel type and axle count. Using these, we define six fuel-axle categories (CNG and diesel across 2-axle, 3-axle, and 4+ axle trucks).

We then compute the percentage distribution of truck entries across these categories in both the RFID dataset and the survey. For the RFID dataset, distributions are based on total truck entries (not unique vehicles). For each category, we calculate the ratio of the RFID share to the corresponding survey share. These ratios are used as post-stratification weights and applied to the unit-level survey data to correct for sampling imbalances.

I. Fuel-Axle Composition

CNG dominates the 2-axle segment, while diesel dominates the larger truck segments.¹⁴⁶ As discussed in the RFID dataset, we find a strong relationship between fuel type and axle configuration. CNG trucks are concentrated in the 2-axle category, while diesel trucks dominate higher axle segments.

Table 1(E)-1 • Percent Distribution of Fuel Type Stratified by Axle Number

Fuel Type	2 Axle	3 Axle	4 Axle	5+ Axle
CNG	68.1	30.8	20.2	9.2
Diesel	31.9	69.2	79.8	90.8
Total	100	100	100	100.0

A majority (83%) of CNG trucks are 2-axle vehicles, with very limited presence in higher axle categories. In contrast, diesel trucks are more evenly distributed, with roughly 20% each across 3-axle, 4-axle, and 5+ axle categories. When viewed as a combined distribution, CNG 2-axle trucks alone account for ~40% of total truck movement in Delhi. This is followed by diesel 2-axle trucks (~20%), while diesel trucks in the 3-, 4-, and 5+ axle categories each contribute approximately ~10%.

Table 1(E)-2: Distribution of Number of Axles by Fuel Type

Fuel Type	CNG	Diesel
2 axle	83.0	38.1
3 axle	9.8	21.8
4 axle	7.2	40.1
Total	100	100

¹⁴⁶ Note: the survey results described below include the post-stratification weights.

Yet another representation of the fuel and number of axle distribution is to express the percentages so that the total across these categories sum to 100 percent (see Table 1(E)-3). According to this, 40% of all truck movement in Delhi is CNG-based 2-axle trucks, followed by close to 20% of diesel-based 2-axle trucks. The three diesel categories of 3, 4 and 5+ axles are about 10% each.

Table 1(E)-1 · Percent Distribution of Fuel Type Stratified by Axle Number

Fuel Type	CNG	Diesel
2 axle	41.1	19.2
3 axle	4.9	11
4 axle	3.6	20.3
Total	100	

II. Age Profile

The diesel fleet is younger than the CNG fleet. We find notable differences in age distribution across fuel types. While the share of CNG and diesel trucks is similar in the 0-5 year category (62-64%), divergence emerges for older vehicles. Diesel trucks are more than twice as likely as CNG trucks to fall in the 8-year category, whereas CNG trucks are significantly more likely to be older than 8 years (25% vs. 10%). Overall, this indicates that the diesel fleet is younger than the CNG fleet. This is likely driven by regulatory restrictions in Delhi, which prohibit diesel trucks older than 10 years from operating.

Table 1(E)-4 · Age distribution by fuel type

Age Group	CNG	Diesel
0-5 years	63.8	61.8
5-8 years	11.2	27.9
>8 years	25.0	10.3
Total	100.0	100.0

III. Emission Standards

Diesel trucks skew toward higher BS norms. The observed age differences are reflected in emission standards. Diesel trucks are more likely to comply with newer BS norms, while CNG trucks have a higher share in older categories. CNG trucks are roughly twice as likely to be BS-III compared to diesel trucks. At the same time, the share of BS-VI vehicles is similar across both fuel types (62-64%), consistent with the comparable share of newer vehicles (0-5 years). Given current policy restrictions, the phase-out of non-BS-VI diesel vehicles could affect a significant share (~38%) of diesel truck entries.

Table 1(E)-5 · Percentage distribution of emission standards by fuel type

BS norms	CNG	Diesel
BS-III	13.3	6.2
BS-IV	22.7	32.1
BS-VI	64.0	61.7
Total	100.0	100.0

IV. Registration

Most trucks are registered in Haryana, Uttar Pradesh, and Rajasthan. The registration state was extracted from the license plate number of the truck as recorded in the survey. Largest contribution of state registrations is from Haryana (43%), Uttar Pradesh (18%) and Rajasthan (16%), with the vehicles registered in the three states covering more than three-quarters (77%) of all trucks. While Haryana and Uttar Pradesh are contiguous to Delhi, Rajasthan is a large state, and is near contiguous. Only 9% of the trucks are Delhi-registered.

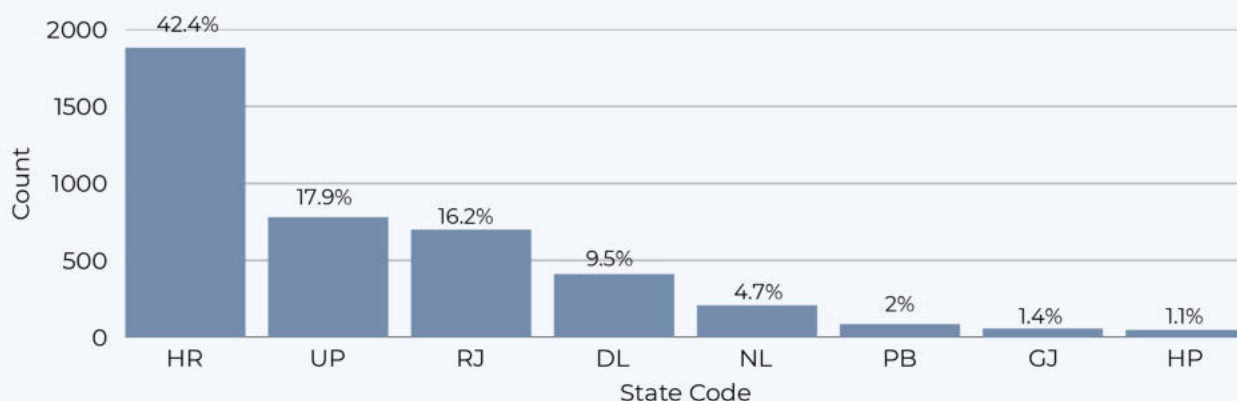


Figure 1(E)-1: Distribution of registration state for unique trucks (remaining states contribute <1%)

V. Origins

Most trucks originate within NCR states, and the registration state does not reliably indicate where trucks operate. The distribution of states from where trucks entering into Delhi have originated shows that 43% of all trucks came from Uttar Pradesh, 27% from Haryana, and 7% from Rajasthan. It is the districts from these three states that along with Delhi also form NCR.

At the same time, the distribution of origin states does not identically mirror the distribution of registration states. While Uttar Pradesh, Haryana, and Rajasthan are the three largest states in both cases, their shares differ substantially. For example, 26% of trucks entering Delhi are registered in Rajasthan, but about one-third of that share is reported to have originated there. Similarly, Nagaland is the fourth-largest registration state in the survey, but does not appear among the top twenty origin states. This **suggests that registration state is not a meaningful indicator of where a truck is operating and is likely influenced by differences in registration costs and practices across states.**

Within the NCR-origin truck population, we find that 60% are CNG and 40% are diesel. There is also substantial variation in fuel composition across origin states (refer Table 1(E)-6). For instance, nearly 60% of all CNG trucks entering Delhi are reported to originate in Uttar Pradesh, whereas only about 27% of diesel trucks do so. Haryana accounts for a relatively similar share of both CNG and diesel trucks, while states such as Gujarat and Maharashtra account for a much larger share of diesel than CNG trucks.

Table 1(E)-6 · Distribution of origin state by fuel type

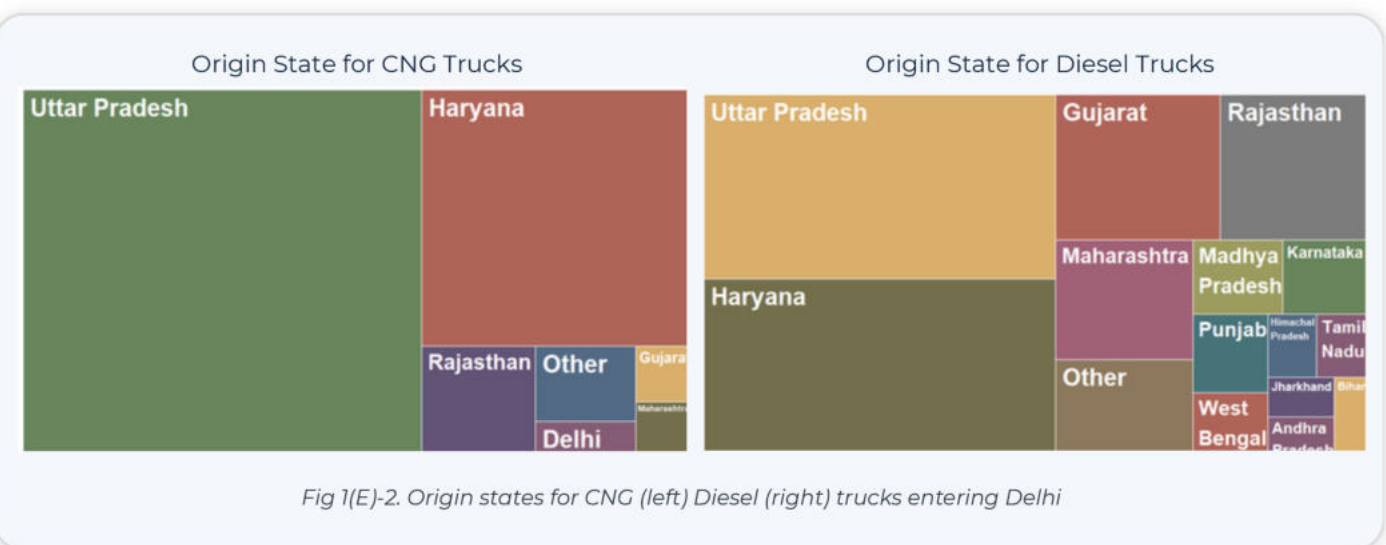
Origin State	CNG	Diesel
Uttar Pradesh	59.6	27.3
Haryana	28.5	25.7
Gujarat	1.3	10.1
Rajasthan	5	8.9
Maharashtra	1.2	6.9
Madhya Pradesh	0.3	2.8
Karnataka	0.6	2.6
Punjab	0.6	2.5
West Bengal	0.5	1.9
Himachal Pradesh	0.2	1.3

Origin State	CNG	Diesel
Other	2.2	10
Total	100	100

When the origin-state distribution is expressed jointly by fuel type so that all categories sum to 100%, the single **largest category is CNG trucks originating in Uttar Pradesh (29.5%)**, followed by CNG trucks from Haryana (14.1%), diesel trucks from Uttar Pradesh (13.8%), and diesel trucks from Haryana (13.0%). Together, these four categories account for roughly 70% of all truck entries in the survey-weighted population (refer Table 1(E)-7).

