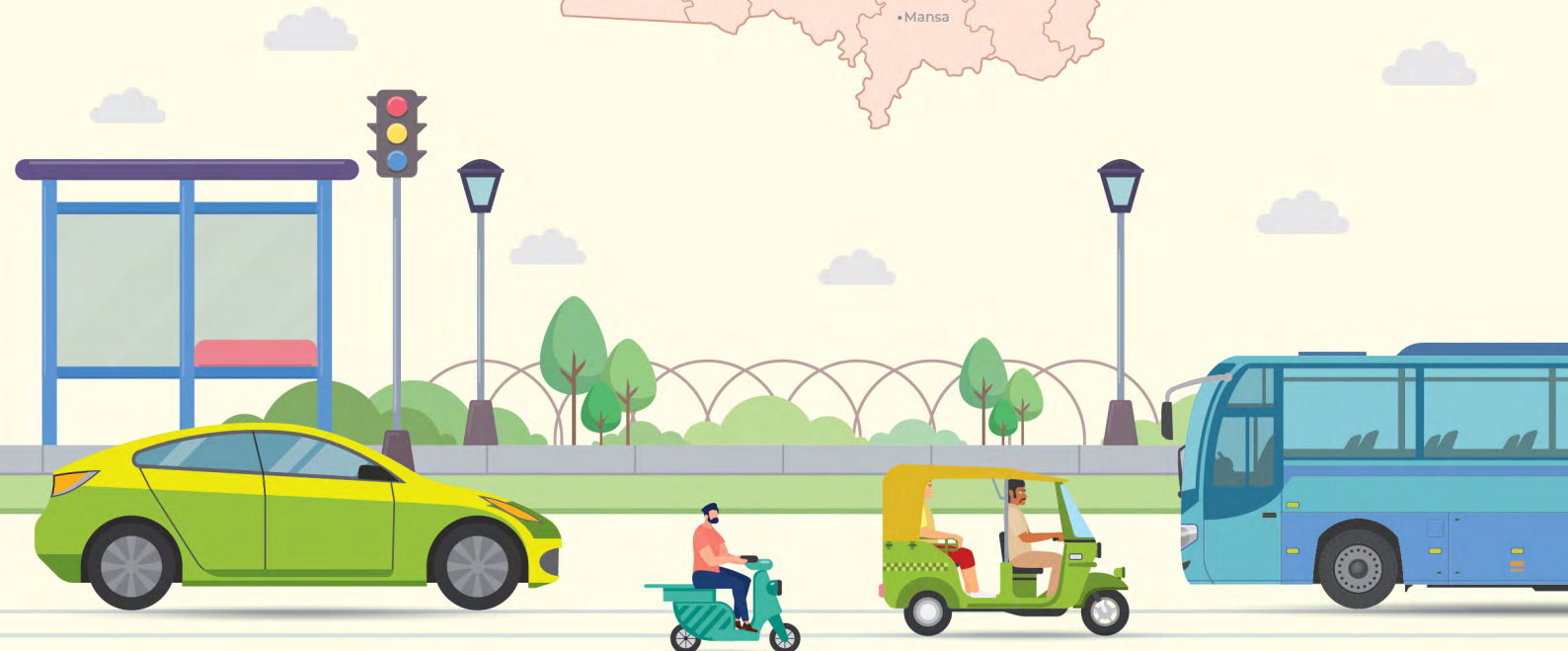


Pathways for Clean Transportation in Punjab



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Executive Summary

Punjab has undertaken several policy initiatives and programmes to improve air quality. Building on these efforts, strengthening action on the transport sector presents an important opportunity to achieve further reductions in air pollution across the state. Transport emissions contribute substantially to $PM_{2.5}$ levels, even in districts without designated non-attainment cities under the National Clean Air Programme (NCAP). This study analysed Punjab's vehicular fleet and its emission profile using category-wise, district-wise, and Bharat Stage (BS)-wise estimates. This report particularly focuses on the role of super-emitters (SEs) owing to their higher emission factors (typically 4–11 times those of non-super-emitters). While the category-wise distribution was based on data from the Vahan dashboard, age-wise and district-wise analyses were carried out for selected districts using primary surveys.

Our analysis showed that across Punjab's vehicle fleet, two-wheelers, three-wheelers (3Ws), and four-wheelers dominate numerically, but their relative contributions to total emissions are smaller. Although freight vehicles, particularly heavy commercial vehicles (HCVs), comprise only 1%–2% of the total registered fleet, they account for a disproportionate share of vehicular emissions owing to their reliance on diesel and high emission factors. Further, despite representing only a fraction of the fleet, SEs constitute a disproportionately large share of total emissions in nearly all districts, frequently contributing more than half of $PM_{2.5}$ levels.

The age-wise distribution of vehicles plying on road based on ground survey data showed that vehicles aged 10–15 years continue to ply across categories, especially among 3Ws and the commercial fleet (HCVs and light commercial vehicles), extending their operational lifespan and emission impact.

Surveys conducted across six districts (Patiala, Ludhiana, Amritsar, Jalandhar, Moga, and Hoshiarpur) showed that the majority of vehicles (89%) plying on road were registered in Punjab, indicating that a strong state-level regulatory framework could significantly reduce transport emissions. However, among HCVs, the share of out-of-state registrations was significant (28%). The survey findings also showed major cross-district vehicle movement within Punjab, suggesting that the current city-specific approach, as enshrined in the NCAP, may not be best suited to addressing the problem.

Under the current situation, Punjab's on-road fleet is expected to continue to expand through 2035; however, depending on the number of BS III vehicles plying (along with BS IV and BS VI), the total $PM_{2.5}$ emissions are projected to decline by 30%–66% from 2024 to 2035, reflecting the penetration of cleaner BS-VI vehicles and the steady uptake of electric vehicles (EVs). Yet, despite cleaner technology adoption lowering the current BAU emissions, the load remains SE-heavy across all years, accounting for the majority of $PM_{2.5}$ in 2024, 2030, and 2035. While the traffic police are currently empowered to penalise visibly polluting vehicles, a more scientific and data-driven mechanism should be institutionalised for detecting and managing SEs.

Key barriers

- Lack of formal definition and policy framework for SEs
- Lack of regulatory mechanisms to monitor and control non-road diesel emissions from agricultural vehicles
- Limited policy instruments and physical infrastructure for scrappage and retrofitting
- High upfront costs for EVs and alternative-fuel (compressed natural gas [CNG]/liquefied natural gas [LNG]) vehicles
- Over-reliance on road freight
- Fragmented institutional responsibilities among departments and local bodies

Strategic priorities and actions

Priority	Key actions	Expected impacts
Target super-emitters	◦ Deploy remote sensing technology or similar pilots to identify on-road super emitters. This has been tested in Europe and Kolkata, along with pilot studies in Delhi NCR. ◦ Mandate periodic in-use testing and build more Automated Testing Stations (ATSS). ◦ Mandatory 6-month testing of heavy commercial vehicles (HCVs) and light commercial vehicles (LCVs) at ATSS.	With an estimated cost of INR 2 crore per setup, installing remote sensing units at major entry and exit points of cities and industrial corridors and linking them with the vehicle registration portal could significantly reduce the regional PM _{2.5} load.
Mandatory scrappage of super-emitters (SEs) and end-of-life vehicles	◦ Mandatory retirement of poorly maintained vehicles that fail testing or are identified as SEs from remote sensing studies. These could include older LCVs and HCVs, as well as two-wheelers (2Ws) and four-wheelers (4Ws) aged over 15 years. ◦ Punjab has approximately 3 lakh vehicles that may qualify for scrappage, for which the state requires 15 operational registered vehicle scrapping facilities (RVSFs). ◦ With only five operational RVSFs in the state, an investment of about INR 140 crore would be needed to build 10 more RVSFs. ◦ Scrappage incentives should be linked with low-emission zone (LEZ) and electric vehicle (EV) schemes.	◦ Accelerated fleet renewal ◦ Tailpipe emission reduction by 100%, if scrapped vehicles are replaced by EVs or not replaced at all ◦ If replaced by BS-VI diesel vehicles, PM emission reduction is estimated to be 70%
Promote retrofitting	◦ Subsidise installation of partial flow filters (PFFs) and selective catalytic reduction (SCR) systems in BS-IV HCVs. Retrofitting with PFFs and diesel oxidation catalysts (DOCs) is estimated to cost around INR 50,000 per vehicle.	PFFs have the potential to reduce PM emissions by 55%–65%, and SCR systems are effective in reducing nitrogen oxides (NO _x) by up to 90%.

Priority	Key actions	Expected impacts
Promote retrofitting	◦ Mandate certification standards for retrofit kits. ◦ Provide financial incentives such as subsidies, reduce tolls, or lower road taxes to accelerate uptake.	
Increase the uptake of cleaner fleets	◦ Promote EVs among 2Ws, 3Ws, 4Ws, and city buses; fasten the adoption of BS6 and vehicles with stricter emission standards; expand compressed natural gas (CNG) networks; and pilot liquefied natural gas (LNG) corridors for freight.	Transition to a cleaner fleet and reduction in diesel dependence
Promote modal shift to railways	◦ Strengthen freight corridors and inter-modal hubs. ◦ Develop public-private partnership-based terminals that will introduce cost-sharing models ◦ Enable multi-commodity transport	◦ Significant reduction in diesel truck traffic ◦ Aggregation models that allow small-scale and multiple commodity consignments in a single train will enhance utilisation and reduce logistics costs.

Policy recommendations

- Develop a state-level policy for Punjab's transport sector with emission reduction strategies that prioritise high-emitting freight segments, SEs, and non-road diesel emissions.
- Institutionalise real-time emission monitoring and remote sensing for detecting and repairing SEs.
- Create financial incentives for fleet transition to EVs, CNG, or LNG, especially in freight and last-mile delivery segments.
- Establish regulatory provisions for low-emission zones (LEZs) and integrate enforcement through the digital infrastructure.
- Scale up scrappage and retrofitting infrastructure and mandate scrappage for persistent polluters (older and poorly maintained vehicles that repeatedly fail the PUC certification and other fitness tests).
- Facilitate public-private partnerships for alternative fuel adoption.
- Strengthen inter-agency coordination among transport, industry, and urban local bodies for clean mobility planning.

Conclusion

A cleaner transport future in Punjab will require a combination of data-driven regulation, targeted interventions, and infrastructure investment. With over 89% of vehicles being locally registered, state-level enforcement of age-based retirement, LEZs, and retrofitting of BS-IV HCVs can yield substantial emission reductions. Complementary efforts, such as fleet electrification, CNG/LNG corridor development, and strong institutional collaboration, will be essential to sustain air quality improvements and accelerate Punjab's clean transport transition.

Table of Contents

- 1. Introduction..... 15
- 2. Transport-Related PM_{2.5} Emissions in Punjab 17
- 3. Ground Survey Observations..... 25
- 4. Current Policy Instruments..... 28
- 5. Future Projections 30
 - 5.1. Comparison of total emissions and fleet size: SEs vs NSEs (2024–2035) 30
 - 5.2. Scenarios for emission reduction 32
- 6. Recommendations..... 35
 - 6.1. Removal of older vehicles and replacement with cleaner alternatives 35
 - 6.2. Removal of SEs 40
 - 6.3. Establishing LEZs 41
 - 6.4. Modal share shift 42
- 7. MEL Framework for Implementation..... 43
- 8. Conclusion..... 46
- 9. References..... 47
- 10. Appendices..... 50

List of Figures

Figure 1: EDGAR-HTAP (2019) emission inventories for Punjab	15
Figure 2: Percentage share of the transport sector in PM _{2.5} emissions in non-attainment cities in Punjab (Source: PRANA Portal).....	16
Figure 3: Year-wise vehicle fleet estimated using survival fraction (SF), plotted against year-wise registration data for Punjab.....	17
Figure 4: PM _{2.5} emissions from different vehicle classes using the survival fraction for Punjab.....	18
Figure 5: Percentage share of super-emitters and non-super-emitters in category-wise vehicle fleet and their emissions.....	18
Figure 6: District-wise emission and fleet share of super-emitters and non-super-emitters	21
Figure 7: Top five districts with the highest PM _{2.5} emissions from farm vehicles	23
Figure 8: (a) Fleet distribution percentage and (b) PM _{2.5} emission contribution share by TREM standards for agricultural vehicles in Punjab (2024)	23
Figure 9: Agricultural tractor operating in Punjab (stock image)	24
Figure 10: Distribution of vehicle registrations based on survey data.....	25
Figure 11: Distribution of surveyed vehicles based on registration data	26
Figure 12: Percentage share of vehicles registered in and outside the surveyed districts in Punjab.....	26
Figure 13: Comparison of survival fractions (SFs) of heavy commercial vehicles in Ludhiana based on the literature and survey data (surv _l = literature-based SF used in the study).....	27
Figure 14: Comparison of survival fractions (SFs) of three-wheelers in Punjab based on the literature and survey data (surv _l = literature-based SF used in the study).....	27
Figure 15: Comparison of total emissions and fleet size: Super-emitters vs non-super-emitters (2024–2035).....	30
Figure 16: Four-wheeler emissions and fleet size (2024–2035)	31
Figure 17: Heavy commercial vehicle emissions and fleet size (2024–2035)	31
Figure 18: Percentage share of (a) vehicles by category and (b) their PM _{2.5} emissions in 2024 using the survival fraction for Chandigarh (including super-emitters).....	33
Figure 19: Percentage share of (a) fuel penetration as per vehicle category and (b) their PM _{2.5} emissions (including SEs and NSEs) for Chandigarh (2024)	34
Figure 20: Percentage share of fuel types in Punjab (2024).....	39
Figure B1: (a) BS-wise fleet share and (b) their emission share in Punjab for 2024 (including SEs).....	55
Figure B2: District-wise % share of SE and NSE in (a) the total vehicle fleet and (b) their PM _{2.5} emissions for 2024.....	56
Figure B3: District-wise PM _{2.5} emissions (%) of SE and NSE in (a) 4W and (b) HCVs fleet for 2024	56
Figure B4: District-wise % share of SE and NSE in (a) the total vehicle fleet and (b) their PM _{2.5} emissions projected for 2030.....	57

Figure B5: District-wise PM _{2.5} emissions (%) of SE and NSE in (a) 4Ws and (b) HCVs fleet for 2030	57
Figure B6: District-wise % share of SE and NSE in (a) the total vehicle fleet and (b) their PM _{2.5} emissions (%) projected for 2035	58
Figure B7: District-wise PM _{2.5} emissions (%) of SE and NSE in (a) 4Ws and (b) HCVs fleet for 2035.....	58
Figure B8: Two wheelers' emissions and fleet size (2024–2035)	59
Figure B9: PM _{2.5} emissions share from agricultural vehicles in Punjab for 2024.....	60
Figure C1: Survey locations in Punjab	61
Figure C2: Comparison of survival fractions (SFs) based on the literature and survey data for HCVs in Punjab (surv1 = literature-based SF used in the study)	63

List of Tables

Table 1: Year-wise breakdown of super-emitter (SE) heavy commercial vehicles (HCVs)	19
Table 2: Overview of existing state- and national-level policies for transport-related emission reduction	28
Table 3: Emission reduction potential under the high-adoption scenario	32
Table 4: Projected percentage share of replacement vehicles for 2030 and 2035	36
Table 5: Comparison of the total cost of ownership for different vehicle categories	38
Table 6: Proposed Monitoring, Evaluation, and Learning Framework	44
Table A1: Bharat Stage-I emission factors	51
Table A2: Bharat Stage-II emission factors	52
Table A3: Bharat Stage-III emission factors	52
Table A4: Bharat Stage-IV emission factors	53
Table A5: Bharat Stage-VI emission factors	53
Table C1: Summary of survey logistics (location, sample size, and dates of survey)	61
Table C2: Toll booth survey form and fuel pump survey form	63
Table D1: Details of existing policies	64
Table E1: Scenario table for lower and medium targets	68
Table F1: General details used in TCO calculations across different vehicle categories	70

Abbreviations

2W	Two-wheeler
3W	Three-wheeler
4W	Four-wheeler
ARAI	Automotive Research Association of India
ATS	Automated testing station
BAU	Business-as-usual
BC	Black carbon
BS	Bharat Stage
CNG	Compressed natural gas
EDGAR-HTAP	Emissions Database for Global Atmospheric Research – Hemispheric Transport of Air Pollution
ELV	End-of-life vehicle
EV	Electric vehicle
FAME	Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles
HCV	Heavy commercial vehicle
LCV	Light commercial vehicle
MEL	Monitoring, Evaluation, and Learning
NAC	Non-attainment city
NCAP	National Clean Air Programme
NO _x	Nitrogen oxides
NSE	Non-super emitter
PM ₁₀	Particulate matter with a diameter of 10 microns or less
PM _{2.5}	Particulate matter with a diameter of 2.5 microns or less
RAAHI	Rejuvenation of Auto-rickshaws in Amritsar through Holistic Intervention
SATAT	Sustainable Alternative Towards Affordable Transportation
SE	Super-emitter
SF	Survival fraction
SO ₂	Sulphur dioxide
TCO	Total cost of ownership
VKT	Vehicle kilometres travelled



1. Introduction

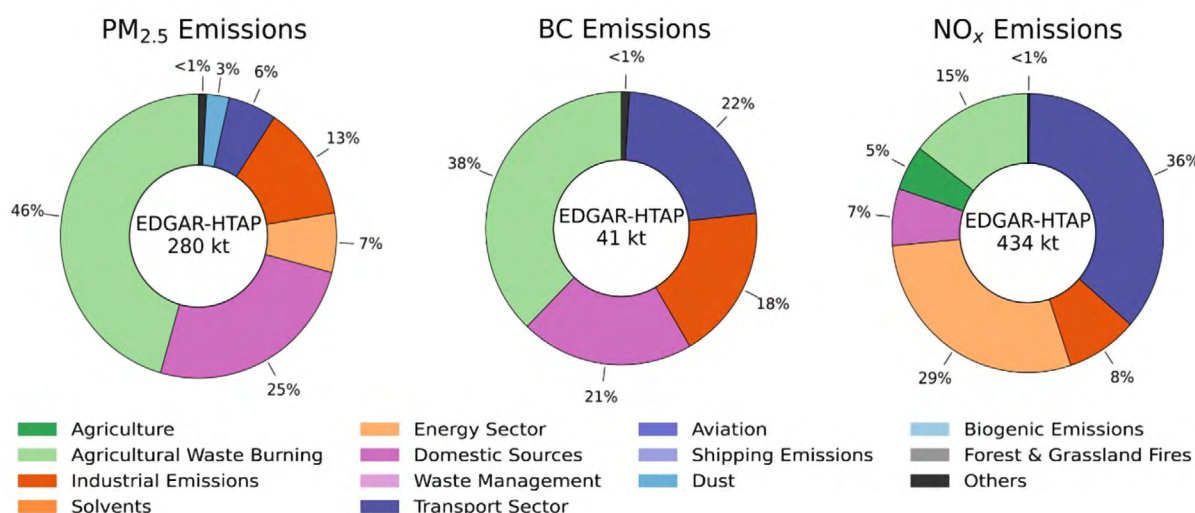
Punjab, traditionally an agrarian state, has undergone rapid industrialisation and urbanisation. Having played a predominant role in India's Green Revolution, the state is also a leading producer of wheat and paddy in India. It is among the most industrially advanced states in the country, with its small-scale industries manufacturing a wide range of products, including bicycles and their components, sewing machines, hand tools, machine tools, auto parts, electronic devices, sports equipment, surgical instruments, and textiles. The movement of these agricultural outputs and manufactured goods relies heavily on inland road transport, making it central to the smooth functioning of the two major economic drivers in the state—agriculture and industry. However, the expansion of transport activity has led to increasing vehicular emissions, which contribute significantly to ambient air pollution.

In 2019, the National Clean Air Programme (NCAP) was launched by the Ministry of Environment, Forest and Climate Change of India, Government of India, to improve air quality in 131 non-attainment cities (NACs). In Punjab, nine cities across eight districts were designated as NACs. For most of these cities, the findings of source apportionment studies for particulate matter (PM) are available on the Portal for Regulation of Air-Pollution in Non-Attainment cities (PRANA), a portal for managing and monitoring the implementation of NCAP.

While source apportionment studies are primarily focused on cities, the vehicular movement between cities, along with the extensive use of farm vehicles that run on diesel, extends the pollution well beyond NAC boundaries. Therefore, focusing solely on NACs may fail to capture the full scope of the problem, necessitating state-level interventions for tackling air pollution.

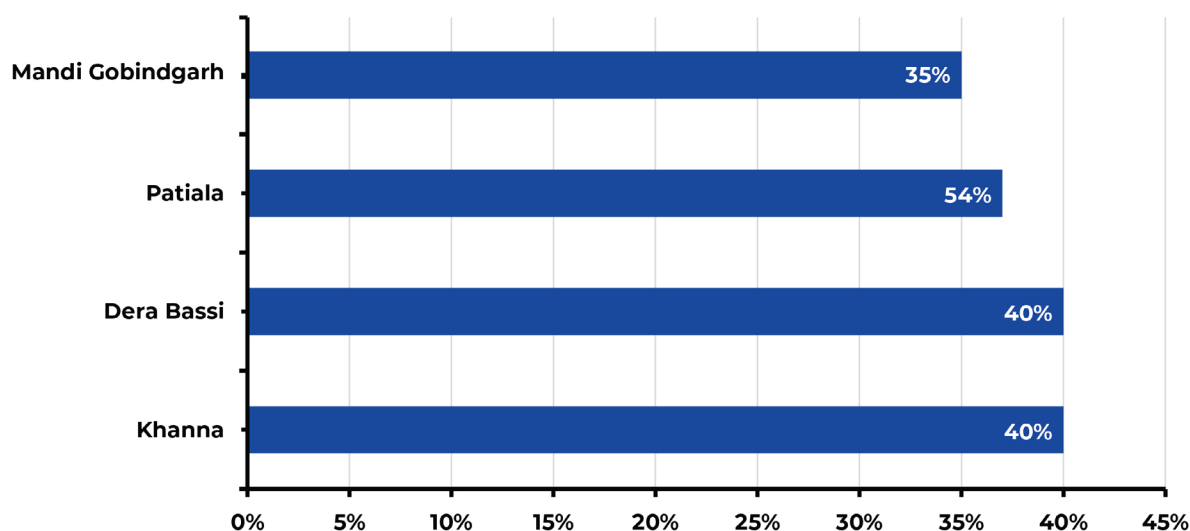
This becomes evident when comparing different emission datasets at the global and city levels. The Emissions Database for Global Atmospheric Research-Hemispheric Transport of Air Pollution (EDGAR-HTAP) provides a broad overview of sectoral emissions covering PM_{2.5}, black carbon (BC), and nitrogen oxides (NO_x) in Punjab, in which transport appears to be a relatively minor contributor compared with agriculture, domestic, and energy sectors (Figure 1).

