Report | September 2026

Greenhouse Gas Accounting for On-road Transport Emissions

A Global Protocol for Community-scale Compliant Inventory for Erode

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Erode Municipal Corporation building.

Image: CEEW

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FOREWORD

Erode is a rapidly growing urban centre and an important hub for trade, industry, agriculture, and regional mobility in Tamil Nadu. As our city continues to expand and economic activity grows, ensuring sustainable, climate-resilient urban development has become a priority for the Erode City Municipal Corporation.

Transport is central to the functioning of our city. It enables the movement of people, goods, and services that support livelihoods and economic growth. At the same time, increasing vehicle ownership, freight movement, and travel demand are contributing to higher greenhouse gas emissions and placing greater pressure on urban infrastructure. Understanding these trends is essential for planning a cleaner, more efficient, and future-ready transport system.

I am pleased to present this report, **"Greenhouse Gas Accounting for On-Road Transport Emissions: A GPC-Compliant Inventory for Erode"**, prepared by the Council on Energy, Environment and Water (CEEW) under the India–UK Partnering for Accelerated Climate Transition (UK PACT) programme. The report provides Erode's first city-level greenhouse gas inventory for the on-road transport sector and establishes an evidence-based foundation for integrating climate considerations into transport planning and urban development.

The study offers valuable insights into the city's transport emissions profile and highlights practical pathways for reducing future emissions while supporting economic growth and mobility needs. Importantly, it also introduces a transparent and replicable framework that can be periodically updated to monitor progress and assess the impact of policy interventions over time. As cities increasingly play a critical role in achieving national and state climate goals, local governments require reliable data and analytical tools to support informed decision-making. This report is an important step towards strengthening Erode's capacity for data-driven planning and climate-responsive governance. The findings will help guide future discussions on sustainable mobility, infrastructure investments, and long-term urban development.

I appreciate the efforts of CEEW, UK PACT, and all stakeholders who contributed to this important initiative. I am confident that this report will serve as a valuable resource for policymakers, planners, and practitioners working towards a more sustainable and resilient future for Erode, while also offering useful lessons for other growing cities across India.

Commissioner
Erode City Municipal Corporation

Erode central bus station with the carrying capacity of 200 buses.

Image: CEEW

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The Council on Energy, Environment and Water (CEEW)—a homegrown institution with headquarters in New Delhi—is among the world's leading climate think tanks. The Council uses data, integrated analysis, and strategic outreach to support public policy, transform markets, shape technology, and nudge behaviour. It addresses pressing regional and global challenges through an integrated and internationally focused approach. The Council prides itself on the independence of its high-quality research and strives to impact sustainable development at scale.

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SELECT POLICY ENGAGEMENTS

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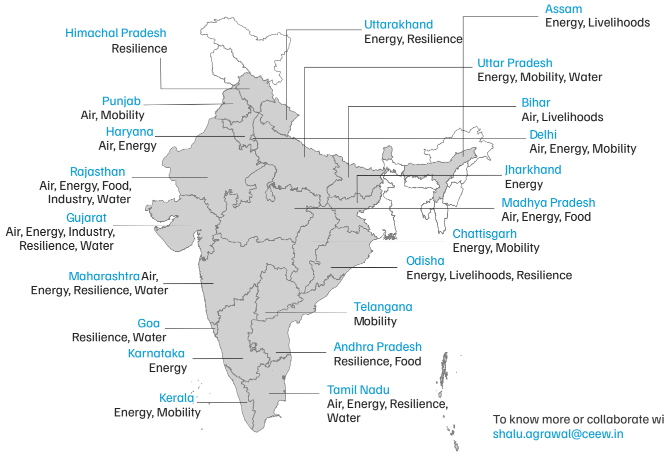
2011 | National Water Resources Framework
2014 | 175 GW renewables target
2015 | International Solar Alliance
2016 | PM *Ujjwala Yojana*
2017 | *Saubhagya Scheme*
2019 | India Cooling Action Plan
2021 | Net Zero by 2070
2022 | *Mission LiFE*
2022 | *National Bioenergy Programme*
2022 | E-waste (Management) Rules
2023 | G20 Green Development Pact
2023 | *National Green Hydrogen Mission*
2024 | Green Steel Taxonomy
2024 | *PM Surya Ghar Yojana*
2025 | *National Critical Mineral Mission*
2025 | Rajya Sabha Guidelines on Crop Residue Burning
2025 | India's Carbon Credit Trading Scheme (CCTS)
2025 | IFSCA's Framework for Transition Bonds
2026 | Disaster Risk Index for 16th Finance Commission
2026 | India's NDC 3.0
2026 | India's Scenarios towards Viksit Bharat and Net Zero

STATE
2022 | *Rajasthan Organic Farming Mission*
2022 | *Jharkhand State Solar Policy*
2022 | *Uttar Pradesh Vidyut Sakhi programme*
2023 | *Rajasthan Renewable Energy Policy and Green Hydrogen Policy, 2023*
2023 | *Uttarakhand Solar Policy*
2025 | Green Odisha Initiative
2025 | *Maharashtra Climate Action Plan 2.0*
2025 | *Delhi Clean Air Action Plan*
2026 | *Delhi EV Policy 2.0*
2026 | Bihar Promotion of New and Renewable Energy Sources
2026 | Gujarat Integrated Renewable Energy Policy and Green Hydrogen Policy
2026 | *Uttarakhand Mukhyamantri Saur Swarojgar Yojana*
2024-26 |
Directives of Commission on Air Quality Management
Net Zero Roadmaps (BH, GJ, TN, UK)
Agroforestry Roadmaps (AS, MH, OD)
140+ Heat Action Plans (GJ, MH, OD, TN)
Treated Used Water Reuse Plans (MH, UP)
Flood Risk Mitigation Plans (GJ, MH)

21 STATES SUPPORTED



To know more or collaborate with us, email shalu.agrawal@ceew.in

Erode central bus station

Image: CEEW

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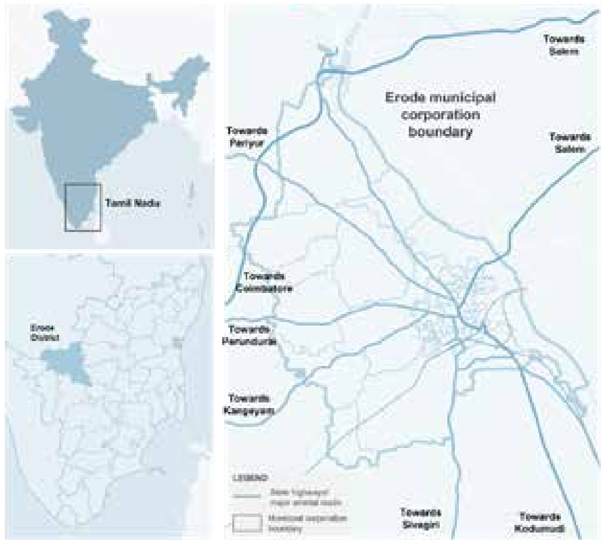
Executive summary

In India, transport sector contribute ~14 per cent of national greenhouse gas (GHG) emissions (MoEFCC 2024). Although India's annual per capita emissions remain below the global average (2.4 tonnes of CO_2 equivalent [tCO_2e] per capita compared with 6.3 tCO_2e per capita globally) (Shinde et al. 2023), tier-2 and tier-3 cities are experiencing growth in population, vehicle ownership, and economic activity, leading to an increase in transport emissions (Ramachandra et al. 2015). Strengthening city-level GHG accounting is therefore essential to enable India to achieve the goals outlined in the nationally determined contributions (NDCs) (GoI 2022). Without such granular data, designing targeted mitigation strategies and tracking progress remains challenging.

This study develops a *Global Protocol for Community-Scale (GPC)-compliant Greenhouse Gas Emission Inventories* (GHG) accounting framework for on-road transport emissions in Erode Municipal Corporation (EMC), Tamil Nadu. Although Tamil Nadu has adopted progressive climate action plans across sectors, including road transport, cities continue to face systemic gaps in data, infrastructure, and institutional capacity limiting the integration of emissions data into transport planning. Undertaken under the India–UK Partnering for Accelerated Climate Transitions (UK PACT) programme, Erode is one of the cities selected under the partnership, as it is one of the major regional trade centres for textiles and agriculture.The study aims to establish a transferable methodological model tailored to the data realities and institutional capacities of tier-2 and tier-3 Indian cities. The framework is designed to be **scalable and transparent, enabling consistent reporting and policy alignment across comparable urban contexts. It accommodates varying levels of data availability, governance capacity, and transport system characteristics.**

Image: iStock

Figure ES1. Erode Municipal Corporation is a rapidly growing tier-2 city with increasing mobility demand



~5 lakh population

Population density **~4,500 people/sqm**

Primary surveys were conducted in Erode (≈6,000 samples)

~3.2 lakh are registered during 2011—2025 as per VAHAN 2011—2025

~80% of the cumulative number of vehicles registered (2011—2015) is 2Ws

52% of the ~6,000 vehicle samples were registered outside the EMC boundary

60-80% of public transport and freight trips are transboundary

47% of the ~6000 vehicle samples are between 5 and 10 years

>75% of the 2W, 3W, 4W trips are regular home-based trips

5% of the fleet as per cumulative registration data is LCVs, buses and trucks

~99% of buses and trucks are diesel-fueled as per the VAHAN dataset and survey

Erode is located along the **industrial corridor** Salem—Erode—Tiruppur—Coimbatore and is a **regional trade centre** for trade, textile, and agriculture

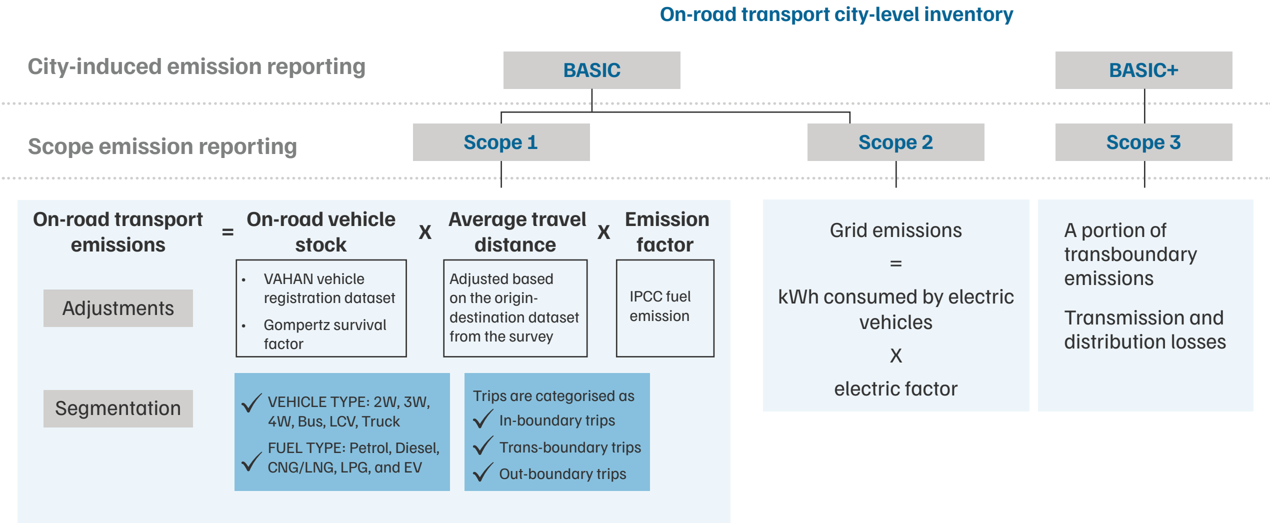
Source: Authors' analysis.

Note: 2Ws: two-wheelers; 3Ws: three-wheelers; 4Ws: four-wheelers; EMC: Erode Municipal Corporation; LCVs: light commercial vehicles

Methodology and tool development

The study adopts a GPC-compliant, city-scale emissions-accounting framework at the BASIC+ reporting level, using a bottom-up, modified production-based methodology (Activity–Share–Intensity–Emission Factor). The analytical framework quantifies Scope 1 (tailpipe emissions), Scope 2 (emissions associated with grid electricity consumption associated with electric vehicles [EVs]), and selected Scope 3 emissions, such as trans-boundary trips and transmission and distribution (T&D) losses linked to electricity use.

Figure ES2. Framework for GPC-compliant on-road emissions inventory



Source: Authors' analysis.

Note: 2W: two-wheeler; 3W: three-wheeler; 4W: four-wheeler; CNG: compressed natural gas; EV: electric vehicle; IPCC: Intergovernmental Panel on Climate Change; LCV: light commercial vehicle; Gompertz survival curve is a mathematical model used to predict the lifespan and retirement (scrappage) rate of vehicles.

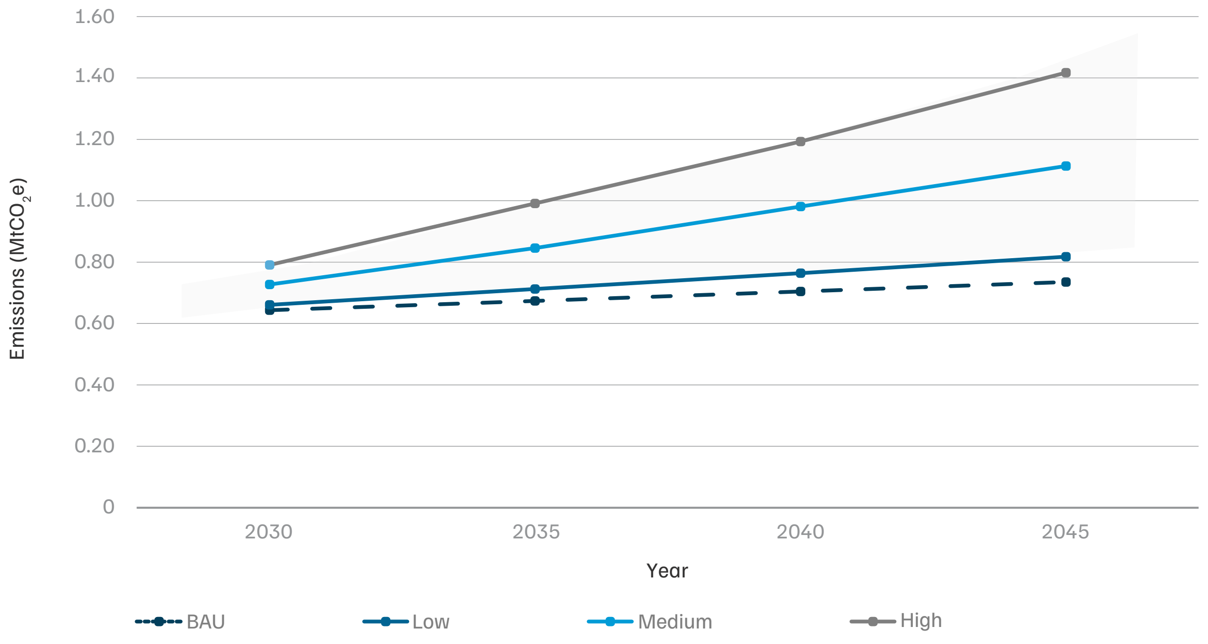
To operationalise the framework, we developed an Excel-based GHG calculator for EMC. The tool is designed to support periodic inventory updates, features transparent documentation of assumptions, and enables scenario modelling within consistent methodological boundaries. It can simulate business-as-usual (BAU) scenarios and multiple alternative scenarios (activity-driven and energy-efficiency-driven) for the period 2030–45.

Key findings

1. **On-road transport emissions could nearly double by 2045 under a high-growth scenario.**

   Erode generates ~0.61 million tonnes of CO_2 equivalent ($MtCO_2e$) annually from on-road transport, of which Scope 1 (tailpipe) emissions account for ~86 per cent of total emissions, highlighting their significant contribution. By 2030, emissions are projected to range from ~0.66 $MtCO_2e$ (low-development case) to ~0.79 $MtCO_2e$ (high-development case). Under a high-growth scenario, which combines increased vehicle registrations and vehicle kilometres travelled (VKT), emissions could reach ~1.42 $MtCO_2e$ by 2045, nearly double the 2025 baseline (Figure ES3). Therefore, early intervention is more cost-effective than attempting to reduce emissions after the vehicle fleet and travel demand have expanded.

Figure ES3. Without intervention, on-road transport emissions could nearly double by 2045, reaching ~1.42 $MtCO_2e$ under high growth conditions, compared to the BAU scenario



Source: Authors' analysis.

Note: These are decadal growth rates, with 2025 as the baseline year.

BAU: business-as-usual

Rate of development	Vehicle registration growth rate (%)	Increase in VKT (%)
Low	10	5
Medium	30	7
High	50	9

**Development means an increase in vehicle registration and an increase in average VKT.*

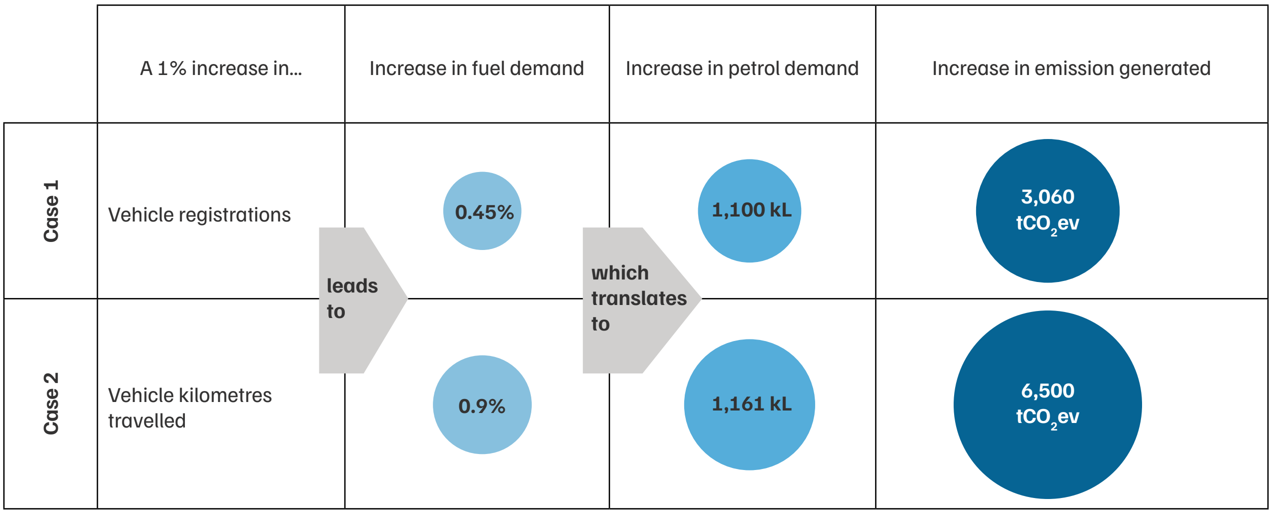
Source: Authors' analysis.