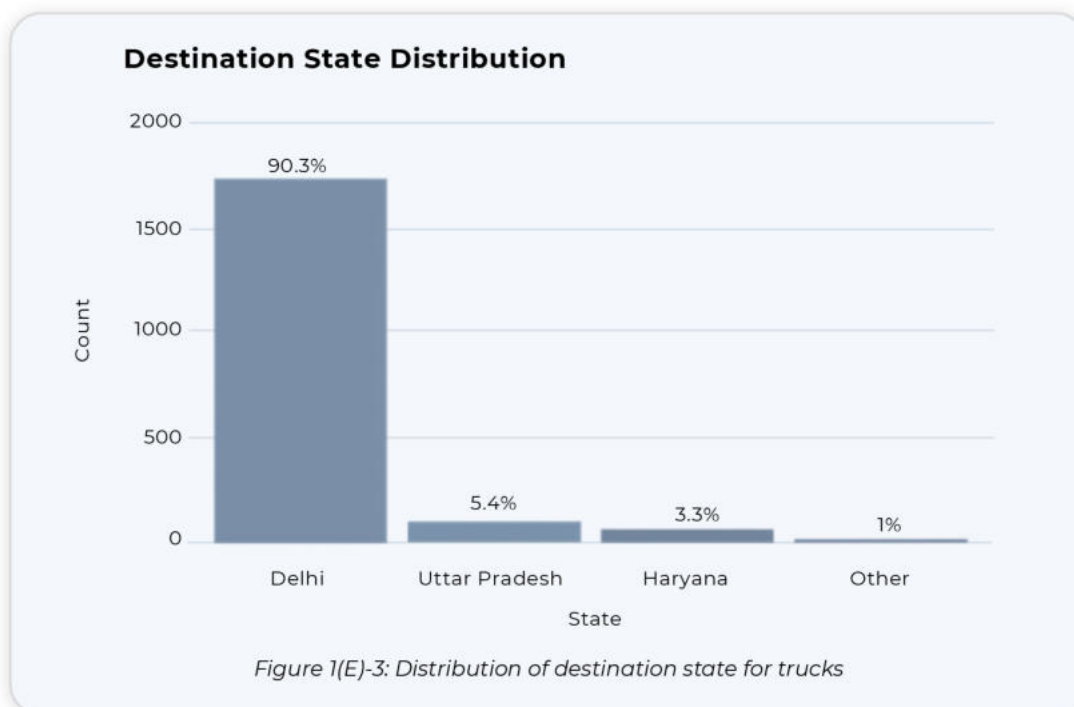
Table 1(E)-7 · Percentage distribution of fuel and their origin state

Origin State	CNG	Diesel	Sum
Uttar Pradesh	29.5	13.8	43.3
Haryana	14.1	13.0	27.1
Rajasthan	2.5	4.5	7.0
Gujarat	0.6	5.1	5.7
Maharashtra	0.6	3.5	4.1
Karnataka	0.3	1.3	1.6
Punjab	0.3	1.3	1.6
Madhya Pradesh	0.1	1.4	1.5
West Bengal	0.2	1.0	1.2
Delhi	0.6	0.2	0.8
Other	0.5	5.6	6.1
Total	49.3	50.7	100



VI. Destination

Almost all the trucks (92%) were reported to be destined for Delhi, and 8% of the vehicles reported bypassing the city. Out of the trucks that reported bypassing while entering Delhi, 86% originated in an NCR state, and 95% were destined to an NCR state, showing that most of such trips happened within NCR states, not for long-distance trucks. As expected, a majority (65%) of such trucks are CNG 2-axle, as compared to 41% in the general population.



V. Ownership

More than 75% of the trucks surveyed were company-owned as opposed to being owned by an individual. This percentage varies from 60% for trucks registered in Gujarat and Rajasthan to 80% for trucks registered in Uttar Pradesh, Haryana and Delhi. When stratified by the type of ownership, there are significant differences in the distribution of fuel type. Company-owned trucks have an even distribution of CNG and diesel, while self-owned vehicles are predominantly diesel (refer Table 1(E)-8).

Table 1(E)-8 · Percentage distribution of fuel type by type of truck ownership

Fuel Type	Company	Self
CNG	52.8	39.2
Diesel	47.2	60.8
Total	100.0	100.0

At the same time, we do not find major differences in BS emission norms by ownership type. Driver-owned or self-owned trucks have only a somewhat higher share of BS-III vehicles than company-owned trucks (refer Table 1(E)-9).

Table 1(E)-9: Percentage distribution of norm type by type of truck ownership

BS Norms	Company	Self
BS-III	8.9	12.0
BS-IV	27.0	28.9
BS-VI	64.1	59.1
Total	100.0	100.0

As seen in Figure 1(E)-4, company-owned vehicles are maintained somewhat more frequently, with 25% of company-owned trucks undergoing maintenance at least once in 3 months. Out of the company owned trucks entering Delhi, 28% were empty, while this was 19% for self-owned vehicles. This shows a potential for optimizing truck movement in company-owned vehicles to reduce emissions.



Figure 1(E)-4: Maintenance frequency of trucks by ownership type

V. Average Travel Distance

We find that average daily travel distance does not vary substantially across most truck categories, with one clear exception: **2-axle trucks travel distinctly shorter distances than larger vehicles**. When stratified by age, the daily distance travelled by 2-axle trucks younger than 3 years is about 25% lower than the average for larger axle categories in the same age group. Among the oldest vehicles, the gap widens further: 2-axle trucks older than 10 years travel about 35% less than larger trucks in the same age group (Table 1(E)-10).

Table 1(E)-10: Average daily travel distance (in km) of trucks by number of axle and age group

Age group	2 axle	3 axle	4+ axle
0-3 years	208	289	312
3-7 years	225	267	287
7-10 years	227	255	253
>10 years	166	213	230

This shorter average travel distance for 2-axle trucks is consistent with earlier findings from the RFID dataset, which show that smaller trucks make more frequent repeat trips into Delhi and are more likely to be engaged in shorter-haul movement.

Table 1(E)-11: Average daily travel distance (in km) of trucks by number of axle and fuel type

Fuel type	2 axle	3 axle	4+ axle
CNG	188	202	214
Diesel	259	295	302

A note on the introduction of BS norms

We present a summary of the timeline of the implementation of emission standards.

1. BS-IV had a phased implementation.
 - a. Fuel availability implemented in the National Capital Region (NCR) and 10 other major cities from 2010.
 - b. The fuel availability was extended nationwide in 2017.
 - c. Also note that the major factor that reduced the emissions from BS-IV compared to BS-III was the reduction in sulphur content from 350 ppm to 50 ppm.
2. Similar to BS-IV, implementation of BS-VI was also phased, though at a much faster pace.
 - a. BS-VI fuel, further reducing sulphur content to 10 ppm, was available in Delhi by April 2018, followed by NCR by April 2019, and then nationwide by 2020.
 - b. Only BS-VI vehicles were allowed to be sold or registered nationwide from April 2020, although this was extended by 6 months due to the pandemic.
 - c. Unlike BS-IV, in BS-VI, there were significant additions of aftertreatment technology to reduce emissions. These include a Diesel Oxidation Catalyst (DOC), which oxidises hydrocarbons and carbon monoxide, a Diesel Particulate Filter (DPF), which traps and oxidises soot, and Selective Catalytic Reduction (SCR), which reduces nitrogen oxides to inert nitrogen and water.

Since the survey of truck drivers was conducted in 2025, the age of vehicles is calculated for that year. Therefore, a BS-IV vehicle registered in 2017 will be 8 years old in 2025, a BS-VI vehicle registered in 2018 will be 7 years old, and a BS-VI vehicle registered in 2020 will be 5 years old. It is important to note that a recent policy from the government has banned the entry of BS-III commercial diesel vehicles from November 2025 and has further decided to ban entry for BS-IV vehicles starting November 2026.¹⁴⁷

VI. Vehicle Loading and Commodity

Out of all the trucks entering Delhi surveyed, 77% were loaded, and construction material is the single largest commodity category. The distribution of commodities carried by loaded trucks indicates a wide variety of goods, though a relatively small number of categories account for most traffic.

After construction material (which accounts for 26% of loaded trucks), this is followed by industrial inputs (18%), food products (15%), and fruits and vegetables (12%). Together, these four categories account for close to two-thirds of all trucks. Courier items (11%) and household goods (6%) are the next two largest categories; taken together, the six largest commodity groups account for 88% of all surveyed trucks.

The survey also provides insight into return movement; among the 150 trucks observed exiting Delhi, 51% were empty. This suggests a high incidence of empty return trips, while also indicating that outward movement estimates should be interpreted with some caution given the limited sample size.¹⁴⁸

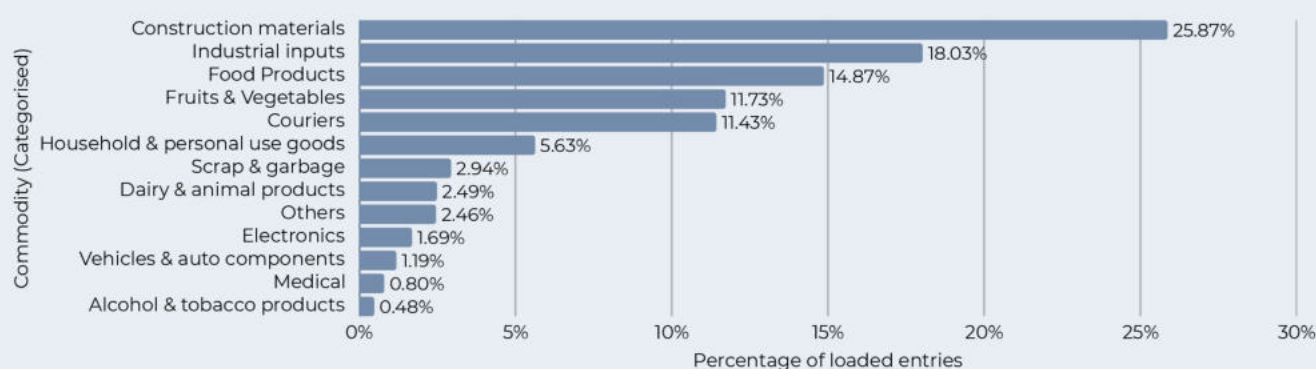


Figure 1(E)-5: Categorisation of goods in loaded trucks

¹⁴⁷ CAQM (2025). Amendment to Direction No. 88, 17 Oct 2025

¹⁴⁸ We also classify loaded trucks according to the categories of goods that were exempt from the Environment Compensation Charge (ECC) under Delhi Government rules (2015). Using this classification, we find that 20% of loaded trucks carry goods that would be considered essential, while 80% carry non-essential goods. Among the essential categories, raw vegetables and fruits account for approximately 12% of loaded entries, grains for 4%, petroleum products for 2%, and milk for a little under 2%. The policy relevance of this classification has changed over time: by October 2025, Supreme Court directions removed these exemptions, partly because it was difficult to verify truck contents externally and because such checks contributed to congestion.