Figure 1: EDGAR-HTAP (2019) emission inventories for Punjab



However, city-level source apportionment studies available on the PRANA portal reveal a contrasting trend, with vehicular $PM_{2.5}$ emissions contributing over 30%–50% in most NACs in Punjab (Figure 2). This disparity underscores the limitations of global emission inventories in capturing local conditions and highlights the need for state-specific and high-resolution assessments that reflect Punjab’s actual fleet characteristics, fuel use, and operating patterns. Building on such assessments, Punjab can adopt coordinated, statewide measures that address the combined impact of freight, passenger, and farm vehicles in an integrated manner.

Figure 2: Percentage share of the transport sector in $PM_{2.5}$ emissions in non-attainment cities in Punjab
(Source: PRANA Portal)



Our study aimed to develop a comprehensive understanding of Punjab’s transport emissions and identify priority areas for effective, state-wide mitigation. This report analyses Punjab’s vehicular fleet and its emission profile using category-wise, district-wise, and Bharat Stage (BS)-wise estimates, explicitly accounting for the role of super-emitters (SEs). It provides comparative insights on registered and actual on-road fleets, highlights the contribution of freight vehicles and SEs, and projects future emission trajectories under a business-as-usual (BAU) pathway to 2035. The study demonstrates why NAC-focused plans fall short and argues for a state-wide transport emission reduction strategy that prioritises high-emitting freight segments and SEs. Thus, this study offers the first comprehensive, statewide, bottom-up assessment of Punjab’s transport emissions, integrating district-level fleet characterisation, BS-wise profiling, and explicit SE accounting to establish the evidence base for a coordinated, statewide mitigation strategy.

Super-emitters (SEs) release significantly higher levels of pollutants than other vehicles in a fleet because of factors such as old age, excessive vehicle use, overloading, poor maintenance, or a combination of these (Debbarma et al., 2024). In the current study, all vehicles older than 15 years and 17% of vehicles below 15 years of age (Prakash et al., 2020) were categorised as SEs

2. Transport-Related PM_{2.5} Emissions in Punjab

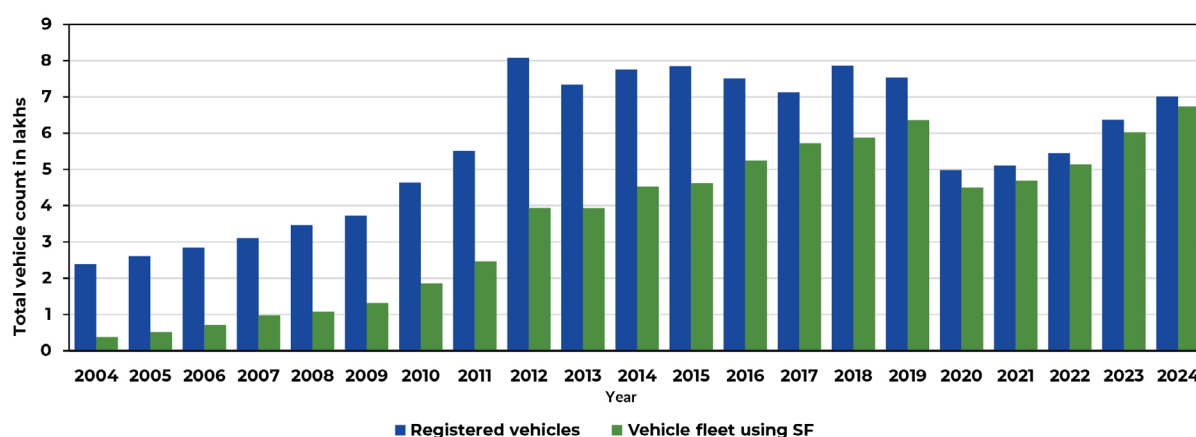
Emissions were estimated using vehicle registration data from 2002 to 2024 from the Vahan Dashboard (Ministry of Road Transport & Highways, Government of India, n.d.). Although this provided a cumulative number, not all vehicles continue to ply on the road throughout their registered lifetime. Moreover, retired vehicles are rarely deregistered, and often, a vehicle is sold and registered in another state.

Because the number of vehicles plying on the road progressively reduces with age, an age-dependent function called survival fraction was used. It represents the probability of a vehicle remaining in use as a function of its age and is therefore critical to derive the on-road active fleet from the registration database (Guttikunda, 2024). The survival function typically shows a decreasing trend; as vehicles get older, the survival fraction goes down (Hao et al., 2011).

In this study, emissions were estimated based on the number of vehicles plying on the road, after applying a survival fraction (Pandey & Venkataraman, 2014) to the vehicle registration data, fuel type, vehicle kilometres travelled (VKT), and emission factors. It was represented using a Weibull distribution function, consistent with approaches used in the literature (Li et al., 2024). The detailed methodology for emission estimation for the base year 2024 is given in Appendix A.

Figure 3 illustrates the difference between the registered vehicle stock and the active on-road fleet after applying the survival fraction for Punjab over 2004–2024. About 118.2 lakh vehicles were registered in the state from 2004 to 2024, and applying the survival fraction reduced the vehicle fleet to 76.6 lakh. The sharpest decline in the tapering probability was observed in vehicles aged over 10–15 years.

Figure 3: Year-wise vehicle fleet estimated using survival fraction (SF), plotted against year-wise registration data for Punjab



Data were disaggregated by vehicle category and fuel type, and corresponding survival fractions were then applied to estimate the active on-road fleet. Subsequently, PM_{2.5} emissions from the active fleet were calculated.

The age-distributed active fleet was further disaggregated by fuel type and vehicle category. The total transport-related PM_{2.5} emissions in Punjab were estimated at 8,135 tonnes/year across all vehicle categories. Notably, although heavy commercial vehicles (HCVs) comprise only 1.6% of the total vehicle fleet, they account for 2,102

tonnes/year of $PM_{2.5}$ emissions, excluding SEs; including SEs increases this to 5,438 tonnes/year (Figure 4). In contrast, two-wheelers (2Ws) account for a majority of Punjab's vehicle fleet but contribute only 228 tonnes/year of $PM_{2.5}$ emissions. Similarly, light commercial vehicles (LCVs), comprising 1.5% of the fleet, are responsible for 1,089 tonnes/year of $PM_{2.5}$ emissions. This highlights that the emissions are driven by vehicle type and usage characteristics rather than by sheer fleet size.

Figure 4: $PM_{2.5}$ emissions from different vehicle classes using the survival fraction for Punjab

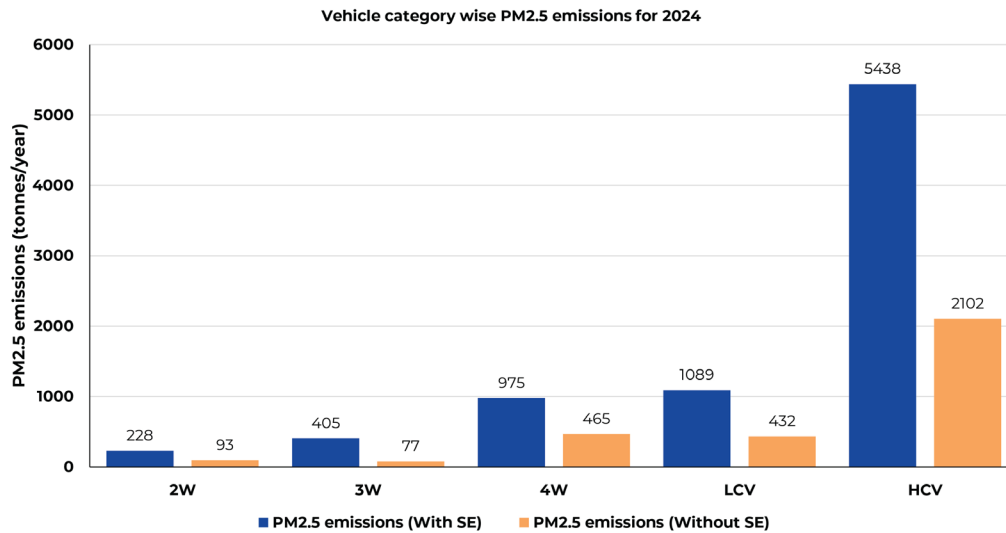
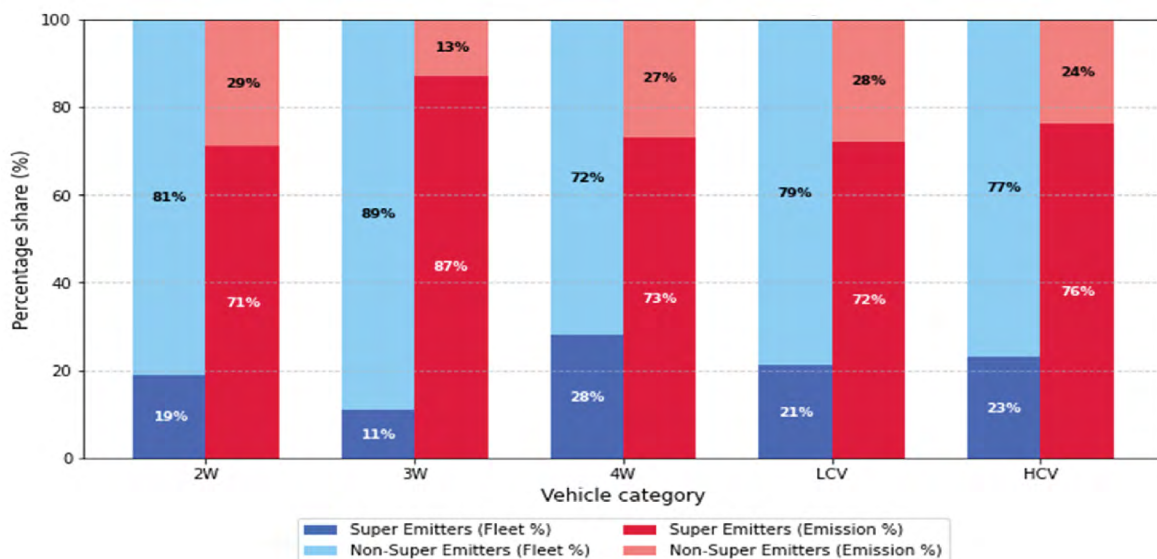


Figure 5 compares emission and fleet shares of SEs and non-super-emitters (NSEs) across vehicle categories. Despite forming a small portion of the total fleet (11%–28%), SEs contribute disproportionately to the total emissions (>70%). Across categories, four-wheelers (4Ws) made up the largest share of SEs, but HCVs (comprising 23%) emerged as the target group because of their high emission factors, higher VKTs, and exclusive reliance on diesel. About 76% of HCV emissions come from 23% SEs in the class. The 3W category is also important, although majority of 3Ws run on petrol and CNG. These high-VKT diesel vehicles, often poorly maintained and subject to weaker enforcement of emission and fitness regulations, are a critical target for clean transportation interventions.

Figure 5: Percentage share of super-emitters and non-super-emitters in category-wise vehicle fleet and their emissions



Further, vehicle fleet share is disaggregated by fuel type and BS wise (BSI–BSVI) along with their respective emission shares (Figure B1, details in Appendix B). Fuel-type distribution across vehicle categories showed that HCVs and LCVs were almost entirely diesel-dependent, whereas 2Ws and 4Ws were predominantly petrol-driven, with rising electric vehicle (EV) penetration in the 2W segment. At present, BS-IV and BS-VI vehicles dominate registrations, but BS-I and II dominate emission share, indicating that SEs across BS categories heavily skew emissions upwards.

Percentage share of SE HCVs: Table 1 shows the year-wise breakdown of the SE HCV fleet. Roughly one-third (33%) of the SE HCVs were older than 15 years, while the remaining two-thirds (~67%) were under 15 years of age, with 27% falling in the 6–10-year bracket and 20% in the 1–5-year bracket. Although only one-third of the vehicles are over 15-year old, they emit disproportionately relative to their numbers. This highlights that vehicle age is only part of the problem, and emission intensity is equally shaped by operational practices, such as overloading and poor maintenance.

Table 1: Year-wise breakdown of super-emitter (SE) heavy commercial vehicles (HCVs)

Age of vehicles (in years)	SE HCV fleet
>15	9499
11–15	5489
6–10	7693
1–5	5747
Total number of SEs	28,428

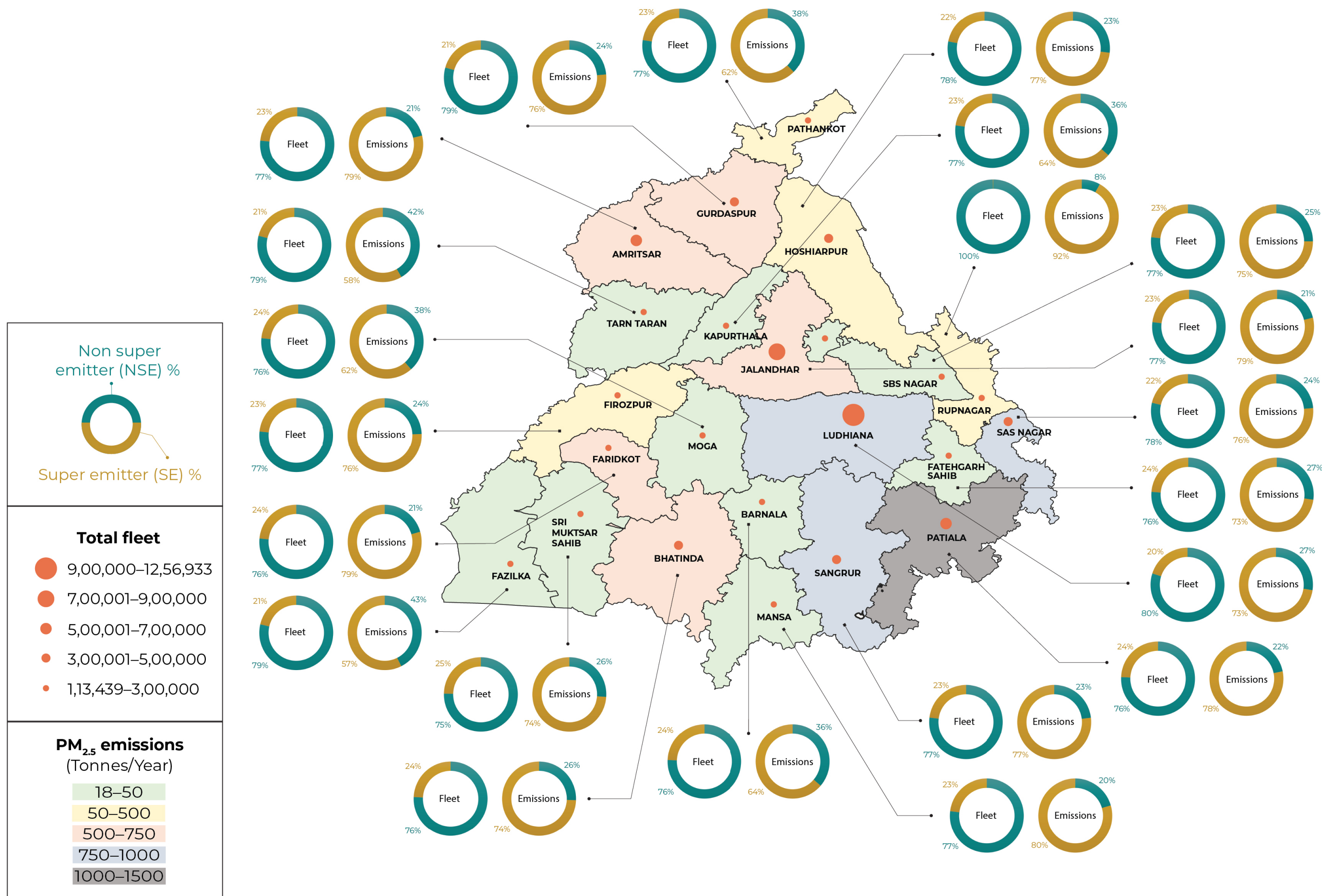
The presence of relatively newer SEs is particularly concerning because these vehicles are expected to run cleaner but are already slipping into high-emitter status within just a few years. Removing HCVs older than 15 years would, therefore, address only one-third of the issue. Therefore, in-use emission testing, roadside checks, and stricter load regulation would be important to periodically identify and remove SEs of any age.

District-wise emissions:

Figure 6 shows the district-wise fraction of SEs and NSEs in the total fleet and the $PM_{2.5}$ emissions in 2024. SEs account for a substantial share of the total fleet across all districts, ranging from ~20%–30%, with every district having at least one-fifth of its fleet classified as SEs. Malerkotla, Punjab’s newest (23rd) district, was carved out of Sangrur in 2021. As our analysis covers the 2002–2024 period, Malerkotla is included within Sangrur district for the entire dataset.



Figure 6: District-wise emission and fleet share of super-emitters and non-super-emitters



First, SEs constitute a disproportionately large share of the total emissions across most districts, frequently contributing more than half of the district-level $PM_{2.5}$ emissions, despite representing only a fraction of the fleet. Second, districts with high absolute emissions (>251 tonnes/year), such as Ludhiana, Patiala, and Sangrur, and districts with emissions ranging between 151 and 251 tonnes/year, such as SAS Nagar, Jalandhar, Bhatinda, Amritsar, and Hoshiarpur, account for higher SE shares. Third, even in districts with lower absolute loads (e.g. Gurdaspur, Firozpur, and Tarn Taran), SEs remain a dominant source of emissions. This pattern shows that the problem is systemic and not confined to one or two hotspots. SEs are especially rich in BC emissions; thus, their dominance implies not only severe health risks but also broader climate-related implications for the larger Indo-Gangetic Plain (Prakash et al., 2020; Verma et al., 2022).

Additionally, out of the top 10 districts contributing to $PM_{2.5}$ emissions, five are home to NACs (Ludhiana [Khanna and Ludhiana], SAS Nagar [Derra Bassi], Patiala, Jalandhar, and Amritsar), with Patiala making the highest contribution. Interestingly, districts such as Sangrur and Bhatinda, which do not comprise any NAC, are found to be among the top five contributors to transport-related $PM_{2.5}$ emissions in Punjab. This suggests that city-level action plans limited to NACs may miss key emission hotspots.

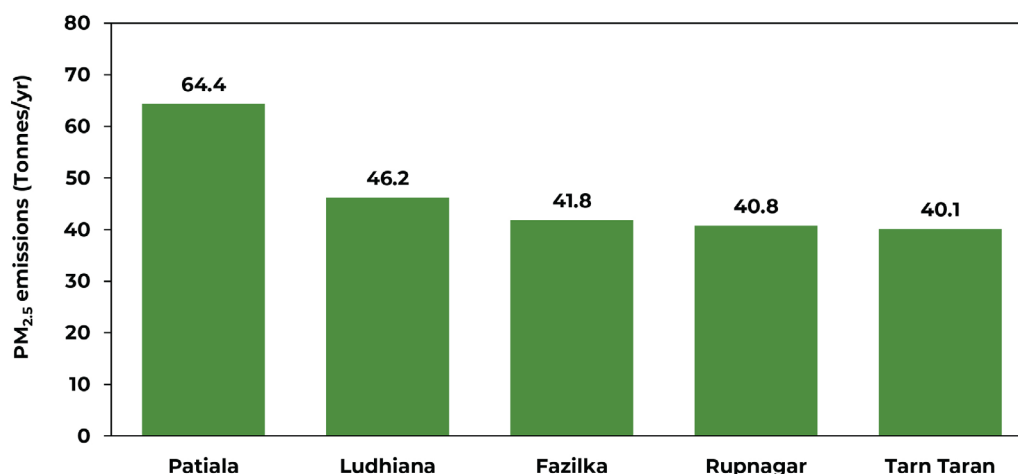
Further, disaggregating by vehicle categories (Appendix B), Figure B3 (4Ws and HCVs) reveals that SE fractions are especially significant for freight vehicles. The contribution of SE HCVs to $PM_{2.5}$ emissions is substantial, often exceeding one-third of the total HCV emissions across districts. This is particularly concerning given the higher baseline emission factors of HCVs, implying that SE status in this category translates to disproportionately high emission loads. These results thus establish that while SEs cut across all vehicle categories, their prevalence and impact are especially concentrated in the freight sector, reinforcing the importance of targeted regulatory focus on HCVs.

Non-road emissions from tractors and farm vehicles

Farm vehicles, particularly tractors, are integral to Punjab's intensive agricultural economy, facilitating land tilling, harvesting, and crop residue management. The active agricultural vehicle fleet (7,06,909 vehicles in total, estimated using survival fractions applied to Vahan registration data from 2002 to 2024) is dominated by tractors (93.3% or 6,59,858 units). Harvesters constitute the second-largest category, accounting for 6.6% or 46,713 units. The remaining fleet consists of a negligible proportion of agricultural trailers (0.05% or 336 units) and power tillers (2 units). Critically, this entire fleet is nearly 100% reliant on diesel fuel, as per our analysis of the 2002–2024 fuel-share data retrieved from the Vahan portal, resulting in substantial non-road emissions. The total $PM_{2.5}$ emissions from agricultural vehicles in Punjab are estimated at 1,268 tonnes per year in 2024, with agricultural tractors being the primary pollutant source (91.75%), followed by harvesters (8.19%) and minimal contributions from power tillers and agricultural trailers (Figure B9, Appendix B).