Note: VKT: vehicle kilometres travelled

2. Heavy-duty diesel vehicles contribute disproportionately to emissions.

Diesel trucks constitute only 1.4 per cent of the fleet but account for ~21 per cent of total emissions. Similarly, buses account for less than 0.3 per cent of the fleet, yet contribute ~7 per cent of emissions. This is because per-vehicle emissions are high, and because of diesel dependence, an older vehicle fleet (average age of ~9 years for trucks and ~7 years for buses), low mileage, and longer average daily travel distances. Buses have the highest annual per-vehicle emissions intensity, followed by trucks (36.6 tCO_2e per bus and 20.7 tCO_2e per truck). This underscores the need to prioritise heavy-duty diesel vehicles in city-level emission-reduction strategies to maximise the impact of transport-sector interventions.

Figure ES4. Growth in vehicle kilometres travelled leads to a greater increase in fuel demand and carbon dioxide (CO_2) emissions than growth in vehicle registration



Source: Authors' analysis.

Note: (i) Conversion units used to convert multiple fuel types into petrol equivalents: diesel (1.11), CNG/LNG (0.68), LPG (1.15), and EVs (0.1), as per Corporate Average Fuel Economy (CAFE) norms (2024).
(ii) For the study's business-as-usual (BAU) scenario, a decadal growth rate of 10% is assumed.

CNG: compressed natural gas; EV: electric vehicle; LNG: liquefied natural gas; LPG: liquefied petroleum gas

3. Emissions are significantly more sensitive to increases in VKT than to growth in vehicle registration.

To ensure comparability, both parameters were normalised, where the decadal growth rates of vehicle registrations and VKT were independently varied by a per cent change from their respective baseline growth trajectories (Figure ES4). The analysis shows that an increase in travel demand has nearly twice the impact on fuel consumption and consequently emissions, as an equivalent increase in vehicle registration growth.

- A 1 per cent increase in decadal vehicle registration growth rate results in a ~0.45 per cent increase in fuel demand, equivalent to ~3,060 tCO_2e annually.

- A 1 per cent increase in the VKT growth rate results in a ~0.9 per cent increase in fuel demand, equivalent to ~6,500 tCO_2e annually.

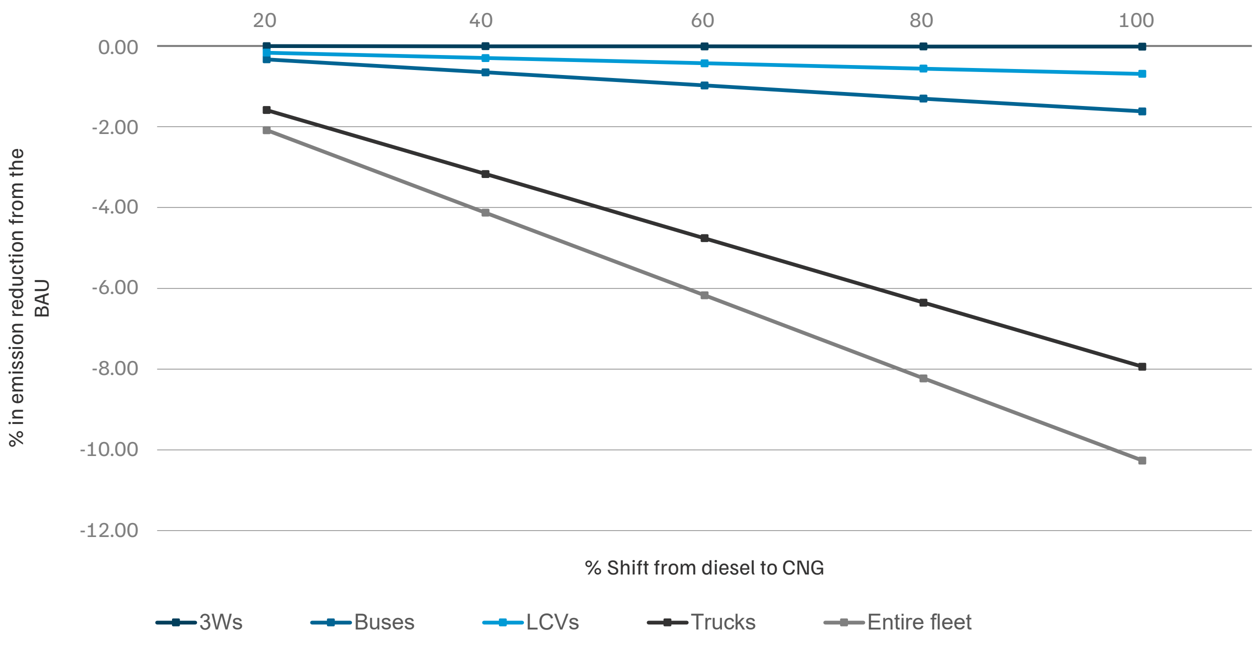
4. **Improving fleet fuel economy offers substantial emission reduction potential.**

   Improving fleet fuel economy by 20–30 per cent could reduce emissions by 17–23 per cent relative to the BAU scenario by 2030, lowering emissions to ~0.64 $MtCO_2e$. This can be supported through strengthened vehicle inspection, maintenance programmes and enforcement of in-use emissions compliance.

5. **Diesel-to-CNG transition delivers limited fleet-wide emissions reductions.**

   A full transition from diesel to compressed natural gas (CNG) yields a maximum emission reduction of ~10 per cent by 2030, primarily driven by trucks (Figure ES5). The CNG transition in three-wheelers (3Ws) and light commercial vehicles (LCVs) is likely to have a marginal impact (less than 1 per cent) due to methane-related CO_2e factors and limited net fuel-efficiency gains.

Figure ES5. In the full transition scenario, emission reductions are driven primarily by trucks, while transitions to CNG in 3Ws and LCV show negligible impact



Source: Authors' analysis.

Note: 3Ws: three-wheelers; BAU: business-as-usual; CNG: compressed natural gas; LCV: light commercial vehicle

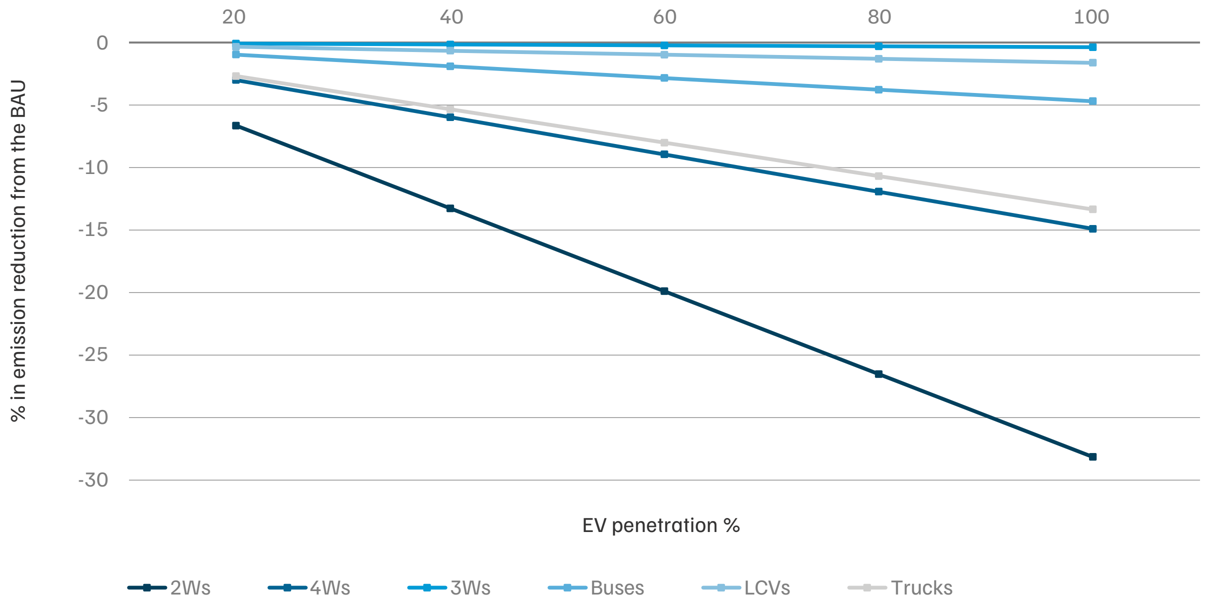
6. **The benefits of electrification can be achieved through volume-driven reductions in two-wheeler (2W) and four-wheeler (4W) vehicles, and intensity-driven emission reductions from heavy-duty freight vehicles.**

    - High-volume segments (2Ws and 4Ws) generate substantial aggregate emission reductions. Electrifying 50 per cent of 2Ws alone could reduce total emissions by ~17 per cent (Refer to figure ES6).

    - High-intensity segments (trucks and buses) provide larger annual per-vehicle reductions due to elevated baseline emissions (36.6 tCO_2e per bus; 20.7 tCO_2e per truck) (Refer to figure ES6).

    - Electrifying 30 per cent of the total fleet by 2030 could reduce emissions by ~20 per cent relative to the BAU scenario (~0.64 $MtCO_2e$). It would also shift the emissions composition from Scope 1 dominance (85 per cent to 74 per cent) towards a greater contribution from Scope 2 (0.3 per cent to 12 per cent), reinforcing the importance of grid decarbonisation.

Figure ES6. e2Ws and e4Ws deliver the highest aggregate emission reductions due to the overall higher fleet share



Source: Authors' analysis.

Note: BAU: business-as-usual; e2Ws: electric two-wheelers; e3Ws: electric three-wheelers; e4Ws: electric four-wheelers; EV: electric vehicle; LCVs: light commercial vehicles

Policy recommendation and priorities

1. **Manage transport demand and align planning with emissions outcomes.**
   (High impact | Medium–long term)

   - Estimate the annual transport-sector GHG baseline to model the emissions impacts of policy scenarios, such as accelerated fleet electrification and diesel vehicle scrappage. While the impacts of these measures are primarily modelled at the state and national levels, translating them into measurable city-level targets is essential. City-level GHG assessment can support context-specific planning, prioritisation, and monitoring.
   - Integrate the GHG calculator into comprehensive mobility plans (CMPs) and master plans, where interventions propose altering VKT or modal share, the calculator can be used to assess fleet-level emission impacts.
   - Introduce location- and time-based differential parking pricing in the central business district and high-congestion corridors. Pricing may be scaled according to vehicle size and engine type to limit the use of private and freight vehicles during peak hours and in congested areas.

   Concerned stakeholders: EMC, Directorate of Town and Country Planning (DTCP), Department of Transport (Government of Tamil Nadu)

2. **Target high-intensity diesel freight and bus segments.**
   (High impact | Medium term)

   - Identify diesel trucks and private buses that are over 10 years old and introduce scrappage-linked incentives (e.g., permit prioritisation, fee waivers, or access benefits) for private operators and drivers, given their high emissions intensity per vehicle.
   - Designate green freight access zones within the city core, with restricted entry for older diesel vehicles and preferential loading and unloading bays for compliant fleet operators.
   - Initiate a corridor-level study of the Salem–Erode–Tiruppur–Coimbatore freight route to assess the feasibility and impacts of long-haul trucks transitioning to cleaner fuels.
   - Mandate the procurement of e-buses for government fleets.

   Concerned stakeholders: state transport department, regional transport offices (RTOs), Tamil Nadu State Transport Corporation (TNSTC), EMC, district collectors

3. **Accelerate electrification across high-volume and public fleet segments.**
   (High impact | Medium–long term)

   - Erode Municipal Corporation can conduct awareness campaigns on EV purchase incentives under the *Tamil Nadu Electric Vehicles Policy, 2023,* and the *PM Electric Drive Revolution in Innovative Vehicle Enhancement (PM E-DRIVE) scheme,* including purchase subsidies, registration fee waivers, and road tax exemptions.
   - The TNSTC should plan for depot charging infrastructure through the public–private partnership (PPP) model, drawing on lessons and guidance from Chennai and Coimbatore.

   Concerned stakeholders: TNSTC, Tamil Nadu Generation and Distribution Corporation Limited (TANGEDCO), state transport department

4. **Strengthen in-use emissions compliance and fleet transition.**
   (Low impact | Medium term)

   - Conduct emission checks at city-level cordon points (entry and exit points) and along high-traffic corridors to identify non-compliant vehicles. Implement phased restrictions on pre-Bharat Stage-VI vehicles in high-emission zones.
   - Strengthen enforcement of annual Pollution Under Control (PUC) certification requirements for freight vehicles more than 10 years old by linking permit renewal at the RTO level.
   - Address gaps in PUC testing verification and quality and support the gradual retirement of highly polluting vehicles from the active fleet.
   - Pilot CNG/liquefied natural gas (LNG) retrofit programmes for heavy-duty truck fleets where technically feasible.

   Concerned stakeholders: traffic police, state transport department

5. **Institutionalise data and governance structures.**
   (Low-hanging | Short term)

   - Notify the EMC as the custodian of the annual GHG inventory, with defined responsibilities for sourcing, updating, and publishing data on fleet composition from VAHAN, fuel sales, and travel characteristics from periodic surveys to ensure fixed annual updates rather than ad hoc reporting.
   - Establish standardised data-collection protocols and reporting formats, along with mechanism for regular data transmission to the state government, to support state-level planning and reporting.
   - Establish data-sharing memoranda of understanding (MoUs) with RTOs, oil marketing companies (OMCs), and fleet operators to facilitate the regular provision of anonymised vehicle activity and fuel sales data at the city level.
   - Operationalise existing Integrated command and control centre (ICCC) infrastructure to generate periodic monitoring data on the vehicle mix, fleet age distribution, and traffic volumes at key junctions and freight corridors to generate annual GHG inventory updates and help identify areas for demand-management interventions.
   - Create a city-level transport decarbonisation task force, co-chaired by the EMC and the state transport department, with representation from TNSTC, TANGEDCO, and RTOs, to review annual inventory results and align actions with Tamil Nadu's net-zero commitments.

   Concerned stakeholders: EMC, TANGEDCO, TNSTC, state transport department

   Note: Short term: 1–2 years; medium-term: 3–5 years; long term: >5 years

For more detailed recommendations, please refer to Section 6.8.

Image: CEEW

1. Introduction

Urban areas are major contributors to global greenhouse gas (GHG) emissions. They currently account for 62–72 per cent of global GHG emissions, amounting to ~29 Giga tonnes CO_2e in 2020, and are projected to rise to 34–40 GtCO_2e by 2050 in the absence of strong mitigation efforts (Lwasa et al. 2022). The UN-Habitat's World Cities Report 2024 further underscores the disproportionate environmental impact of major cities, despite their occupying only 2 per cent of the world's land area (UN-Habitat 2024). The 100 largest cities alone are responsible for ~18 per cent of global CO_2 emissions (6.8 billion tonne CO_2e), despite representing only ~10 per cent of the global population (~8 billion) (Dasgupta et al. 2021). In addition, urban per capita emissions increased from 5.5 tonnes of CO_2 equivalent (tCO_2e) to 6.2 tCO_2e per person during 2000–15, reflecting rising incomes, changing consumption patterns, and evolving lifestyles that have contributed to higher urban emissions (Lwasa et al. 2022).

India's nationally determined contributions (NDCs), formulated in response to the Paris Agreement, commit to reducing the emissions intensity of its GDP by 45 per cent by 2030 relative to 2005 levels and achieving approximately 50 per cent cumulative installed electricity capacity from non-fossil-fuel sources by 2030 (GoI 2022). India was among the world's four largest emitters in 2024 (UNFCCC 2022). Its total GHG emissions were 2,959 million tonnes of CO_2 equivalent (MtCO_2e) in 2020. The energy sector, which includes transport, is the dominant source of emissions, responsible for ~75 per cent of national GHG emissions. Road transport alone accounts for 9 per cent of total national emissions (MoEFCC 2024). India's per capita emissions remain below the global average (2.4 tCO_2e vs 6.3 tCO_2e globally) (Shinde et al. 2023). Indian metropolitan cities, such as Delhi, Chennai, Mumbai, and Bengaluru, have the largest footprints (~70 per cent of ~3,000 MtCO_2e), whereas tier-2 and tier-3 cities are experiencing rapid increases in GHG emissions due to population growth, land conversion, increased mobility, and freight demand (Ramachandra et al. 2015). This underscores the need for city-level GHG accounting and context-specific policies to support India's climate goals.

The study seeks to develop a GHG accounting approach for the on-road transport sector in Erode, one of the cities selected under the UK Partnering for Accelerated Climate Transitions (UK PACT)–India urban planning and mobility portfolio. While major Indian cities continue to receive significant attention in climate and emissions research, tier-2 and tier-3 cities often face constraints related to data availability, technical capacity, and financial resources. These cities also receive comparatively less attention in policy discussions on GHG accounting and sector-specific mitigation measures. Accordingly, the broader objective of this study is to **develop a replicable and scalable model for tier-2 and tier-3 Indian cities.**

Erode is a rapidly growing tier-2 city in Tamil Nadu with a strong economic base in textiles, trade, and agriculture. The state has established a supportive policy environment for climate action through initiatives such as the *Tamil Nadu Action Plan on Climate Change* (TNAPCC), the *Electric Vehicles Policy* (2023), district climate action plans (DCAPs), and the Climate Action Tracker.

The TNAPCC emphasises mitigation and adaptation across sectors such as energy, transport, and urban development, aligning with India's NDCs through sustainable housing and energy-efficiency initiatives (ECC&F 2022). Transport emissions in Tamil Nadu were estimated at 167 $MtCO_2e$ in 2022–23, accounting for 15–18 per cent of the state's total emissions (IITM 2023). To address this, the state's *Electric Vehicles Policy* (2023) aims to achieve 30 per cent EV penetration in state bus fleets by 2030 and deploy over 2,500 e-buses (GoTN 2019). The Tamil Nadu Green Climate Company (TNGCC) further supports EV initiatives and manages district climate action plans (DCAPs). Pilot studies indicate that up to 92 per cent of emissions could be reduced by 2050, and the state has introduced a real-time Climate Action Tracker to monitor progress (ECC&F 2025). Together, these policies provide a framework through which tier-2 cities, such as Erode, can develop tailored GHG accounting systems and mitigation pathways.