VII. Axle Load Measurement

Axle loads were measured for 145 trucks, at Kundli and Auchandi toll plazas. Among these 92 were loaded and the rest were unloaded. Of the loaded ones, 52 were overloaded, i.e., their measured weight exceeded GVW. Table 1(E)-12 shows that overloading is especially pronounced among 3-axle and 4-axle trucks. However, given that this is a small sample of trucks, we should be careful in extrapolating the prevalence of overloading from this survey to the overall population of trucks.

Table 1(E)-12 · Comparison of allowed and measured weight of loaded trucks

Vehicle type	Count of vehicles	Average GVW (tonnes)	Average measured weight (tonnes)	Average difference (tonnes)
2 axle	39	22.7	17.4	8.7
3 axle	27	25.4	32.9	7.5
4+ axle	26	39.4	43.2	3.8
Total	92	-	-	-

For trucks reported to be empty, we compare the measured empty weight (kerb weight) with the self-reported weight provided by drivers (refer Table 1(E)-13). We find that the measured weight is, on average, higher than the self-reported value, with an average error of about 10% when expressed relative to GVW. By axle category, the average difference ranges from 0.5 tonnes for 3-axle trucks to 1.5 tonnes for 5-axle trucks. This is an important methodological finding, as it provides some insight into the reliability—and limitations—of self-reported weight information in the survey.

Table 1(E)-13 · Comparison of reported and measured weight of unloaded/empty trucks

Vehicle type	Count of vehicles	Average GVW (tonnes)	Average measured weight (tonnes)	Average difference (tonnes)
2 axle	16	8.0	8.4	0.4
3 axle	17	11.3	12.5	1.2
4+ axle	23	14.4	15.5	1.1
Total	56	-	-	-

Annexure 2(A)

VS3 Equipment Details

Table2(A)-1 · Details of the VS3 equipment setup

Name	Model	Parameter measured (unit)	Accuracy
Flue gas analyser	TESTO 350	HC, CO, NO _x , SO ₂ (ppm), CO ₂ in % and Temperature	± 5 ppm, ± 0.3 to 0.5 % and ± 0.5°C
Relative humidity and temperature monitor	Polltech PSI-RHT-4S	R.H (%) and Temperature	RH: ± 1.0% and Temperature: ± 0.2°C
Pitot tube	TESTO 480	Pressure difference (hpa), and exhaust velocity (m/s)	± 0.2 m/s
PM _{2.5} multi-channel sampler	URG PM _{2.5} Cyclone @ 10 LPM	PM mass collection on filter substrate (µg)	-
Aethalometer	Magee Scientific AE33	Black carbon (ng/m ³)	³ 1 ng m ⁻³
Nephelometer	Air photon IN102	Light scattering wavelengths 450, 532 and 632 (Mm ⁻¹)	0.1 Mm ⁻¹
Nano-scanning mobility particle sizer (Nano-SMPS)	TSI 3910	Number particle concentration (Size range: 10 nm -1.0 µm) (#/cm ³)	0.01%
Optical particle sizer (OPS)	TSI 3330	Number particle concentration (Size range: 10 nm- 10 µm) (#/cm ³)	0.01%
Micro-orifice uniform deposit impactor (MOUDI)	TSI MOUDI 125R	Size-fractionated particle mass in 13 impactor stages (10 nm - 10 µm)	-
Clean air generation system	Polltech Thomas UK make compressor, Regenerative Heatless Air Dryer	Clean air supply (5 - 60 LPM)	-

Annexure 2(B)

VS3 Experiments — Detailed Results

Study Design

A set of 45 experiments were conducted on 34 unique trucks. The vehicles were classified based on their gross vehicle weight (GVW) and according to their emission norms. Out of the 45 trucks, 20 were loaded and the rest were unloaded. The distribution of the samples is shown in Table 2(B)-1. Of these, 36 are diesel and 9 are CNG. Of the 9 CNG trucks, 5 are BS-VI and 4 are BS-IV. The emission factors are presented as grams per kilometre (gm/km). We have also covered a range of ages in each BS norm category, as seen in Figure 2(B)-1. The GVW is proportional to the number of axles. 12-16 tonnes includes the 2-axle trucks, 16-30 tonnes contains both 2 and 3 axle trucks and 4-5 axle trucks are included in the 30-42 tonnes group.

Table 2(B)-1 • Sample Distribution for VS3 Measurements

BS Norms	12-16t		16-30t		30-42t		Grand Total
	Unloaded	Loaded	Unloaded	Loaded	Unloaded	Loaded	
BS-III	1	0	1	0	3	0	5
BS-IV	3	4	5	4	2	1	19
BS-VI	3	4	2	3	5	4	21
Grand Total	15		15		15		45

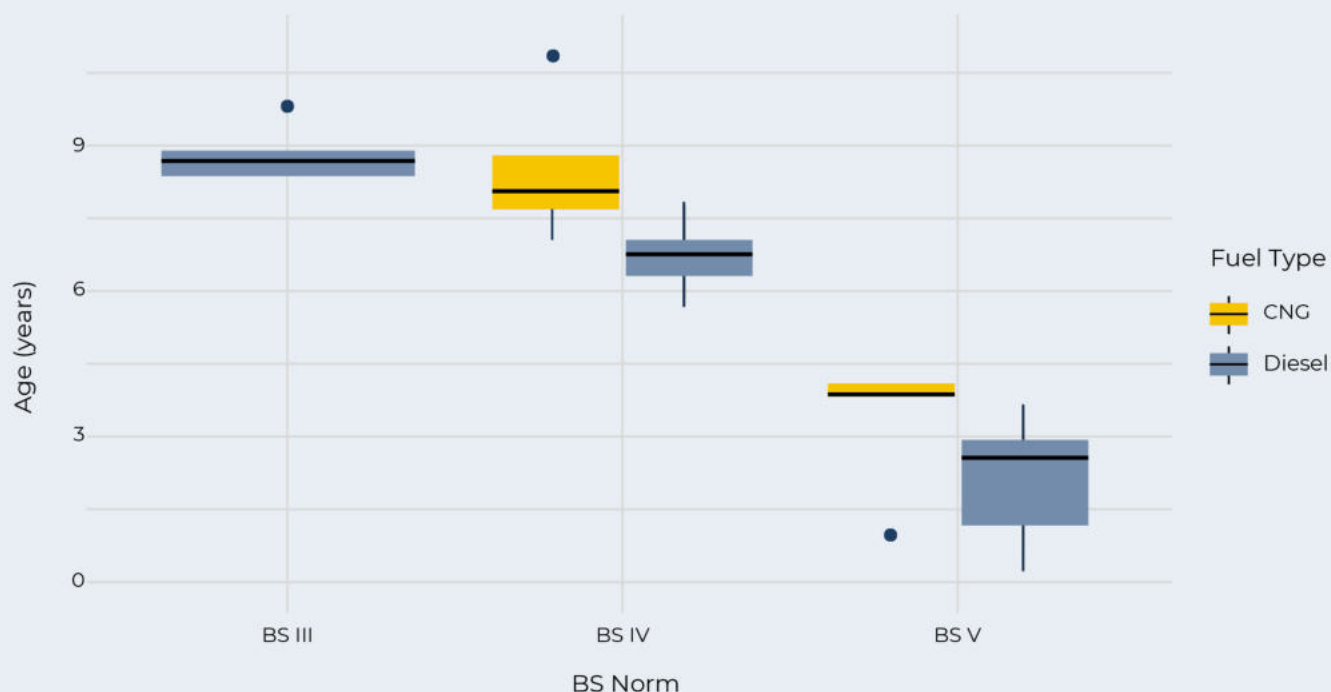


Figure 2(B)-1: Age and emission standards (Bharat Stages) of the 45 trucks used for VS3 experiments

The experiments were conducted between August 2025 and April 2026, each experiment lasting almost 1.5 hours. The truck was driven on a pre-defined route, with a length between 30 and 70 kilometres. The experiments were conducted at night for diesel trucks and during the afternoon for CNG trucks, as per observed

volumes and permissible hours for trucks on Delhi roads. While this limits comparability between the emission factors of CNG and diesel trucks, as the experiment vehicles were exposed to different driving cycles, since the truck traffic at night is predominantly diesel and during the day is predominantly CNG, their measurement times reflect their usage patterns.

Measurements were started at around 2km from the start point, so that cold start emissions were avoided. The routes were tracked using a GPS device, data from which is shown in Figure 2(B)-2. All the major truck routes in the city were included, and the drivers were instructed to drive the vehicle as they normally would. The total emissions measured during the trip are divided by the length of the route covered to obtain the emission factors, given in Tables 2(B)-3,4 and 5.