As shown in Figure 7, Patiala records the highest $PM_{2.5}$ emissions from farm vehicles, followed by Ludhiana, Fazilka, Rupnagar, and Tarn Taran. While Ludhiana and Patiala are often recognised as air pollution hotspots, districts such as Fazilka and Tarn Taran exhibit high $PM_{2.5}$ loads from farm vehicles, suggesting poor rural air quality that currently falls outside the purview of NCAP.

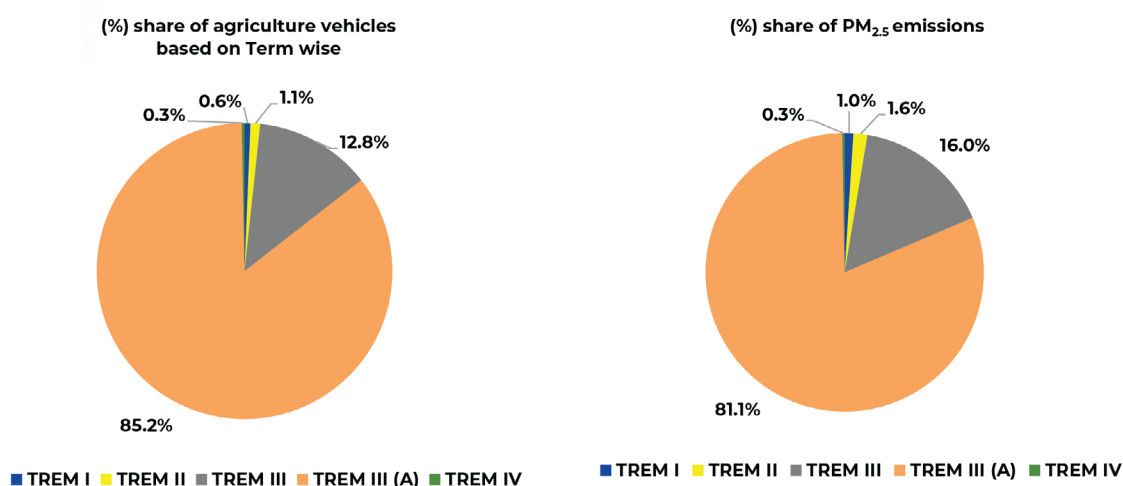
Figure 7: Top five districts with the highest $PM_{2.5}$ emissions from farm vehicles



Among these districts, Fazilka and Tarn Taran currently have no NACs but contribute substantial $PM_{2.5}$ loads from diesel-based farm vehicles. This indicates that agricultural mechanisation, dominated by older tractor fleets, is a significant emission source even in districts not covered under NCAP. These results suggest the need for strategies that address both on-road and non-road vehicle segments to reduce Punjab's $PM_{2.5}$ burden effectively.

Figure 8 illustrates the distribution of agricultural vehicles based on the Tractor Emission Norms (TREM; MoRTH, 2018) and the $PM_{2.5}$ emission contributions from different generations of agricultural vehicles in Punjab in 2024. The analysis revealed that the $PM_{2.5}$ emission problem is predominantly a legacy issue, with the largest segments (TREM I, II, III, and IIIA) accounting for over 99.7% of emissions. These segments correspond to older, less-regulated vehicles that permit higher emission limits. In contrast, the newest and most stringent standards (TREM IV) are represented by minor segments, demonstrating that modern agricultural vehicles equipped with advanced emission control technologies contribute only a negligible share to the total $PM_{2.5}$ burden.

Figure 8: (a) Fleet distribution percentage and (b) $PM_{2.5}$ emission contribution share by TREM standards for agricultural vehicles in Punjab (2024)



This heavy reliance on a large fleet of older, highly polluting diesel tractors poses a significant air quality challenge.

Figure 9: Agricultural tractor operating in Punjab (stock image)



Given these findings, Punjab needs a structured monitoring and regulatory framework for non-road diesel emissions, on par with on-road emission control policies. This should include robust incentives for mandatory scrappage policies targeting pre-TREM IV vehicles to quickly phase out the oldest, highest-PM_{2.5}-emitting farm vehicle fleet. At present, the EV share among farm vehicles is negligible. Hence, long-term strategies must include targeted subsidies to support the adoption of cleaner agricultural machinery. Implementation of zero-tolerance highway checkpoints and Automated Number Plate Recognition (ANPR) in key districts (such as Amritsar, Ludhiana, and Patiala) will help penalise and impound vehicles without number plates and visibly polluting ones, improving compliance and traceability for emission testing.

3. Ground Survey Observations

To complement the secondary data analysis, primary surveys (Figure C1, Appendix C) were conducted across six districts of Punjab (Patiala, Ludhiana, Amritsar, Jalandhar, Moga, and Hoshiarpur) to capture real-world fleet, registration patterns, and vehicle movement characteristics. These districts were selected to capture transport conditions across diverse economic and industrial areas, including districts that share borders with other states (details in Appendix C).

Survey data (survey form in Table C2) were collected from toll booths along major freight corridors and petrol pumps during morning and evening peak hours (Table C1). Toll booths were chosen to capture truck and freight movement, while petrol pumps were included to increase the sample size and capture a wide range of vehicle types, including 2Ws and 3Ws

Figure 10 shows that nearly 89% of the vehicles considered in the ground survey were registered in Punjab, indicating that most of the vehicular activity is dominated by state-registered fleets. This suggests that with robust enforcement of emission norms, inspection and maintenance systems, and age-based regulations at the state level, Punjab can substantially control its transport-related emissions without relying heavily on external interventions.

Figure 10: Distribution of vehicle registrations based on survey data

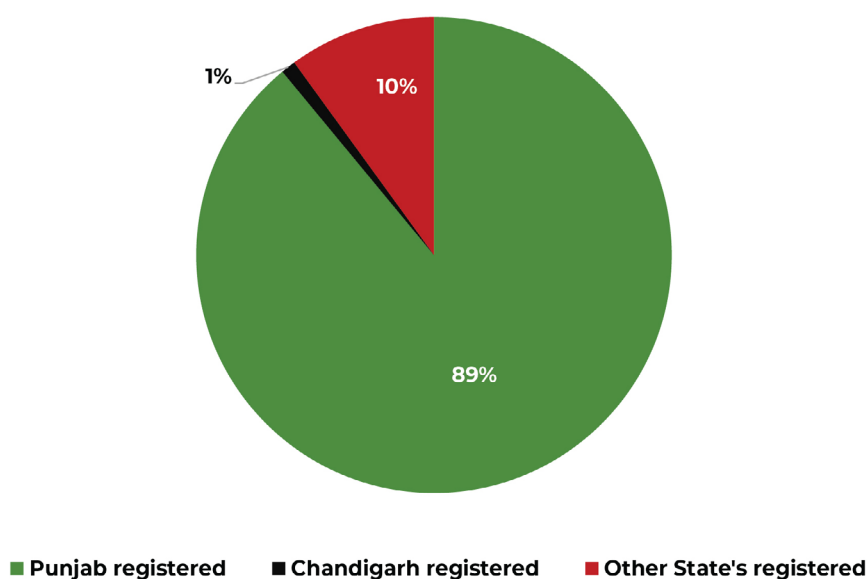
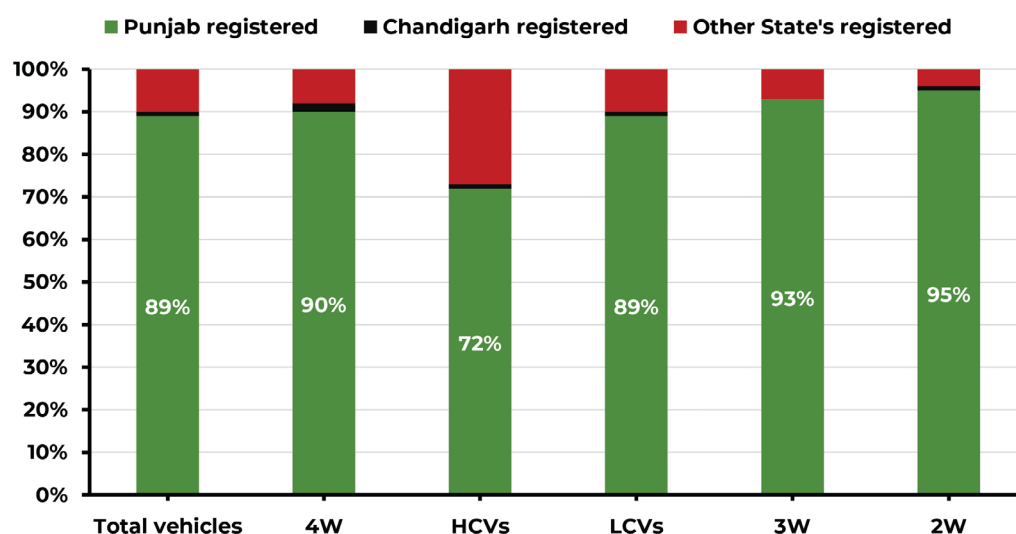


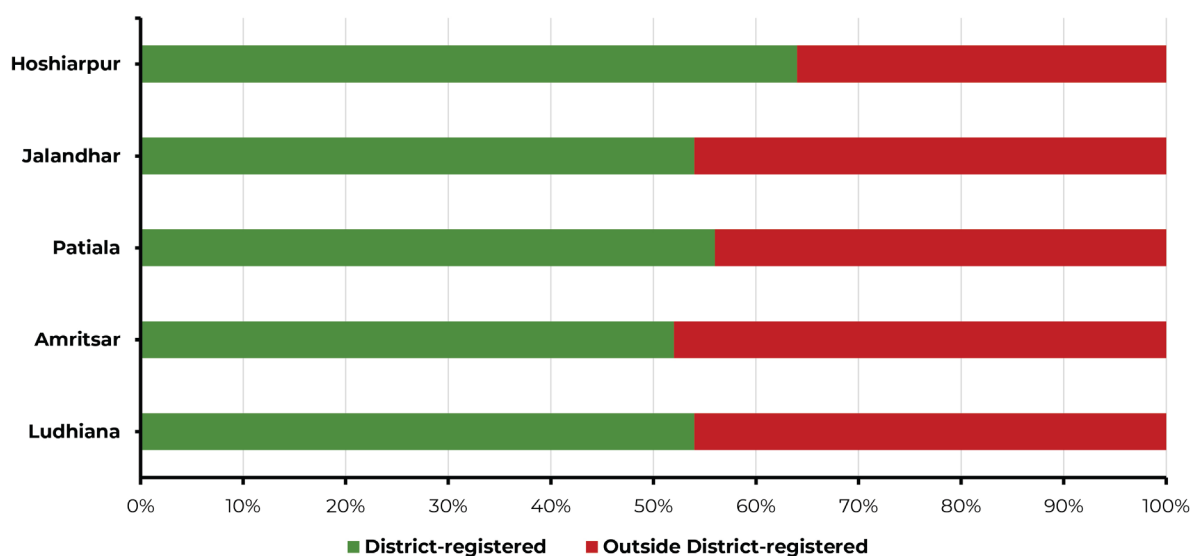
Figure 11 shows the distribution of registered vehicles across different categories. Although the majority of vehicles plying within Punjab were locally registered, there was a relatively higher share of out-of-state registration vehicles among HCVs. This indicates that Punjab's freight activity is strongly influenced by inter-state vehicular movement. Therefore, while a strong state-level strategy can address most on-road vehicle emissions, regional coordination for HCVs will be crucial to effectively manage cross-border freight emissions and ensure consistency in regulatory implementation.

Figure 11: Distribution of surveyed vehicles based on registration data



The survey findings also indicate significant cross-district vehicle movement within Punjab, suggesting that a city-specific approach will not be effective. Figure 12 shows that across the five surveyed districts, excluding Moga, only about 52%–64% of vehicles were registered within the same district, while the remaining originated from other districts. Moga showed a significantly different distribution, warranting further research and verification. This pattern highlights the need for a state-wide strategy to address vehicular emissions, considering the high degree of inter-district fleet movement across Punjab. Of note, surveys were conducted at toll booths and petrol pumps and therefore may have a bias towards capturing more out-of-district vehicles.

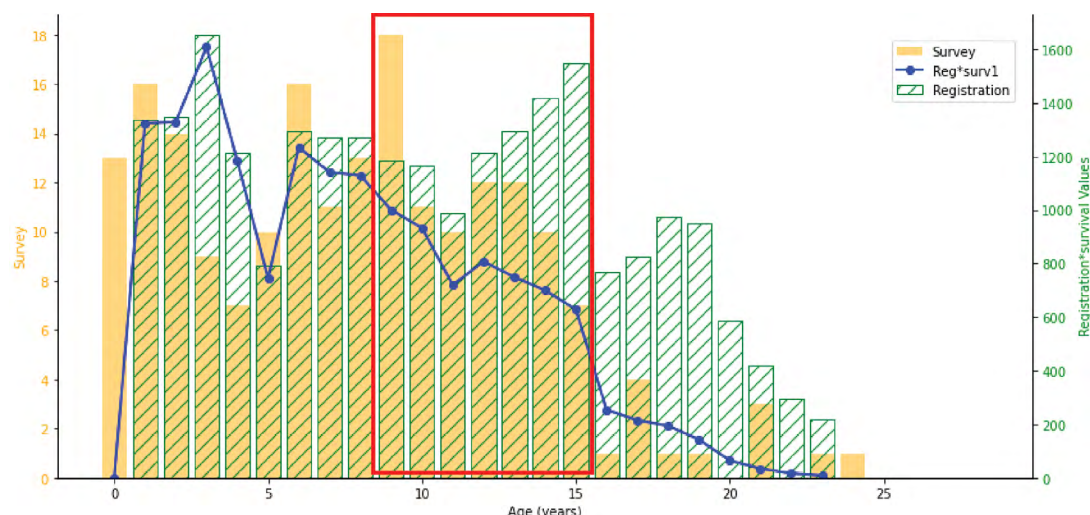
Figure 12: Percentage share of vehicles registered in and outside the surveyed districts in Punjab



The age-wise distribution of vehicles plying on the road, derived from ground survey data, shows a strong alignment with the literature-based survival fraction values used in this study for HCVs in Ludhiana (Figure 13). Both datasets exhibit a similar variation pattern, with a notable concentration of vehicles aged 10–15 years that continue to operate on Punjab's roads. The decline beyond 15 years indicates the gradual retirement of older vehicles, while the comparatively higher registration

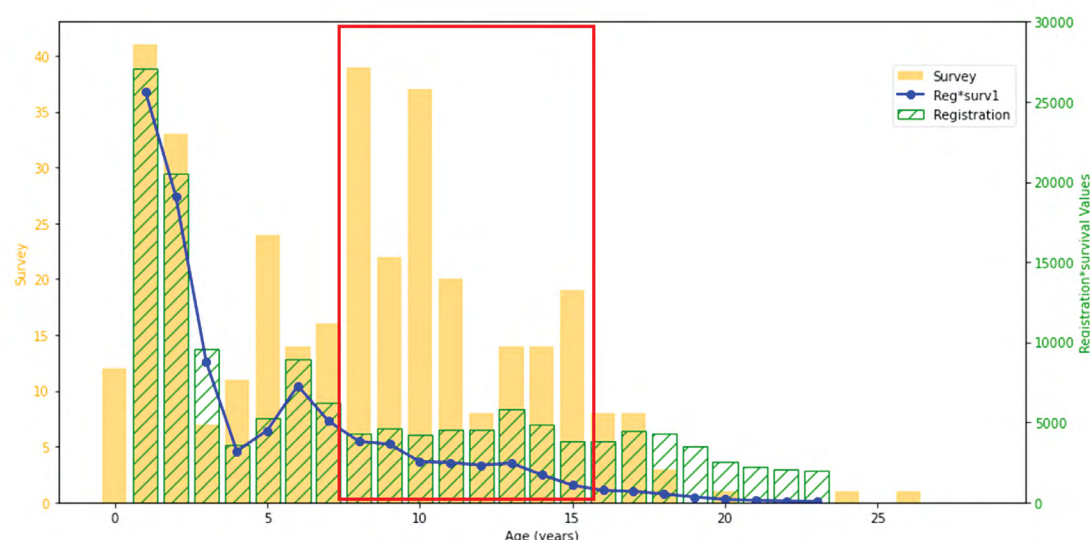
counts in older categories likely represent vehicles that remain on record but are no longer in active use. This consistency highlights the persistence of older vehicles that significantly influence on-road emissions. Comparison plots for HCVs in Punjab are shown in Appendix C (Figure C2).

Figure 13: Comparison of survival fractions (SFs) of heavy commercial vehicles in Ludhiana based on the literature and survey data (surv1 = literature-based SF used in the study)



In contrast, the 3W survey counts remain elevated across the 5–15-year age category (Figure 14), whereas literature-based survival fractions predict a sharper fall in these cohorts. This highlights that 3Ws have longer real-world lifespans than those indicated by the survival fractions. This divergence implies that survival fractions may underestimate the on-road mid-aged 3W population in Punjab.

Figure 14: Comparison of survival fractions (SFs) of three-wheelers in Punjab based on the literature and survey data (surv1 = literature-based SF used in the study)



4. Current Policy Instruments

A combination of state and national initiatives is driving Punjab's transition towards cleaner and more sustainable transport. These policies aim to achieve emission reductions through fleet renewal, vehicle electrification, and alternative fuel adoption. Key policy instruments influencing transport-related PM_{2.5} emissions in Punjab are listed in Table 2. A detailed analysis can be found in Appendix D (Table D1).

Table 2: Overview of existing state- and national-level policies for transport-related emission reduction

 Fleet Modernisation and Emission Control
• Punjab Vehicle Scrappage Policy ◦ The state is currently at par with the national policy on mandating the scrapping of older government vehicles. ◦ Voluntary scrapping of old vehicles with tax incentives ◦ Five registered vehicle scrapping facilities (RVSFs) operational, and ~3000 vehicles scrapped • Auto Fuel Vision and Policy 2025 ◦ A roadmap for controlling fuel quality and emission standards for vehicles ◦ Leapfrogged from BS-IV to BS-VI in 2020 to align with global best practices ◦ Mandate for installing diesel particulate filters (DPFs) and selective catalytic reduction (SCR) systems to reduce emissions • Green Tax on Old Vehicles ◦ Guidelines for levying green tax on older vehicles (8 years for transport and 15 years for non-transport vehicles) ◦ Implementation of green tax in states, such as Andhra Pradesh, Telangana, Karnataka, Maharashtra, Punjab, Uttar Pradesh, and Jharkhand, and Union Territories, e.g. Dadra and Nagar Haveli
 Clean Fuel and Alternative Energy Adoption
• Compressed Natural Gas (CNG) Adoption ◦ Tax incentives and CNG infrastructure development ◦ About 306 CNG stations are operational in Punjab as of April 2026 (Petroleum and Natural Gas Regulatory Board, 2026). • Sustainable Alternative Towards Affordable Transportation (SATAT; Compressed Biogas Scheme) ◦ Compressed biogas as a clean transport fuel, targeting fossil CNG substitution in fleets ◦ Four operational compressed biogas plants in Punjab



Fleet Electrification and Green Mobility

• Punjab EV Policy

- Launched in 2022; incentives for electric two-wheelers, three-wheelers (3Ws), bicycles, light commercial vehicles, and buses
- Total 1.28 lakh electric vehicles (EVs) registered in Punjab, as of October 2025

• Rejuvenation of Auto-rickshaws in Amritsar through Holistic Intervention (RAAHI)

- Piloted in Amritsar, with a focus on financial incentives for electric 3Ws and women empowerment
- Approximately 1,200 auto-rickshaws shifted to electric; 200 pink autos allocated to women

• Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles in India - Phase II (FAME II)

- Flagship scheme to accelerate EV adoption; implemented till March 2024
- Outlay of INR 11,500 crore

• PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) Scheme

- Launched in September 2024; total budget of INR 10,900 crore for October 2024–March 2028
- Promote EV adoption among 2Ws, 3W trucks, buses, and ambulances

• PM eBus Sewa Scheme

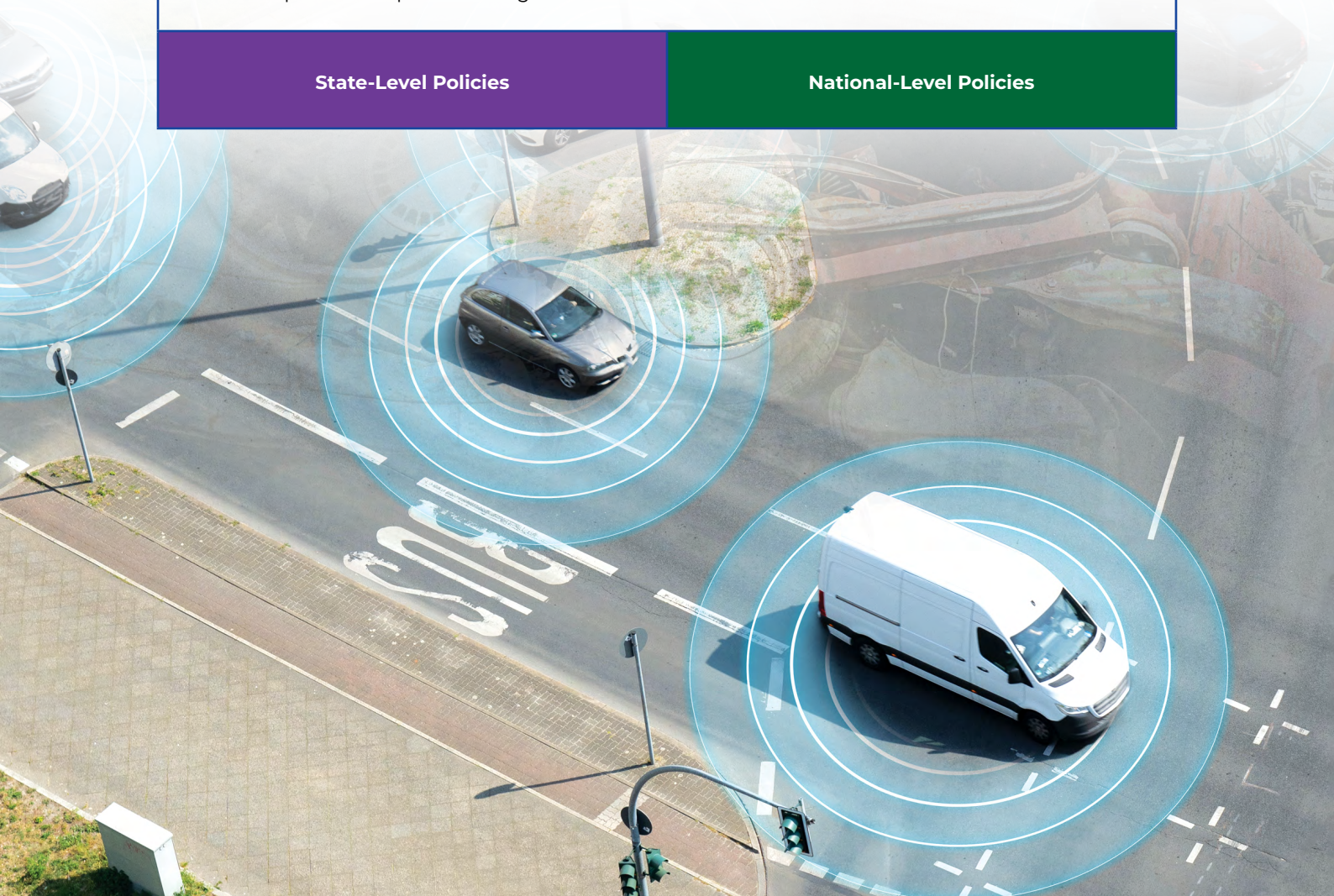
- Budget INR 3,435.33 crore
- Deploy 10,000+ electric buses across India under public–private partnerships (gross cost contract model)