1.1 Different methods for city-scale greenhouse gas accounting

Two broad approaches are used for city-scale GHG accounting: top-down and bottom-up approaches (refer to Table 1). The top-down approach estimates city-level emissions by disaggregating aggregate emissions data (e.g., national or regional inventories) using proxy indicators, such as population, economic activity, or fuel consumption. This approach ensures consistency with higher-level inventories and is useful for rapid assessments and cross-city comparisons. However, it may not accurately reflect local activity patterns or source-specific variations. It relies on regional databases, such as national and regional statistics, multi-region input–output (MRIO) models, and global emission factors (EFs) to estimate emissions. This approach is used for quick estimates and cross-city comparisons but does not capture comprehensive sector-wise emissions (Fan and Guan 2025; Maksyutov et al. 2022). In contrast, the bottom-up approach relies on granular data collected for each sector. It offers a detailed emissions inventory and facilitates the identification of specific emission sources (Zhao et al. 2024).

Table 1. Comparison between city-level GHG accounting approaches

Feature	Top-down approach	Bottom-up approach
Database	Regional/Macro	Individual/Sectoral
Granularity	Low	High
Accuracy	Low	High
Resource Intensity	Less time-intensive and less costly	Resource-intensive and costly
Application	Suited for large-scale and initial assessments	Suited for regulatory reporting and detailed mitigation planning

Source: Fan, Lei, and Haoyu Guan. 2025. "A Comparative Overview of City-Level Carbon Accounting: Key Processes and Considerations." AIMS Environmental Science 12 (3): 400–18. https://doi.org/10.3934/environsci.2025018; Zhao, Ruixi, Andante Hadi Pandyaswargo, and Hiroshi Onoda. 2024. "A Bottom-Up Approach for Greenhouse Gas Emission Estimation at the Community Level: a Case Study in Japan." Energy 307. https://doi.org/10.1016/j.energy.2024.132530; Maksyutov, Shamil, Dominik Brunner, Alexander J. Turner, et al. 2022. "Applications of Top-Down Methods to Anthropogenic GHG Emission Estimation." In Balancing Greenhouse Gas Budgets: Accounting for Natural and Anthropogenic Flows of CO_2 and Other Trace Gases, edited by Benjamin Poulter, Joseph Canadell, Daniel Hayes, and Rona Thompson. Amsterdam: Elsevier. https://doi.org/10.1016/B978-0-12-814952-2.00006-X.

Note: This study considers the bottom-up approach.

Bottom-up approaches can be further categorised into three methods: production-based (territorial), consumption-based, and hybrid approaches (refer to Table 2).

- The **production-based method** attributes GHG emissions to the locations where they are physically emitted into the atmosphere. As a result, it does not capture emissions embedded in imported goods and services (Franzen and Mader 2018).
- The **consumption-based method** attributes emissions associated with activities at the point of final consumption, irrespective of origin. This method captures indirect emissions related to supply chains and consumption patterns (Davis and Caldeira 2010).
- The **hybrid method** combines elements of production-based and consumption-based accounting by accounting for both direct and indirect emissions associated with trade flows. This typically requires extensive data collection (Franzen and Mader 2018; Fan and Guan 2025).

Table 2. Comparison between bottom-up greenhouse gas emissions estimation methods

Feature	Production-based	Consumption-based	Hybrid
Emission coverage	Emissions generated within the boundary	Emissions linked to consumption, including imports	A combination of production and consumption data
Responsibility attribution	Polluter pay	Consumer pay	Mixed responsibility
Complexity	Low	High – supply chain tracing	Highly complex
Advantages	Easy to implement	Captures trade flow emissions	Balanced and comprehensive accounting
Disadvantages	Does not consider imported goods	Data intensive	Complex modelling and assumptions

Source: Fan and Guan 2025; Zhao, Pandyaswargo, and Onoda 2024; Maksyutov et al. 2022; Franzen and Mader 2018; Davis and Caldeira 2010.

Note: The study adopts the modified production-based method (including Scope 2 and selected Scope 3 emissions, such as transmission and distribution losses, due to data limitations).

Cities worldwide adopt various GHG accounting methods to formulate and implement climate action plans. These approaches vary in system boundaries, sectoral coverage, and treatment of indirect emissions. Consequently, their reliability, suitability, and comparability remain uncertain due to variations in system boundaries, data measurement and collection practices, sectoral coverage, and methodologies used to estimate indirect emissions (Driscoll et al. 2016).

Table 3. Literature landscape of different greenhouse gas accounting techniques

Framework	Type	System boundary	Key features	Limitations
CRF	Production-based	Territorial	Covers energy, transport, waste; allows additional reporting	Limited treatment of indirect emissions
IEAP	Hybrid	Community + local government operations	Separates city-wide and municipal emissions	Fragmented accounting; less standardised
ISDGC	Consumption-based (including upstream)	Includes supply chain emissions	Captures upstream emissions from goods	Less suitable for sector-specific territorial analysis
BEI/MEI	Production-based	Final energy use	Simple, widely used in EU	Limited to CO_2; excludes broader GHGs
USCP	Hybrid	Source/Activity-based	Focuses on actionable emission sources	Reduced global comparability
PAS 2070	Hybrid	Territorial + consumption	Includes supply chains and consumption footprint	Complex, less standardised

Source: Global Covenant of Mayors for Climate and Energy 2023; ICLEI 2009; Cities Alliance 2010; Meath County Council 2024; ICLEI 2013; Wee et al. 2021.

Note: CRF: common reporting framework; IEAP: International Local Government Greenhouse Gas Emissions Analysis Protocol; ISDGC: International Standards for Determining Greenhouse Gas Emissions for Cities; BEI: baseline emissions inventory; MEI: monitoring emissions inventory; USCP: United States Community Protocol for Accounting and Reporting of Greenhouse Gas Emissions; PAS 2070: Publicly Available Specification 2070

To address these challenges, the *Global Protocol for Community-Scale Greenhouse Gas Emission Inventories* (GPC) was developed to promote consistent and transparent reporting of urban emissions through defined scopes (Dahal and Niemelä 2017). The GPC promotes consistent and transparent reporting of urban emissions through defined scopes; therefore, during COP21 (Paris), the GPC was recognised to track and disclose emissions as a global standard for community-scale reporting (Erickson and Morgenstern 2016). Although both the Intergovernmental Panel on Climate Change (IPCC) and GPC frameworks estimate emissions using activity data, the GPC distinguishes between stationary and mobile energy sources (Fan and Guan 2025) and provides more comprehensive sectoral accounting, including a clear distinction between core and optional emissions across sectors. Accordingly, this study adopts a GPC-compliant approach for estimating on-road transport emissions.

1.2 Prioritising on-road transport in city-scale emission inventories

Most city-level emissions inventories, including those based on the IPCC and GPC frameworks, require cities to report emissions across multiple sectors, including stationary energy, transportation, waste, industrial processes and product use (IPPU), agriculture, forestry and other land use (AFOLU), and other Scope 3 emissions within city boundaries (Wee et al. 2021).

GPC-compliant city inventories enable targeted, data-driven transport decarbonisation.

The transport sector accounts for approximately 12–14 per cent of national GHG emissions, making it the third-largest emitting sector after the power and industrial sectors (Jain and Rankavat 2023; Sinha and Sharma 2021). Within the sector, on-road transport alone contributes approximately 90 per cent of transport-related emissions (NITI Aayog 2026). Given the rapid growth in vehicle ownership and changing travel patterns in tier-2 and tier-3 cities, on-road transport represents a critical area for targeted decarbonisation strategies.

In metropolitan areas, the growing share of private vehicles has contributed to higher per capita emissions and increasing congestion. Similar trends are now emerging in smaller cities as incomes and motorisation rates rise (Mohan et al. 2025; Shinde et al. 2023; Ramachandra et al. 2015).

Understanding the share of road transport emissions and categorising them by vehicle type is essential for designing effective policies in rapidly urbanising areas. Recent studies highlight that improved data quality and locally tailored inventories can support the identification of clean and green solutions for cities (Kumar et al. 2022).

The GPC framework accounts for emissions from all urban activities. Within the transport sector, it distinguishes between Scope 1 emissions (direct emissions from transport occurring within city boundaries) and Scope 2 emissions (emissions associated with imported energy used within the city for transportation services) (Wee et al. 2021). In contrast, frameworks such as the *IPCC guidelines*, the US Energy Information Administration (EIA), the International Energy Agency (IEA), and the Emissions Database for Global Atmospheric Research (EDGAR) primarily classify transport emissions at national or regional levels (Fan and Guan 2025; Lwasa et al. 2022; IPCC 2006; UNFCCC 2025). These methodologies rely on aggregated activity data at national or regional scales, which often fail to capture localised sources unique to cities, such as intra-city travel patterns, vehicle profiles, and future scenario prospecting. This makes them less suitable for identifying city-scale decarbonisation strategies.

1.3 UK PACT urban planning and portfolio relevance

The India–UK PACT (*Partnering for Accelerated Climate Transitions*) Country Fund supports local governments in rapidly growing tier-2 cities through technical assistance and capacity-building initiatives focused on urban planning, mobility, and climate resilience. Erode is one of the cities participating in the programme, which seeks to integrate climate considerations into city-level urban plans, utilising climate-data-driven approaches to urban planning and mobility and accessing accelerated climate finance (UK PACT 2025). The programme aims to strengthen Erode's long-term sustainable development trajectory by integrating climate considerations into planning, governance, and implementation through three broad approaches:

- **Engage and assess:** Collaborate with stakeholders to identify mobility concerns and priorities, ensure inclusivity, and evaluate existing urban plans, such as comprehensive mobility plans (CMPs), master plans, and community action plans, for opportunities to integrate climate-resilient and sustainable mobility solutions. This stage sets the foundation by aligning project objectives with local realities and ensuring broad stakeholder buy-in.

- **Embed and create:** Integrate data-driven and climate-focused mobility strategies into planning processes and initiate pilot projects related to non-motorised transport, public transport, and electric mobility.

- **Expand and inspire:** Support access to innovative financing mechanisms for climate-resilient mobility interventions and strengthen institutional capacity within the municipal corporation to support long-term implementation.

By combining data-driven planning, innovative financing, and capacity-building, the programme seeks to establish a scalable, inclusive, and climate-resilient urban mobility framework that reduces emissions, improves accessibility, and supports the transformation of Erode's transport system.

Currently, Erode's CMPs and transport studies do not account for city-level on-road GHG emissions. Establishing and maintaining a GHG calculator, therefore, represents an important step towards evaluating the effectiveness of mobility interventions and tracking progress towards emissions-reduction goals. The programme will generate a range of outputs, including guidance notes, manuals, roadmaps, reports, workshops, and surveys, many of which may be relevant to other rapidly growing tier-2 cities. However, as with any city-scale climate initiative, successful implementation will depend on sustained bureaucratic leadership, political commitment, and public support.

1.4 Research objectives

This study aims to develop a GPC-compliant GHG emissions calculator for the on-road transport sector in Erode Municipal Corporation (EMC). Designed for institutional use, the calculator will support periodic inventory updates, scenario analysis, and evidence-based transport planning. Together, the report and the accompanying Excel-based GHG calculator aim to inform local policy and sustainable transport planning in Erode while providing a framework that can be adapted for other tier-2 and tier-3 cities.

The study has two objectives:

- To establish a baseline GHG emission profile for the on-road transport sector by categorising and comparing emissions across vehicle segments (e.g., two-wheelers [2Ws], three-wheelers [3Ws], cars, buses, LCVs and trucks) and fuel types (e.g., petrol, diesel, compressed natural gas [CNG], liquefied petroleum gas [LPG], and electric vehicles [EVs]).

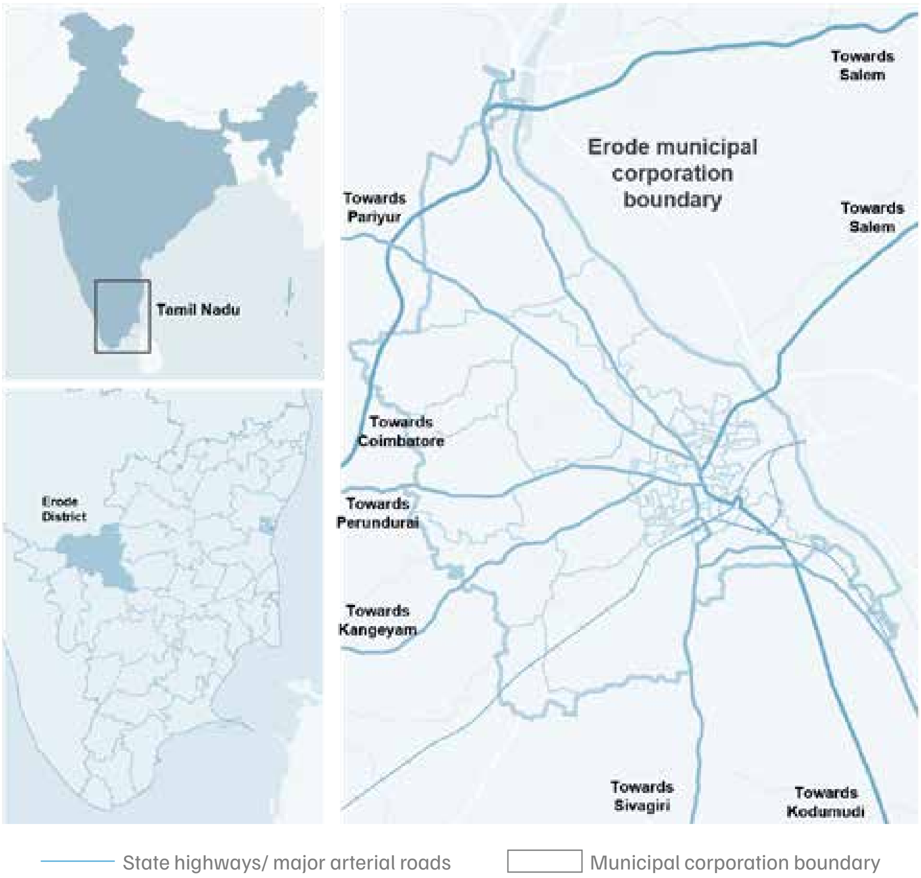
- To simulate and compare business-as-usual (BAU) and alternative future scenarios, including cleaner fuel adoption, technological improvements, and policy interventions, in order to assess their emissions-reduction potential and support evidence-based decision-making for city-level climate action planning.

2. About Erode and Erode Municipal Corporation

Erode is one of the 38 districts of Tamil Nadu and is located in the northern part of the state. It shares borders with Karnataka and the Tamil Nadu districts of Namakkal, Karur, Dindugal, Coimbatore and Nilgiris. The district is well connected by rail and road to major cities, such as Coimbatore, Chennai, and Madurai (GoTN 2025). Erode lies along the Salem–Erode–Tiruppur–Coimbatore transport corridor (ABP 2025), which has been identified as a spatially prioritised urban region (SPUR), and is connected to the Coimbatore–Erode–Salem Expressway and the Perundurai Industrial Park. Erode has the country's largest textile market and is also known as the 'turmeric capital of India' (TNUIFSL 2015). According to the 2011 census, the Erode municipal boundary had the highest urban population in the district, at 4.98 lakh, and a population density of 4,548 people per km^2, significantly higher than Tamil Nadu's (555 people per km^2) (ECMC n.d.).

Erode Municipal Corporation is located on the north-western bank of the Kaveri River. Administratively, it is divided into 4 zones and 60 wards (ECMC n.d.). The city has a radial road network, with primary arterial roads originating from the city centre, which now functions as the central business district. The urban core is characterised by narrow roads, commercial and industrial land uses, and surrounding residential neighbourhoods (TNUIFSL 2015).

Figure 1. Location and connectivity of Erode Municipal Corporation



Source: Authors' analysis.

2.1 On-road vehicle stock in the Erode municipal boundary

To understand the vehicle stock characteristics of Erode's on-road fleet, the study utilises two datasets: (i) the official VAHAN registration database (MoRTH n.d.) and (ii) the Fuel Station User Survey (FuSS). The VAHAN dataset includes vehicle category, vehicle type, registration year, and fuel type. However, it does not include on-road vehicle characteristics or travel patterns. To understand these vehicle characteristics (vehicle model, vehicle age, fuel type, and mileage) and travel patterns (distances, trip origins and destinations, etc), the FuSS (~6,000 samples) was conducted at multiple locations in the city (September 2025). For a detailed description of the survey methodology and results, please refer to *Movement of People and Goods: A Case Study of EMC* (CEEW 2026).

The FuSS encompasses a diverse sample of users and drivers across 2Ws, 3Ws, four-wheelers (4Ws), buses, light commercial vehicles (LCVs), and trucks. The largest share of responses came from 2Ws (~33 per cent; n = 2,000/6,000), followed by LCVs and 4Ws. The sample distribution was determined based on the observed share of vehicle registrations in the VAHAN dataset to ensure representativeness. A minimum of 300 samples was collected for each vehicle category to maintain statistical robustness. Survey data were collected at fuel stations, auto stands, bus stands, bus stops, parking lots, loading and unloading areas, and an old commercial market. The survey records information across two broad themes: (i) vehicle characteristics (e.g., make, model, manufacturer, registration year, and fuel type) and (ii) travel patterns (e.g., origin and destination locations, trip type, trip distance, and travel time).