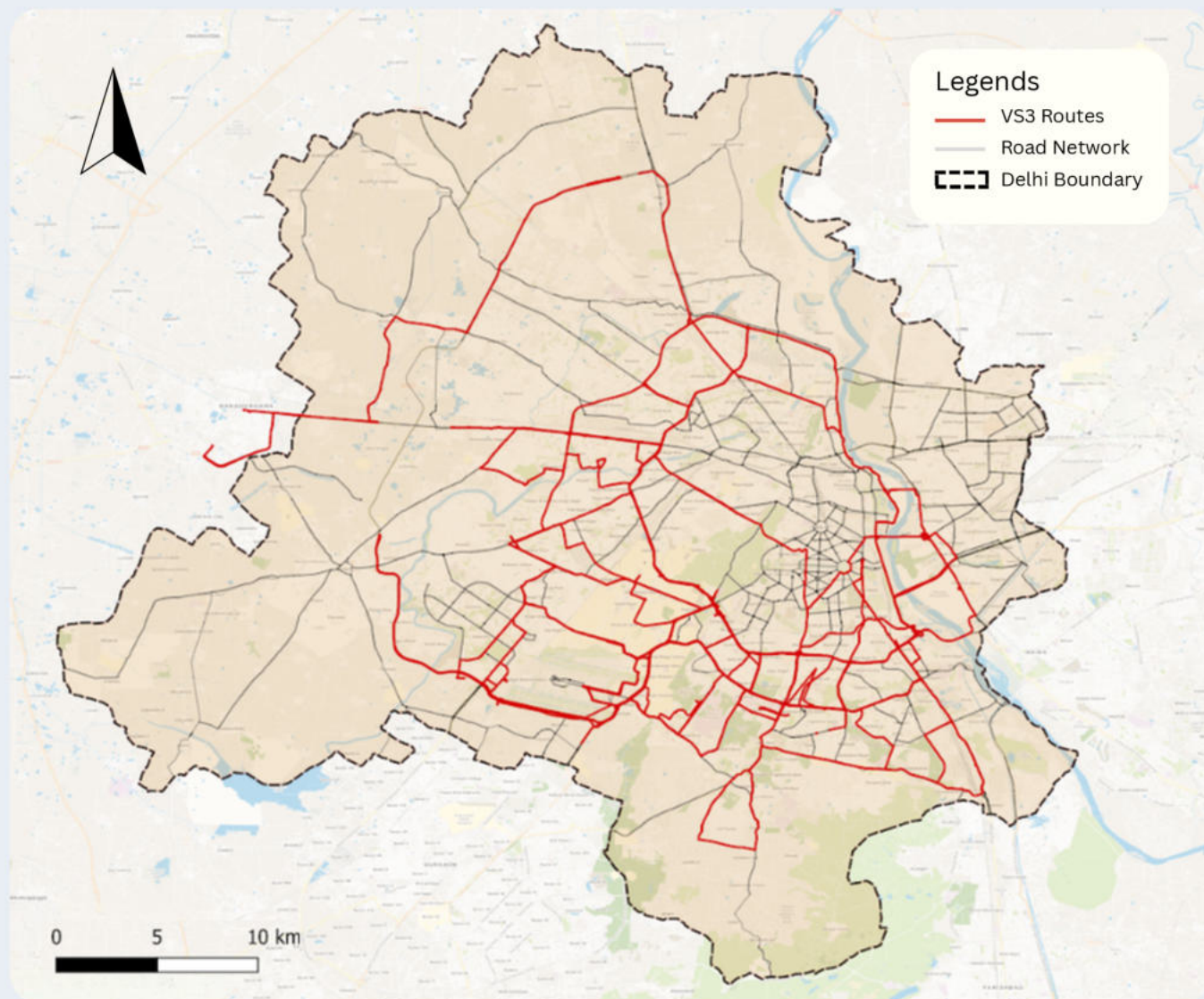


Figure 2(B)-2: Consolidated routes from GPS mapping for VS3 experiments

Comparison of Emission Factors by Bharat Stage Norms

The effect of emission norms on emission factors is different for PM_{2.5} and NO_x (Table 2(B)-2 and Table 2(B)-3). Let's look at the results of diesel and CNG vehicles combined. From BS-III to BS-IV, there is significant reduction in the PM_{2.5} emission factor, and that remains largely the same from BS-IV to BS-VI. Average PM_{2.5} emission factor reduces by 4.8 times from BS-III to BS-IV, while the reduction from BS-IV to BS-VI is only by 1.6 times. However, from BS-III to BS-IV, the reduction of NO_x emission factor is not as significant as PM_{2.5} - it reduces by half. A greater reduction is observed from BS-IV to BS-VI for NO_x, where there is at least a six fold reduction. Similarly for CO (Table 2(B)-4), the emissions are reduced by 3 times from BS-III to BS-IV, and by another 7 times from BS-IV to BS-VI.

The large reduction of CO and PM2.5 emission factors is in line with the improved aftertreatment systems introduced in the trucks such as diesel oxidation catalysts. However, BS-VI was also accompanied by mandatory application of Diesel Particulate Filter (DPF), and it is surprising that the PM2.5 emissions did not reduce more significantly than expected. One explanation is that the urban driving conditions do not result in the high enough temperature of exhaust gases that are needed for effective workings of aftertreatment technologies. The reduction in NOx emission factors in BS-VI trucks can similarly be explained by the inclusion of Selective Catalytic Reduction (SCR) technology. As this is a cross-sectional sample, it is possible that the age and lack of proper maintenance in the BS-IV and BS-III vehicles has also contributed to the higher emissions as compared to later norms.

Table 2(B)-2: PM2.5 emission factors (gm/km) for different emission standards and fuel type

Norms	Diesel		CNG	
	Mean (median)	Range	Mean (median)	Range
BS-III	0.335 (0.319)	0.092 - 0.758	NA	NA
BS-IV	0.074 (0.055)	0.03-0.290	0.046 (0.057)	—
BS-VI	0.049 (0.049)	0.017-0.102	0.036 (0.03)	—

Table 2(B)-3 · NOx emission factors (gm/km) for different emission standards and fuel type

Norms	Diesel		CNG	
	Mean (median)	Range	Mean (median)	Range
BS-III	8.23 (6.62)	4.71 - 15.05	NA	NA
BS-IV	4.58 (3.41)	0.59-12.39	7.28 (5.28)	0.15-18.40
BS-VI	0.80 (0.68)	0.01-2.09	0.734 (0.11)	0.06-2.08

Table 2(B)-4 · CO emission factors (gm/km) for different emission standards and fuel type

Norms	Diesel		CNG	
	Mean (median)	Range	Mean (median)	Range
BS-III	3.878 (3.600)	1.270 - 8.580	NA	NA
BS-IV	1.073 (0.370)	0.020 - 5.810	2.90 (2.49)	2.39-3.81
BS-VI	0.164 (0.090)	0.010 - 0.600	0.262 (0.140)	0.060 - 0.540

Comparison of emission factors by fuel type

We now look at the differences between CNG and Diesel, keeping the emission norms constant. When comparing BS-VI CNG trucks with BS-VI diesel trucks (Figure 2(B)-3), we found that CNG has much lower emissions than diesel for PM2.5 and NOx, thus agreeing with the overall sample averages without restricting to any emission standard. However, the CO emissions are almost twice as high for CNG trucks under BS-VI (see Table 2(B)-4).

Among BS-IV vehicles, there is not much difference between diesel and CNG emissions for PM 2.5 and NOx (Figure 2(B)-4). Similar to BS-VI, CO is twice as high for CNG (Table 2(B)-4). It is important to note that this is based on a small sample of trucks, and a further investigation would be required to understand the differences between the two fuel types.