• PM Electric Freight Accelerator for Sustainable Transport (PM E-FAST) Scheme

- National platform to promote freight electrification and zero-emission trucks

State-Level Policies

National-Level Policies



5. Future Projections

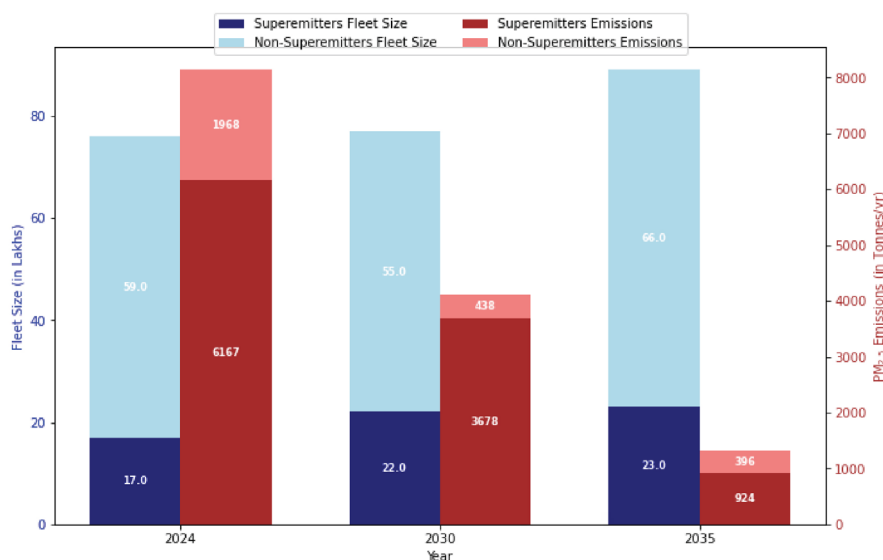
5.1. Comparison of total emissions and fleet size: SEs vs NSEs (2024–2035)

Under the scenario that considers the mandates that vehicles do not ply beyond 15 years (including BS IV, BS VI, and some BS III vehicles), Punjab's on-road fleet continues to expand through 2035. The total $PM_{2.5}$ emissions decline by ~66%. Considering that only 50% BS III vehicles are plying, along with BS IV and BS VI vehicles, total emissions will decline by 29% overall from 2024 to 2035. In contrast, greater reductions can be observed when all vehicle segments are in operation.

The vehicle categories projected for both 2030 and 2035 were based on past registration data from the Vahan portal, calculated using the best-fit method. Each vehicle category was projected by fuel type to account for future fuel penetration. The year-wise projected vehicles were then used to estimate emissions. The BAU emissions are calculated for 2024, 2030, and 2035, after applying a survival fraction that accounts for vehicles operating for more than 15 years, up to 20 years.

Figures 15–17 compare SEs and NSEs under the BAU scenario by fleet size and contributions to $PM_{2.5}$ emissions, both in total and disaggregated by vehicle categories (4Ws and HCVs), reflecting the penetration of cleaner BS-VI vehicles and the steady uptake of EVs (Figure 15). Normatively, the $PM_{2.5}$ emissions of BS-VI vehicles are approximately 70% lower than those of their BS-IV counterparts, mainly because of advancements in engine technology and in-built diesel particulate filters (DPFs).

Figure 15: Comparison of total emissions and fleet size: Super-emitters vs non-super-emitters (2024–2035)

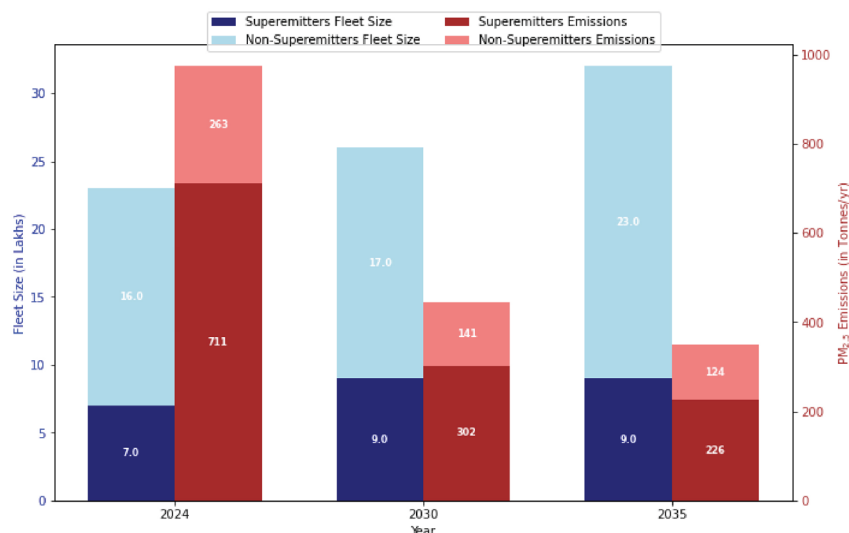


However, the emission composition exhibits a contrasting trend. Despite cleaner technology lowering the baseline, SEs continue to dominate the emissions every year. Even as SEs become a small fraction of the fleet, they still account for the majority of $PM_{2.5}$ emissions in 2024, 2030, and 2035. Thus, technological progress alone cannot solve the problem, as SEs continue to drive the residual emission

burden, highlighting the need to phase out SEs in favour of cleaner alternatives.

As observed in the overall trend, 4W projections (Figure 16) show rapid growth and significant emission reductions, with SEs remaining the major contributors, through 2030 and 2035.

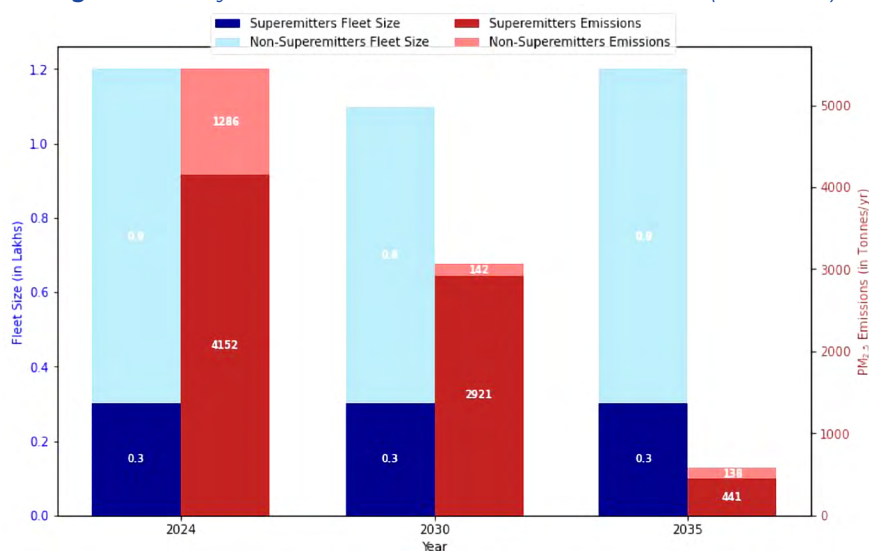
Figure 16: Four-wheeler emissions and fleet size (2024–2035)



Total HCV emissions (Figure 17) decline from 5438 tonnes/year in 2024 to 3063 tonnes/year in 2030 (-44%) and further to 579 tonnes/year in 2035 (-81%). Notably, the SE share climbs from 76% in 2024 to 96% in 2030, before falling back to 76% in 2035. This shows that by 2030, SEs drive nearly all HCV emissions. The sharp decline after 2030 reflects the phase-out of older cohorts and the lower baseline emission factors of newer vehicles, even among SEs. This trajectory implies that without timely interventions, Punjab would have to wait until 2035 for the natural fleet turnover to phase out the older SE-heavy cohorts and for the benefits of cleaner vehicles to translate into air quality gains.

Further, detailed district-wise future projections showing the percentage share of SEs and NSEs are given in Figures B4–B8 (Appendix B).

Figure 17: Heavy commercial vehicle emissions and fleet size (2024–2035)



5.2. Scenarios for emission reduction

Three scenarios based on existing and potential policies for emission reduction were developed in this study. The high-emission-reduction scenarios are delineated in Table 3. For other scenarios, please refer to Appendix E (Table E1).

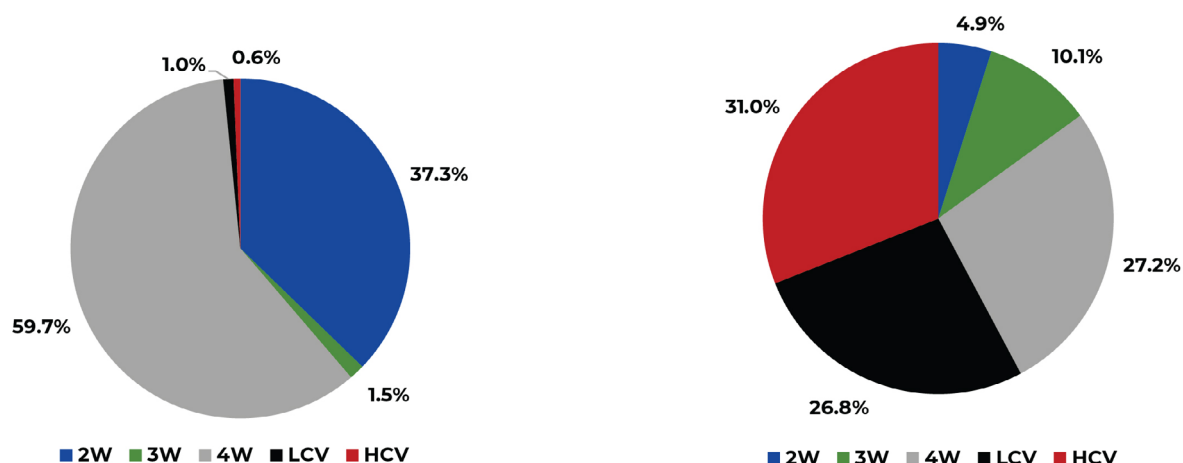
Table 3: Emission reduction potential under the high-adoption scenario

Category	Control measure	Vehicle category	Baseline scenario		Higher adoption scenario (in %)		Reduction in PM _{2.5} emissions (in tonnes/year)	
			Current adoption 2030	Current adoption 2035	2030	2035	2030	2035
Retrofitting	Installation of diesel oxidation catalysts and partial flow filters for Bharat Stage-IV vehicles	Heavy commercial vehicles (HCVs)	0%		50%	-	35.2	-
Switching to cleaner fuels	Electricity	Two-wheeler (2W)	1%	11%	15%	25%	333.0	82.7
		Two-wheeler (3W)	37%	80%	50%	90%		
		Four-wheeler (4W)	0.20%	1%	15%	16%		
		Light commercial vehicle (LCV)	1%	1%	8%	12%		
		Bus	0.05%	0.50%	9%	15%		
		Trucks and trailers	0%	0%	8%	9%		
	Compressed natural gas	3W	45%	16%	48%	-		
		4W	1.30%	1.70%	5%	9%		
		LCV	7.50%	11%	14%	25%		
		Bus	1.50%	2.50%	5%	9%		
	Liquefied natural gas	Bus	0%	0%	5%	6%		
		HCV	0%	0%	4%	5%		
Mandatory Scrappage	Scrappage of vehicles older than 10 years (commercial)	3W			20%	25%	882.4	188.5
		Private cars			20%	25%		
		LCV			20%	25%		
		Bus			20%	25%		
		Trucks, trailers			20%	25%		
	Scrappage of vehicles older than 15 years (private)	2W			25%	30%		
		Personal cars			25%	30%		

Special case: Chandigarh

Chandigarh is administratively a Union Territory and the shared capital of Punjab and Haryana. It is part of the same airshed as SAS Nagar (Mohali), Patiala, and the surrounding districts. Hence, its transport emissions are directly relevant to Punjab's air quality management. Figure 18 shows the percentage share of vehicles by category and their respective $PM_{2.5}$ emissions. Unlike Punjab, where 2Ws dominate the fleet (64.6%), Chandigarh's fleet is led by 4Ws (59.7%), followed by 2Ws (37.3%) and only small shares from LCVs (1%) and HCVs (0.6%).

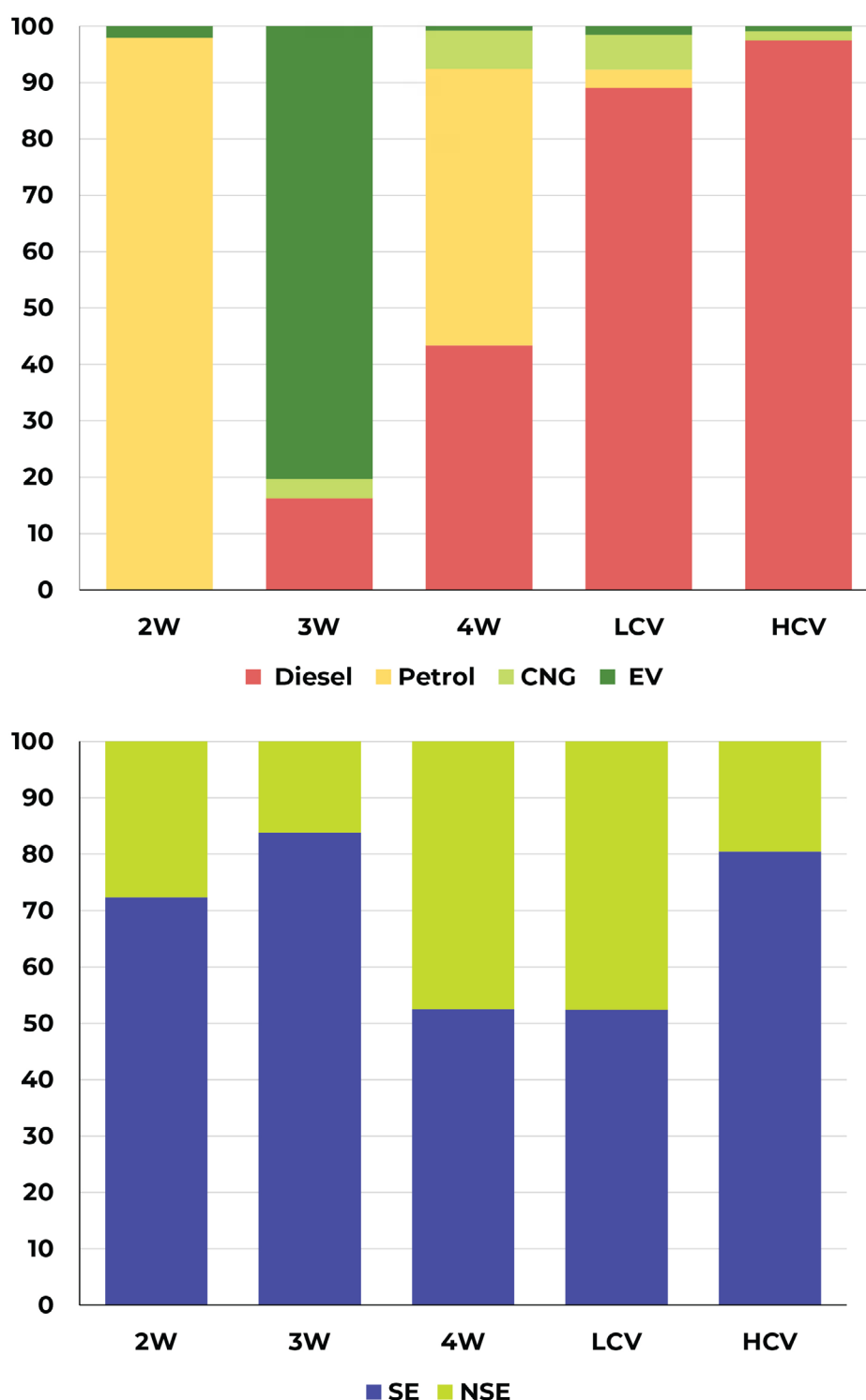
Figure 18: Percentage share of (a) vehicles by category and (b) their $PM_{2.5}$ emissions in 2024 using the survival fraction for Chandigarh (including super-emitters)



Despite their limited numbers, HCVs contribute disproportionately to $PM_{2.5}$ emissions (31%), whereas LCVs contribute 27%. Together, these two commercial categories account for more than half of the transport emissions in Chandigarh. The largest fleet segment, 4Ws, contributes ~27%, whereas emissions from 2Ws and three-wheelers (3Ws) are negligible.

Figure 19 shows fuel distribution as per vehicle category and their corresponding emissions. The 2W fleet is almost entirely petrol-based, with limited EV penetration. The 3W segment shows a strong presence of compressed natural gas (CNG) and EVs, reflecting the impact of favourable policies and availability of charging infrastructure to support EVs. Further, SEs dominate $PM_{2.5}$ emissions in all vehicle categories. Overall, 4Ws show a mixed fuel profile, with nearly half running on petrol, ~45% on diesel, and a small but visible share on CNG (6.8%). However, LCVs and HCVs are almost entirely diesel-dependent, mirroring Punjab's freight profile.

Figure 19: Percentage share of (a) fuel penetration as per vehicle category and (b) their $PM_{2.5}$ emissions (including SEs and NSEs) for Chandigarh (2024)



These comparisons highlight a common structural pattern. Whether in a large agrarian-industrial state like Punjab or a compact urban Union Territory like Chandigarh, SEs and commercial diesel vehicles disproportionately contribute to transport emissions, despite their small numbers. The magnitude varies, but the policy message is consistent: strategies targeting freight vehicles and in-use SEs can deliver the greatest impact on transport-related $PM_{2.5}$ reductions.

6. Recommendations

Punjab's transport-related tailpipe emissions are largely driven by diesel freight, SEs across all vehicle categories, and weak on-road enforcement of emissions and fitness regulations. Thus, a multifaceted, state-specific approach that combines technological upgrades, regulatory reforms, and infrastructure development is required. Below are key strategies, implementation challenges, and recommendations for the path forward.

6.1. Removal of older vehicles and replacement with cleaner alternatives

Reducing on-road emissions in Punjab requires a two-fold strategy: phasing out older, high-emitting vehicles and accelerating the transition to cleaner technologies. A significant share of Punjab's fleet, particularly HCVs and mid-aged 2Ws and 3Ws, continues to operate beyond their efficient lifespan, contributing disproportionately to transport emissions. Addressing this requires an integrated policy approach that combines mandatory scrappage; targeted retrofitting; and promotion of alternative fuels, such as electricity, compressed natural gas (CNG), and liquefied natural gas (LNG), which are discussed below in detail.

6.1.1. Vehicle Scrappage Policy

A scrappage policy, if made mandatory and implemented well, will be pertinent in reducing vehicular emissions by removing SEs and end-of-life vehicles (ELVs). This will also add to the volume of vehicles that need to be scrapped. Punjab notified its State Vehicle Scrappage Policy in 2022, aligned with the National Voluntary Vehicle-Fleet Modernisation Programme (VVMP), to phase out ELVs. The Punjab Scrappage Policy sets an end-of-life limit of 8 years for transport vehicles and 15 years for non-transport vehicles. To encourage vehicle owners to scrap ELVs, 15%–20% road tax rebates are offered to owners who voluntarily scrap their vehicles, and a green tax is applied to ELVs. The policy aimed to scrap 2,950 government vehicles by February 2024. Between August 2022 and October 2025, 'Certificates of Deposit' have been issued under the policy to 1,013 government and 3,583 private vehicles.

Emission reduction potential: Reduction in emissions from the scrappage of vehicles depends on the tailpipe emissions of the replacement vehicle. Vehicle scrappage directly removes older, high-emission vehicles from the fleet, thereby reducing PM and NOx emissions. If a scrapped vehicle is replaced by an EV or not replaced at all, the tailpipe emission reduction potential is 100%. Even in the most likely scenario, if a scrapped vehicle is replaced with a BS-VI diesel vehicle, the PM emission reduction is estimated at 70%.

Cost associated with scrappage: Building a scrappage infrastructure is capital-intensive, and each centre requires around INR 14 crore to set up a registered vehicle scrapping facility (RVSF) with an annual capacity of 28,000 vehicles (Investment Opportunities under VVMP, 2023). The estimated breakeven period is after 7 years of operation. Further, according to the estimates by industry stakeholders, less than 5% of HCVs are formally scrapped at present, although the actual number

may be slightly higher when accounting for grey market activity. HCVs are formally scrapped, although the actual number may be slightly higher when accounting for grey market activity. Usually, older HCVs are resold and reused in smaller towns.