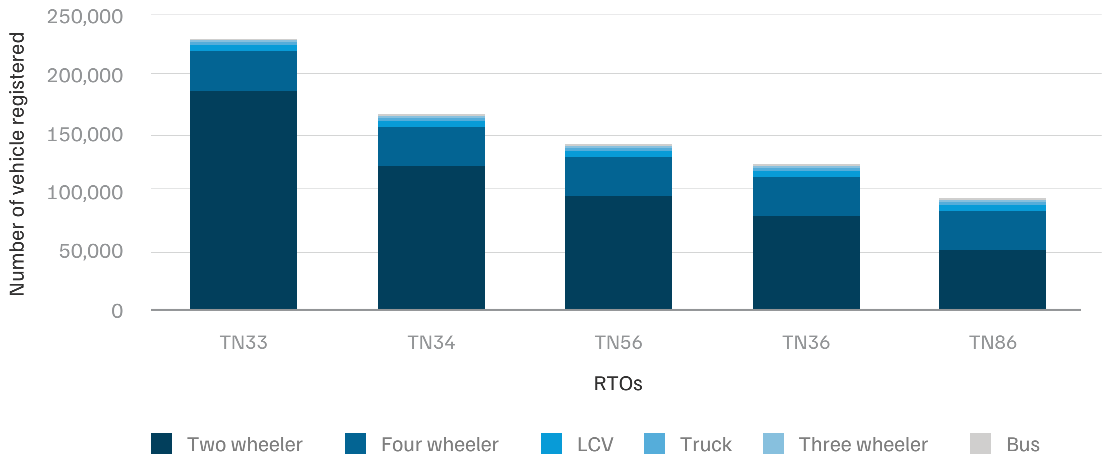
According to the survey, 98 per cent of vehicles are registered in Tamil Nadu, of which only 48 per cent are registered within the Erode municipal boundary (RTOs TN33 and TN86); the remainder are registered in nearby RTOs. TN33, TN86, TN56, TN34, and TN36 are the five most represented RTOs and together account for approximately 65 per cent of the FuSS sample.

VAHAN registration (2011–25)

According to the FuSS survey, Erode RTO (TN33) has the largest share of vehicle registrations among nearby districts, followed by Tiruchengode (TN34), which has a larger share of truck registrations than Erode RTOs (TN33 and TN86), as shown in Figure 2.

According to VAHAN data, cumulative annual vehicle registrations within the EMC area (TN33 and TN86) from 2011 to 2025 total approximately 3.2 lakh vehicles. Registrations declined by approximately 30 per cent in 2020 compared with the previous year (from ~23,056 in 2019 to 15,962 in 2020), likely due to the pandemic. By 2025, registrations had recovered to ~21,700 vehicles, approaching pre-pandemic levels (21,488 registrations in 2014). In terms of vehicle composition, the 2W segment dominates, accounting for approximately 80 per cent of total registrations, followed by 4Ws at approximately 14 per cent. The remaining ~5 per cent comprises 3Ws, buses, LCVs, and trucks (Figure 3).

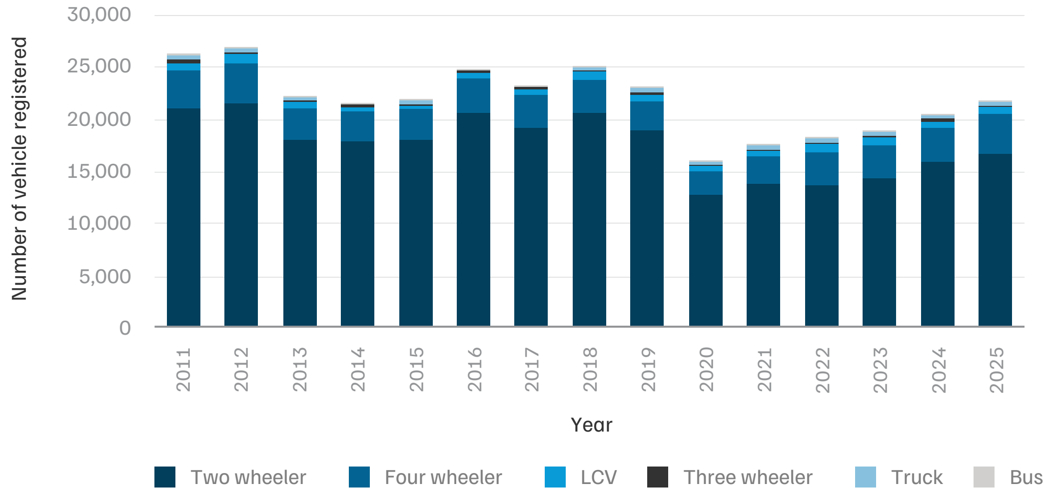
Figure 2. Cumulative vehicle registrations (2011–25) from the top five RTOs, which together constitute 65% of the on-road fleet in EMC



Source: MoRTH (Ministry of Road Transport and Highways).2025. "VAHAN Dashboard." Government of India.

Note: LCV: light commercial vehicle; RTO: regional transport office

Figure 3. Vehicle registrations (2011–25) in Erode Municipal Corporation (TN33 and TN86) have been steadily increasing during the post-pandemic period



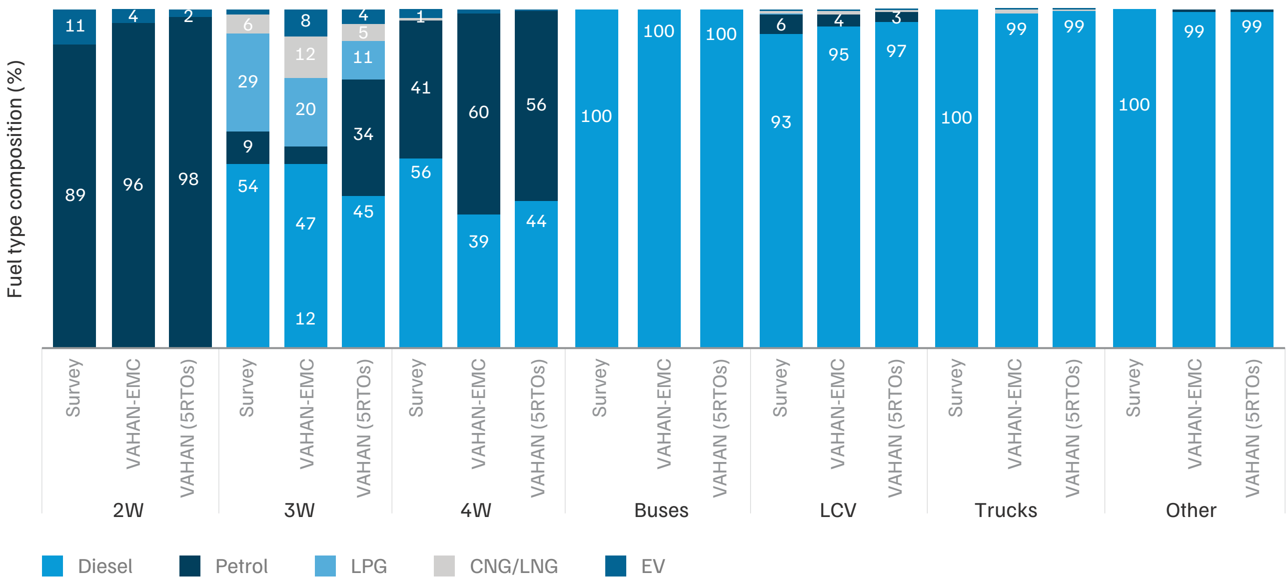
Source: MoRTH (Ministry of Road Transport and Highways).2025. "VAHAN Dashboard." Government of India.

Note: LCV: light commercial vehicle; RTO: regional transport office

The fuel-type distribution across vehicle categories shows a strong dominance of fossil fuels, namely, petrol and diesel. Petrol accounts for the largest share of 2Ws (96 per cent) and 4Ws (60 per cent), while diesel dominates the freight vehicle segment, accounting for 95 per cent of LCVs, 99 per cent of trucks, and almost all buses. Electric vehicles represent a relatively small share of the fleet and are primarily concentrated in the 3W and 2W segments. Penetration of CNG is highest in the 3W segment (12.3 per cent), while LCVs and trucks each account for ~1 per cent. Similarly, LPG is largely concentrated in the 3W segment (20 per cent). Hybrid vehicles account for only a small share of the 4W segment.

Formal parking at thindal road in Erode.

Figure 4. Vehicle registration data (all five RTOs and EMC) and survey results show similar fuel-type distributions across vehicle categories



Source: Authors' analysis.

Note: 2W: two-wheeler; 3W: three-wheeler; 4W: 4-wheeler; CNG: compressed natural gas; EMC: Erode Municipal Corporation; EV: electric vehicle; LNG: liquefied natural gas; LPG: liquefied petroleum gas; RTO: regional transport office

Figure 4 compares the primary survey with VAHAN registration statistics and suggests that the survey is broadly representative of the registered vehicle fleet. For 2Ws and 4Ws, petrol remains the dominant fuel type, with EVs emerging only in recent registrations. Among 3Ws, the survey records a slightly higher share of LPG and a lower share of CNG/liquefied natural gas (LNG) and EVs, with very limited representation of petrol vehicles compared with VAHAN data. Buses, LCVs, and trucks consistently show a dominant diesel share in both datasets, indicating good representation in the survey. There is currently no EV penetration in the bus or truck fleet in Erode.

The fuel-type distribution observed in the VAHAN dataset for EMC is broadly similar to that observed across the five major RTOs (TN33, TN86, TN56, TN34, and TN36), reinforcing the reliability of both datasets for subsequent analysis.

A few points regarding sample-to-population representativeness are worth noting. First, the VAHAN dataset captures all registered vehicles but does not distinguish between registered and in-use vehicles. Second, the FuSS provides a cross-sectional snapshot of vehicle composition and travel patterns and may under- or over-represent certain vehicle or fuel types. Third, aggregation at the RTO level masks inter-city vehicle movement and the floating vehicle population, including vehicles not registered under TN33 or TN86. All emissions estimates in this study are therefore based on the VAHAN registration data for TN33 and TN86.

2.2 Vehicle characteristics and travel demand

Table 4. Descriptive statistics for vehicle category characteristics

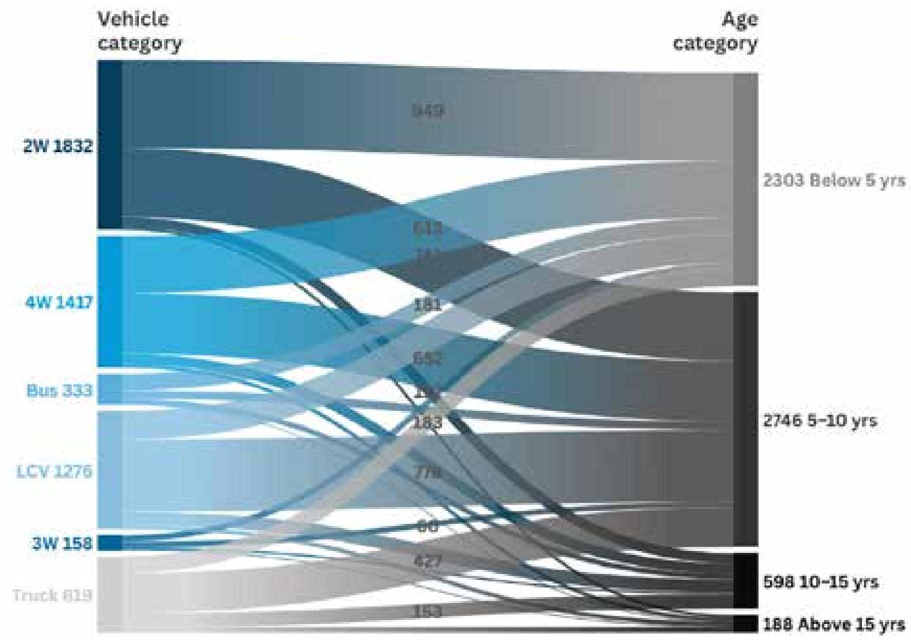
Vehicle category	Vehicle type	Vehicle age	Occupancy	Mileage (P, D, LPG-km/kg CNG/LNG-km/kg; EV-Wh/km)
		Mean (μ) ± standard deviation (σ)		
2W	2W-P	6.0 ± 4.3	1 ± 0	27.8 ± 12.1 (P) 98.0 ± 27.7 (EV)
	2W-C	5.7 ± 3.7	1.0 ± 0	42.4 ± 9.7 (P) 105.3 ± 20.9 (EV)
3W	3W-P	7.3 ± 5.5	2.3 ± 1.1	21.1 ± 3.7 (D); 20.5 ± 4 (P); 19.7 ± 3.6 (CNG); 19.5 ± 3(LPG); 115 ± 49.5 (EV)
	3W-S	11.1 ± 6.3	2.5 ± 1.2	16.6 ± 2.9 (D); 20 (P); 20.3 ± 2.1 (CNG); 15 (LPG)
4W	CJV	6.4 ± 3.9	4.8 ± 5.1	16.3 ± 5.7 (D); 20.1 ± 2.9 (P); 18 (CNG)
	4W-C	6.6 ± 4.2	2.9 ± 1.3	19.3 ± 3.3 (D); 19.7 ± 3 (P); 20.4 ± 2.8 (CNG); 19 (LPG); 337.0 ± 132.1 (EV)
Bus	Intercity	5.6 ± 4.3	45.9 ± 10.7	7.5 ± 1.7 (D)
	Intracity	7.4 ± 3.8	46.7 ± 10.2	7.4 ± 1.6 (D)
LCV	LCV-3W	8.9 ± 5.2	-	19.3 ± 4.4 (D); 21.5 ± 3.1 (P); 20 ± 3.8 (CNG/LNG); 19.0 ± 1.3 (LPG); 104.3 ± 46.9 (EV)
	LCV-4W	7.4 ± 3.2	-	16.1 ± 4.2 (D); 15.9 ± 5.4 (P); 18 ± 4.2 (CNG/LNG)
Trucks	2AT	8.8 ± 4.5	-	7.6 ± 1.6 (D)
	3AT	9.0 ± 5.2	-	7.4 ± 1.7 (D)
	MAV	8.4 ± 3.3	-	7.4 ± 1.6 (D)

Source: Fuel-station survey conducted by CEEW (2025).

Note: P: petrol; D: diesel; 2W-P: two-wheeler–personal; 2W-C: two-wheeler–commercial; 3W-P: three-wheeler–private; 3W-S: three-wheeler–shared; CJV: car/jeep/van; 4W-C: four-wheeler–commercial; LCV: light commercial vehicle; 2AT: two-axle truck; 3AT: three-axle truck; MAV: multi-axle vehicle; Mileage is self reported in the survey.

According to the survey (Table 4), Erode's on-road vehicle stock is predominantly mid-aged, with 5–10-year-old vehicles comprising the largest share across all categories (47 per cent of the 6,000 samples). A notable proportion (~20–30 per cent) is relatively new (less than 5 years old), particularly among personal vehicles, such as 2Ws and 4Ws. In the 3W and truck segments, ~15 per cent of the fleet is over 15 years old. In public transport, ~30 per cent of the stock is over 10 years old, underscoring the local government's deferred replacement cycles. Overall, ~14 per cent of vehicles are over 10 years old, of which ~50 per cent are diesel-fuelled trucks.

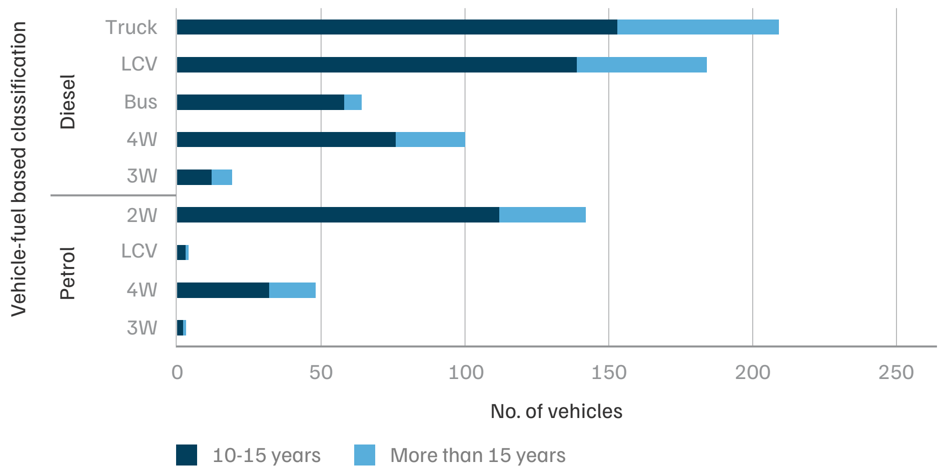
Figure 5. 14% of the vehicles are over 10 years old



Source: Authors' analysis.

Note: 2W: two-wheeler; 3W: three-wheeler; 4W: four-wheeler; LCV: light commercial vehicle

Figure 6. 75% of the vehicles over 10 years old are diesel-dominant and heavy-duty trucks



Source: Authors' analysis.

Note: 2W: two-wheeler; 3W: three-wheeler; 4W: four-wheeler; LCV: light commercial vehicle

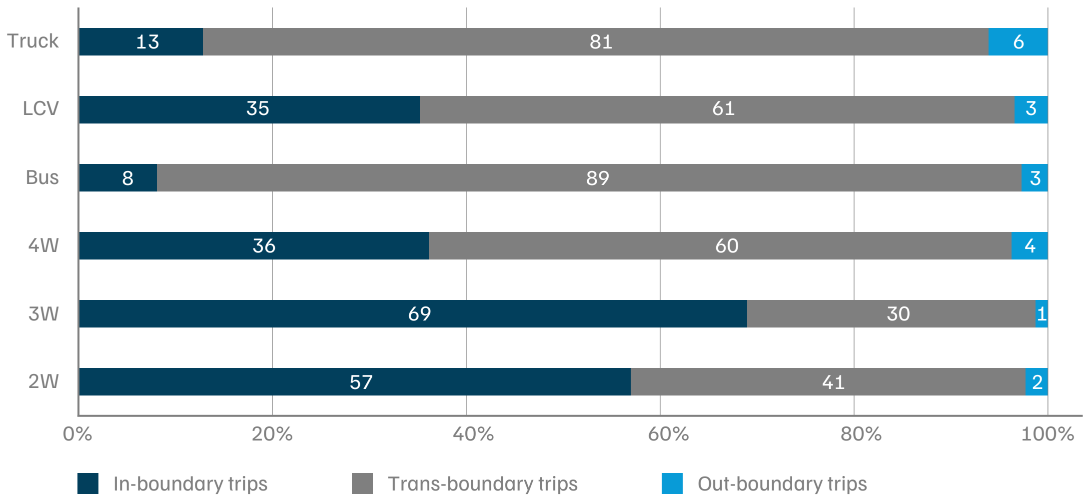
Table 5. Descriptive trip and average daily distance (ADT) statistics by vehicle fuel type

Vehicle category	Vehicle type	Trip distance (km)	Trips /day	ADT self-reported (km)	ADT calculated (km)*
2W	2W-P	11.5	3.6	31	40.8
	2W-C	12.6	4.3	35	44.6
3W	3W-P	7.5	3.7	23.5	28.2
	3W-S	8.1	4.8	41.3	38.4
4W	4W-P	22.7	3.7	54	64.3
	4W-C	28.8	3.0	68.8	99
Bus	Intercity	70	3.6	282	243.8
	Intracity	18	3.3	160	58.2
LCV	LCV-3W	12.7	3.6	34	47
	LCV-4W	24.6	2.9	54	68
Trucks	2AT	53	2	121	104
	3AT	103	1.8	180	146.7
	MAV	72.8	2.5	174	107.4

Source: Fuel-station survey conducted by CEEW (2025).
Note: *Average daily distance (ADT) = no. of trips per day x distance per trip
P: petrol; D: diesel; 2W-P: two-wheeler–personal; 2W-C: two-wheeler–commercial;
3W-P: three-wheeler–private; 3W-S: three-wheeler–shared; CJV: car/jeep/van; 4W-C: four-wheeler–commercial;
LCV: light commercial vehicle; 2AT: two-axle truck; 3AT: three-axle truck; MAV: multi-axle vehicle

In-boundary trips are those whose origin and destination lie within the EMC boundary, trans-boundary are those where either the origin or destination lies outside the EMC boundary, and out-boundary (or pass-through) trips reflect the vehicles passing through the city, whose origin and destination both lie outside the city's boundary. In accordance with GPC guidelines, outbound/pass-through trips are excluded from the inventory. In-boundary travel is most common among 2Ws and 3Ws, with 57 per cent and 69 per cent of trips, respectively, occurring within the city. In contrast, ~60 per cent of 4W and LCV trips are trans-boundary. Buses and trucks account for the largest share of trans-boundary trips, reflecting Erode's role as an important urban centre for passenger mobility and freight movement. Outbound trips remain at 1–6 per cent across vehicle segments, indicating that most travel either originates or terminates within the city boundary.