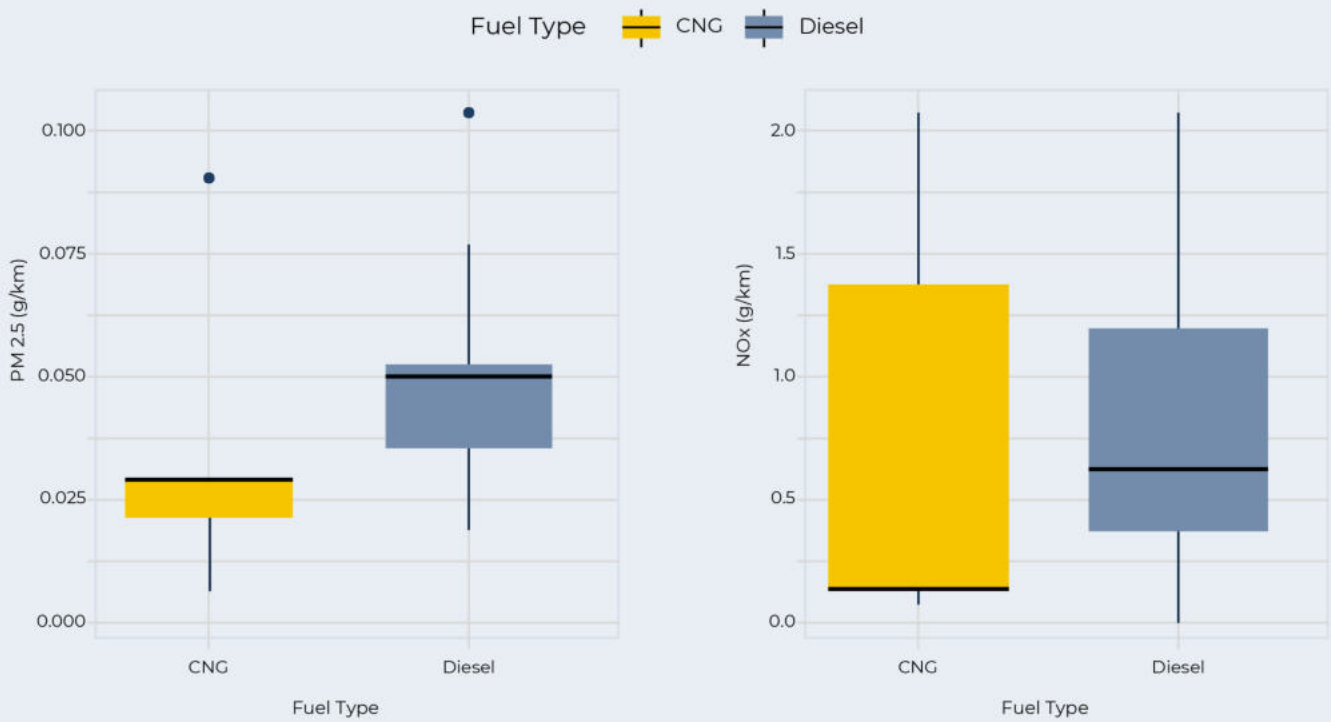


Figure 2(B)-3: PM2.5 and NOx emission factors for BS-VI CNG & diesel trucks

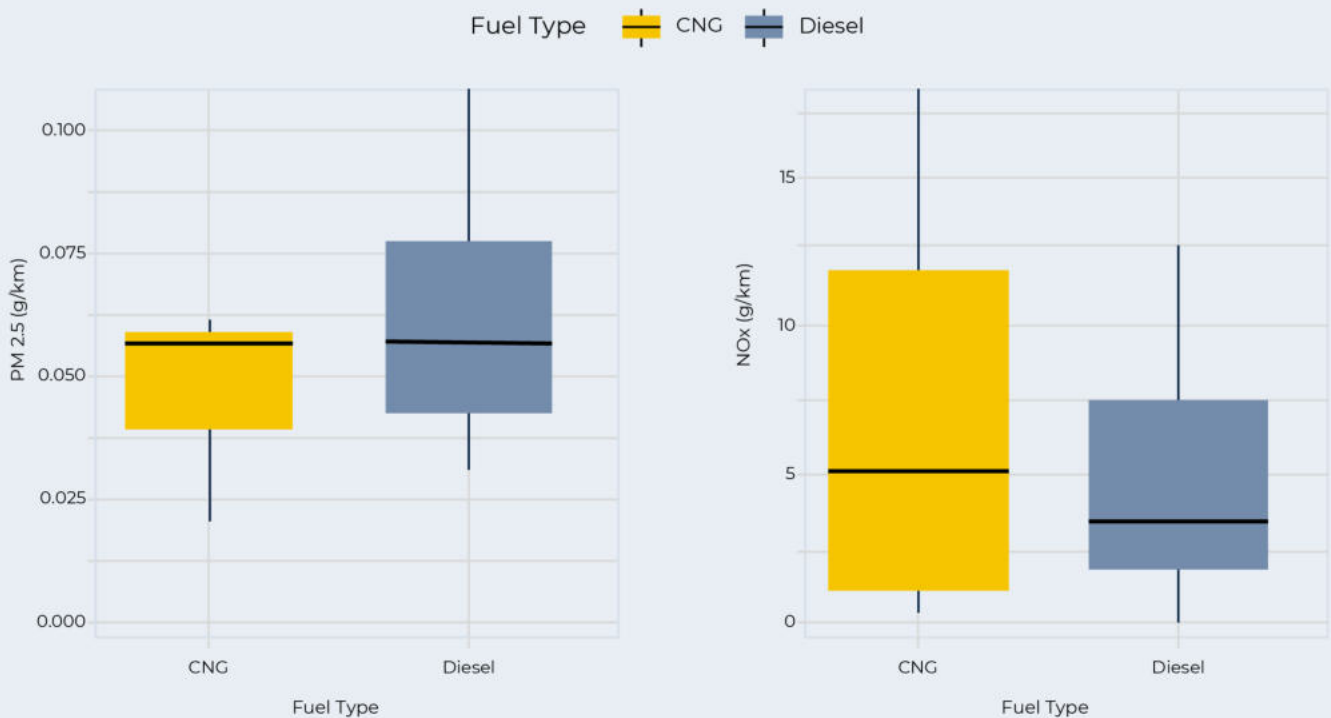


Figure 2(B)-4: PM2.5 and NOx emission factors for BS-IV CNG & diesel trucks

Comparing VS3 emission factors (EFs) with Automotive Research Association of India (ARAI) EFs:

The measured average emission factors are compared with the ARAI-reported factors.

- BS-III trucks:** Diesel emissions are consistently higher than ARAI factors—CO is approx. 2.2x higher and NOx 1.2x higher. CNG is not applicable.

- 2. BS-IV trucks:** Across both diesel and CNG, PM_{2.5} is 2-2.5x higher (while PM_{2.5} from CNG is 15x higher, note that the baseline is low) and CO 2-6x higher than ARAI factors. For NO_x, CNG is 1.6x higher, while diesel is 15% lower than ARAI.
- 3. BS-VI trucks:** Unlike BS-IV, comparisons with ARAI emission factors did not show a consistent pattern. For diesel trucks, our study estimated PM_{2.5} EFs that are an order of magnitude *lower* than ARAI value. CO is also lower by 3x, and NO_x is slightly higher. For CNG, the PM_{2.5} EF estimated in our study is an order of magnitude *higher*, and similar to diesel, CO is lower and NO_x is higher than ARAI.
- 4. Overall:** While newer norms deliver clear reductions in PM_{2.5} and CO, NO_x consistently exceeds ARAI benchmarks, indicating a need for targeted NO_x control given its role in secondary PM formation.

Table 2(B)-5 · ARAI vs VS3 emission factors (g/km)

Norms	BS-III	BS-IV	BS-VI*	BS-III	BS-IV	BS-VI
Diesel (g/km)	ARAI Factors			VS3 Factors		
PM _{2.5}	0.38	0.03	0.015	0.335	0.074	0.0049
CO	1.77	0.49	0.486	3.88	1.07	0.164
NO _x	7.08	5.35	0.612	8.23	4.58	0.8
CNG (g/km)	ARAI Factors			VS3 Factors		
PM _{2.5}	0.03	0.003	0.001484	-	0.046	0.036
CO	1.77	0.49	0.486	-	2.9	0.262
NO _x	6.16	4.46	0.51	-	7.28	0.734

**In the absence of ARAI BS-VI factors, the EF for the BS-VI category of vehicles was extrapolated from BS-IV emissions factors based on differences in BS-IV and BS-VI norms for heavy-duty vehicles.*

Extrapolating results to population

Since our VS3 sample does not cover the complete variety of vehicles that are observed on the road, we used a regression-based approach to estimate the emission factors of those categories. We developed regression models for PM_{2.5} and NO_x emission factors with the following four explanatory variables: fuel type, number of axles, BS norm, and loading condition. Using a regression model, not only can we predict the emission factors for specific vehicle categories that we did not measure in the VS3 measurement, but we can also learn the independent effects of each of the parameters.

We found that for all trucks, emission factors, number of truck axles, and BS norms were the statistically significant variables. Neither the loading condition nor the fuel type has an independent effect. That means, for the same emission standard and number of axles, whether a vehicle is loaded or not, or whether a vehicle is diesel or CNG, does not have an impact on the emission factors. In other words, the number of axles and BS norms are the two most important drivers of emission factors. Note that BS norms account for age. The predicted values for the truck sub-populations are shown for the three pollutants in Table 2(B)-6.

Table 2(B)-6 · Predicted emission factors for emissions inventory calculation, modelled using regression

Vehicle Type	Fuel	PM _{2.5} (g/km)			NO _x (g/km)			CO (g/km)		
		BS-VI	BS-IV	BS-III	BS-VI	BS-IV	BS-III	BS-VI	BS-IV	BS-III
2 Axle Truck	Diesel	0.04	0.07	0.26	0.73	6.07	13.06	0.04	0.4	2.31
	CNG	0.03	0.05	0.19	0.62	5.18	11.15	0.34	3.16	18.41

¹⁴⁹ ARAI 2008. *Emission Factor Development for Indian Vehicles*. ARAI, TERI 2018. *Source Apportionment of PM_{2.5} & PM₁₀ of Delhi NCR for Identification of Major Sources*.

Vehicle Type	Fuel	PM2.5 (g/km)			NOx (g/km)			CO (g/km)		
		BS-VI	BS-IV	BS-III	BS-VI	BS-IV	BS-III	BS-VI	BS-IV	BS-III
3 Axle Truck	Diesel	0.05	0.07	0.29	0.9	7.48	16.09	0.08	0.76	4.45
	CNG	0.04	0.05	0.21	0.76	6.39	13.74	0.65	6.08	35.43
4 Axle truck	Diesel	0.06	0.08	0.33	1.1	9.22	19.82	0.16	1.47	8.56
	CNG	0.04	0.06	0.24	0.94	7.87	16.92	1.24	11.7	68.19
5 Axle truck	Diesel	0.06	0.09	0.37	1.36	11.36	24.42	0.3	2.82	16.47
	CNG	0.05	0.07	0.27	1.16	9.7	20.42	2.39	22.51	131.21

Annexure 3(A)

Mitigation Strategies

Table 3(A): Longlist of mitigation strategies

Bucket	Category	Point-of-view following literature review
I. Low & zero emissions vehicles (LEVs & ZEVs)	1. Hydrogen fuel-cell electric vehicles (H2 FCEVs)	Conversion of trucks to hydrogen fuel is not recommended in Delhi-NCR. HICE trucks do not qualify as zero-emission due to NOx emissions, while HFCEVs face prohibitive costs and infrastructure gaps. Deployment is constrained by the lack of refuelling infrastructure, high vehicle and fuel costs, and an immature hydrogen supply chain. Hydrogen production, distribution, and refuelling remain at a feasibility stage, limiting operations to small, captive pilots rather than scalable freight use.
	2. Battery electric vehicles (BEVs; incl. charging infra)	Transitioning the freight fleet towards battery electric trucks is feasible & recommended in Delhi, but should be strategically phased, beginning with 2- and 3- axle trucks engaged in short-haul, high-utilisation operations. E-trucks eliminate 100% of tailpipe emissions (PM, NOx, CO2), making them a critical solution. However, large-scale deployment is constrained by high upfront costs (220-270 lakh for 28-42 tonne trucks vs. 42-49 lakh for diesel), limited range (100-350 km), sparse charging infrastructure (1:400) EV to public charger ratio) and grid readiness challenges. These barriers are particularly significant for heavier, long-haul trucks, making 2- and 3-axle trucks the most viable near-term segment for electrification. Accelerating adoption will require targeted financing support, especially for small and informal fleet operators facing high upfront costs and limited access to credit. Hybrid trucks exist, but are not considered here due to minimal fuel savings on highway-dominant operations, high GST, and poor real-world emission performance.
	3. LNG	Conversion to Liquefied Natural Gas (LNG) trucks is not recommended for Delhi-NCR. While LNG technology is technically mature and offers operational advantages such as long driving range and rapid refuelling, deployment is constrained by underdeveloped refuelling infrastructure, high upfront vehicle costs (₹11-12 lakh premium over diesel), and exposure to fuel price volatility. Although LNG can deliver incremental PM reductions relative to diesel, particularly compared to pre-2007 vehicles, large-scale adoption remains dependent on substantial infrastructure build-out (1,000 stations targeted vs ~20 operational in 2024) and coordinated supply-chain development.
	4. Biofuel/biogas	Conversion of trucks to biogas and biofuel is not feasible for Delhi-NCR given short-haul movement patterns, prohibitive production costs (bio-LNG: ₹87-96/kg vs. diesel ₹30-40/litre), and severe feedstock-supply constraints. While bio-CNG can reduce PM emissions (270 kg PM daily from a 10-tonne CBG plant), large-scale adoption remains dependent on subsidies and policy support. Bio-CNG holds marginal potential only for captive urban fleets (municipal waste collection, organised retail logistics with predictable routes), not general inter-state freight. Long-haul viability (where biofuels theoretically offset cost) is negated by underdeveloped refueling infrastructure (~24 LNG stations vs. government target of 1,000 by 2030) and seasonal feedstock variability that prevents reliable year-round production.