If older vehicles are scrapped from the 2030 and 2035 fleet, the following alternative technologies are expected to replace them (Table 4).

Table 4: Projected percentage share of replacement vehicles for 2030 and 2035

Category	Alternative for new vehicles	2030	2035
Two-wheeler	Bharat Stage (BS)-VI+	60% (Petrol)	50% (Petrol)
	Electric Vehicle (EV)	40%	50%
	Compressed natural gas (CNG)/liquefied natural gas (LNG)	--	--
Three-wheeler	BS-VI+	40% (Diesel)	20% (Diesel)
	EV	40%	60%
	CNG/LNG	20%	20%
Four-wheeler	BS-VI+	40% Petrol + 30% Diesel	30% Petrol + 20% Diesel
	EV	20%	40%
	CNG/LNG	10%	10%
Light commercial vehicle	BS-VI+	85%	70%
	EV	5%	8%
	CNG/LNG	10%	22%
Bus	BS-VI+	90%	80%
	EV	5%	10%
	CNG/LNG	5%	10%
Heavy commercial vehicle	BS-VI+	90%	80%
	EV	3%	5%
	CNG/LNG	7%	15%

Barrier, entry points, and way forward: The existing scrappage infrastructure (i.e. RVSFs) is inadequate to handle the growing number of ELVs. As of September 2025, 5 RVSFs have been established in Punjab. Each of these facilities has a processing capability of 10,000–20,000 vehicles (all categories) per year. As per Investment Opportunities under the VVMP (2023), approximately 2,70,000 HCVs aged more than 15 years are currently plying on Indian roads. Considering HCVs account for about 3%–7% of the total scrappage-eligible vehicles, around 300 operational RVSFs would be required across the country to manage HCV scrappage alone.

In Punjab, there are around 3 lakh vehicles reaching end-of-life (ELV), including 18,386 3Ws and LCVs older than 10 years; 15,820 HCVs older than 10 years; and 2,66,739 2Ws and 4Ws older than 15 years. Considering that each RVSF can process about 20,000 vehicles per year, the state would require a total of around 15 operational scrappage centres to effectively manage SEs and ELVs, and establishing 10 new RVSFs would require an investment of INR 140 crore. Although existing RVSFs should first be utilised to their full processing capacity, in anticipation of wider implementation of the Central Vehicle Scrapping Policy and the increasing number of vehicles reaching ELV, Punjab could consider developing a more decentralised scrappage network across the state. A geographically distributed network would improve accessibility for vehicle owners and facilitate timely processing of ELVs in Punjab.

Furthermore, tax benefits remain inadequate for encouraging people to voluntarily give up their vehicles. The informal scrapping sector remains more financially attractive, often paying up to INR 100/kg of truck weight (unladen) in comparison to around INR 25/kg at authorised scrappage centres (CSE, 2020). To strengthen policy support and scale up scrappage adoption, Punjab could link scrappage incentives with low-emission zone (LEZ) plans and EV schemes, ensuring that ELVs are permanently removed from circulation rather than being resold in other states.

6.1.2. Retrofitting

Retrofitting existing commercial BS-IV fleet with diesel oxidation catalysts (DOCs), partial flow filters (PFFs), and selective catalytic reduction (SCR) systems can curb tailpipe emissions. Given that one-third of Punjab's HCV fleet is older than 15 years and a large share continues to operate under BS-IV norms, retrofitting presents an opportunity to mitigate emissions without waiting for a full fleet turnover to newer, cleaner BS-VI vehicles or electric HCVs.

Emission reduction potential: Expert consultations revealed that the DPF is not suitable for Indian city road conditions; however, by capturing soot particles in the exhaust stream, PFFs could reduce PM emissions by 55%–65%. SCR systems are effective in reducing NO_x by up to 90%, especially under high-temperature operating conditions, typical of long-haul diesel engines (Mera et al., 2020). Retrofitting is particularly relevant for Punjab's freight-intensive corridors, such as Ludhiana, Jalandhar, and Amritsar, where HCVs contribute disproportionately to local air pollution.

Cost associated with retrofitting: As per our stakeholder consultation on HCVs, only BS-IV vehicles can be retrofitted with a combination of DOC and PFFs. Retrofitting older vehicles with PFFs and DOC will cost around INR 50,000 per vehicle. The associated maintenance cost largely depends on the vehicles' running condition.

Barriers, entry points, and way forward: The absence of regulatory requirements and certification standards for retrofit kits currently limits adoption. Fleet operators, especially smaller ones, are deterred by high upfront costs and maintenance needs, while passive regeneration challenges in congested traffic further reduce efficiency. Introducing a regulatory mandate for retrofitting older HCVs in high-emission or industrial zones, supported by financial incentives such as subsidies, reduced tolls, or lower road taxes, can accelerate uptake. Punjab could pilot retrofitting programmes along industrial and freight corridors, integrating them with LEZ designations to allow continued operation of certified retrofitted vehicles within restricted areas.

6.1.3. Switching to cleaner fuels (electricity, CNG, and LNG)

Transitioning to cleaner fuels, such as electricity, CNG, and LNG, offers significant potential to reduce emissions from the transport sector, with EVs in particular eliminating 100% of tailpipe emissions. While EV adoption has gained traction in the 2W, 3W, and bus categories under the Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles in India (FAME) Phase II and PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) schemes, the penetration of electric trucks in Punjab remains minimal. However, considering that HCVs contribute disproportionately to vehicular emissions, accelerating electrification in this segment could deliver substantial air quality benefits.

Cost associated with the adoption of EVs: EV adoption in Punjab is currently concentrated in the 2W and 3W segments, which together constitute nearly ~65% of the total fleet. A total cost of ownership (TCO) analysis (Table 5) shows that these categories have already achieved or are approaching cost parity with internal combustion engine (ICE) vehicles, driven by lower operational costs and central or state government incentives. However, the capital expenditure for 4Ws is more than that for ICE vehicles, but in the long term, the TCO of EVs is lower. Further details are given in Appendix F.

Table 5: Comparison of the total cost of ownership for different vehicle categories

Total cost of ownership (INR/km)				
Vehicle Category	Electric vehicle (EV)	Diesel	Petrol	Compressed natural gas
Two-wheeler	2.04	--	2.97	--
Three-wheeler	1.54	4.06	4.98	3.55
Four-wheeler	8.55	--	11.54	8.79
Bus (EV_12m_fast charger (FC) or high-end diesel bus)	40.91	41.27	--	--
Bus (EV_12m_SC or low-end diesel bus)	33.60	36.17	--	--

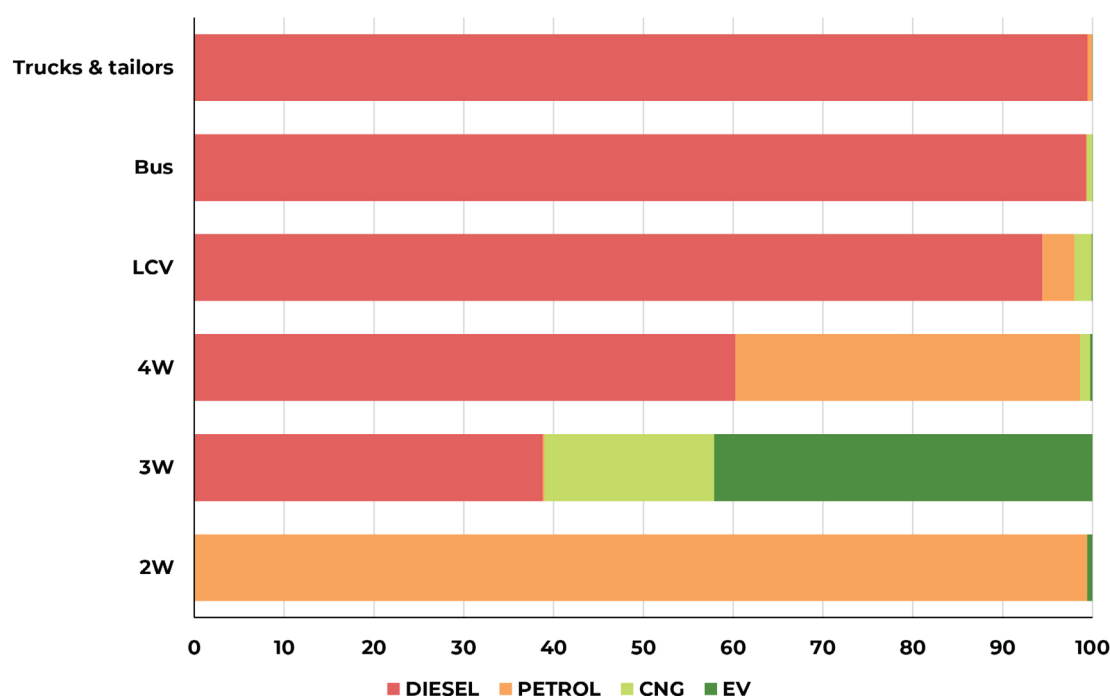
As per the literature and our stakeholder consultation, EV adoption is showing significant growth in the bus segment through schemes like PM eBus Sewa. For other categories, EV models are still limited and in early stages of market release. Based on stakeholder inputs, the upper-range electric bus (12 m) operating with

fast-charging (FC) infrastructure and the lower-range bus with slow-charging (SC) infrastructure were analysed. It was found that even after accounting for incentives, electric buses currently cost more than diesel buses, primarily because of high battery costs and infrastructure requirements.

The TCO of a truck is typically 14%–22% higher than that of its ICE counterpart (RMI, 2025). Based on data provided by original equipment manufacturers (OEMs), installation of fast chargers (50–150 kW DC) costs around INR 5–15 lakh, whereas ultra-fast 350-kW chargers can exceed INR 20 lakh, depending on land requirements and equipment costs. Despite these costs, Punjab’s growing EV ecosystem, supported by the State EV Policy (2022), provides a conducive environment for expanding electrified fleets, particularly across intra-city routes and municipal corridors.

Promotion of CNG and LNG vehicles: Other alternative fuels, such as CNG and LNG, can complement EV adoption, particularly in sectors where electrification is currently less viable. CNG penetration in Punjab (Figure 20) remains below 5%, mainly within urban fleets such as 3Ws. Expanding CNG refuelling networks in key districts, such as Mohali, Ludhiana, and Amritsar, could significantly lower tailpipe emissions from intra-city freight and passenger transport.

Figure 20: Percentage share of fuel types in Punjab (2024)



For long-haul freight, LNG vehicles provide a cleaner alternative to diesel but remain in early stages of adoption due to limited infrastructure. The adoption of both CNG and LPG is hindered by an inadequate number of refuelling stations, especially on highways and rural routes. Further, there are fewer LNG vehicles available in the market, with infrastructure and awareness still lacking. Further, upfront costs limit fleet adoption. Establishing LNG corridors along freight routes, such as Ludhiana–Delhi and Amritsar–Bhatinda, can enable gradual adoption among heavy vehicle operators.

Barriers, entry points, and way forward: The FAME scheme was launched by the Government of India to promote the adoption of electric and hybrid vehicles, with a budget of INR 895 crore. To continue the momentum of FAME-I and boost the adoption of EVs, FAME-II was launched with a total budget of INR 11,500 crore. The objectives of FAME-I and FAME-II include a 40% EV penetration for buses. Although electric buses are being widely adopted (specifically by city governments), electric trucks are still being evaluated by manufacturers.

In 2024, the PM E-DRIVE scheme was introduced with a budget of INR 10,900 crore for 2 years, of which INR 500 crore was allocated for incentivising electric trucks and INR 4,391 crore for electrifying 14,028 buses by state transport agencies. While encouraging, the INR 500 crore allocation for trucks is insufficient and requires additional funding to meet current demand.

Currently, electric trucks face high upfront costs (two to three times those of their ICE counterparts), and only a limited range of commercial models are available. Additional concerns include long charging times and a lack of charging stations, particularly outside city limits. Solutions include enhancing financial incentives for single-owner EV trucks, increasing the availability of fast-charging stations along major routes, and supporting battery subscription models. Establishing automated or manual battery swapping stations could reduce downtime, ease range anxiety, and lower upfront costs. However, battery inter-operability poses a challenge among different OEMs.

Therefore, to advance the transition of Punjab's vehicle fleet to cleaner fuels, short-term goals may include prioritising EV deployment in the 2W, 3W, and city bus segments and strengthening the CNG infrastructure in major cities. Medium-term goals may include developing LNG and CNG freight corridors, supported by fiscal incentives for commercial fleets. In the long term, through coordinated adoption of EV, CNG, and LNG technologies, Punjab can substantially reduce vehicular emissions, improve fuel efficiency, and build a more resilient and cleaner transport system.

6.2. Removal of SEs

Considering that SEs contribute disproportionately to $PM_{2.5}$ tailpipe emissions, reducing their number should be a key priority for achieving substantial emission reductions. Targeted interventions, particularly for commercial vehicles, should focus on the systematic identification and removal of these high-emitting vehicles. While the traffic police are currently empowered to penalise visibly polluting vehicles, a more scientific and data-driven mechanism should be institutionalised for detecting and managing SEs. In this regard, the current Pollution Under Control (PUC) programme provides an important testing system, but there is scope to enhance its effectiveness in addressing SEs.

Adoption of remote-sensing technology for real-time identification of SEs on road: Remote-sensing technologies offer a practical solution for identifying high-emitting vehicles in real time. Using high-resolution cameras and remote-sensing units (Narla et al., 2024), on-road emissions can be measured without interrupting the traffic flow. Detected vehicles can then be flagged, issued challans, and directed for mandatory maintenance checks. Penalties should be progressively increased until compliance improves or older and highly polluting vehicles are scrapped. Building

on this, Kolkata's efforts for almost a decade and Delhi NCR's pilots demonstrate how remote sensing can complement the PUC framework, paving the way for wider national adoption as regulatory support strengthens.

Bringing SE HCVs and LCVs into compliance through repairs can reduce emissions by up to 75%, as SEs typically emit four times more than their NSE equivalents. With an estimated cost of INR 2 crore per setup, installing remote-sensing units at major entry and exit points of cities and industrial corridors could significantly reduce the regional PM_{2.5} load.

Mandating periodic in-use emission testing to ensure compliance and sustained emission control: While remote sensing can identify on-road violators, compliance requires regular in-use emission testing. Mandatory testing every 6 months for HCVs and LCVs at automated testing stations (ATSs; costing around INR 800 per vehicle) using on-board diagnostics (OBDs) can help monitor engine performance and maintenance status.

Despite its potential, the current infrastructure is inadequate, with only 137 operational ATSs across India (as of October 2025, based on the AFMS Dashboard) and no standardised OBD-based emission protocols (MoRTH, n.d.). At present, although Punjab does not have any ATSs, the state has formalised a tender and an Expression of Interest for establishing six ATSs.

Older commercial vehicles, particularly those manufactured before 2010, lack OBD systems. Increasing ATS capacity, developing uniform OBD emission standards, and integrating results with PUC databases for enforcement continuity can help expand this solution. Although the focus could initially be on HCVs and LCVs owing to their emission intensity, the same framework can gradually be extended to the 2W, 3W, and 4W segments, where the absolute number of vehicles is high and early detection of SEs can prevent cumulative emission build-up.

6.3. Establishing LEZs

LEZs are designated areas where the entry of high-polluting vehicles, typically older or non-compliant with current emission standards, is restricted. These zones aim to improve local air quality by focusing on reducing tailpipe emissions.

Emission reduction potential: Global evidence suggests that LEZs can reduce PM and NO_x levels by 15%–30% within designated zones and accelerate fleet modernisation, as vehicle owners are incentivised to upgrade to cleaner alternatives to maintain access (Santos et al., 2019; Shin et al., 2024). In India, such zones are still in a nascent stage, with limited pilot implementations (e.g. in the Pimpri Chinchwad area of Pune). In the context of Punjab, the age-wise distribution of vehicles based on ground survey data shows a concentration of vehicles aged 10–15 years plying on roads. LEZs could play a crucial role in targeting high-emitting fleets operating in densely populated or industrial corridors.

Barriers, entry points, and way forward: Punjab's transport system is characterised by high inter-district and cross-state vehicle movement. Survey findings show that over 40% of the vehicles observed in major districts were registered elsewhere, and in Moga, nearly 95% of the vehicles were externally registered. This pattern suggests that conventional, city-centric LEZs may not effectively address Punjab's emission profile. Therefore, a multi-tiered strategy, comprising city-based, corridor-based, and cluster-level LEZs, may be more suitable.

City-based LEZs are most relevant for densely populated or tourist-centric cities, such as Amritsar, where reducing tailpipe emissions can directly enhance local air quality and public health. Implementation could be supported through designated parking hubs at the periphery, with last-mile connectivity provided by zero-emission vehicles. Collectively, these LEZs can regulate entry or apply differential tolling for vehicles below BS-VI standards, using Automatic Number Plate Recognition (ANPR) and FASTag-linked compliance systems at toll plazas and freight terminals.

Currently, there is no enabling provision that empowers state or local agencies to enforce such restrictions. A state-wide LEZ framework should, therefore, focus on integrating vehicle registration, PUC, and BS-compliance data with ANPR and GIS-based monitoring systems, linking LEZ access with incentives under scrappage, retrofitting, and electric mobility schemes.

6.4. Modal share shift

Punjab has 4 private freight terminals, 11 container rail terminals, 133 loading locations, and 209 unloading locations (Indian Railways, n.d.). This makes the state an ideal candidate for offloading freight loads to railways.

Punjab Logistics Infrastructure Ltd, a joint venture company with the Ministry of Railways and Punjab State Container and Warehousing Corporation Ltd (CONWARE), is setting up a Multi-Modal Logistics Park, providing cargo storage near industrial hubs in Jalandhar, Amritsar, Bhatinda, Sangrur, Patiala, Fatehgarh Sahib, and Hoshiarpur, and private freight terminal facilities for effortless rail-road connectivity. Additionally, the construction of two dedicated freight corridors is nearing completion, enabling the transportation of goods to and from the state.

We recommend building public-private partnership-based terminals with cost-sharing models to facilitate the development of freight terminals, particularly near busy junctions, and to improve their operational efficiency.

Furthermore, aggregation models that enable the transportation of small-scale and multiple commodity consignments in a single train should be promoted to enhance utilisation and reduce logistics costs (The Energy and Resources Institute, 2023).



7. Monitoring, Evaluation, and Learning (MEL) Framework for Implementation

Punjab's transport system is managed by state bodies, corporations, and local authorities, creating a distributed governance structure that benefits from shared understanding and coordinated action. The Transport Department, led by the State Transport Commissioner, serves as the central regulatory authority, overseeing licensing, registrations, taxation, and permits. It serves as the nodal agency for implementing and reviewing the Punjab State EV Policy. Complementing this, public transport operations are managed by Punjab Roadways (Punjab State Bus Stand Management Company Ltd or PUNBUS) and the Pepsu Road Transport Corporation, whose future strategies for integrating cleaner bus fleets are key to advancing clean transportation in the state.

While this multi-agency arrangement brings diverse strengths, it also creates gaps in implementation. Particularly, as clean air targets fall under the purview of urban local bodies and regulators, activities like fleet upgradation are not always aligned with clean air objectives. To support coherent strategies and ensure the effective implementation of the recommended measures, this section proposes a simple MEL framework to track progress in cleaning up Punjab's vehicular fleet and achieving measurable air-quality gains.

The MEL framework is a systematic approach that not only supports policy implementation but also helps monitor the long-term impacts of the interventions (World Bank, 2023; Wright, 2009). Broadly, it focuses on the following aspects:

- 1. Monitoring:** Regularly tracking the project to ensure that everything is going as planned and why.
- 2. Evaluation:** Assessing certain milestones to determine progress or outcomes.
- 3. Learning:** Using information from monitoring and evaluation to make better decisions for the present and the future.

Table 6 provides a suggested MEL framework for the transport sector in Punjab, including interventions such as scrappage, strategies for reducing emissions from trucks, and electrification.

Table 6: Proposed Monitoring, Evaluation, and Learning Framework

Category	Details and Key Questions
Theory of Change	Implementing targeted interventions to reduce emissions from super-emitters, especially in the heavy commercial vehicle (HCV) segment, through electrification, cleaner fuels, scrappage policies, retrofitting, and efficiency improvements will result in significant reductions in emissions from the on-road transportation sector, leading to overall improvement in air quality
Monitoring Questions	1. Are electric vehicle (EV) registration targets for buses being met?
	2. Is the scrappage policy for older HCVs and buses being implemented effectively?
	3. Are cleaner fuel options (e.g. compressed natural gas [CNG], electricity, and liquefied natural gas [LNG]) increasing among new vehicle registrations?
	4. Are retrofitting and anti-tampering measures in place for ageing vehicles?
Purpose/Rationale	Reduce air pollution from HCVs by transitioning to clean fuel technologies, enforcing vehicle scrappage, and improving freight efficiency.
Success Criteria	1. 3%–9% of buses transitioned to EVs or 2%–5% to CNG by 2030.
	2. 30% reduction in PM _{2.5} emissions by 2030.
	3. Mandatory scrappage policy should be in place for HCVs older than 10 years, and at least 10% of eligible HCVs should be scrapped by 2030 under a lower-adoption scenario.
Data Sources	1. Vehicle registration records
	2. Scrappage policy compliance reports and scrappage certificates issued
	3. Fleet emission data (PM _{2.5} and NO _x)
	4. Air quality monitoring data or source apportionment studies
	5. EV infrastructure reports (charging stations)
Indicators	1. Percentage of EVs and CNG vehicles among HCV registrations + EV charging stations and CNG pumps
	2. Percentage reduction in PM _{2.5} and NO _x emissions from HCVs
	3. Percentage increase in rail freight (vs road)
	4. Percentage of public transport vehicles using clean fuels
Frequency of Reporting	Annual review of vehicle registrations, air quality data, and scrappage compliance
	Quarterly updates on EV infrastructure (charging points per 20 EVs)
Responsible Authority	Transport Department; Punjab Pollution Control Board; and local transport authorities including Punjab Roadways (Punjab State Bus Stand Management Company Ltd or PUNBUS), Pepsu Road Transport Corporation, and Punjab Municipal Infrastructure Development Company (PMIDC)

Category	Details and Key Questions
Activities and Mechanisms for Change	1. Implementation of scrappage incentives and enforcement of scrappage rules for older HCVs
	2. Policy support for EV charging infrastructure expansion
	3. Financial incentives for fleet retrofitting and use of cleaner fuels
	4. Investment in rail freight infrastructure
Enabling Factors	1. Government subsidies and incentives
	2. Private and government scrappage yards
	3. Availability of cleaner fuel alternatives
Short-Term Outcomes	1. Increase in registrations of CNG and LNG HCVs
	2. Higher scrappage compliance among older HCVs
	3. Improved public awareness of clean fuel advantages
Medium-Term Goals	1. Reduction in HCV and bus emissions
	2. Increase in freight traffic on rail
	3. Adoption of anti-tampering measures and regular maintenance standards for all HCVs
Risk Management	1. Reluctance from vehicle owners to scrap older vehicles
	2. Potential under-development of EV infrastructure in remote areas
	3. Difficulty in tracking and enforcing anti-tampering measures
Learning and Adjustments	Monitoring trends in EV and CNG adoption rates, vehicle scrappage compliance, and feedback from HCV operators on maintenance requirements
Sustainability Considerations	1. Development of a circular economy for EV battery recycling
	2. Expansion of rail infrastructure as a cleaner alternative for freight transport
Long-Term Impact Goals	1. Achieve a low-emission, sustainable transport system for HCVs by 2035
	2. Reduce fossil fuel reliance by maximising clean fuel adoption and emission reductions for heavy commercial fleets.