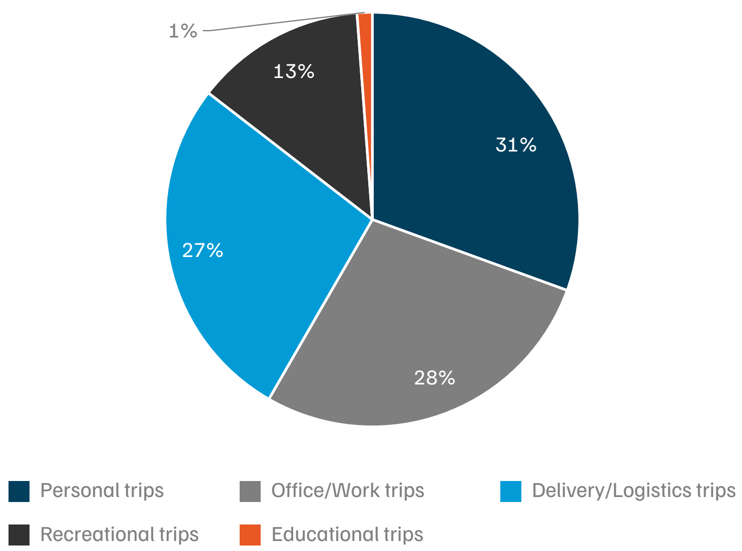
Figure 7. Trans-boundary movement dominates for freight and public transport



Source: Authors' analysis.

Note: 2W: two-wheeler; 3W: three-wheeler; 4W: four-wheeler; LCV: light commercial vehicle

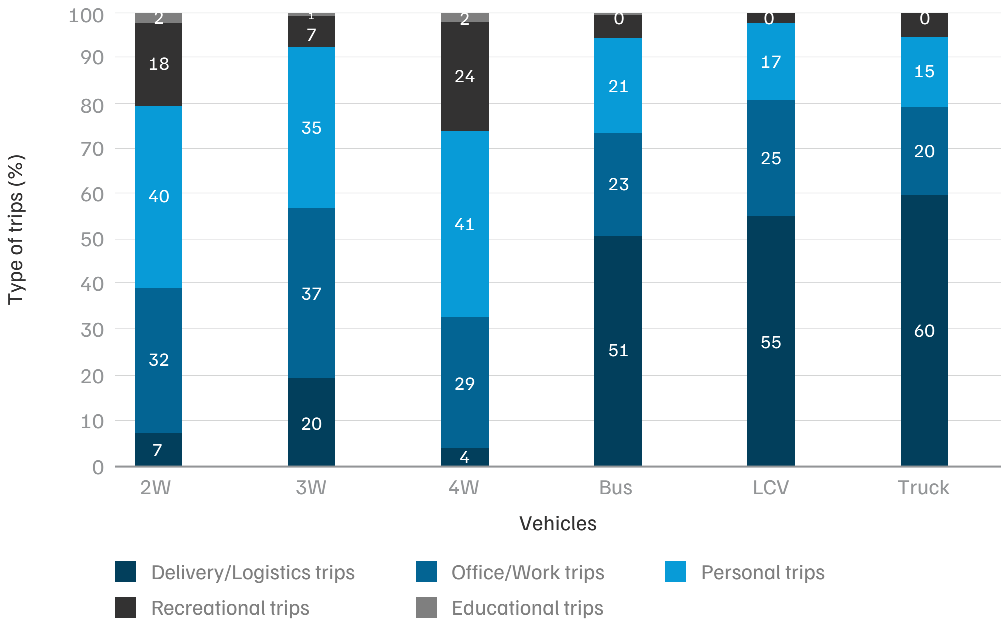
Figure 8.56% of the trips are daily trips (work and personal)



Source: Authors' analysis.

Delivery and logistics trips are dominated by freight modes such as two-axle trucks (2ATs), three-axle trucks (3ATs), multi-axle vehicles (MAVs), and LCVs, consistent with the use case and vehicle type. Personal and work-related trips account for the largest share of travel by 2Ws, 3Ws, and 4Ws (~60–70 per cent). Recreational trips are particularly notable among 4Ws (28 per cent) and moderate in 2Ws and shared autos. 53 per cent of bus trips are associated with travel to and from transit stops. Overall, the trip profile highlights a clear distinction between personal mobility modes and commercial/public transport modes based on dominant trip purposes.

Figure 9. Two-thirds of two-wheeler, three-wheeler, and four-wheeler trips are personal and work-related



Source: Authors' analysis.

Note: Delivery/Logistics trips in passenger segments are shared, as well as on-demand passenger trips for 3Ws and 4Ws. Personal trips are part of home-based trips, such as people returning from school or work, or last-mile trips.

2W: two-wheeler; 3W: three-wheeler; 4W: four-wheeler; LCV: light commercial vehicle

Stakeholder consultation between CEEW, ITDP, and TNSTC at the TNSTC office for public transport data collection.

3. Methodology and tool development

This chapter is structured into four parts: (i) the GPC reporting framework and its adaptation to the on-road transport sector, (ii) methodology, (iii) data parameters and modelling components, and (iv) forecasting and scenario-modelling framework. Together, these components establish the analytical basis for baseline estimation and future emissions projections.

The GPC was developed through a collaborative effort of the World Resources Institute (WRI), the C40 Cities Climate Leadership Group (C40), and Local Governments for Sustainability (ICLEI). The guidelines were first introduced in 2012 (Wee et al. 2014) and subsequently revised in 2020–21 to align with the 2006 IPCC Guidelines. The GPC provides a consistent and transparent framework for cities to measure, report, and track GHG emissions. It supports cities in setting emissions-reduction targets, monitoring progress, and enabling the comparison and aggregation of city-level inventories at national scales (Wee et al. 2021). The GPC inventories adhere to the principles of relevance, completeness, consistency, transparency, and accuracy as outlined in the *GHG Protocol Corporate Standard* (WBCSD 2015). The GPC inventory captures emissions generated within the boundary as well as select trans-boundary emissions, thereby incorporating both production- and consumption-based activities.

The guidelines require defining the geographic boundary, time period, gases covered (e.g., CO_2, CH_4, and N_2O), and emission sources (sector-wise classification). Hence, emissions are reported by sector, subsector, and scope and are aggregated in CO_2e units. The sources are classified based on different activities and distinguished into six sectors (Table 6).

Table 6. Sectors considered as per the GPC city-level emissions inventory

Sectors	Description
Stationary energy	Includes emissions from buildings, industries, agriculture, forestry, fishing, and fugitive sources (including mining, processing, oil, and natural gas systems).
Transportation	Includes emissions from on-road transport, railways, waterways, aviation, and off-road transport.
Waste	Includes emissions from solid waste (including disposal, biological treatment, and incineration) and wastewater treatment and discharge.
IPPU	Includes emissions from industrial processes as well as from product use and disposal.
AFOLU	Includes emissions from livestock as well as from land use and land-use change (LULUC).
Other (Scope 3)	Includes emissions occurring outside the city boundary that are related to city activities (T&D losses, waste disposal and treatment outside the city, etc), which are not reported above.

Source: Wee, K. F., M. Sotos, M. Doust, Seth Schultz, A. Marques, and C. Deng-Beck. 2021. Global Protocol for Community-Scale Greenhouse Gas Inventories: An Accounting and Reporting Standard for Cities Version 1.1.

Note:
(1) Sectors are further divided into sub-sectors and sub-categories.
(2) T&D losses: transmission and distribution losses.
(3) The study is limited to the on-road transport sector.
(4) AFOLU: agriculture, forestry, and other land use; GPC: Global Protocol for Community-Scale Greenhouse Gas Emission Inventories; IPPU: industrial processes and product use; LULUC: land use and land-use change; T&D: transmission and distribution

The GPC-GHG inventory uses two reporting approaches for city-level emissions inventories:

1. **Scope framework**
   Emissions are classified into three categories: Scope 1, Scope 2, and Scope 3. Emissions from sources located within the city boundary are classified as Scope 1 emissions and are also referred to as territorial emissions. Emissions associated with grid-supplied energy are classified as Scope 2 emissions. Scope 3 emissions occur outside the city boundary but result from activities taking place within the city (Wee et al. 2021).

2. City-induced framework

The city-induced framework estimates emissions based on activities occurring within the city boundary. It comprises two reporting levels:

- **BASIC:** Covers emissions generated within the city boundary, including stationary energy, in-boundary transport, waste, and energy consumption.

- **BASIC+:** Includes all BASIC emissions as well as emissions from industrial processes and product use (IPPU), agriculture, forestry, and other land use (AFOLU), trans-boundary transportation, T&D losses, and other relevant sources.

3.1 GPC framework adaptation for the road-transport sector

The GPC guidelines classify the transportation sector into five subsectors: on-road transportation, railways, aviation, water-borne transport, and off-road transport. This study considers only emissions from on-road transport.

The GPC guidelines broadly classify on-road transport trips as either in-boundary or trans-boundary. Trans-boundary trips can be further categorised into four types: (i) trips originating within the city and terminating outside the city, (ii) trips originating outside the city and terminating within the city, (iii) regional public transit services with multiple stops (e.g., trains and buses), and (iv) trips that both originate and terminate outside the city boundary. Table 6 summarises the reporting requirements under the scope and city-induced frameworks.

Table 7. Reporting requirements for on-road transport emissions

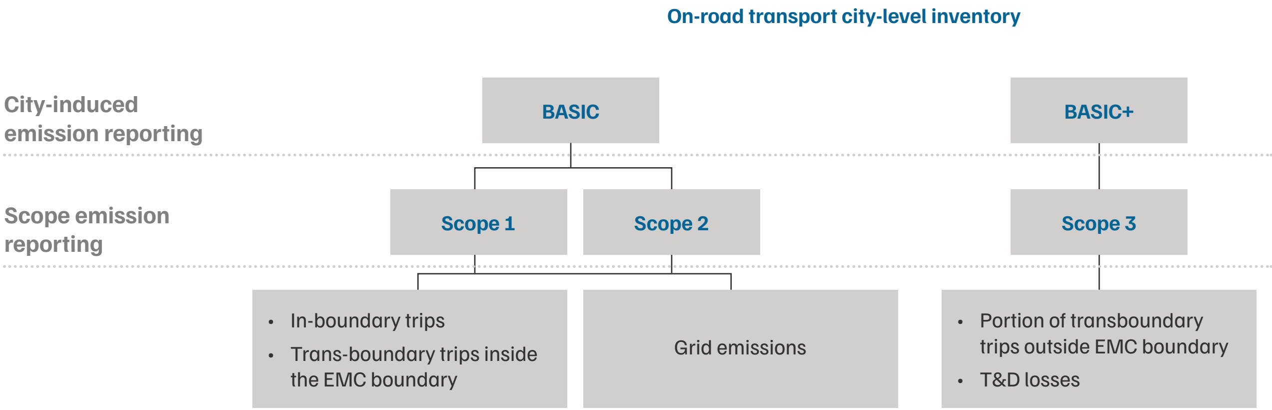
Transport mode	Scope framework		
	Scope 1	Scope 2	Scope 3
On-road transport	Includes IB tailpipe emissions	Includes emissions from the combustion of grid-supplied energy for IB transport	Includes portion of TB emissions originating from OB and T&D losses from grid-supplied energy

Source: Authors' analysis.

Note:(i) BASIC level reporting; BASIC+ level reporting

(ii) IB: in-boundary; TB: trans-boundary; OB: out-boundary; T&D: transmission and distribution losses

Figure 10. Framework for on-road emission inventory



Source: Authors' analysis.

Note: EMC: Erode Municipal Corporation; T&D: transmission and distribution losses

To estimate transport-sector emissions, methodologies can be broadly classified into top-down and bottom-up approaches. One top-down approach uses fuel sales as a proxy for travel activity to estimate emissions, while bottom-up approaches typically apply the ASIF (Activity–Share–Intensity–Fuel) framework. Under ASIF, activity refers to the average daily distance travelled, share refers to the mode share by vehicle and fuel type, intensity refers to vehicle efficiency (influenced by factors such as occupancy or load factor, driving cycle, and speed), and factor refers to the relevant EFs (Sharma et al. 2019).

Under the GPC guidelines, the following methods can be used to estimate transport-sector emissions:

Fuel sales method

This method estimates GHG emissions based on the total fuel sold within the city boundary, as obtained from retail fuel outlets. The fuel sales data are then scaled to represent the on-road vehicle stock factors. Separate surveys are required to estimate the share of trans-boundary trips and determine the corresponding Scope 3 emissions.

Due to challenges in collecting fuel sales data from private establishments and project timeline constraints, this method was not adopted in the present study.

Induced activity method

This method estimates transport emissions by analysing trips that originate, terminate, or occur within the city boundary. Survey data are used to estimate travel distances for different vehicle categories, which are then combined with fuel-efficiency and emission-factor data.

To account for trans-boundary travel, the approach provides two reporting options:

- Include 50 per cent of trans-boundary trips under Scope 3 while excluding pass-through trips.
- Include 100 per cent of departing trips under Scope 3.

This study employs the induced activity method to estimate emissions and applies the first reporting option.

Geographic (territorial) method

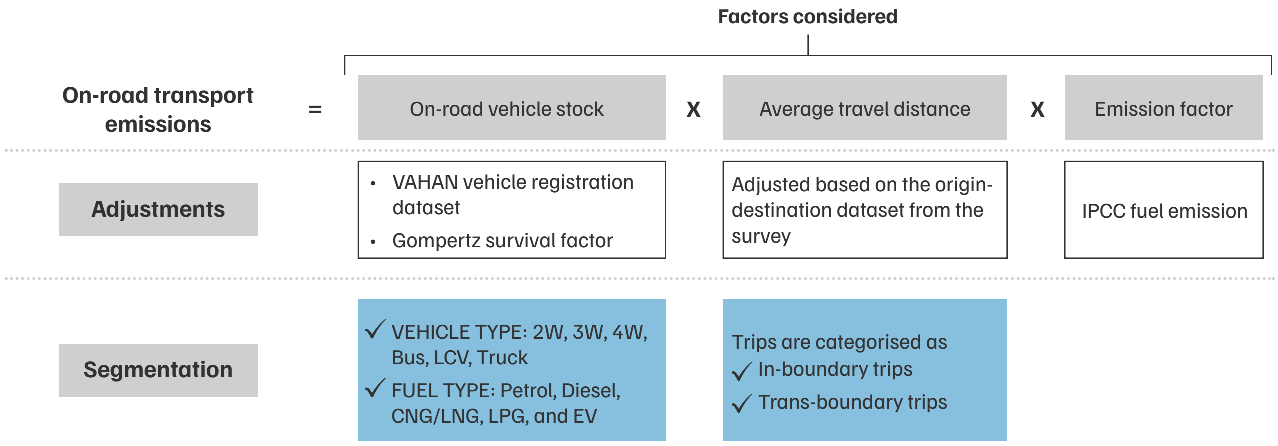
This method estimates emissions from trips occurring within the city boundary. It captures only Scope 1 emissions; additional surveys or methods are required to estimate Scope 3 emissions.

Resident activity method

This method estimates emissions from trips undertaken by city residents. Using household surveys and vehicle registration data, it collects and develops origin–destination datasets to understand travel patterns and estimate both Scope 1 and Scope 3 emissions.

3.2 Activity data and input parameters

Figure 11. Activity data, input parameters, and correction factors



Source: Authors' analysis.

Note: 2W: two-wheeler; 3W: three-wheeler; 4W: four-wheeler; CNG: compressed natural gas; EV: electric vehicle; IPCC: Intergovernmental Panel on Climate Change; LCV: light commercial vehicle; LNG: liquefied natural gas; LPG: liquefied petroleum gas

To synthesise and harmonise the data, VAHAN vehicle categories were grouped into six broader categories: 2Ws, 3Ws, 4Ws, buses, LCVs, and trucks. These categories were further classified by vehicle type based on their primary use (e.g., private, commercial, or public transport), as shown in Table 5. Based on the primary surveys, five fuel categories were identified in Erode: petrol, diesel, natural gas (CNG/LNG), LPG, and EVs.

Table 8. Vehicle categorisation is considered in the GPC-compliant GHG calculator

Vehicle category	
Two-wheeler	Two-wheeler personal, two-wheeler commercial
Three-wheeler	Three-wheeler shared, three-wheeler private
Four-wheeler	Car/Jeep/Van (CJV), four-wheeler commercial
Bus	Intercity bus, intracity bus
Light commercial vehicle	LCV-three-wheeler, LCV-four-wheeler
Truck	2-axle truck, 3-axle truck, multi-axle truck

Source: Authors' analysis.