Bucket	Category	Point-of-view following literature review
II. Retrofitment	5. Retrofitment of CNG trucks for NOx emission with SCRs	Retrofitment of in-use diesel & CNG trucks is feasible in Delhi-NCR. It is considered as an interim strategy to curb air pollution from the existing aging fleet. However, based on extensive stakeholder inputs and current market conditions, deployment is not recommended due to poor cost-effectiveness and regulatory and market-readiness gaps that need to be addressed. Any targeted retrofit deployment will require robust financing support, certified technology ecosystems, and clear regulatory frameworks to improve operator confidence and reduce compliance uncertainty. Transition support mechanisms will be particularly important for small operators that may be unable to absorb retrofit costs independently.
	6. Retrofitment of diesel trucks with SCRs & EGRs (old - DPFs)	
	7. Retrofitment of ICE trucks with EV	
	8. Retrofitment of ICE trucks with H2 Cells	
III. Regulatory interventions	9. Age/pollution criteria	Age-based deregistration is feasible but not recommended in Delhi-NCR. There is limited scientific evidence linking vehicle age alone to emissions; maintenance, usage patterns, and technology largely determine pollution impact. This measure therefore risks penalising well-maintained vehicles that remain non-polluting, while allowing newer, but potentially poorly maintained vehicles to continue emitting disproportionately. It is, therefore, not an effective primary mechanism for reducing inter-state MHDV emissions. A shift toward in-use, performance-based compliance (like a combination of OBD, remote sensing & better fitness testing) would deliver better emission control.
	10. Year-round GRAP ban	A year-round enforcement of a GRAP-like "Green Zone" framework is unfeasible and not recommended in Delhi/NCR. Even short-term GRAP restrictions have shown that construction bans and movement limits disrupt livelihoods, delay projects, and raise costs, especially for construction workers, daily wagers, small contractors, and transport operators. Making these restrictions permanent would disproportionately harm the same groups. Additionally, such a framework would also weaken the city's economy, which relies on continuous construction, steady movement of goods, and regular inter-city commuting. To keep the city functioning, authorities would be forced to label most construction, freight, and work travel as "essential," leading to widespread exemptions and making a permanent Green Zone ineffective and unenforceable.
	11. Low emissions zones (LEZs)	Low Emission Zones (LEZs) are feasible and recommended in Delhi-NCR. They prove to be a superior alternative to GRAP for sustained inter-state truck emission reductions, if phased appropriately. A permanent, norms-based LEZ targeting pre-BS-IV trucks in the NCR could achieve a minimum of 16% PM2.5 and 12% NOx reductions from trucks with ANPR enforcement and fleet financing support. However, without addressing equity impacts on informal operators, LEZs risk exacerbating economic barriers. Optimal design requires phased stringency (grace periods for compliance), targeted fleet upgrade financing, and complementary off-LEZ logistics zones.

Bucket	Category	Point-of-view following literature review
IV. Infrastructural & tech interventions	12. Remote-sensing to monitor on-road emissions (coupled with AI-enabled ANPR)	Remote sensing paired with AI-enabled ANPR is not feasible and only recommended in Delhi-NCR as a supplementary measure . It offers a rapid, non-intrusive method to identify on-road super-emitters, primarily pre-BS-VI diesel and CNG trucks. This could prove to be an effective solution for ~42% of trucks entering Delhi. The technology is now highly mature in India (TRL 7-8), with successful pilot deployments in Delhi, Gurugram. However, remote sensing should be positioned as a screening and prioritisation tool, not a standalone enforcement mechanism. Used in this role, it can also generate evidence on where the current vehicle testing and compliance framework requires strengthening. Its effectiveness is constrained by the absence of notified standards (AIS-170 remains in draft) and misalignment between concentration-based sensor outputs and mass-based regulatory metrics (g/km or g/kg).
	13. OBD integration	Integrating On-Board Diagnostics (OBD) into vehicle testing is feasible and recommended in Delhi-NCR as a supplementary screening tool for identifying high-emitting vehicles. OBD systems are already mandated in BS-VI trucks (~58% of trucks entering Delhi) and can measure pollutants that conventional PUC tests don't. However, OBD data is not yet integrated into in-use enforcement, and vulnerabilities to tampering and regulatory gaps limit its use as a standalone compliance tool. Therefore, OBD integration should function as an early-warning mechanism that triggers targeted physical inspections or confirmatory tests, rather than replacing existing inspection processes.
	14. ANPR with payload sensors	Strengthening freight compliance by deploying payload sensors, with AI-enabled ANPR cameras, is feasible & recommended for Delhi. While these systems need proper calibration for each vehicle type and regular checks to ensure accuracy, they can enable real-time identification of overloaded trucks, which are associated with higher emissions, significant safety risks, and higher accident rates. Scalable deployment will require interoperable digital enforcement systems, reliable sensor infrastructure, and minimisation of compliance burdens for smaller transport operators. Integration with broader freight digitalisation initiatives can further strengthen enforcement efficiency and data coordination.
	15. Dynamic tolling systems	Dynamic Tolling Systems are currently not feasible or recommended for Delhi-NCR. These are data-driven tolling systems that adjust toll rates in real time based on factors such as congestion, time of day, and vehicle characteristics. It requires real-time integration of traffic, vehicle, and emissions data to adjust toll plazas continuously. This has not yet been operationalised in India. In the absence of enabling policy frameworks, inter-agency data integration, and demonstrated pilots linking congestion or emissions to pricing, dynamic tolling remains at a demonstration stage and is not ready for deployment as an emissions or congestion management tool in Delhi-NCR.

Bucket	Category	Point-of-view following literature review
V. Freight infrastructure & logistics optimisation	16. Aerodynamic devices to reduce drag & fuel consumption	Aerodynamic devices are currently not feasible or recommended for Delhi-NCR. Despite being technically mature, their adoption remains fragmented due to the absence of truck-specific standards, certification pathways, and policy incentives. Uncertain verification of emission benefits and misaligned economic incentives between drivers and fleet owners limit their scalability and reliability as an emissions-control measure at this stage.
	17. Expedite establishment of Automated Testing Stations (ATSs)	Establishment of ATSs are feasible and recommended for Delhi-NCR as a core reform to strengthen in-use vehicle fitness and emissions compliance for commercial vehicles. By replacing manual inspection with standardised, machine-based testing integrated with AFMS and VAHAN, ATSs improve transparency, reduce result tampering, and enable pan-India validity of fitness certification. While they do not yet expand the range of emission parameters beyond existing PUC tests, their primary value lies in enabling reliable enforcement and making testing accessible across jurisdictions.
	18. Optimise trucking to prevent empty trucks from plying	Empty truck optimisation is feasible & recommended for Delhi. Empty truck movements account for ~23% of trucks entering Delhi and ~51% of outbound trips. These movements lead to unnecessary fuel consumption, higher emissions, and increased congestion, but optimisation platforms can substantially reduce these inefficiencies through improved backhaul utilisation, with global evidence showing CO2 reductions of up to 34%. However, effective deployment in Delhi remains constrained by ecosystem gaps. These include: absence of any operational MMLPs inside Delhi, inadequate parking/consolidation infrastructure, regulatory time-bound restrictions that limit HDV flexibility, and sector fragmentation (75% of truck operators own <5 trucks). Scaling freight optimisation systems will require widespread adoption of digital freight-matching platforms, real-time GPS and telematics integration, development of freight flow databases and targeted support to improve participation by small and informal fleet operators.
	19. Dedicated truck lanes (DTLs)	Dedicated Truck Lanes (DTLs) are not recommended for Delhi-NCR. While international experience shows DTLs can improve truck speeds and reduce emissions, their implementation in Delhi is constrained by limited road space, competing passenger traffic demands, and significant enforcement and inter-agency coordination requirements. Allocating exclusive road space to freight would likely reduce capacity for general traffic on already congested urban corridors. Instead, priority should be given to measures that optimise the use of existing road infrastructure without permanently dedicating lanes to freight.
	20. Urban consolidation centres (UCCs)	In the long term, UCCs are feasible for Delhi-NCR and offer significant decongestion potential, reducing truck trips by up to 65% and emissions by 70% (as seen in Copenhagen). The Delhi City Logistics Plan (2024 Draft) already proposes 3 peripheral UCCs, and tech components are commercially mature (TRL 7-9). However, integrated UCC deployment remains at TRL 4-5 due to a critical viability gap: high CapEx/OpEx from double-handling costs, land acquisition challenges, and dependence on government subsidies make most UCCs financially unsustainable without sustained public funding. For Delhi, success hinges on designing financially sustainable models (e.g. PPP structures, shared infrastructure costs) alongside the already-supportive policy framework.
	21. Modal shift from road to rail	A limited, DMRC-led metro freight pilot is recommended for short-haul freight movements in Delhi-NCR to assess operational feasibility, infrastructure requirements, and potential emissions and congestion benefits using the existing metro network. However, a conventional road-to-rail freight modal shift for long-haul freight is not recommended , as the region's freight is dominated by short-haul, fragmented movements where rail's operational and economic advantages do not materialise.

Annexure 3(B)

Detailed Global Best Practices for Truck Emission Reduction

China:

China's truck emission strategy is defined by stringent standards, continuous compliance monitoring, and strong local execution, with an explicit focus on real-world emissions. **Top Initiatives:**

1. **Stringent China-VI Emission Standard:** The standard—among the most stringent for heavy vehicles globally—mandates DPFs for all new diesel trucks, continuous emissions reporting (≈10s intervals) via remote OBD, and mandatory PEMS testing for type approval and on-road checks.¹⁵⁰
2. **Strong Subsidies & Operational Incentives:** Between 2015-2022, national subsidies lowered upfront costs for electric and hydrogen trucks. Cities supplemented this with strong operational incentives, e.g., free parking, 24x7 road access, and constructing charging stations against set targets.¹⁵¹
3. **Voluntary Scrappage of High-Polluting Vehicles:** China combined national and local subsidies to accelerate the voluntary retirement of high-polluting diesel trucks. In Beijing alone, over 1,50,000 yellow-label vehicles were scrapped, reducing NOx emissions by ~32 tonnes per day.¹⁵²

USA:

The US model relies on durable standards, post-sale manufacturer accountability, and stable public funding, with California leading implementation. **Top Initiatives:**

1. **Voluntary Fleet Modernisation Program:**¹⁵³ The California-led program covers up to 80% of replacement costs for high-emitting trucks. In its first 7 years, ~7,500 engines were upgraded using USD 170 million, delivering daily reductions of ~24 tonnes NOx and ~1 tonne PM.
2. **Onus on Manufacturers:**¹⁵⁴ In the US, the onus of testing is borne by the manufacturers themselves. Manufacturers have a strong incentive to self-police, as the EPA has authority to require manufacturers to recall vehicles or enforce strict penalties for noncompliance.
3. **Anti-Idling:**¹⁵⁵ Numerous USA states and counties place restrictions on the amount of time that diesel truck drivers can idle their engines. For example, New York City prohibits idling for more than 3 minutes (or 1 minute, if near a school), while California restricts it to less than 5 minutes.