8. Conclusion

Transport emission challenges in Punjab extend beyond NACs, driven by a small subset of high-VKT, diesel-heavy freight vehicles that disproportionately contribute to $PM_{2.5}$ levels. This high-emitter paradox, wherein most vehicles comply with emission norms, but a few poorly maintained HCVs dominate overall emissions, highlights the need for targeted interventions rather than uniform fleet-wide measures.

Focused policies on SEs, including strengthened inspection, scrappage, and retrofitting, can deliver significant emission reductions. Extending a similar regulatory focus to non-road diesel vehicle sources, such as agricultural machinery, and enhancing real-time monitoring and enforcement will further amplify the impact.

A coordinated, state-level emission management strategy, supported by active on-road fleet data and inter-district cooperation, is crucial to achieving sustained air quality improvement and accelerating Punjab's clean transport transition.



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10. Appendices

Appendix A: Methodology

1. Emission estimation methodology

The following equation is used to estimate Punjab transport emissions for the base year 2024. The methodology used for emission estimation development is based on the vehicle fleet for each year; annual kilometres run for each category of vehicle, and respective emission factors based on the vehicle's Bharat Stage category.

$$E_h = \sum (Veh_j \times D_j) \times EF_{i,j,km}$$

Where Veh_j is the on-road vehicle count after multiplying the registered vehicles by the survival fraction rate for each year, considering 2022 as the base year; D_j is the distance travelled annually in kilometres; and EF is the emission factor for vehicle type 'i' and fuel 'j' per kilometre.

To estimate state-wise and district-wise emissions for the base year 2024, activity data are obtained from the Vahan portal (Dashboard, Vahan Sewa), and emission factors are obtained from the Automotive Research Association of India (ARAI). From the Vahan portal, the annual registered vehicle count for each district was downloaded from 2000 to 2024. Vehicles were categorised into two-wheelers (2Ws), three-wheelers (3Ws; auto-rickshaws), four-wheelers (4Ws; both public and private cars), light commercial vehicles (LCVs; pick-ups having gross vehicle weight < 3.5 tonnes), and heavy commercial vehicles (HCVs; buses, trucks, and trailers).

The survival fraction is used to calculate the age-wise distribution of the vehicle fleet (Pandey & Venkataraman, 2014).

$$Sf(i, a) = \frac{1}{1 + e^{[\hat{a}(1 - \frac{a}{L_{50}})]}}$$

where Sf = survival rate, a = age, i = vehicle type, $\hat{a}$ = is the form factor indicating the beginning of substantial retirement, and L_{50} = age at which 50% of vehicles have retired.

The category-wise annual VKT was taken from the stakeholder consultations and literature. Emission factors for diesel-fuelled vehicles for pollutants including particulate matter (PM), nitrogen oxides (NOx), and black carbon (BC) conforming to Indian standards from BS-I to BS-III, were derived from laboratory tests based and values prescribed by ARAI. For BS-IV and BS-VI vehicles, laboratory-tested emission factors are not available. Based on stakeholder consultations, the emission norms have been used as a substitute. These norms specify the maximum allowable emissions from a vehicle and are outlined in the Indian Emission Regulation, released by ARAI in 2021.

2. Vehicular emission factors: Data sources and assumptions

Vehicular emission factors are critical for estimating emissions from diverse vehicle categories. These factors are typically categorised by vehicle type, fuel type, and applicable emission standards, such as Bharat Stage (BS) norms. In India, the

ARAI- an autonomous institution under the Ministry of Heavy Industries-provides standard emission factors. These are derived from laboratory tests conducted using standardised drive cycles and account for pollutants including CO, HC, NO, and PM, reported in grams per kilometre (g/km).

3. Data availability and limitations

Emission factors provided by ARAI cover BS-I to BS-III vehicles and certain categories under BS-IV. Indian Emission Regulation (ARAI, 2021) also includes emission norms for BS-IV and BS-VI vehicles. Tables A1–A5 depict the emission factors for BS-I–VI vehicles compiled from ARAI data (Sarkar et al., 2026). However, these norms, which represent permissible emission limits rather than empirically derived emission factors, were not uniformly available across all vehicle-fuel combinations. To address these data gaps, expert consultations were conducted to establish a methodology for filling in the missing emission factors using logical assumptions and regulatory guidance.

4. Colour-coded legend for emission factors tables

To enhance interpretability, the following colour coding scheme was used in the emission factors tables:

- **Green cells:** Laboratory-tested emission factors from ARAI (2007, 2018)
- **Blue cells:** Assumptions as per ARAI 2021 guidelines: for gross vehicle weight (GVW) > 3.5 tonnes, CNG assumed to be equivalent to diesel, and for GVW < 3.5 tonnes, CNG assumed to be equivalent to petrol.
- **Pink cells:** Emission norms as per Indian Emission Regulation (ARAI, 2021)
- **Yellow cells:** Values derived based on assumptions owing to data unavailability.

5. Bharat Stage-wise methodological notes

BS-I: Emission factors were primarily derived from ARAI’s 2007 laboratory tests. For CNG-fueled trucks where data were lacking, diesel vehicle emission factors were used per ARAI’s 2021 guidelines for vehicles above 3.5 tonnes. **However, for LCVs, the emission factor for pollutant CO was not available; the emission factor corresponding to 4-wheeler petrol and CNG vehicles was considered for LCVs based on stakeholder consultations.**

Table A1: Bharat Stage-I emission factors

Vehicle categories	NO _x (g/km)			CO (g/km)			PM ₁₀ (g/km)			PM _{2.5} (g/km)		
	Diesel	Petrol	CNG	Diesel	Petrol	CNG	Diesel	Petrol	CNG	Diesel	Petrol	CNG
2 W		0.27			1.65			0.035			0.03	
3 W	0.69	0.2	0.5	2.09	1.37	1	0.347	0.045	0.015	0.295	0.038	0.013
4 W	0.84	0.21	0.74	0.72	2.74	0.06	0.19	0.006	0.006	0.162	0.005	0.005
Buses	6.77		6.21	3.97		3.72	1.075		0.044	0.914		0.037
LCV	2.12		5.7	3.66		0.06	0.475		0.058	0.404		0.049
Trucks	9.3		9.3	6		6	1.24		1.24	1.054		1.054

BS-II: Emission factors were primarily derived from ARAI's 2007 laboratory tests. CNG truck emission factors were assumed to be equivalent to those of diesel trucks, as per regulatory guidelines. **However, for LCVs, the emission factor for pollutant CO was not available for both petrol and CNG; the emission factor corresponding to 4-wheeler petrol and CNG vehicles was considered for LCVs based on stakeholder consultations.**

Table A2: Bharat Stage-II emission factors

Vehicle Categories	NO _x (g/km)			CO (g/km)			PM ₁₀ (g/km)			PM _{2.5} (g/km)		
	Diesel	Petrol	CNG	Diesel	Petrol	CNG	Diesel	Petrol	CNG	Diesel	Petrol	CNG
2 W		0.263			1.9			0.005			0.004	
3 W	0.877		0.174	3.267		1.107	0.434		0.567	0.369		0.482
4 W	0.28	0.09	0.74	0.06	0.84	0.06	0.015	0.002	0.006	0.013	0.002	0.005
Buses	6.53		6.21	3.92		3.72	0.3		0.044	0.255		0.037
LCV	2.12	5.7	5.7	3.66	0.84	0.06	0.475	0.058	0.058	0.404	0.049	0.049
Trucks	8.63		8.63	4.13		4.13	0.42		0.42	0.357		0.357

BS-III: Laboratory-tested emission factors from ARAI (2007, 2018) were utilised. Emission equivalence guidelines from the Indian Emission Regulation (ARAI, 2021) were applied to CNG trucks. **For LCVs, the emission factor for Particulate Matter (PM) was not available; the emission factor corresponding to 4-wheeler CNG vehicles was considered for LCVs based on stakeholder consultations.**

Table A3: Bharat Stage-III emission factors

Vehicle Categories	NO _x (g/km)			CO (g/km)			PM ₁₀ (g/km)			PM _{2.5} (g/km)		
	Diesel	Petrol	CNG	Diesel	Petrol	CNG	Diesel	Petrol	CNG	Diesel	Petrol	CNG
2 W		0.199			1.315			0.002			0.002	
3 W	0.717		0.979	0.396		0.869	0.14		0.079	0.119		0.067
4 W	0.292	0.04	0.786	0.349	0.984	3.434	0.033	0.001	0.001	0.028	0.001	0.0085
Buses	5.172		15.156	4.735		9.221	0.482		0.023	0.41		0.019
LCV	1.692	0.21	0.21	1.435	5.22	5.22	0.121	0.001	0.001	0.103	0.0085	0.0085
Trucks	8.353		8.353	4.857		4.857	0.399		0.399	0.339		0.339

BS-IV: Tested emission factors were available for select categories only (e.g., diesel 4-wheelers and LCVs, tested in 2018). For other categories, emission norms from the Indian Emission Regulation (ARAI, 2021) were used as proxy emission factors.

However, for 2-wheelers, 3-wheelers, and LCVs, particulate matter emission norms were not available. In such cases, **the 4-wheeler petrol emission factors were applied to 2-wheelers, while the CNG-based 4-wheeler emission factors were applied to both 3-wheelers and CNG-powered LCVs.** The emission factors were missing for petrol-based LCVs. For CNG-fuelled LCVs, emission factors were assumed to be equivalent to petrol counterparts, as per regulatory guidelines.

Table A4: Bharat Stage-IV emission factors

Vehicle categories	NO _x (g/km)			CO (g/km)			PM ₁₀ (g/km)			PM _{2.5} (g/km)		
	Diesel	Petrol	CNG	Diesel	Petrol	CNG	Diesel	Petrol	CNG	Diesel	Petrol	CNG
2W		0.39			1.4			0.002			0.0017	
3W	0.38		0.94	0.38		0.94	0.0425		0.001	0.036		0.00085
4W	0.411	0.068	0.034	0.299	0.825	1.021	0.023	0.002	0.001	0.019	0.0017	0.00085
Buses	5.81		1.558	2.49		1.781	0.033		0.013	0.028		0.011
LCV	0.961	0.11	0.11	0.39	2.27	2.27	0.057	0.001	0.001	0.048	0.00085	0.00085
Trucks	5.81		1.558	2.49		1.781	0.033		0.013	0.028		0.011

BS-VI: Emission norms from the Indian Emission Regulation (ARAI, 2021) were uniformly adopted as proxy emission factors. However, for CNG-fuelled 3-wheelers, where data were lacking, petrol vehicle emission norms were used as per ARAI's 2021 guidelines for vehicles less than 3.5 tonnes.

Table A5: Bharat Stage-VI emission factors

Vehicle categories	NO _x (g/km)			CO (g/km)			PM ₁₀ (g/km)			PM _{2.5} (g/km)		
	BS VI			BS VI			BS VI			BS VI		
	Diesel	Petrol	CNG	Diesel	Petrol	CNG	Diesel	Petrol	CNG	Diesel	Petrol	CNG
2W		0.06	0.06		1	1		0.005	0.005		0.004	0.004
3W	0.16		0.13	0.22		0.44	0.025		0.005	0.0213		0.004
4W	0.08	0.06	0.06	0.5	1	1	0.005	0.005	0.005	0.004	0.004	0.004
Buses	0.664		0.664	2.49		2.49	0.017		0.017	0.014		0.014
LCV	0.125	0.082	0.082	0.74	2.27	2.27	0.005	0.005	0.005	0.004	0.004	0.004
Trucks	0.664		0.664	2.49		2.49	0.017		0.017	0.014		0.014

6. Emission norms for agricultural diesel tractors and implementation timeline

Stage	Month of implementation	Engine power (kW)	Emission (g/kWh)				
			CO	HC	NO _x	HC+ NO _x	PM
I	October 1999	All	14	3.5	18		
II	June 2003	All	9	-	-	15	1
III	October 2005	All	5.5	-	-	9.5	0.8
IIIA	April 2010	<8	5.5	-	-	8.5	0.8
		8 to <19	5.5	-	-	8.5	0.8
		19 to <37	5.5	-	-	7.5	0.6
	April 2011	37 to <56	5	-	-	4.7	0.4
		56 to <75	5	-	-	4.7	0.4
		75 to <130	5	-	-	4	0.3
		130 to <560	3.5	-	-	4	0.2
	IV	January 2023	<8	5.5	-	-	8.5
8 to <19			5.5	-	-	8.5	0.8
19 to <37			5.5	-	-	7.5	0.6
37 to <56			5	-	-	4.7	0.025
56 to <130			5	0.19	0.4	-	0.025
130 to <560			3.5	0.19	0.4	-	0.025

Source: ICRA Tractor Industry Check (n.d.); Ministry of Road Transport and Highways (2017); Shao (2016)

7. Super-emitters

A. What are super-emitters?

Some HCVs might emit much more than the recommended standards owing to poor maintenance or age. These are called super-emitters. Their mean emission factor is estimated to be 4–11 times higher than that of non-super-emitters (Prakash et al., 2020).

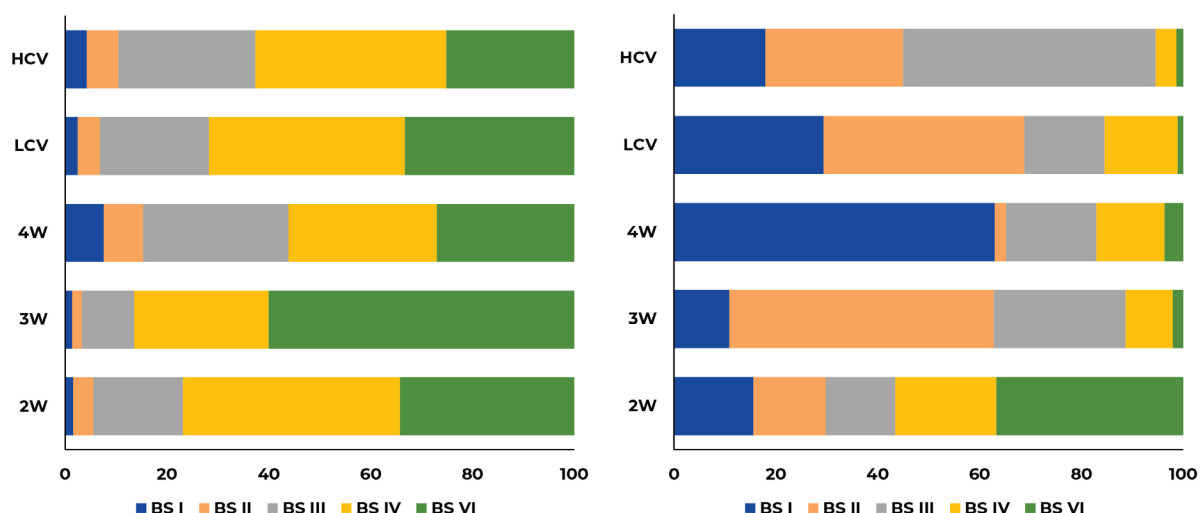
B. How were the calculations done?

All vehicles older than 15 years and 17% of the fleet from each newer age group were considered super-emitters. This resulted in an estimated 23% of the on-road fleet in 2022 being super-emitters, compared with 25% in Prakash et al. and 43% in Debbarma et al. $PM_{2.5}$ emissions of super-emitters were estimated using the emission factor multipliers compiled by Prakash et al. and are reported for the base year (2024) in Appendix B. Emissions were also estimated for the years 2030 and 2035 by including super-emitters (Appendix B).

Appendix B: $PM_{2.5}$ Emissions

BS-wise vehicle fleet share and emission share in Punjab for 2024 (with SEs):

Figure B1: (a) BS-wise fleet share and (b) their emission share in Punjab for 2024 (including SEs)



District-wise PM_{2.5} emissions for 2024

Figure B2: District-wise % share of SE and NSE in (a) the total vehicle fleet and (b) their PM_{2.5} emissions for 2024

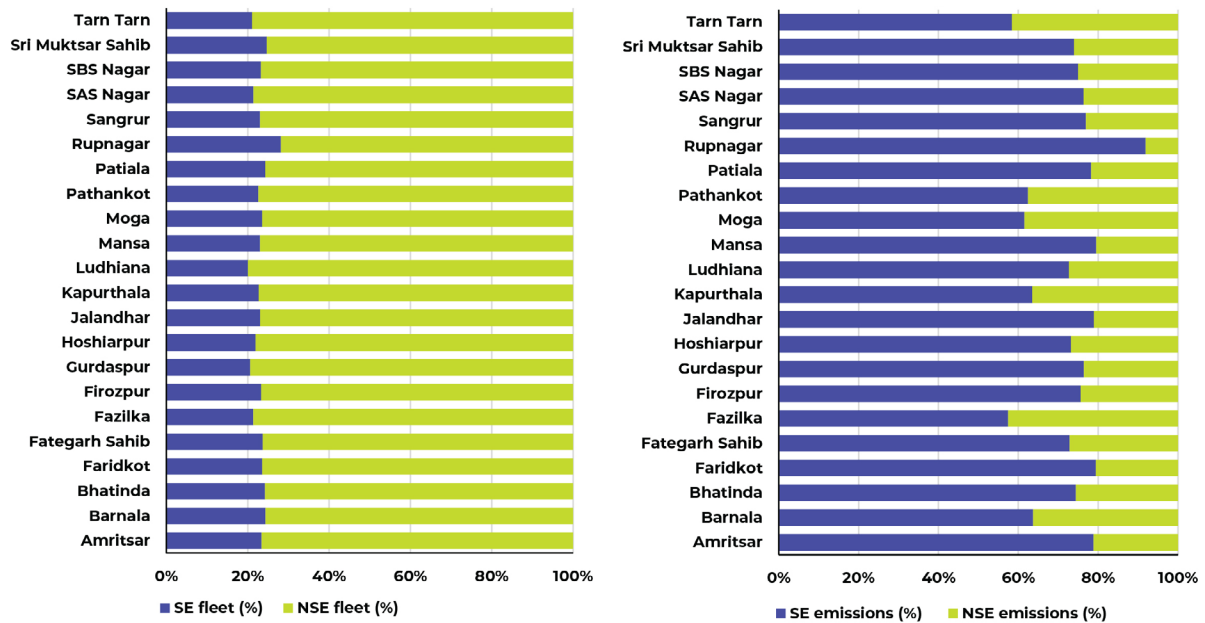
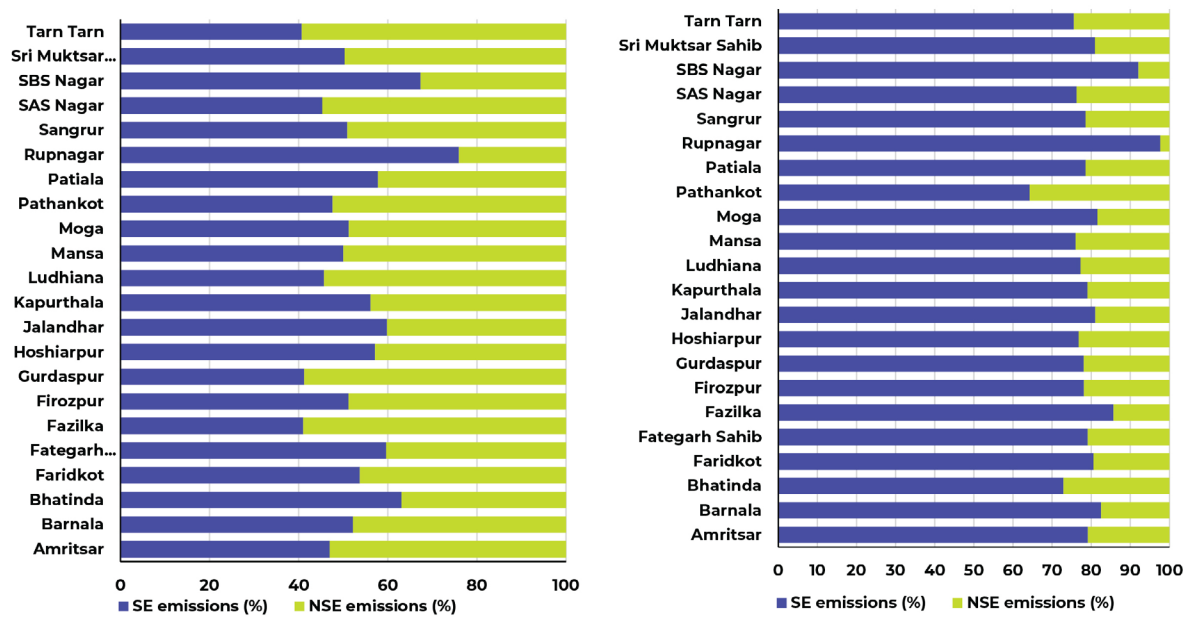