Multiple datasets are considered for calculating emissions and are mentioned in Table 8.

Table 9. Sources and description for input parameters for the GHG calculator

S.No.	Data type	Description	Source
1.	On-road vehicle stock	Includes the vehicle registered by year, category, and fuel type	VAHAN
2.	Average annual distance travelled (AADT)	Includes the annual distance travelled (ADT) (km) by each vehicle category and fuel type	Fuel-station survey
3.	Average mileage	Calculates the average of the mileage (l/km) reported and the mileage calculated	Fuel-station survey
4.	Emission factor (EF)	Includes EFs of the fuel type (Kg/TJ)	IPCC (2006)
5.	Fuel density	Includes the fuel density (TJ/kg) of multiple fuel types	MoPNG (PPAC 2025)
6.	Calorific value	Includes the calorific value (kg/l) of various fuel types	(World Nuclear Association 2025)
7.	GWP conversion factors	Conversion factor for each GHG expressed in terms of CO_2e	(IPCC 2021)

Source: Authors' analysis.

Note: GWP: global warming potential

On-road vehicle stock

To estimate the on-road vehicle fleet, de-registration or scrappage data is required. Due to the dataset's unavailability, the Gompertz survival function is used to estimate the proportion of vehicles remaining active in the fleet over time, accounting for vehicle scrappage and attrition (Mohan et al. 2025). The survival function is represented as:

$$S(t) = e^{-\alpha e^{\beta t}} \qquad \text{(Equation 1)}$$

where S(t) is the survival function at year t, and α and β are shape parameters that determine curve steepness.

The on-road vehicle stock in year y is estimated as:

$$\textit{On road vehicle stock}_y = \Sigma_{i=0}^{n} \mathrm{Re}\ g_{y-i} \times S(i) \qquad \text{(Equation 2)}$$

where Regy-i represents the number of vehicles registered in the previous year and S(i) represents the survival probability estimated using the Gompertz survival function. It is assumed that vehicles phase out after 15 years of operational life. For more details, please refer to *How Will India's Vehicle Ownership Grow? A District-Level Outlook to 2050* by CEEW (Mohan et al. 2025).

Emission factors (EFs)

According to IPCC (2006), the EF varies by fuel type, as shown in Table 9. For reporting purposes, GHG emissions are accounted for globally in CO_2e as the universal unit of measurement, as mentioned in Table 10.

Table 10. Emission factors as per IPCC guidelines

Fuel type	CO_2 (kg/TJ)	CH_4 (kg/TJ)	N_2O (kg/TJ)
Motor gasoline	69,300	33	3.2
Gas/Diesel oil	74,100	3.9	3.9
Liquefied petroleum gas (LPG)	63,100	62	0.2
Compressed natural gas (CNG)	56,100	92	3
Liquefied natural gas (LNG)	56,100	92	3
Grid emissions	**0.716 kg/kWh**		

Source: CEA (Central Electricity Authority). 2023. CO_2 Baseline Database for the Indian Power Sector. Ministry of Power, Government of India. https://static-cdn.publive.online/saur-energy/media/pdf_files/2025/01cea-report.pdf; IPCC (Intergovernmental Panel on Climate Change). 2006. "Chapter 3: Mobile Combustion." In 2006 IPCC Guidelines for National Greenhouse Gas Inventories, edited by H. S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe. Institute for Global Environmental Strategies.

Table 11. CO_2e conversion units as per IPCC guidelines

Greenhouse gas	IPCC 2nd Assessment	IPCC 3rd Assessment	IPCC 4th Assessment	IPCC 5th Assessment	IPCC 6th Assessment
Carbon dioxide (CO_2)	1	1	1	1	**1**
Methane (CH_4)	21	23	25	28	**27.2**
Nitrous oxide (N_2O)	310	296	298	265	**273**

Source: IPCC (Intergovernmental Panel on Climate Change). 2021. IPCC Sixth Assessment Report Global Warming Potentials. Intergovernmental Panel on Climate Change.

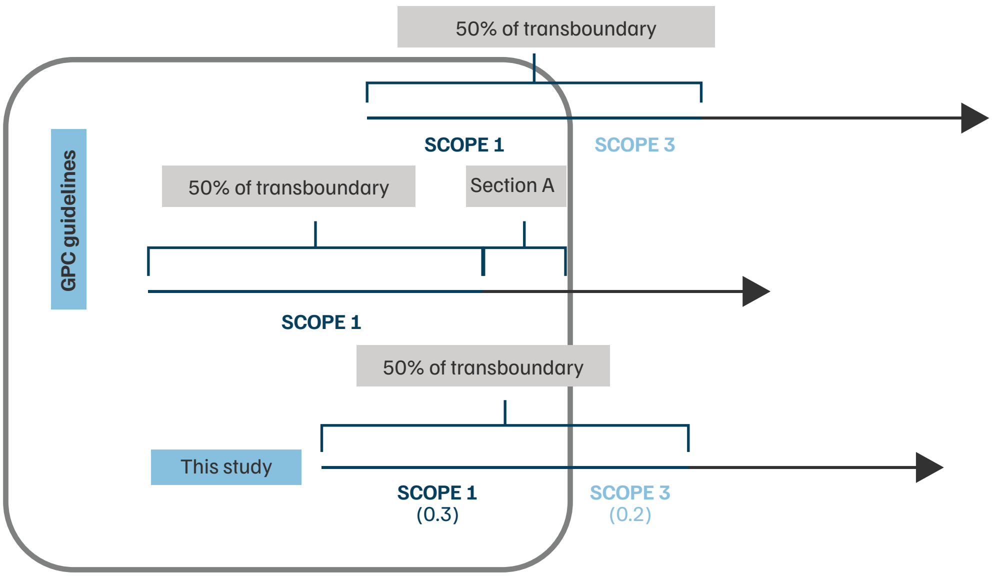
Note: (i) The study uses IPCC AR6 (GWP 100) factors to remain consistent with international practices.

(ii) IPCC: Intergovernmental Panel on Climate Change; AR6: Sixth Assessment Report

Assumptions and correction factors

Scope 1 emissions include in-boundary emissions and a portion of trans-boundary emissions within the city boundary. According to the induced activity method, only 50 per cent of the trans-boundary trip distance is considered. Also, the part that is 50 per cent inside the boundary falls under Scope 1, and the rest falls under Scope 3. The study assumes that 20 per cent of the 50 per cent trans-boundary trip distance (as per GPC guidelines) is happening outside the boundary.

Figure 12. Boundary condition on average distance travelled based on GPC guidelines



Source: Authors' analysis.

Note: (i) Section A is not considered in the study.

(ii) GPC: Global Protocol for Community-Scale Greenhouse Gas Emission Inventories

The study considers a correction factor for estimating GHG emissions from on-road transport. The study accounts only for vehicles registered with RTOs within the EMC boundary (TN33 and TN86). However, according to the survey, 52 per cent of the vehicles are registered outside the EMC boundary. Hence, the correction factor for the floating vehicle inside the EMC boundary is considered as given in equation 3:

$$CF_E = \left(\frac{1}{0.48}\right) = 2.08 \quad \text{(Equation 3)}$$

3.3 Emissions calculation approach

Estimation of GHG emissions for on-road transport is divided into three scopes. To calculate Scope 1 emissions, the activity-based approach (ASIF) is used. To calculate Scope 2 grid emissions, the grid energy consumption model is used. For Scope 3 emissions, trans-boundary transport emissions are calculated using ASIF, and T&D losses are calculated using a loss-rate-based approach. Under the loss-rate-based approach, the grid's average loss rate is estimated from the energy transmitted. The GHG emissions are calculated using equation 4, where EV represents emissions by vehicle type, and the sum of all fuel types, EFF represents the emission factor for the fuel type, and A_{VF} represents the activity of vehicle type 'V' and fuel type 'F'

$$E_V \text{ (in tonnes)} = \sum_{i=O}^{F} EF_F \text{ X } A_{VF} \quad \text{(Equation 4)}$$

The activity data (A_{VF}) refers to the total fuel consumed based on VKT, N_{VF} represents the number of on-road vehicles, AADTVF represents the annual average distance travelled, and MVF represents the mileage of vehicle type 'V' and fuel type 'F'.

$$A_{VF} = (N_{VF} \text{ X } AADT_{VF}) / M_{VF} \quad \text{(Equation 5)}$$

To estimate emissions, IPCC EFs are expressed in kg/TJ; they are then calibrated to kg/l by multiplying them by fuel type 'F''s calorific value and density; CV_F is the calorific value of the fuel type 'F', and D_F is the fuel density of fuel type 'F'.

$$EF_F = EF_{F(IPCC)} \text{ X } CV_F \text{ X } D_F \quad \text{(Equation 6)}$$

According to the GPC guidelines, the emissions are recorded in tCO_2e. The conversion factors are listed in Table 10.

$$E_{V'} \text{ in } tCO2e = A_{VF} \text{ X } \frac{(EF_{CO2} \text{ X } 1 + EF_{CH4} \text{ X } 27.2 + EF_{N2O} \text{ X } 273)}{1000} \quad \text{(Equation 7)}$$

3.4 Forecasting and scenario prospecting

Scenario modelling and future emissions estimation help analyse historical trends and inform future policy, planning, and investment decisions. In the context of national and state net-zero commitments for 2070, these projections help governments and cities understand potential emissions trajectories under different assumptions. Such assumptions may include travel demand patterns, fuel mix, technology adoption, and policy interventions.

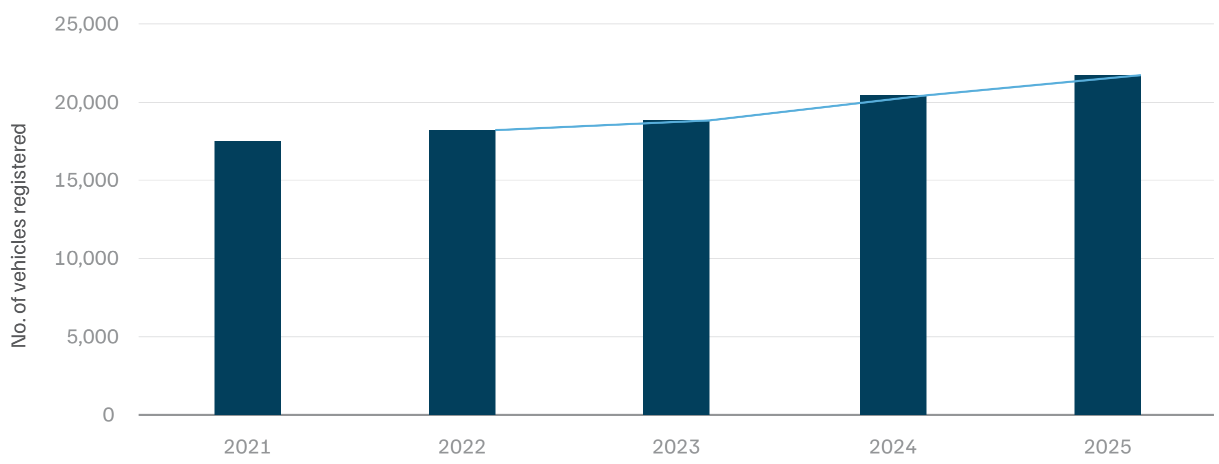
Scenario modelling also helps capture uncertainties associated with economic growth, behavioural patterns, and technological transitions, enabling decision-makers to evaluate multiple pathways and targets, including BAU and low-carbon scenarios. As such, it supports evidence-based decision-making by assessing the implications of current policies and informing future investment decisions.

On-road vehicle stock projection

To project future vehicle registrations, a conventional trend-analysis approach was not adopted because the historical dataset is heavily influenced by the COVID-19 period. The pandemic resulted in an artificial suppression of vehicle sales, producing a statistically misleading negative long-term growth trend (~–1 per cent) when the full time series is analysed. However, more recent data (2021–25) indicate a clear recovery, with annual growth rates of 4–9 per cent.

Relying solely on long-term trend fitting would therefore underestimate future growth and fail to reflect current market conditions and demand patterns. To minimise this bias, the projection approach prioritises post-pandemic recovery trends while remaining conservative. A default decadal growth rate of 10 per cent (~1 per cent annually) is assumed. This assumption balances recent market recovery with long-term uncertainty, ensuring that projections remain realistic, defensible, and conservative for emissions estimation.

Figure 13. Vehicle registrations in Erode are increasing from 2021 to 2025



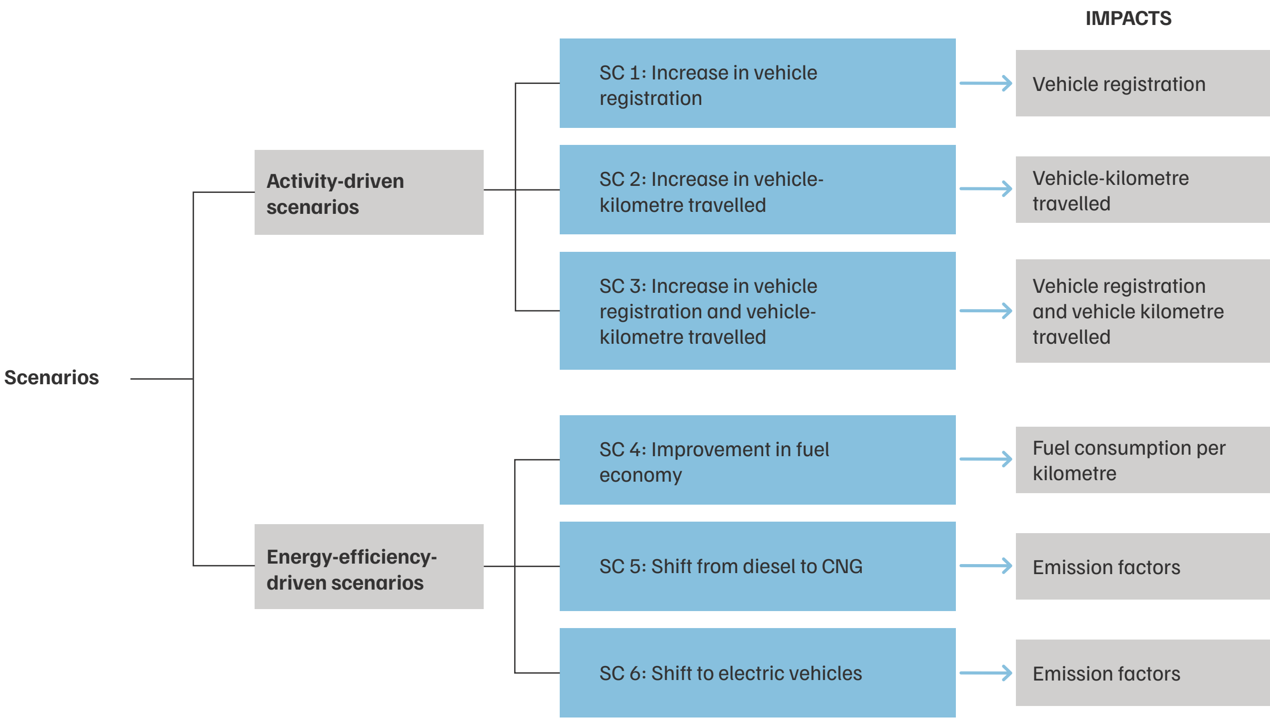
Source: Authors' analysis.

Scenario generation and selection

A multi-scenario assessment framework was developed to evaluate the potential impacts of different policy pathways and development trajectories. Based on baseline vehicle-registration trends (2011–25), on-road fleet projections were estimated for 2030, 2035, 2040, and 2045.

For scenario analysis, interventions are broadly classified as activity-driven or energy-efficiency-driven. Activity-driven scenarios influence travel demand and vehicle-use patterns through changes in vehicle ownership, urban form, and travel distances, thereby affecting vehicle kilometres travelled (VKT) and overall transport energy demand. In contrast, energy-efficiency scenarios focus on improving the transport system's emissions performance through measures such as fuel-efficiency improvements and transitions to lower-carbon fuels. Together, these approaches provide a comprehensive assessment of how behavioural, planning, technological, and fuel-related interventions may influence future transport emissions.

Figure 14. Activity-driven and energy-efficiency-driven side scenarios



Source: Authors' analysis.

Note: CNG: compressed natural gas

Scenario 1 (SC 1): Increase in vehicle registrations

This scenario assumes faster-than-baseline growth in vehicle registrations, driven by rising incomes, improved access to vehicle financing, and increasing preferences for private mobility. Higher vehicle registration can significantly increase fuel demand, road congestion, and transport-sector GHG emissions. This scenario helps decision-makers assess the environmental and infrastructure implications of vehicle dependence and evaluate the potential role of demand-management measures such as parking regulations, congestion pricing, and public transport expansion.

Scenario 2 (SC 2): Increase in VKT

This scenario assumes increasing urban sprawl, resulting in longer trip distances. As VKT increases, fuel consumption and emissions also rise, even when vehicle-ownership growth remains moderate. This scenario supports urban planning decisions by highlighting the importance of integrated land-use and transport planning in limiting future emissions.

Scenario 3 (SC 3): Increase in vehicle registrations and VKT

This scenario combines increases in vehicle registrations and VKT. It represents a high-demand mobility pathway in which both vehicle ownership and travel distances increase simultaneously. The scenario helps define potential lower- and upper-bound emissions trajectories and supports decision-makers in evaluating existing transport and climate strategies.

Scenario 4 (SC 4): Improvement in fuel economy

This scenario assumes improvements in vehicle fuel economy, resulting in reduced fuel consumption per kilometre travelled, thereby lowering overall fuel consumption and associated emissions. It demonstrates near- to medium-term mitigation potential, even as the total number of vehicles increases

Scenario 5 (SC 5): Shifting from diesel to CNG

This scenario assumes a transition from diesel to CNG, particularly within heavy-duty vehicle segments, such as trucks and buses. Given the significant contribution of diesel-powered vehicles to particulate matter (PM), nitrogen oxides (NOx), and CO_2 emissions, fuel switching may yield air quality co-benefits in addition to GHG reductions. The scenario can help decision-makers evaluate fleet conversion or retrofitting incentives and assess short- to medium-term low-carbon fuel-transition strategies.