Japan:

Japan's approach centred on strict urban in-use controls, fuel quality enforcement, and early efficiency regulation, supported by strong local-national coordination. **Top Initiatives:**

1. **Ban on Polluting Diesel Trucks:** Starting 2003, diesel trucks that fail local PM standards have been banned in Tokyo; they are instead replaced, converted to clean fuels, or retrofitted with verified and subsidised DOCs/DPFs. Consequently, roadside SPM fell by 20%+ between 2002-04.¹⁵⁶
2. **Crackdown on Adulterated Fuel:** Mixing heavy oil with diesel fuel and kerosene increases PM by 15% and NOx by 7% from diesel vehicles. Over 11,000 inspections and chemical monitoring led by Japan resulted in spurious diesel supply falling from ~14% to ~1% within two years.¹⁵⁷
3. **Stringent Fuel Efficiency Standards:** Japan pioneered mandatory fuel-efficiency standards for commercial trucks using the 'Top Runner' method, where the most efficient model in each class sets future compliance benchmarks.¹⁵⁸

Brazil:

Vehicular emissions are the largest contributor to air pollution in the São Paulo Metropolitan Area (SPMA), to which freight vehicles contribute significantly.¹⁵⁹ **Top Initiatives:**

1. **First 100% e-Freight Transport Corridor:** The e-Dutra corridor—which included stops at strategic charging points along the highway—aims to connect São Paulo to Rio de Janeiro. In September '25, a pilot trip was made covering ~800 km, with an 11-ton e-truck.¹⁶⁰

¹⁵⁰ International Council on Clean Transportation. (2018, July 20). China's Stage VI emission standard for heavy-duty vehicles (policy update). https://theicct.org/wp-content/uploads/2021/06/China_VI_Policy_Update_20180720.pdf

¹⁵¹ Smart Freight Centre. (2023, August). China zero emission freight status report 2022. https://smart-freight-centre-media.s3.amazonaws.com/documents/EN_China_Zero_Emission_Freight_Status_Report_2022_final.pdf

¹⁵² ICCT (2025), ICCT (2013)

¹⁵³ CARB, ICCT (2013)

¹⁵⁴ ICCT (2013)

¹⁵⁵ ICCT (2013)

¹⁵⁶ ICCT (2013)

¹⁵⁷ ICCT (2013)

¹⁵⁸ ICCT (2019)

¹⁵⁹ ICCT: Assessment of Real-World Vehicle Emissions in São Paulo (2025)

¹⁶⁰ C40 (2025)

2. **Enforcement of Euro-VI Equivalent Norms:** The introduction of the PROCONVE norms drove down emissions by setting strict emission limits based on Euro-VI norms.¹⁶¹
3. **Push for Biofuels & Other Fuel Blends:** Brazil has ensured its light trucks are predominantly flex-fuel vehicles (FFVs)—fueled by any mixture of ethanol and gasoline—and heavy trucks must be powered by biodiesel blends. Both ethanol and biodiesel are produced mainly from domestic sugarcane and soybeans, and their use has been widely promoted in Brazil to reduce reliance on fossil fuel imports.¹⁶²

Europe—United Kingdom & Norway:

United Kingdom: The UK model relies on urban access restrictions, targeted capital subsidies, and centrally funded pilots to de-risk zero-emission trucks for operators. Implementation is driven by cities, with national funding support. **Top Initiatives:**

1. **Purchase Subsidies on Electric Trucks:** The Plug-in Truck Grant provides upfront subsidies of up to ~£25,000 per electric HGV (and higher support via trials), directly reducing the price gap between diesel and zero-emission trucks.
2. **Clean Air & Low Emission Zones with Charges:** Cities such as London, Birmingham, and Bristol charge non-compliant diesel trucks daily fees (e.g. £50-£100/day) unless they meet Euro VI standards, creating a strong incentive to upgrade or replace vehicles.
3. **Dedicated Funding for Electric Truck Deployment & Infrastructure:** The UK has committed ~£200 million to fund real-world deployment of battery-electric and hydrogen trucks plus depot charging, covering vehicle costs, infrastructure, and operational learning for fleets.

Norway: Norway's model relies on strong price signals, public procurement, and regulatory access controls, using taxation and local authority powers to make zero-emission trucks economically and operationally preferable. **Top Initiatives:**

1. **Subsidies for Electric Heavy Trucks:** The state agency Enova covers a large share (often 40-60%) of the incremental cost of electric trucks versus diesel, bringing upfront costs within fleet operators' willingness to pay.
2. **Tax & Fee Exemptions for Electric Trucks:** Zero-emission heavy vehicles are exempt from registration tax and VAT and benefit from reduced or zero road tolls, significantly lowering lifetime operating costs compared with diesel trucks.
3. **Legal Authority for Municipal Zero-Emission Zones:** National legislation allows cities (e.g. Oslo) to restrict access to urban areas for fossil-fuel vehicles, enabling local zero-emission zones that directly limit diesel truck operations.

¹⁶¹ ICCT: Assessment of Real-World Vehicle Emissions in São Paulo (2025)

¹⁶² ICCT: Assessment of Real-World Vehicle Emissions in São Paulo (2025)

Annexure 3(C)

Details on OBD Diagnostics

OBD (On-Board Diagnostics) systems are electronic systems within the vehicle that monitor engine and emission parameters via the Engine Control Unit (ECU). They detect malfunction and alert operators via the Malfunction Indicator Lamp (MIL). OBD data can be accessed remotely and near-real time using telematics hardware.

Table 3(C)-1 · Key Components of OBD system

Component	Function
Engine Control Unit (ECU)	Central computer that processes sensor data and manages engine functions.
Sensors	Collect data on various parameters like oxygen levels, temperature, and pressure.
Diagnostic Trouble Codes (DTCs)	Codes stored by the ECU when it detects anomalies, aiding in pinpointing issues.
Malfunction Indicator Lamp (MIL) within Instrument clusters	Dashboard light that alerts drivers to potential issues detected by the ECU.
Diagnostic Link Connector (DLC)	Port that allows external diagnostic tools to interface with the OBD system.

Table 3(C)-2 · Parameters measured by OBD

Category	Parameter	Description	Significance
Emission Control & Exhaust Monitoring	Oxygen (O ₂) Sensors	Measure oxygen levels in exhaust gases before and after the catalytic converter	Assess combustion efficiency and catalytic converter performance
	Nitrogen Oxides (NO _x) Sensors	Monitor NO _x levels in diesel engines	Ensure compliance with emission standards
	Particulate Matter (PM) Sensors	Detect soot levels in exhaust gases	Monitor diesel particulate filter (DPF) efficiency
	Exhaust Gas Recirculation (EGR) System	Monitors the EGR system's operation	Reduces NO _x emissions by recirculating a portion of exhaust gases back to the engine
	Evaporative Emission Control System	Detects leaks or malfunctions in the fuel vapor containment system	Prevents release of fuel vapors into the atmosphere

Category	Parameter	Description	Significance
Engine Performance & Combustion Control	Engine Coolant Temperature	Measures the temperature of the engine coolant	Prevent engine overheating and optimize performance
	Fuel System Status	Monitors fuel system operation	Detect issues like fuel pressure anomalies or injector malfunctions
	Throttle Position Sensor	Measures the position of the throttle valve	Determine engine load and driver demand
	Mass Air Flow (MAF) Sensor	Measures the amount of air entering the engine	Calculate proper fuel injection for optimal combustion
	Manifold Absolute Pressure (MAP) Sensor	Measures pressure within the intake manifold	Assess engine load and adjust fuel delivery
	Engine Coolant Temperature	Measures the temperature of the engine coolant	Prevent engine overheating and optimize performance
Driving and Motion Sensors	Vehicle Speed Sensor	Tracks the speed of the vehicle	Aid in transmission control and cruise control functionality
	Crankshaft Position Sensor	Monitors the position and rotational speed of the crankshaft	Essential for ignition timing and fuel injection sequencing
	Camshaft Position Sensor	Monitors the position of the camshaft	Coordinates valve timing with ignition and fuel injection

Annexure 3(D)

Details on Aftertreatment Technologies

Table 3(D) · Aftertreatment technologies for truck emission control

Technology	Pollutants Targeted	Typical Use Case	Emission Reduction	Cost Range (INR)	Comments
SCR (Selective Catalytic Reduction)	NOx	Diesel, CNG trucks	70-95%	~₹1.5-2.5 lakh	Needs AdBlue, optimal at high temp
DPF (Diesel Particulate Filter)	PM	Diesel trucks	50-90%	~₹1.2-3 lakh	Requires regeneration, needs ECU/OBD
DOC (Diesel Oxidation Catalyst)	CO, HC, PM (partial)	Diesel trucks	30-50% (PM)	~₹80,000-1 lakh	Paired with PPF for better performance
EGR (Exhaust Gas Recirculation)	NOx	Diesel trucks	30-60%	~₹50,000-1 lakh	Comes pre-fitted in BS-VI vehicles
LNT (Lean NOx Trap)	NOx	Select diesel light-duty	40-60%	Not widely used	Used in combo with SCR/EGR
DOC + PPF Combo	PM	Older diesel trucks	50-60%	~₹80,000-1 lakh	Ideal for BS-III and earlier

Note: EV retrofitment kits also exist; however, these are still in nascent, experimental stages and hence have been omitted from this comparison.

Annexure 3(E)

Details on Emission Reduction Potential Calculation in Roadmap

Scenario 1:

In Scenario 1, emission reductions are estimated through a sequential application of three strategies: electrification, Urban Consolidation Centres (UCCs), and reduction in empty backhaul trips applied across the freight vehicle fleet. The electrification strategy is implemented in a phased manner, beginning with 2-axle and 3-axle trucks during the initial years (2027, 2028, and 2030), and subsequently expanding to cover all truck categories in the later years. This phased rollout reflects realistic constraints related to technology adoption and infrastructure readiness.

Following the electrification step, the remaining fleet i.e, vehicles not transitioned to electric is subjected to the UCC strategy. In this scenario, the UCC system is assumed to operate entirely using EVs. for last-mile freight distribution. The UCC intervention is applied uniformly across the residual fleet, assuming consolidation of freight movement and reduction in the number of trips through improved logistics efficiency. This ensures that the emission reduction from UCCs is calculated on the post-electrification baseline rather than the total fleet. Subsequently, the reduction in empty backhaul trips is applied to the vehicles remaining after both electrification and UCC implementation. This strategy targets operational inefficiencies and is assumed to affect 51% of the applicable fleet, representing the share of trips that typically occur without load. The resulting emission reductions are therefore estimated based on a reduction in vehicle kilometers traveled for this subset of freight movement.

Scenario 2:

In Scenario 2, emission reductions are estimated through a more stringent and front-loaded sequence of interventions, beginning with the implementation of a regulatory ban on selected vehicle categories. This initial step directly removes a portion of the most polluting vehicles from the fleet, resulting in an immediate reduction in baseline emissions.

Following the ban, the UCC strategy is applied across all remaining vehicle categories. In contrast to Scenario 1, the UCC system in this scenario is assumed to operate using a mixed fleet comprising 50% CNG vehicles and 50% EVs. This reflects a transitional pathway where cleaner conventional fuels coexist with electric mobility. The UCC intervention reduces the number of trips and improves load efficiency, and its impact is calculated on the post-ban fleet to ensure consistency in emission accounting.

Subsequently, the reduction in empty backhaul trips is applied to 51% of the remaining fleet, representing the proportion of trips typically undertaken without load. This step captures additional emission savings through improved logistical efficiency and reduced vehicle kilometers traveled and is applied after accounting for both the ban and UCC impacts.