Figure B3: District-wise PM_{2.5} emissions (%) of SE and NSE in (a) 4W and (b) HCVs fleet for 2024



Future Projections

Year 2030

Figure B4: District-wise % share of SE and NSE in (a) the total vehicle fleet and (b) their $PM_{2.5}$ emissions projected for 2030

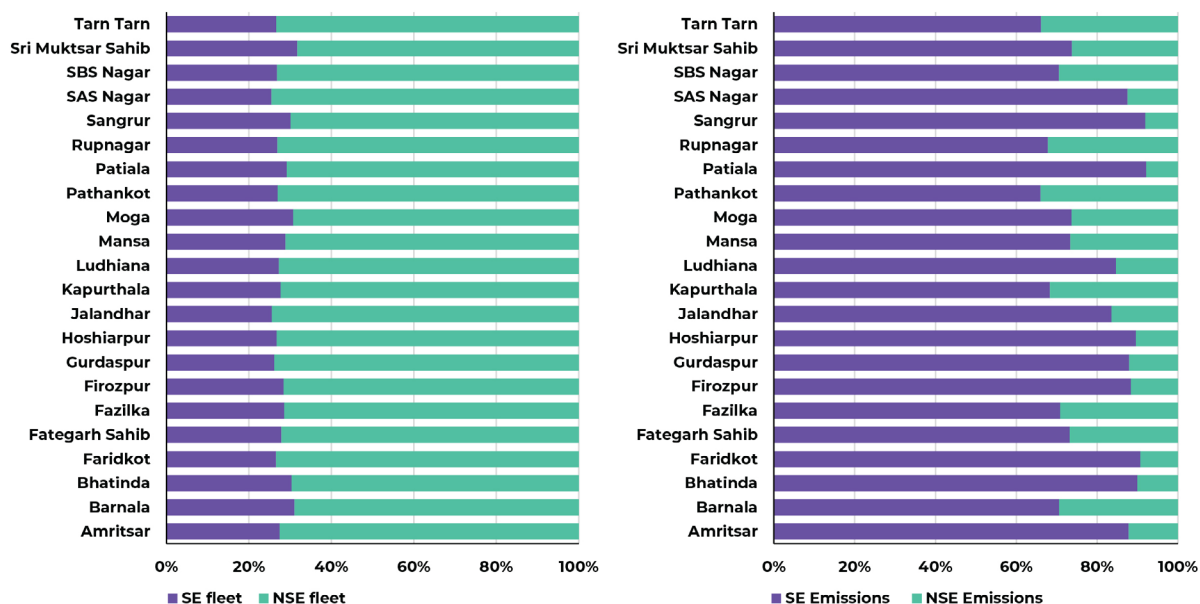
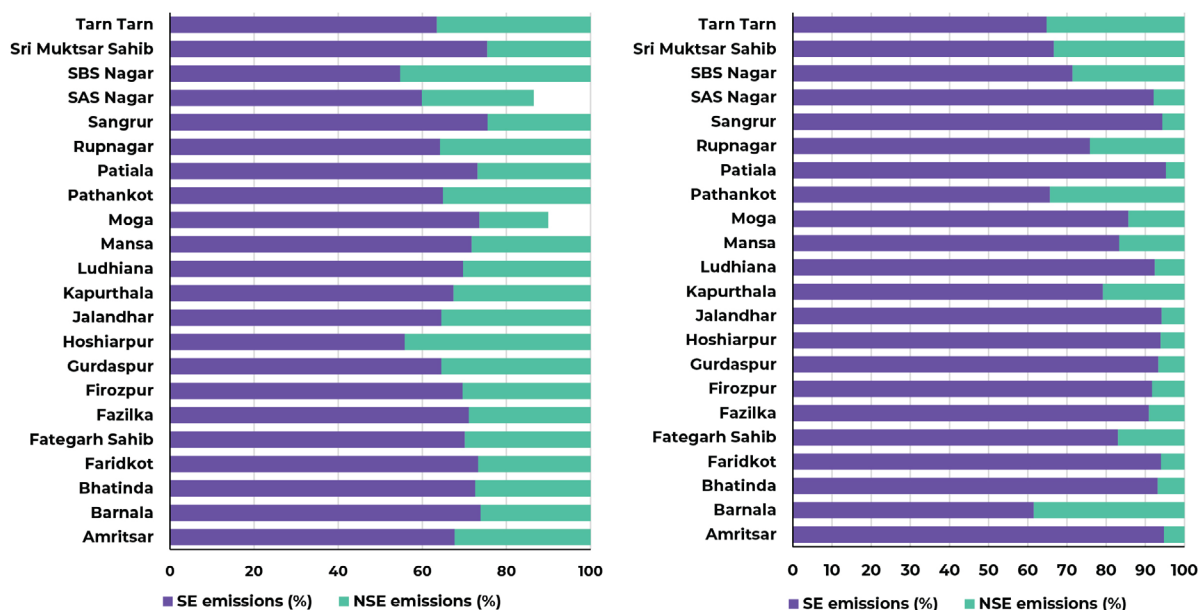


Figure B5: District-wise $PM_{2.5}$ emissions (%) of SE and NSE in (a) 4Ws and (b) HCVs fleet for 2030



Year 2035

Figure B6: District-wise % share of SE and NSE in (a) the total vehicle fleet and (b) their $PM_{2.5}$ emissions (%) projected for 2035

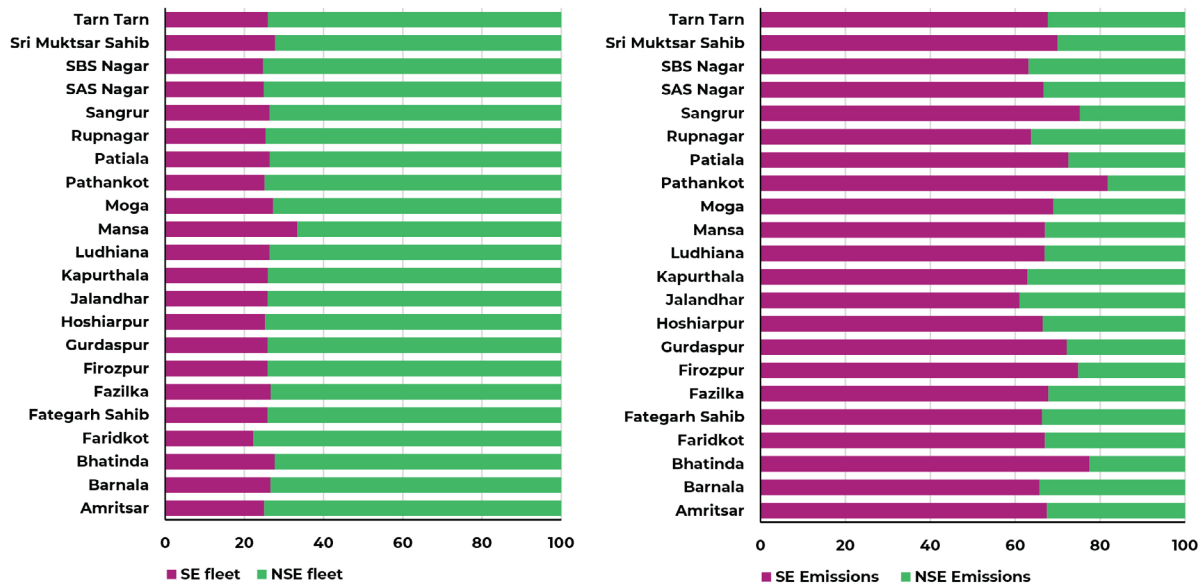
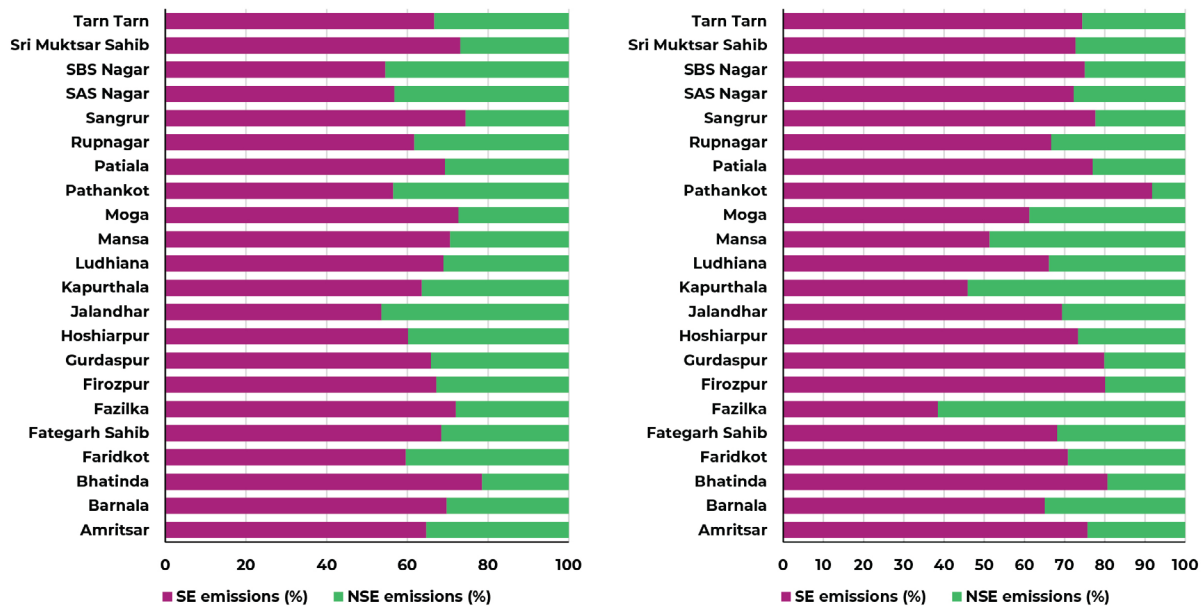
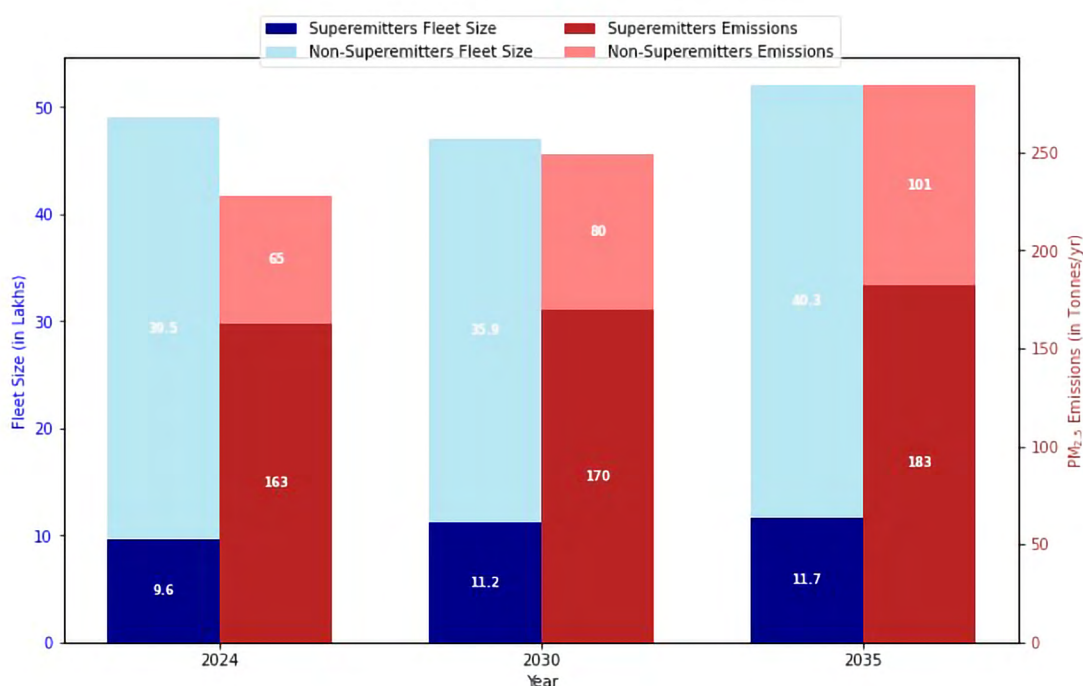


Figure B7: District-wise $PM_{2.5}$ emissions (%) of SE and NSE in (a) 4Ws and (b) HCVs fleet for 2035



Unlike 4Ws and HCVs, $PM_{2.5}$ emissions from 2Ws (Figure B8) show a modest increase from 228 tonnes/year in 2024 to 284 tonnes/year in 2035. This reflects continued fleet growth and the persistence of petrol 2Ws under the BAU scenario, where EV uptake remains limited. Although BS-VI norms improve per-vehicle emission factors, 2Ws lack advanced after-treatment (e.g. DPFs), so aggregate emissions rise slightly as the fleet expands. SEs consistently contribute the majority (~70%) of 2W emissions across all years, but their absolute scale remains small compared to HCVs and 4Ws. For $PM_{2.5}$ specifically, therefore, 2Ws are not a priority sector for control in the BAU case, and targeting SEs in HCVs would yield far greater benefits.

Figure B8: Two wheelers' emissions and fleet size (2024–2035)

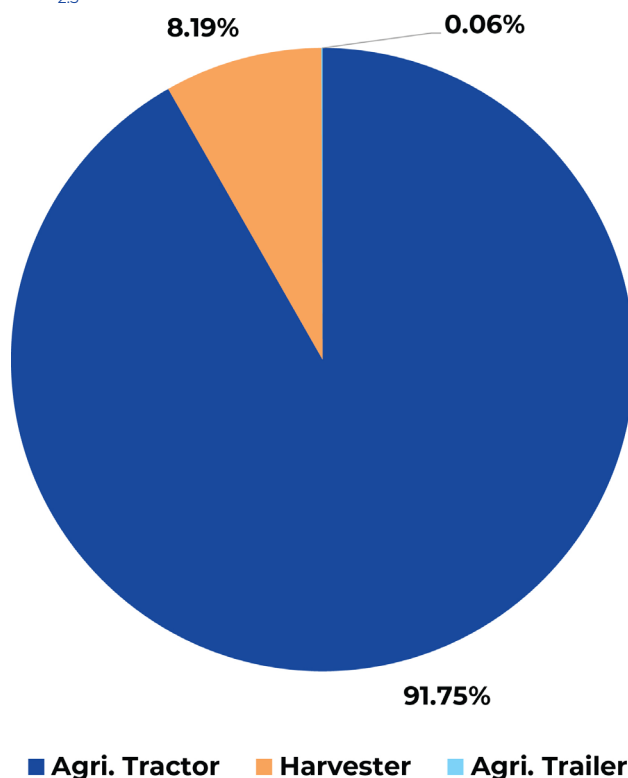


District-wise results (Appendix B, Figures B4–B7) for 2030 and 2035 confirm these trends. SEs remain widespread (typically $\geq 20\%$ of fleets) and account for the majority of emissions across all districts, whether or not they have designated NACs. Whether for total fleet, 4Ws or HCVs, SE dominance is consistent, reinforcing that the phenomenon is systemic rather than localised. If Punjab can systematically target SEs either through in-use testing, roadside checks, load regulation, scrappage or retrofits, the state can multiply the benefits of fleet renewal and achieve deeper reductions by 2030-2035.

PM_{2.5} emissions share from agricultural vehicles in Punjab for 2024

Figure B9 on PM_{2.5} emissions from farm vehicles shows that Agricultural Tractors are the primary polluters, accounting for 91.75% of emissions. Harvesters account for the remaining significant share at 8.19%, while Power Tillers and Agricultural Trailers contribute negligibly. This data suggests that emission-reduction efforts in this sector must focus on agricultural tractors.

Figure B9: $PM_{2.5}$ emissions share from agricultural vehicles in Punjab for 2024



Appendix C: Ground surveys details

- The six districts selected for the survey are detailed below:
- Patiala: High transport emissions contribution and shares a border with Chandigarh
- Ludhiana: High transport emissions contribution and Industrial cluster
- Amritsar: High transport emissions contribution and RAAHI project
- Jalandhar: High emission contribution and Industrial cluster
- Moga: Moderate economic condition (to check movement of HCVs)
- Hoshiarpur: Border state with Himachal Pradesh, therefore influx of tourist vehicles and an industrial district



Figure C1 : Survey locations in Punjab

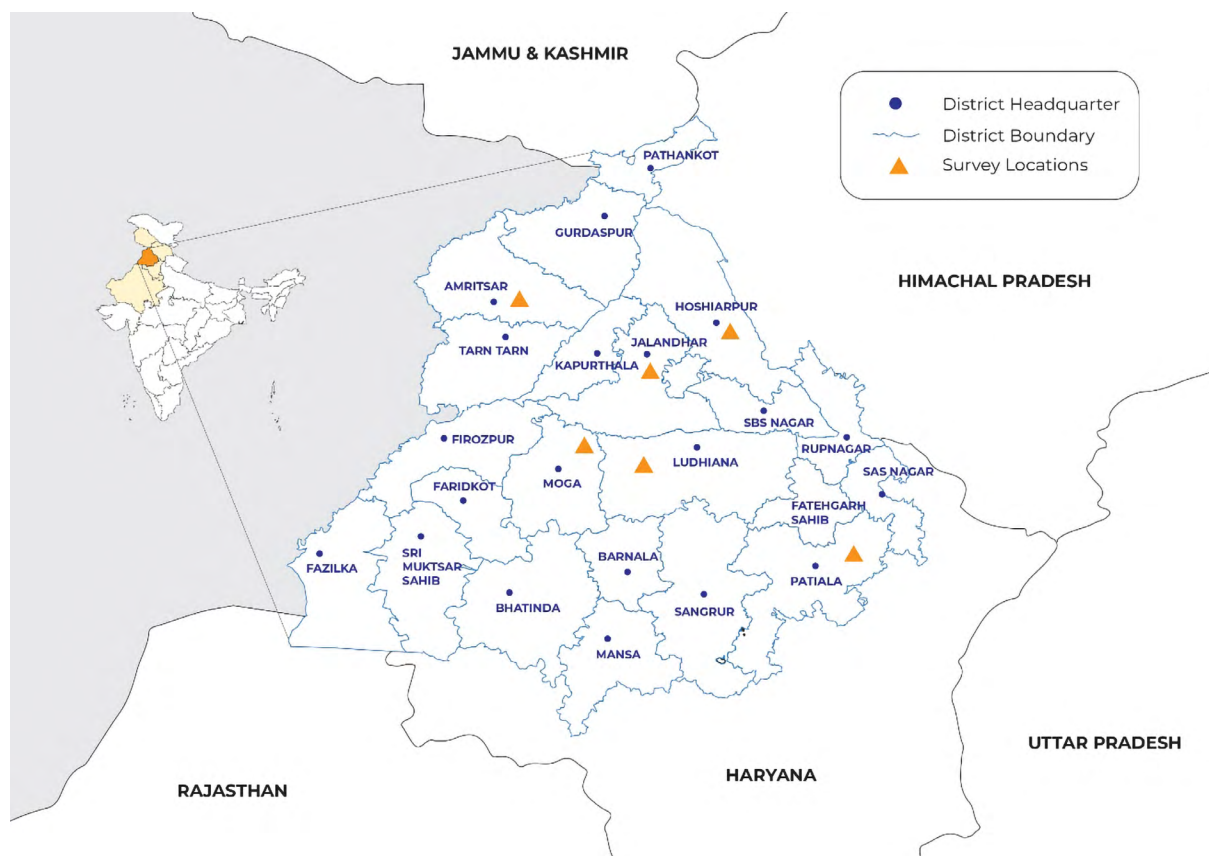


Table C1: Summary of survey logistics (location, sample size, and dates of survey).