Scenario 6 (SC 6): Shifting to EVs

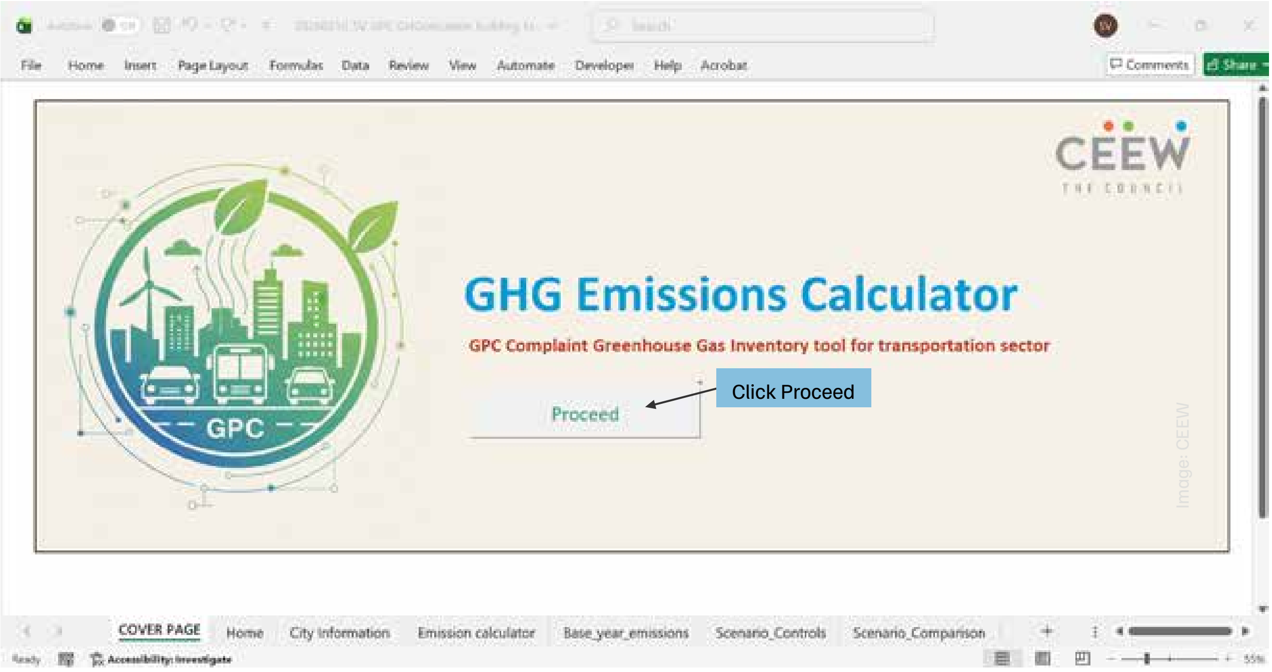
This scenario assumes increasing EV penetration across vehicle segments. Electrification represents a long-term pathway for transport decarbonisation, particularly when supported by a low-carbon electricity grid. The scenario can be used by policymakers to assess charging-infrastructure requirements, estimate future electricity demand from the transport sector, and design EV incentive schemes, regulatory mandates, and phased transition strategies aligned with long-term net-zero goals.

Hands-on exercise during capacity-building workshop on GHG Accounting for On-road Transport Emissions at Erode Municipal Corporation

4. How to use the greenhouse gas calculator: A visual guide

The GHG calculator features six tabs: ‘Home’, ‘City Information’, ‘Emission Calculator’, ‘Base Year Emissions’,’ Scenario Controls’ and ‘Scenario Comparison’.

Step 1. Click 'Proceed' for the 'Home' page



The 'Home' tab provides an overview of the GHG calculator, including its purpose, scope, and guiding principles. It introduces the methodological framework, boundary conditions, and key assumptions used in estimating transport-related GHG emissions. This tab serves as the starting point for users to understand the structure of the tool.

The Home page describes the calculator's purpose and reporting framework. The GPC-compliant GHG calculator tracks emissions from the transport sector, including on-road transport, and reports Scope 1, Scope 2, and Scope 3 emissions under both BASIC and BASIC+ reporting levels.

The 'City Information' tab provides information on the city's characteristics and socioeconomic profile and allows users to define parameters required for GHG emissions estimation.

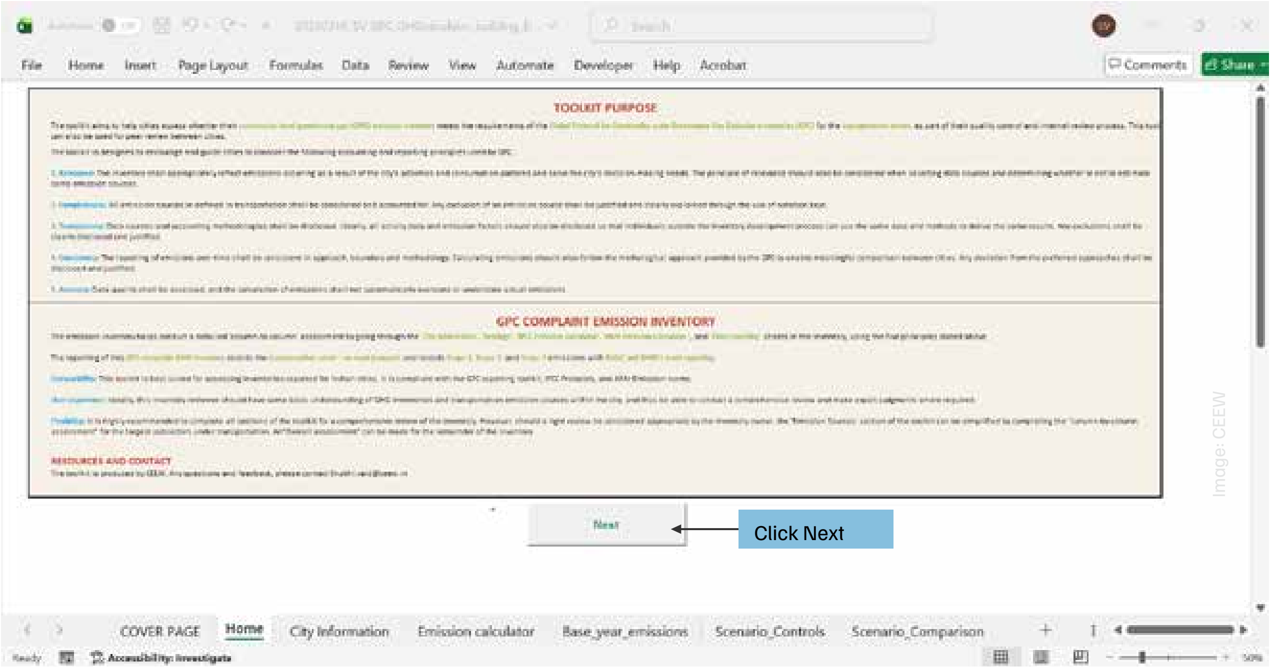
The 'Emission Calculator' tab estimates GHG emissions using vehicle fuel consumption, EFs, and vehicle activity data. Emissions are calculated across vehicle categories and fuel types using a bottom-up methodology.

The 'Base Year Emissions' tab summarises total GHG emissions for the selected base year by scope, vehicle category, and fuel type.

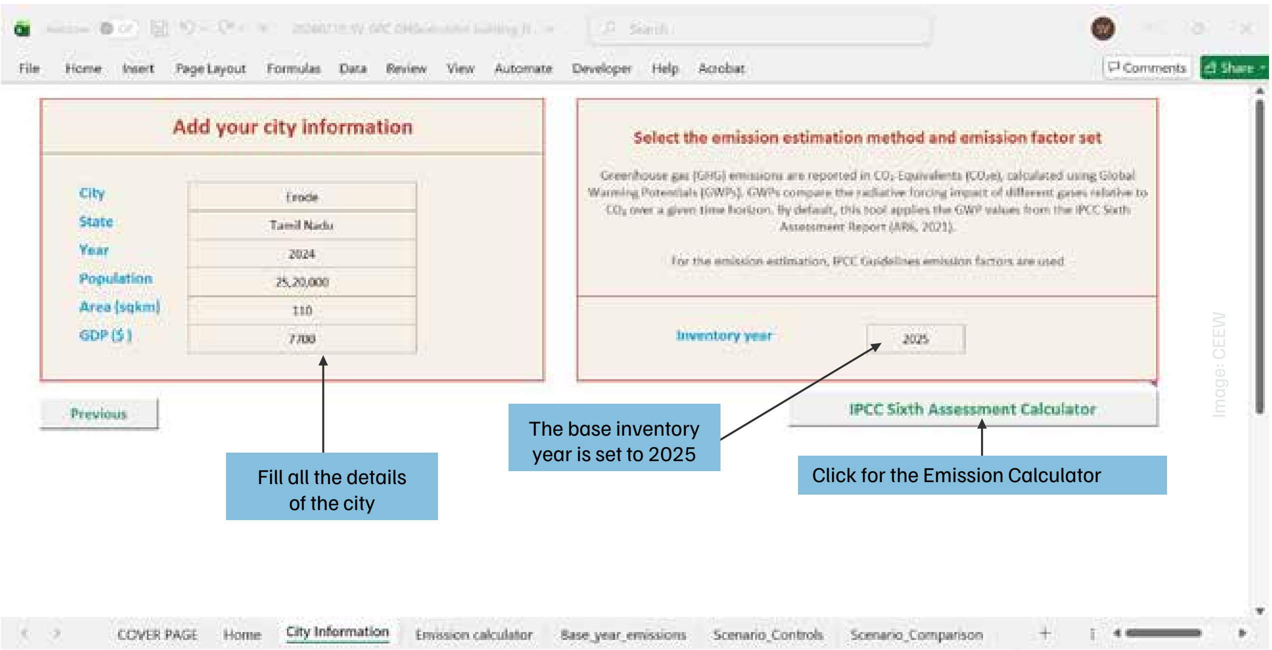
The 'Scenario Controls' tab allows users to define assumptions for different future scenarios, including growth rates, technological changes, and fuel transitions.

The 'Scenario Comparison' tab compares emissions outcomes across multiple scenarios relative to the projected baseline and to one another, enabling users to assess the relative effectiveness of different policy and technology pathways.

Step 2. Click 'Next' to access 'City Information'



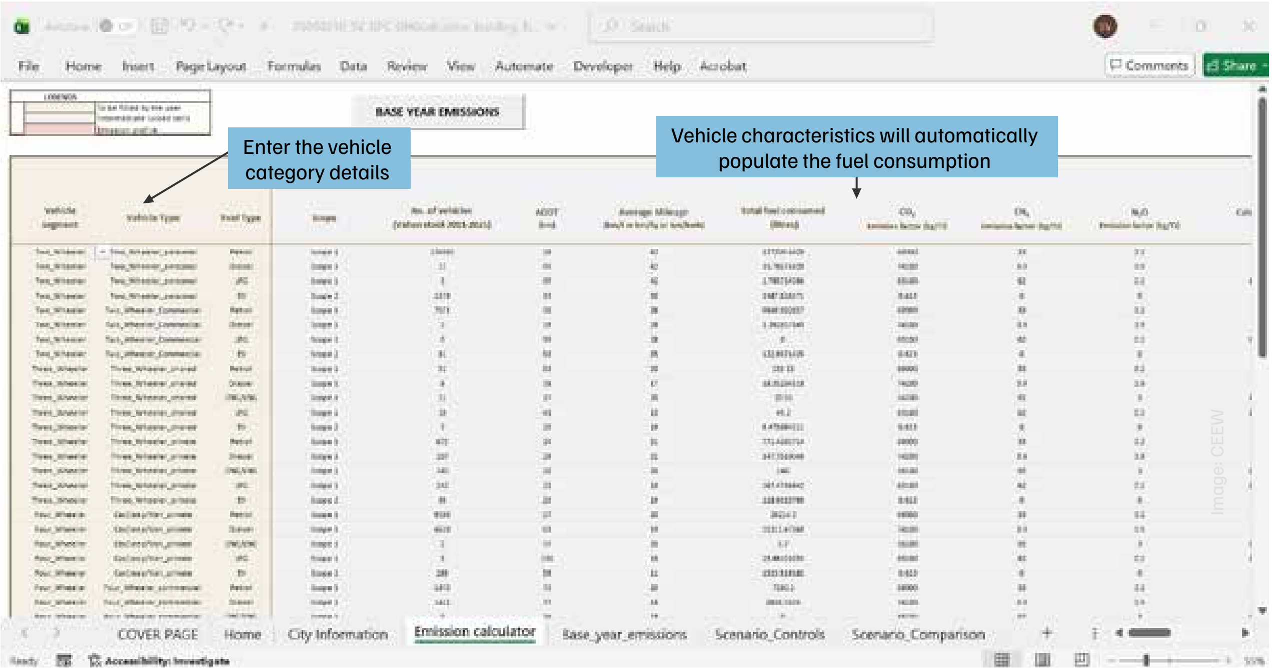
Step 3. Fill in the city information



Enter the city, state, and base year for GHG emissions estimation. For GPC reporting, users should also specify the population, area, and gross domestic product (GDP) corresponding to the selected boundary. Currently, 2025 is the default base year.

Step 4. Click next for 'IPCC Sixth Assessment Calculator' for the emission calculator

Step 5. Enter the vehicle category details (such as vehicle segment, vehicle type, and fuel type)



In the 'Emission Calculator' tab, columns highlighted in cream are user-input fields.

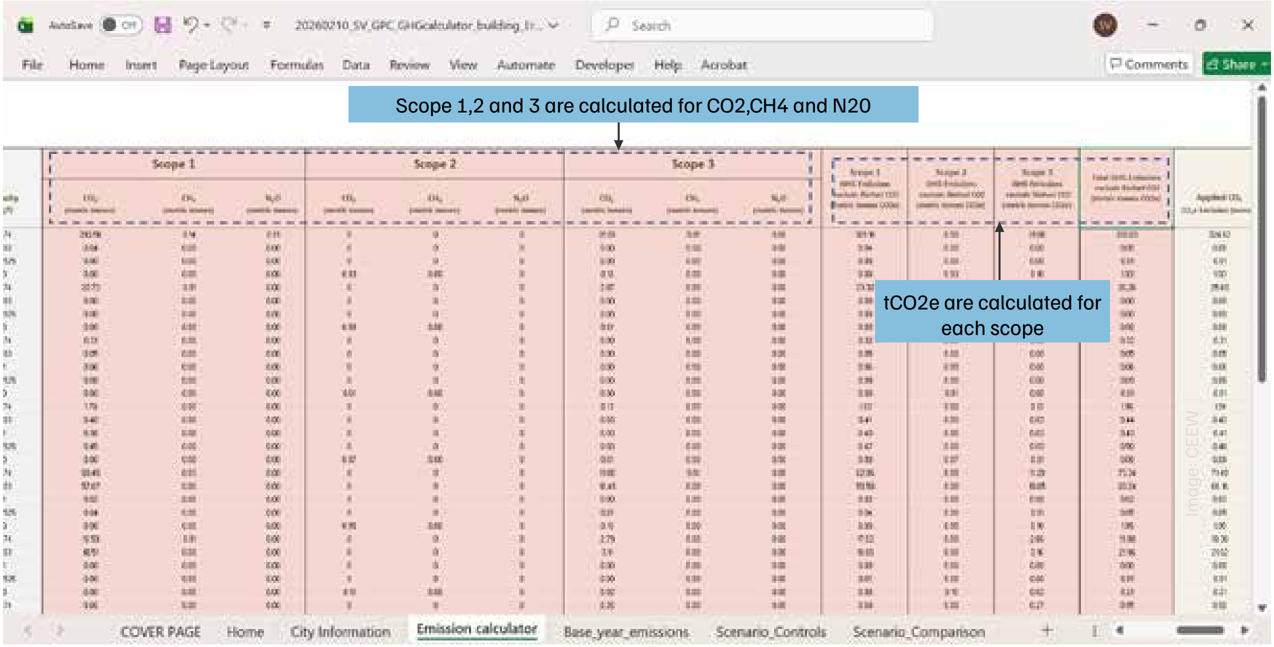
Users must enter the vehicle segment, vehicle type, and fuel type. Vehicle segments include 2Ws, 3Ws, 4Ws, buses, LCVs, and trucks. Each category contains additional subcategories based on vehicle type. Users must also select the relevant fuel type (petrol, diesel, CNG/LNG, LPG, or EV) for each vehicle category.

Based on the selected inputs, vehicle registration data are automatically populated from the VAHAN database. The calculator estimates on-road vehicle stock using vehicle survival factors and boundary movement assumptions. It incorporates cumulative vehicle registrations from 2011 to 2025, adjusted for survival rates.

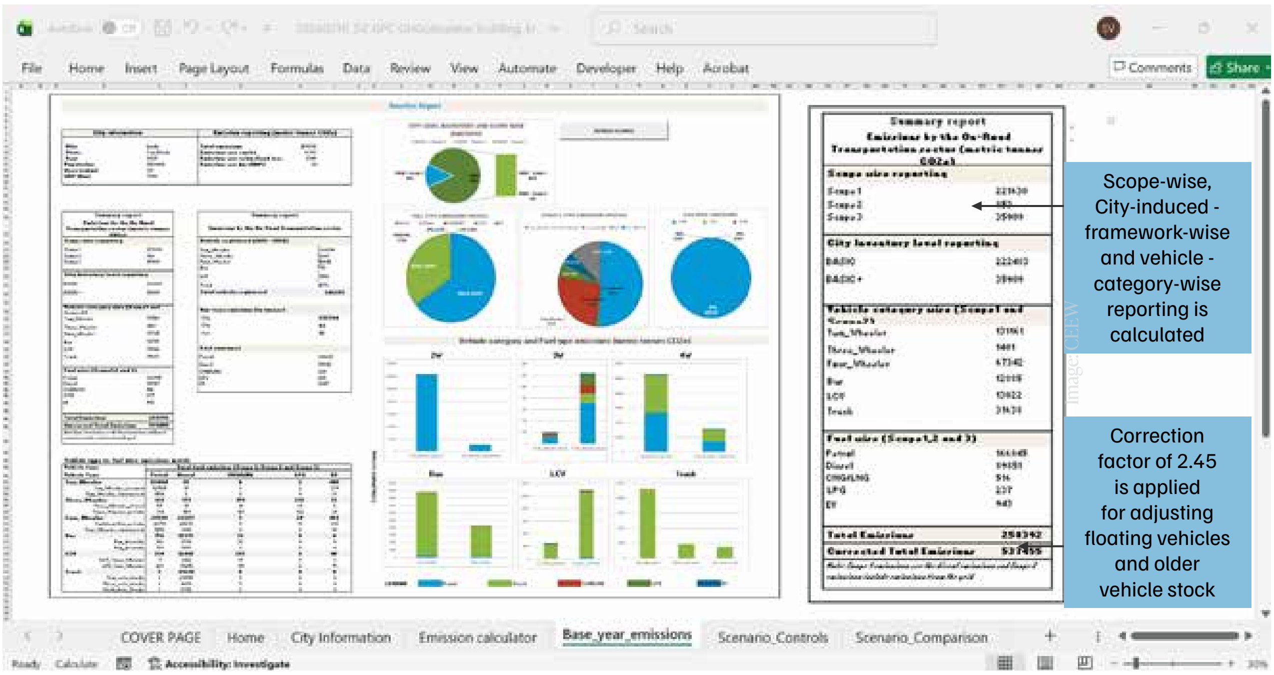
Average mileage and average daily distance values are derived from the FuSS. Based on these inputs, the calculator estimates total fuel consumption and associated emissions. The model uses the IPCC global EFs to calculate N_2O, CH_4, and CO_2 emissions. Scope-based emissions (Scope 1 [boundary], Scope 2, and Scope 3 [trans-boundary]) are then calculated, and total CO_2e emissions are estimated in accordance with GPC reporting guidelines.