Finally, a phase-out strategy is implemented on the residual fleet that remains after all prior interventions. This represents the gradual removal or replacement of the remaining conventional vehicles, leading to further emission reductions over time. Overall, the methodology follows a hierarchical and non-overlapping approach, where each strategy is applied sequentially to the remaining emission base. This avoids double counting of reductions and ensures a realistic estimation of the combined impact of multiple interventions.

Annexure 3(F)

Details on Emission Reduction Potential Calculation of Individual Strategies

This annexure describes the methodology and assumptions used to estimate emission reduction from individual implementation of strategies considered in the report. Unlike in the roadmap analysis, the same baseline is considered here for each strategy.

Strategy I: Shift to Electric Trucks

I. Targeted Segments:

In the initial phase, electrification is applied to 2-axle and 3-axle trucks, which together account for ~76% of total truck entries. In the long term, electrification expands to include 4+ axle trucks, covering the entire fleet.

II. Key Assumptions:

1. For calculation of the baseline, base year emissions are taken from the emission inventory. Next, a 6.5% annual growth rate is applied to: number of trucks & corresponding emissions. This results in year-wise projected emissions (BAU) for 2027, 2028, 2030, 2032, and 2035.
2. Electric trucks are assumed to produce zero tailpipe emissions. Therefore, emissions from diesel trucks that are electrified are considered fully eliminated.
3. Emission reduction is applied only to: share of trucks electrified and the truck categories included in each phase.
4. No change in trip length or freight demand patterns
5. Upstream emissions from electricity are not included

III. Targets:

In the short term (2027-2030), electrification is applied to 2-axle and 3-axle trucks, which dominate truck entries and are more suitable for short-haul operations. In the long term (post-2030), electrification expands to include 4+ axle trucks, as technology and infrastructure improve. The following cumulative electrification targets are applied:

Year	Target
2027	10%
2028	15%
2030	30%
2032	50%
2035	100%

IV. Methodology

1. Project future emissions using 6.5% growth rate.
2. Apply electrification targets for each year.
3. Restrict electrification to 2- and 3-axle trucks in early years, and expand later.
4. Estimate emissions avoided from electrified trucks.
5. Aggregate reductions across all truck categories.
6. Calculate percentage reduction with respect to BAU emissions for that year.

V. Limitations:

- 1.Upstream emissions emitted (like electricity generation etc.) are not considered
- 2.Adoption barriers (financing, behaviour) are not explicitly modelled
- 3.Uniform adoption assumed within each truck category

Strategy II: Ban on Entry of Pre-BS-VI Trucks

I. Targeted Segments:

This strategy targets pre-BS-VI trucks only (~38% of total entries). It assumes restriction through a Low Emission Zone (LEZ) by allowing only: BS-VI trucks (CNG & Diesel), Electric trucks and other low-emission vehicles (e.g. hydrogen fuel vehicles).

II. Key Assumptions:

- 1.For the calculation of the baseline, base-year emissions are taken from the emission inventory. Next, a 6.5% annual growth rate is applied to: number of trucks & corresponding emissions. This results in year-wise projected emissions (BAU) for 2027 (when the ban will be applied).
- 2.Emissions from restricted pre-BS-VI trucks are fully eliminated within Delhi boundary. Full compliance with LEZ restrictions in 2027.
- 3.No change in freight demand.
- 4.Replacement vehicles assumed to meet BS-VI or cleaner standards.

III. Targets:

The following cumulative targets are applied:

Year	Target
2027	15%

IV. Methodology:

- 1.Project 2027 emissions using 6.5% growth rate
- 2.Identify emissions attributable to pre-BS-VI trucks and remove based on 100% restriction
- 3.Calculate total reduction as % of BAU emissions

Strategy III: Phase out Trucks Based on Fitness Criteria

I. Targeted Segments:

This strategy applies to the entire fleet. OBD-based diagnostics are applicable to BS-VI trucks.

II. Key Assumptions:

- 1.For calculation of the baseline, base year emissions are taken from the emission inventory. Next, a 6.5% annual growth rate is applied to: number of trucks & corresponding emissions. This results in year-wise projected emissions (BAU).
- 2.High-emitting trucks identified through: PM2.5 and NOx-based testing, OBD diagnostics (for BS-VI vehicles) and ATS-based inspection.
- 3.Phase-out assumed as: removal of non-compliant vehicles from operation and replacement with compliant vehicles (BS-VI or cleaner).
- 4.Full compliance with phase-out requirements
- 5.No change in freight demand

III. Targets:

Targets represent the share of high-emitting trucks identified and phased out each year. The targets are applied on a year-wise basis, i.e., the percentage represents the share of high-emitting trucks phased out from the active fleet in that year. Higher targets are assumed during the initial years as a larger share of non-compliant vehicles is expected to be identified early, while targets reduce over time as the fleet progressively becomes cleaner.

Year	Year
2028	20%
2030	10%
2032-2035	5%

IV. Methodology:

1. Project emissions using 6.5% growth rate
2. Estimate emissions attributable to the pre-BS-VI truck fleet based on the assumed phase-out target.
3. Remove emissions corresponding to the phased-out truck fleet from projected BAU emissions.
4. Calculate total reduction as % of BAU emissions

Strategy IV: Stricter Enforcement via Payload Sensors & ANPR cameras:

This strategy's emission reduction potential was not modelled.

Strategy V: Reduction in Trips via Optimising Empty Backhauls

I. Scope:

This strategy applies to empty truck movements (backhauls). They account for ~23% of inbound trucks and ~51% of outbound trucks.

II. Key Assumptions:

1. For calculation of the baseline, base year emissions are taken from the emission inventory. Next, a 6.5% annual growth rate is applied to: number of trucks & corresponding emissions. This results in year-wise projected emissions (BAU) for 2027, 2028, 2030, 2032, and 2035.
2. Emissions are assumed to be proportional to vehicle kilometres travelled (VKT). Therefore, emission reduction is calculated based on the portion of VKT eliminated due to reduced empty trips.
3. Reduction in empty trips does not affect freight demand.
4. Loaded trips remain unchanged.
5. Adoption of optimisation platforms increases over time.

III. Targets:

Target

Targets represent reduction in empty backhaul trips.

Year	Target
2027	20%
2028	30%
2030	50%

IV. Methodology:

1. Estimate share of emissions attributable to empty trips within total freight movement activity
2. Apply target reduction to empty trips
3. Translate reduction in empty-trip VKT into avoided fuel consumption and emissions.
4. Calculate total reduction as % of BAU emissions.

Strategy VI: Urban Freight Optimisation through UCCs with Cleaner Trucking

I. Targeted Segments:

This strategy applies across all freight categories, including both perishable and non-perishable goods. However, implementation is expected to begin with freight segments that are operationally more suitable for consolidation and scheduled deliveries through UCC systems, before scaling across wider freight movements. The strategy combines reduction in freight trips (via UCCs) with deployment of cleaner last-mile vehicles (CNG / LEVs).

II. Key Assumptions:

1. For calculation of the baseline, base year emissions are taken from the emission inventory. Next, a 6.5% annual growth rate is applied to: number of trucks & corresponding emissions. This results in year-wise projected emissions (BAU)
2. UCCs reduce emissions via reduction in redundant trips through consolidation of loads, reduction in number of trips (VKT) and cleaner vehicles (CNG / LEV) used for last-mile delivery.
3. No change in overall freight demand

III. Targets:

Targets represent share of freight trips optimised through UCCs

Year	Target
2027	15%
2028	30%
2030	60%
2032	100%

IV. Methodology:

1. Apply target and estimate share of freight trips covered under the Urban Consolidation Centre (UCC) system, initially limited to the non-perishable goods segment (~54%).
2. Estimate reduction in vehicle kilometres travelled (VKT) resulting from consolidation.
3. Apply lower emission factors to remaining last-mile trips shifted to CNG and low-emission vehicles (LEVs), relative to diesel trucks.
4. Combine emissions avoided from reduced freight activity and lower emission factors of cleaner last-mile vehicles.
5. Project BAU emissions using a 6.5% growth rate and calculate total reduction as % of BAU emissions.

Strategy VII: Retrofitment of Pre-BS-VI Trucks with PM & NOx Control

I. Targeted Segments:

This strategy targets pre-BS-VI diesel and CNG trucks (~38% of entries). It considered three retrofit technologies:

1. Diesel Particulate Filter (DPF) for BS-IV diesel trucks)
2. Selective Catalytic Reduction (SCR) for CNG trucks
3. Diesel Oxidation Catalyst (DoC) + Partial Flow Filter (PPF) for pre-BS-VI trucks

II. Key Assumption

1. For calculation of the baseline, base year emissions are taken from the emission inventory. Next, a 6.5% annual growth rate is applied to: number of trucks & corresponding emissions. This results in year-wise projected emissions (BAU).
2. Retrofit technologies perform as per indicative efficiency
3. No change in vehicle activity or trip patterns
4. Full compliance assumed for installed systems
5. Retrofitment assumed to reduce emissions from existing vehicles, not remove them
6. No significant impact assumed on: CO emissions and CO₂ emissions

III. Target:

No cumulative adoption trajectory defined. It has been assessed as a one-time indicative intervention (2027).

IV. Methodology:

1. Identify share of emissions attributable to pre-BS-VI trucks eligible for retrofit technologies.

2. Apply technology-specific emission reduction factors at the vehicle level for relevant pollutants.

Indicative reductions used:

a. DPF → PM_{2.5} reduction (~17%)

b. SCR → NO_x reduction (~9%)

c. DoC + PPF → PM_{2.5} reduction (~11%)

3. Estimate avoided emissions as partial reductions in exhaust emissions from retrofitted vehicles

4. Project BAU emissions using a 6.5% growth rate and calculate total reduction as % of BAU emissions.

**Air Pollution Action Group (A-PAG)**

Established in 2019, A-PAG works to bridge the gap between air quality policy and implementation. The organisation supports governments in translating research and policy into effective on-ground action through embedded Project Management Units (PMUs), targeted programmes, and practical tools aimed at reducing emissions from key pollution sources and strengthening implementation system

**Indian Institute of Technology Delhi (IIT Delhi)**

Established in 1961, IIT Delhi is one of India's premier institutions for higher education, research, and innovation in science, engineering, and technology. The contributors for this study are the Transportation Research and Injury Prevention Centre (TRIPC) and the Aerosol Research and Characterisation Lab at IIT Delhi (ARCID).

**The Energy and Resources Institute (TERI)**

TERI is an independent, non-profit research institute working to advance sustainable development through research, policy analysis, and capacity building in the fields of energy, environment, and climate change. Founded in 1974, TERI is widely recognised as one of India's leading sustainability think tanks.