S.No.	District	Dates of survey	Locations	Sample size	Total sample size	Coordinates
1.	Ludhiana	19.08.2025 to 25.08.2025	HP Petrol Pump, Chaukiman, Ludhiana, Punjab 142023	543	2164	30.82, 75.56
			Ladowal Toll plaza, Talwandi Kalan, Punjab 141008	805		30.99, 75.79
		26.08.2025 to 1.09.2025	Chaukiman/Gurhe Toll plaza, RHGR+2R6, Ferozepur – Ludhiana Rd, Punjab 142023	816		30.83, 75.59
2.	Patiala	30.08.2025 to 05.09.2025	HP Petrol Pump, Ground Floor, Mall Rd, Fateh Colony, Patiala, Punjab 147001	966	1609	30.33, 76.39
		30.08.2025 to 05.09.2025	Dhareri Jattan Toll Plaza, 9FRX+JH8, NH 7, Punjab 140701	643		30.39, 76.5
3.	Jalandhar	06.09.2025 to 2.09.2025	1. Indian Oil petrol pump, Ground Floor, GT Road Khajurla, Road, Banga, Phagwara, Punjab 144401	565	1533	31.28, 75.68
		06.09.2025 to 13.09.2025	1. Dhillwan Toll Plaza, F8XF+M6J, next to toll palaza, Kapurthala, Punjab 144601.	968		31.50, 75.32

S.No.	District	Dates of survey	Locations	Sample size	Total sample size	Coordinates
4.	Amritsar	28.09.2022 to 01.10.2025 and 04.10.2025 to 06.10.2025	1. HP Petrol Pump, Ground Floor, Court Rd, Crystal Chowk, INA Colony, Amritsar, Punjab 143001	519	3053	31.64, 74.87
			Chiddan Toll Plaza, National Highway 1, Chhiddan, Punjab 143107.	908		31.62, 74.69
			Waryam Nangal Toll Plaza, National Highway 15, Waryam Nangal, Punjab 143502	853		31.73, 75.04
			2. Bus stand, JVHM+WHQ, Mehar Pura, Amritsar, Punjab 143001	512		31.63, 74.88
			3. Attari Border - Vehicle Parking JH4H+MHP, Wagah, Hardo Rattan, Punjab 143108	261		31.61, 74.58
5.	Moga	25.08.2025 to 31.08.2025	HP Petrol Pump, Ground Floor, Dhuandhar, Moga, Daudhar, Punjab 142053	542	1414	30.72, 75.34
		26.08.2025 to 01.09.2025	Chak Bamniya toll plaza, Moga - Jalandhar Rd, Thamunwal, Rampur, Punjab 142058	872		31.02, 75.30
6.	Hoshiarpur	16.10.2025 to 19.10.2025	Mangarh toll plaza, QPC9+2X5 Mangarh, Punjab 146001	525	840	31.77, 75.72
			Bus stand, GWJ2+222 Hoshiarpur, Punjab 146001	315		31.53, 75.90

Figure C2: Comparison of survival fractions (SFs) based on the literature and survey data for HCVs in Punjab
(surv1 = literature-based SF used in the study)

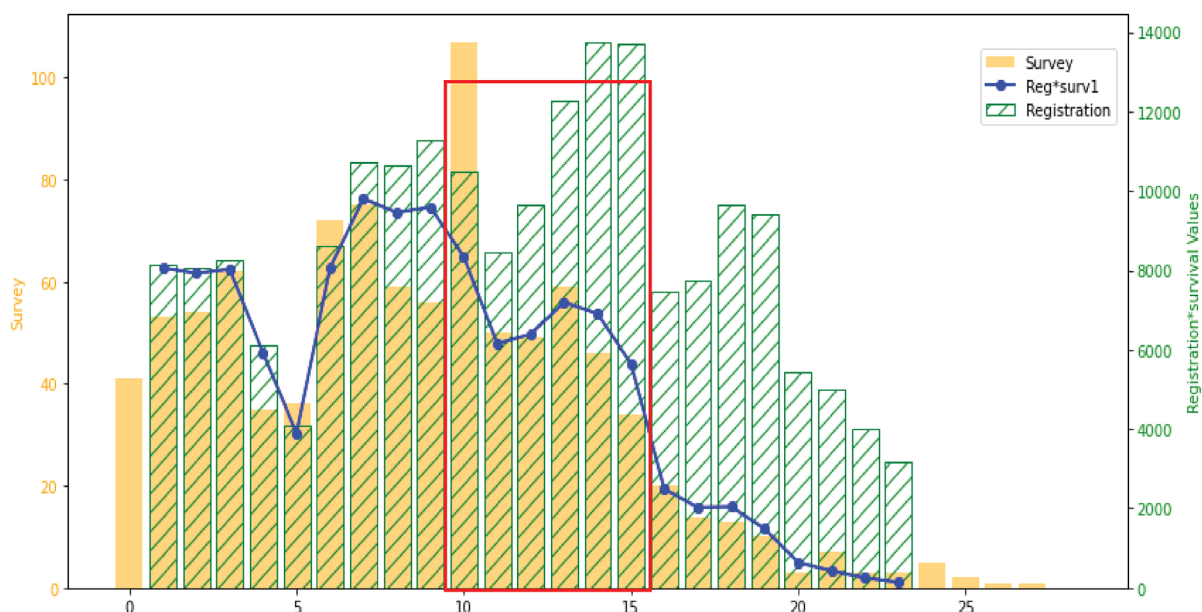


Table C2: Toll booth survey form and fuel pump survey form

S. No.	
Date	
Time Slot (Peak/Non-Peak)	
Location (District/Fuel Station)	
Direction (Entering/Exiting Punjab) ¹	
Vehicle Type (2W/3W/Car/LCV/Bus/Truck/etc.)	
Registration Number	
Registration State	
Registration Year (if visible)	
Fuel Type (Diesel/Petrol/CNG/EV)	
Is Chandigarh Registered? (Yes/No)	
If yes, how frequent? D/W/M/Y	
Estimated Daily Km (driver input)	
Total KM Travel as per Odometer	
Origin District/State (if known)	
Destination District/State (if known)	
Remarks	

¹ Applicable only for toll booth survey

Appendix D: Existing policy Interventions

Table D1: Details of existing policies

State-level Initiatives	
Policy name	Punjab Vehicle Scrappage Notification, 2023
Description	Vehicle scrapping is voluntary. The end-of-life age limit is 8 and 15 years for transport and non-transport vehicles, respectively. Provide 15%–20% road tax compensation for scrapping old vehicles. A green tax is applied to end-of-life vehicles The target aimed to scrap 2,950 government vehicles before February 2024.
Benefit	Policy is instrumental in removing super emitters from road.
Current Progress	From Aug 2022 to Oct 2025: Total 5 RVSFs in Punjab Certificate of Deposit signed: 1,013 (government) and 3,583 (private) Certificate of Vehicle Scrapped signed: 771 (government) and 2,491 (private)
Barrier	Insufficient infrastructure, weak implementation mechanism, and inadequate incentives
Policy name	Punjab Electric Vehicle Policy, 2022
Description	Policy launched in 2022 and implemented for a period of 3 years. Aimed to have 25% of annual vehicle registrations as EVs by the end of the policy period. Provide incentives in addition to national level policies for e-2W, e-3W, e-bicycles, e- LCVs and e-buses Aimed to develop charging infrastructure in the State and Green zones and Green transport corridors in target cities 35 e-goods vehicles & 21 other EVs (excluding 2W, 3W, 4W, ambulances, and construction equipment) sold in Punjab (2021-22). As per Vahan dashboard, 710 e-tractors registered in India as of October 2025 (85 in Punjab).
Benefit	Accelerate Punjab's shift towards electrification and green mobility.
Current Progress	EV registration increased from 14,059 in 2022 to 44,473 in 2024. As of October 2025, a total of 1.28 lakh EVs have been registered in Punjab.
Barrier	Exclusion of freight from the policy and insufficient incentives Technological uncertainties. Poor infrastructure & lack of coordinated incentives and roadmaps for scaling EV in agriculture and HDVs.

Policy name	Rejuvenation of Auto-rickshaws in Amritsar through Holistic Intervention (RAAHI), 2019
Description	Piloted in Amritsar Mandatory scrapping of diesel autos and replacing them with e-autos Provide financial incentives of INR 1.25 lakh and scrapping incentives of INR 15,000. Promotes empowerment. Target of replacing 7,500 diesel autos.
Benefit	Improves electric mobility and strengthens last-mile connectivity.
Current Progress	1,200 autos have shifted to e-autos as of August 2025 200 pink autos allocated to women
Barrier	Insufficient cross-departmental coordination, high up-front costs of E-autos, inadequate financial incentives or support framework, insufficient infrastructure (charging stations, registration support), low awareness of the scheme, and resistance to change from existing fleets.
National-level schemes relevant to Punjab	
Policy name	Auto Fuel Vision & Policy 2025, 2014
Description	National-level policy Provides a roadmap for controlling fuel quality, setting emission standards for vehicles, and promoting transition to clean fuels Leapfrogged from BS-IV to BS-VI in 2020 to align with global best practices
Benefit	Significant reduction in PM and NO _x emissions from vehicular exhaust
Current Progress	New BS VI standards adopted in Punjab. However, a large portion still consists of BS II, BS III & BS IV vehicles.
Barrier	Inadequate contextualised strategy, lack of coordination between fuel policy and scrappage policy and weak enforcement of vehicle inspection regime
Policy name	Guidelines for Expansion of City Gas Distribution Network, 2013
Description	National-level policy Provide tax incentives and develop CNG infrastructure. Targeted to install 18,336 CNG stations by 2034
Benefit	Lowering PM emissions compared to petrol and diesel fuels.
Current Progress	11 states, including Punjab, have notified the city gas distribution policy Total 152 CNG stations in Punjab as of 2022-23
Barrier	Inadequate fleet incentives and insufficient infrastructure

Policy name	PM eBus Sewa Scheme, 2023
Description	The scheme aims to deploy 10,000+ e-buses across India under public-private partnerships (PPPs; GCC model) Budget INR 3,435.33 crore
Benefit	Accelerate EV penetration in public transport.
Current Progress	347 e-buses sanctioned for Punjab- Amritsar (100), Ludhiana (100), Jalandhar (97), Patiala (50). Out of the total budget, INR 45.11 crore is allocated for civil and charging infrastructure.
Barrier	Slow depot development and concession finalisation. Dependence on OEMs/operators. Limited institutional capacity at the Public Transport Authority (PTA) level.
Policy name	Faster Adoption & Manufacturing of Electric Vehicles in India (FAME-II, 2019)
Description	Flagship scheme to accelerate EV adoption across India The scheme was in phase 2 and was being implemented for a 3-year period till March 2024. Outlay: INR 11,500 crore
Benefit	Accelerated EV adoption in the transport sector
Current Progress	High penetration of e-2Ws and e-rikshaws in India, with 8049 (2022-23) and 7624 (2023-24) e-2Ws registered. Subsidy reduced from 40% to 15% on the ex-factory price. Punjab has progressed mainly in 2Ws & 3Ws, while other vehicle types remain unaffected.
Barrier	Weak formal transit electrification. Lack of targeted incentives for informal operators. Inadequate charging infrastructure and lack of e-rikshaw zones.
Policy name	Sustainable Alternative Towards Affordable Transportation (SATAT, 2018) (Compressed BioGas scheme)
Description	Promotes compressed biogas as a clean transport fuel. Target fossil CNG substitution in fleets.
Benefit	Substitute conventional fuels with cleaner alternatives.
Current Progress	4 operational, 38 under development & 34 proposed CBG plants in Punjab. Can process ~30 lakh tonnes of paddy straw (10% of the state total)
Barrier	Weak demand linkage with the transport sector. Limited CBG distribution & grid injection infrastructure. Delays in clearance and post-production issues of bio-manure handling.

Policy name	PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE), 2024
Description	Launched in Sept 2024 with a total budget of INR 10,900 crore for the period from October 2024 to March 2028. Promote EV adoption among 2Ws, 3W trucks, buses, and ambulances.
Benefit	Accelerated EV adoption in the public transport sector and freight
Current Progress	10.27 lakh EVs sold in India and 5.05 lakh e-vouchers issued. In Punjab: 16,553 e-2Ws and 737 e-3Ws sold under this scheme.
Barrier	No dedicated incentives for vehicle types. Limited charging infrastructure. Exclusion of private e-bus operators & commercial e-4Ws.
Policy name	PM E-FAST (Electric Freight Accelerator for Sustainable Transport), 2022
Description	National platform to promote freight electrification & zero emission trucks (ZET).
Benefit	Drives transition to clean freight systems.
Current Progress	2 ZET pilots at JNPA (Navi Mumbai). 16 industry partners to deploy 7,750 e-trucks by 2030. UltraTech is deploying 100 e-trucks for long haul at Dhar and Dhule plants.
Barrier	Lack of fiscal incentives and technological development. Inadequate charging infrastructure. Weak stakeholder coordination.
Policy name	Guidelines for imposing Green tax on older vehicles by States/UTs, 2021
Description	Provide guidelines for levying the green tax on old vehicles. Transport vehicles older than 8 years and non-transport vehicles older than 15 years can be charged with the green tax.
Benefit	Accelerate the removal of old vehicles plying on road by imposing strict regulations.
Current Progress	Punjab has introduced rules for levying the green tax in August 2024. As of October 2025, Punjab has collected INR 52.48 crore green tax.
Barrier	Lack of uniform rules across states and a weak enforcement mechanism.

Appendix E: Scenario development

Three scenarios were developed based on the existing and potential policies for emission reduction. The existing scenario as per the base year and targets considered for the lower and medium scenarios are given in the table below, along with the reduction in PM_{2.5} emissions.

Table E1: Scenario table for lower and medium targets

Category	Control measure	Vehicle category	Baseline scenario (Current adoption) 2030	Baseline scenario (Current adoption) 2035	Lower adoption		Medium adoption		Reduction in PM _{2.5} emissions (tonnes/year) for lower adoption		Reduction in PM _{2.5} emissions (tonnes/year) for medium adoption	
					2030	2035	2030	2035	2030	2035	2030	2035
Retrofitting	Installation of DOC and partial flow filters (PFF) for BS-IV vehicles	Heavy commercial vehicles	0%		10%	-	30%	-	7.0	-	21.1	-
Switching to cleaner fuels	EV	2W	1%	11%	5%	15%	10%	20%	312.5	313	326.2	56.6
		3W	37%	80%	40%	82%	45%	85%				
		4W	0.20%	1%	5%	8%	10%	12%				
		LCV	1%	1%	2%	5%	5%	8%				
		Bus	0.05%	0.50%	3%	5%	6%	10%				
		Trucks, trailers	0%	0%	2%	3%	5%	6%				

Category	Control measure	Vehicle category	Baseline scenario (Current adoption) 2030	Baseline scenario (Current adoption) 2035	Lower adoption		Medium adoption		Reduction in PM _{2.5} emissions (tonnes/year) for lower adoption		Reduction in PM _{2.5} emissions (tonnes/year) for medium adoption	
					2030	2035	2030	2035	2030	2035	2030	2035
Switching to cleaner fuels	CNG	3W	45%	16%	46%	-	46%	-	312.5	313	326.2	56.6
		4W	1.30%	1.70%	2%	3%	5%	6%				
		LCV	7.50%	11%	10%	15%	12%	20%				
		Bus	1.50%	2.50%	2%	3%	5%	6%				
	LNG	Bus	0%	0%	1%	2%	3%	4%				
		HCV	0%	0%	2%	3%	3%	4%				
Mandatory Scrappage	Scrappage of older vehicles >10 years (commercial)	3W			10%	15%	15%	20%	600.7	145.0	740.1	166.2
		Private cars			10%	15%	15%	20%				
		LCV			10%	15%	15%	20%				
		Bus			10%	15%	15%	20%				
		Trucks, trailers			10%	15%	15%	20%				
	Scrappage of older vehicles >15 years (Private)	2W			15%	20%	20%	25%				
		Personal cars			15%	20%	20%	25%				

Appendix F: Techno-economic analysis

The TCO for 2W, 3W, 4W, and HCVs (buses) was calculated. The vehicle cost was either considered an average of prices from multiple models reported by automotive websites or the cost of top-selling brands. For the bus segment, it was calculated by comparing 50-seater interstate e-buses with diesel buses. Both the lower and upper cost ranges were considered following the methodology provided in the literature (WRI, n.d.). Based on the stakeholder consultation, the upper-range e-bus was assumed to utilise fast charging (12m_FC), with a commercial electricity tariff of INR 25/kWh. The lower-range AC e-bus was considered to utilise slow charging (12m_SC), with an electricity tariff of INR 15/kWh.

To estimate the total capital cost, the analysis included vehicle cost, road tax, vehicle insurance, and vehicle resale values, with a 10% discount rate over the evaluation years. The capital cost estimation also includes the PM E-DRIVE scheme incentives, wherever applicable.

Other parameters which were taken into consideration to calculate operational cost are average fuel cost (INR/year), staff cost per month in INR (if applicable), and annual maintenance calculated based on maintenance cost (INR/km) for all the fuel types.

For EVs, the battery capacity, lifespan, and replacement costs were also considered based on projections by Bloomberg NEF (2023), which estimates that the lithium-ion battery price would reach USD 65/kWh by 2030 (NITI Aayog, 2020). We assumed that the price remains constant after 2030. The total cost was calculated using capital and operational costs, with net present value. Table F1 provides additional general details considered in the TCO analysis.

Table F1: General details used in TCO calculations across different vehicle categories

General Details	2W	3W	4W	Bus
Age of the Vehicle (years)	15	10	15	10
Daily VKT (km)	17.26	100	34.52	273
Annual VKT (km)	6300	33,500	12,600	1,00,000
Discount rate (%)	10	10	10	10
Resale rate (%) EV	10	10	10	10
Battery capacity (kWh)	2.2	7.37	24	320 (12m_FC) and 125 (12m_SC)

Appendix G: Letter of Support from the Punjab Pollution Control Board



PUNJAB POLLUTION CONTROL BOARD

ਪੰਜਾਬ ਪ੍ਰਦੂਸ਼ਣ ਕੰਟਰੋਲ ਬੋਰਡ

CEE/PPCB/JAL/No. 1202

(Through Email Only)

Dated. 24.07.2025

To

Ms. Swagata Dey,
Policy Specialist,
Group Head, Air Quality,
Centre for Study of Science, Technology and Policy (CSTEP)
Plot No. 18 & 19, 10th Cross, Mayura Street, Papanna Layout,
Nagashettyhalli (RMVII Stage),
Bengaluru

Subject: Approval of Proposal for Conducting Surveys on Vehicular Emissions and Fuel Usage Patterns in Punjab.

Reference: Your Letter dated 28.08.2025, along with the Work Plan for August-September 2025

It is to inform you that the Punjab Pollution Control Board (PPCB) has approved your proposal to conduct a study on vehicular emissions and fuel usage patterns in Punjab, subject to the following conditions:

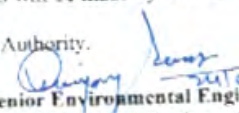
1. Adherence to the outlined Work Plan (August-September 2025)
2. Ensuring minimal disruption to daily operations at the selected petrol pumps and toll booths.

The PPCB extends necessary permissions and support for the successful completion of the study. You are required to conduct the surveys in accordance with the approved Work Plan and ensure effective coordination with other stakeholder departments.

Terms of Approval:

- The surveys will be conducted at selected petrol pumps and toll booths in six districts of Punjab, namely Patiala, Ludhiana, Jalandhar, Amritsar, Sangrur, and Moga.
- The Banyan Foundation, engaged by CSTEP, will carry out on-ground survey activities as per the approved plan.
- PPCB reserves the right to monitor the study's progress and ensure compliance with the approved Work Plan.
- Effective coordination with other stakeholder departments will be made by CSTEP at its own level.

This is issued after the approval of the Competent Authority.


Senior Environmental Engineer
For Chief Environmental Engineer (Air)
Jalandhar

Dated. 24.07.2025

Enclst No. 1203-08

A copy of the above is forwarded to the following for information please: -

1. PS to Chairperson, Punjab Pollution Control Board, Patiala
2. PA to Member Secretary, Punjab Pollution Control Board, Patiala.
3. The Chief Environmental Engineer (Air), Jalandhar.
4. The Senior Environmental Engineer, ZO-I, Patiala.
5. The Environmental Engineer, (Air Lab), Patiala.
6. The Deputy Controller (F&A), PPCB, Patiala


Senior Environmental Engineer
For Chief Environmental Engineer (Air)
Jalandhar

Office Of: Chief Environmental Engineer, Focal Point, Jalandhar

ਦਫ਼ਤਰ : ਮੁੱਖ ਵਾਤਾਵਰਣ ਇੰਜੀਨੀਅਰ, ਫੋਕਲ ਪੁਆਇੰਟ, ਜਲੰਧਰ

Tel No. 0181-2604885 e-mail: - cee.jalandhar@gmail.com Visit us at www.ppcb.gov.in.



Center for Study of Science, Technology & Policy

28th August 2025

Ms. Reena Gupta,
Chairperson
 Punjab Pollution Control Board (PPCB)
 Vafavaran Bhawan, Nabha Road
 Patiala – 147001, Punjab

Handwritten notes in blue and red ink:
 SEE (Ind-Air Lab)
 27/8/25
 28/8/25
 ਨਵੀਂ ਡਾਕ
 ਚੇਅਰਪਰਸਨ
 ਮੈਂਬਰ ਸਕੱਤਰ
 (PPCB)

Subject: Request for Permission to Conduct Vehicular Emission Surveys at Petrol Pumps and Toll Booths in Select Districts of Punjab

Respected Madam,

The Center for Study of Science, Technology and Policy (CSTEP), a not-for-profit research organization, is undertaking a study on vehicular emissions and fuel usage patterns in Punjab. As part of this initiative, The Banyan Foundation has been engaged to carry out the on-ground survey activities.

In accordance with the **Work Plan (August – September 2025)**, as attached in annexure, The Banyan Foundation will be conducting surveys across six districts of Punjab — **Patiala, Ludhiana, Jalandhar, Amritsar, Sangrur and Moga** — at selected **petrol pumps and toll booths**.

The surveys will be conducted in two shifts at each location (Morning: 7–11 AM and Evening: 4–8 PM for petrol pumps; 6–10 PM for toll booths). All activities will be carried out with due coordination to ensure no disturbance to daily operations.

We respectfully seek your permission and support to carry out these surveys at the designated locations. The data collected will provide valuable insights into understanding transport emissions and help in air quality management efforts in Punjab.

We assure you that the survey teams will comply with all guidelines, maintain proper conduct, and work in coordination with relevant stakeholders. We will share the results with PPCB.

We look forward to your approval.

Warm regards,

Swagata Dey

Swagata Dey
 Policy Specialist, Air Quality
 Group Head, Air Quality Policy and Outreach

The Authors



Dr Nidhi Malik

Dr Nidhi Malik is a Senior Associate at CSTEP, with expertise in air quality assessment, techno-economic analysis, and applied research for policy. She led the writing and methodological development of the report and carried out the techno-economic and data analysis.



Harshitha K M

Harshitha K M is a Senior Analyst at CSTEP, specialising in emission inventory development and quantitative air quality assessment. She developed the bottom-up emission inventory and undertook data analysis, validation, and visualisation for the study.



Faiza Khalil

Faiza Khalil is a Consultant at CSTEP, with experience in air quality research and field-based data collection. She led the field surveys, conducted data collection, and provided research support for the report.



Sneha Jadhav

Sneha Jadhav is an Analyst at CSTEP, working at the intersection of environmental research and policy analysis. She carried out the policy analysis and supported the research and synthesis of findings in the report.



Swagata Dey

Swagata Dey is a Policy Specialist and the Group Head of Air Quality Policy and Outreach at CSTEP, leading air quality policy research and programme design. She is the Principal Investigator of this project. She led the conceptualisation and study design; contributed to writing and editing; and oversaw approvals.





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