Step 6. Scope 1, Scope 2 and Scope 3 emissions are calculated by combining the three gaseous (CO_2, CH_4, N_2O) emissions

In this step, CO_2e emissions are calculated using conversion factors for each gas, expressed in a single unit. The calculator shows emissions for each gas and the total in CO_2e based on the GWP conversion factors.



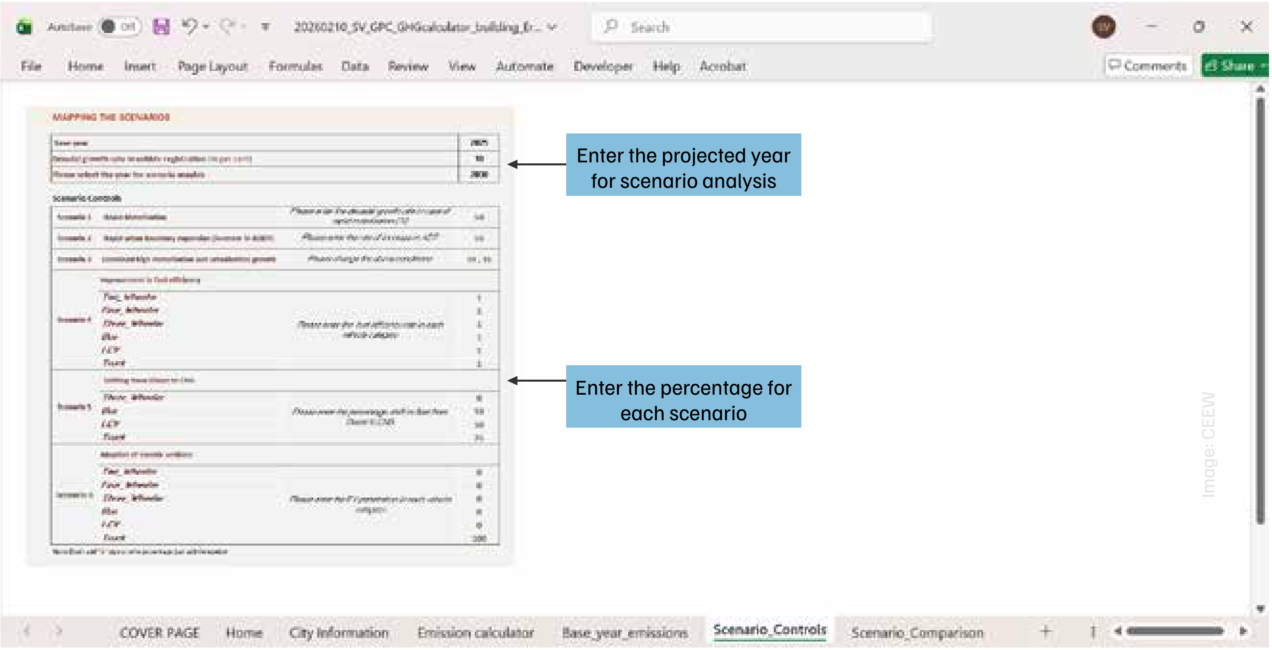
Step 7. After all the details are filled, please move to the base year emissions tab



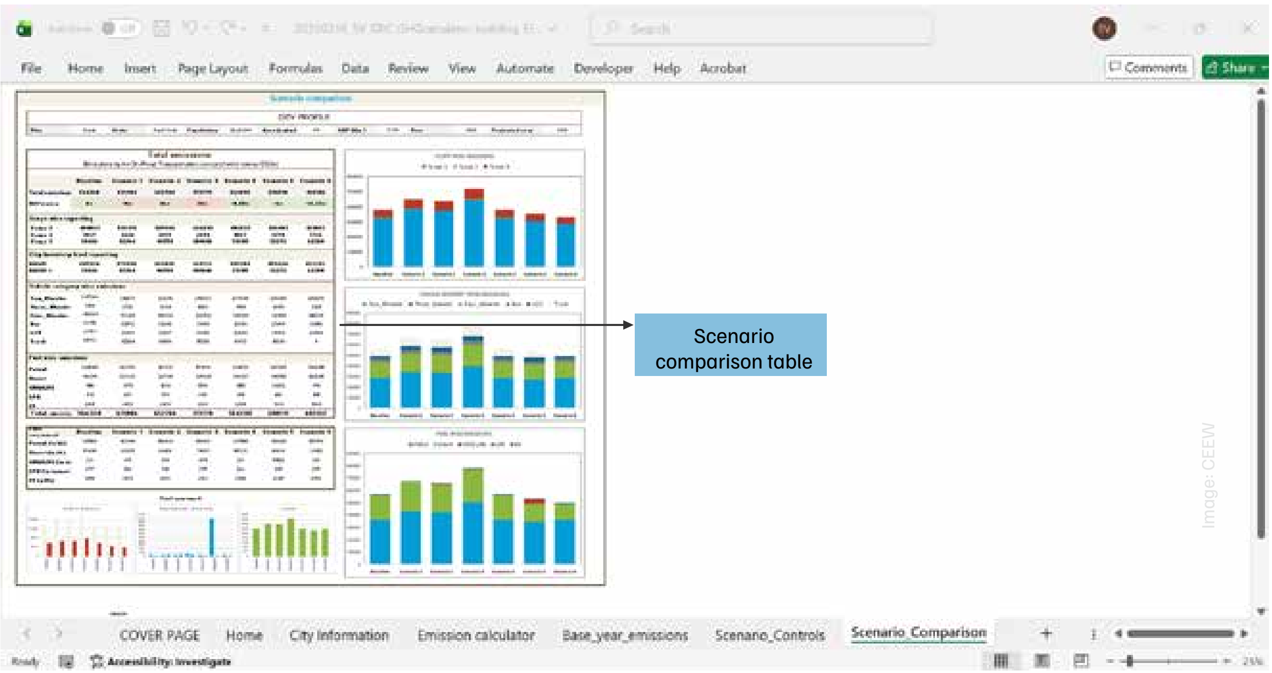
The Base year emissions tab is the summary tab, which reports emissions at both the city and scope levels of the year chosen in the previous 'City Information' tab. The sheet provides details on vehicle type, vehicle category, fuel type, and gas-type reporting. It also reports on vehicle registrations by category, total fuel consumed, and a GHG emissions matrix (in CO_2e) categorised by vehicle type and fuel type. Then, the total estimated emissions are multiplied by the correction factor to account for emissions from overall vehicles on the road.

Step 8. Enter the projection year and scenario-specific percentage values for scenario analysis

The projection year drop-down lists 2030, 2035, 2040, and 2045 as options. Once the scenario inputs are entered, background calculations will automatically update across the workbook.



Step 9. Compare scenario results to evaluate the reductions relative to baseline and other scenarios

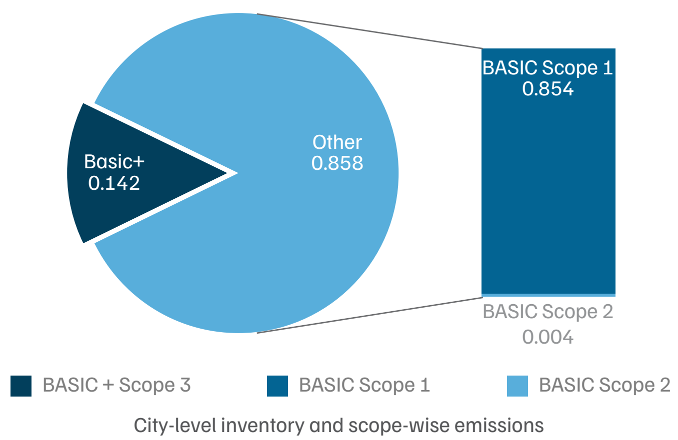


5. Key findings

Based on the emissions-estimation framework and scenario modelling, the key findings are as follows:

5.1 Erode on-road transport generates 0.61 $MtCO_2e$ annually as a baseline for 2025

Figure 15. Scope 1 emissions dominate the city's on-road transport emission profile



Source: Authors' analysis.

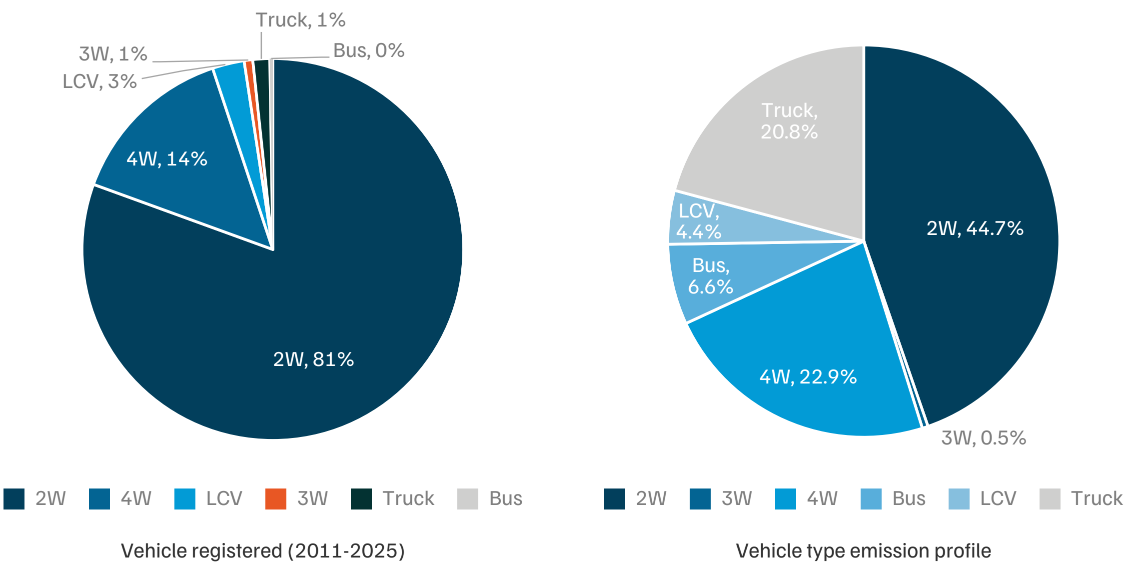
Between 2011 and 2025, ~3.2 lakh vehicles were registered cumulatively across RTOs TN33 and TN86 within the EMC boundary. Based on vehicle characteristics collected through the FuSS survey, the on-road vehicle stock generates ~0.29 $MtCO_2e$ annually within the city boundary. Erode experiences a high influx of floating vehicles, with 52 per cent of road traffic attributed to vehicles registered outside the EMC boundary. Notably, 45 per cent of these are freight vehicles and buses, indicating a significant presence of heavy-duty traffic alongside regular urban mobility. When the correction factor for vehicles registered outside the boundary (2.08) is applied, total annual emissions increase to 0.61 $MtCO_2e$. On average, each vehicle generates ~1.42 tCO_2e annually, highlighting the cumulative impact of a large vehicle population despite relatively low per-vehicle emissions, particularly among 2Ws and 4Ws.

The city's inventory is dominated by BASIC-level reporting (86 per cent), indicating that most emissions occur directly within the municipal boundary. Within BASIC reporting, Scope 1 emissions dominate, reaffirming that on-road fuel combustion is the primary driver of Erode's transport emissions. In contrast, Scope 2 emissions are negligible, reflecting the limited adoption of EVs and the corresponding low dependence on grid-powered transport.

As EV adoption accelerates, the share and dependence on the grid is expected to increase, leading to a rise in Scope 2 emissions. This underscores the importance of monitoring Scope 2 emissions and accelerating grid decarbonisation to support a overall green transition.

5.2 Diesel trucks constitute ~1.4 per cent of the on-road vehicle stock, but contribute ~21 per cent to overall road-transport emissions (CO_2e)

Figure 16. A small share of commercial freight vehicles drives a disproportionately large share of transport emissions



Source: Authors' analysis.

Note: LCV: light commercial vehicle

Erode's transport energy footprint is shaped by two structurally distinct functions: widespread personal mobility, dominated by petrol-powered 2Ws, and energy-intensive freight movement, dominated by diesel vehicles. These vehicles consume ~167 million litres (l) of petrol, primarily in the 2W segment, and ~126 million l of diesel, largely within the freight segment.

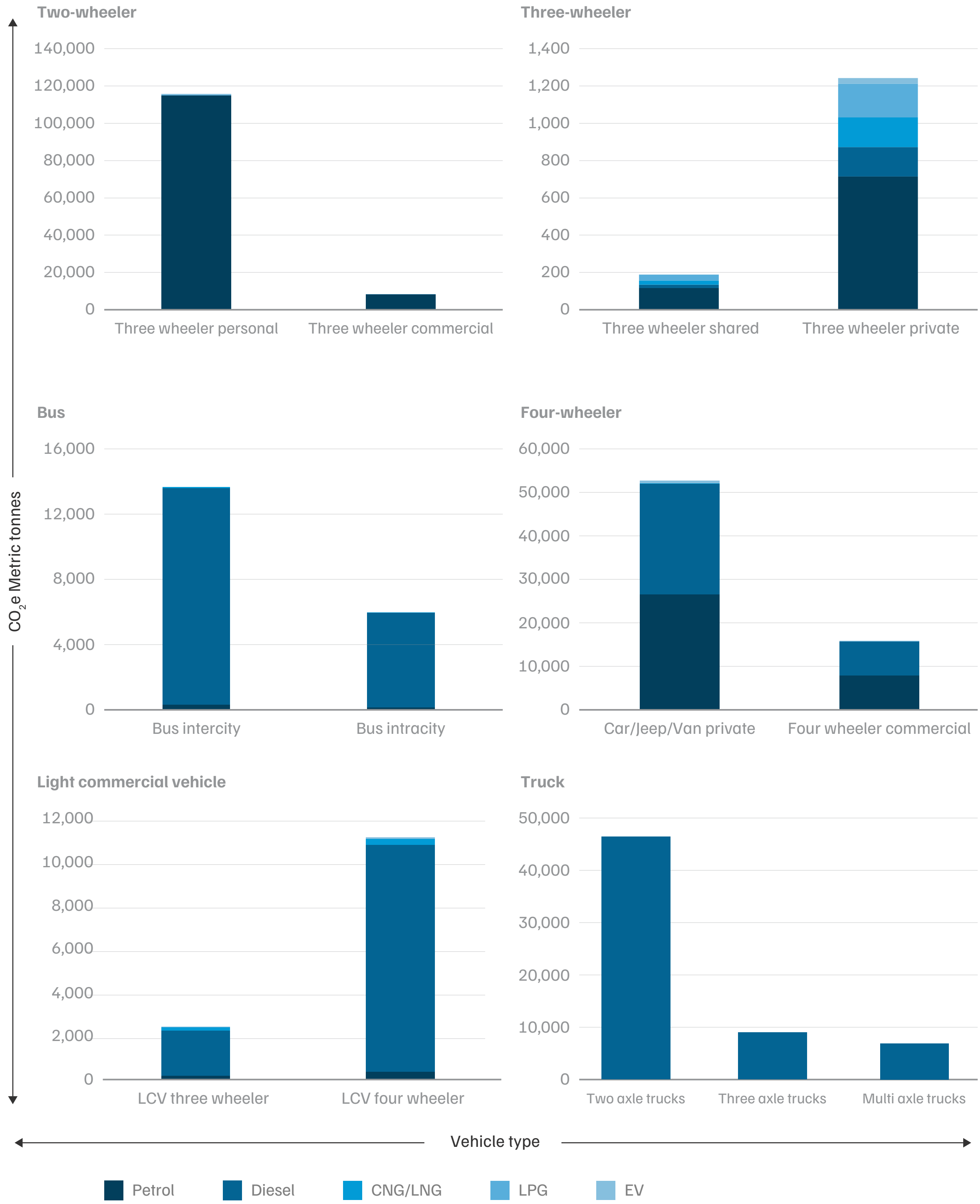
2Ws account for ~81 per cent of vehicle registrations and contribute ~45 per cent of total emissions. 4Ws account for ~14 per cent of registrations and contribute ~23 per cent of total emissions. According to the survey data, these vehicles are predominantly petrol-powered, relatively young (average age of ~6 years), and primarily used for daily work and personal trips. 2Ws are the largest contributors to the emission profile, mainly due to their high share of the on-road vehicle stock.

In contrast, LCVs and trucks account for only 4 per cent of vehicle registrations but contribute ~25 per cent of Erode's road transport emissions. These vehicles are predominantly diesel-powered, older (average age of ~9 years), and travel an average of ~76 km per day, with nearly 80 per cent of their trips being trans-boundary. This combination of age, fuel type, and high daily VKT significantly increases their contribution to emissions.Buses account for only 0.3 per cent of the on-road fleet but contribute up to 7 per cent of total emissions. Their relatively old age, diesel dependence, and lower fuel efficiency contribute to their disproportionately high emissions.

Overall, high-VKT diesel commercial vehicles are among the primary drivers of transport emissions in Erode despite representing a relatively small share of the on-road fleet, highlighting the need for targeted mitigation strategies.

Petrol pumps in Erode

Figure 17. Petrol-based emissions are concentrated in high-volume personal mobility, while diesel-based emissions are concentrated in high-load, low-volume freight activity



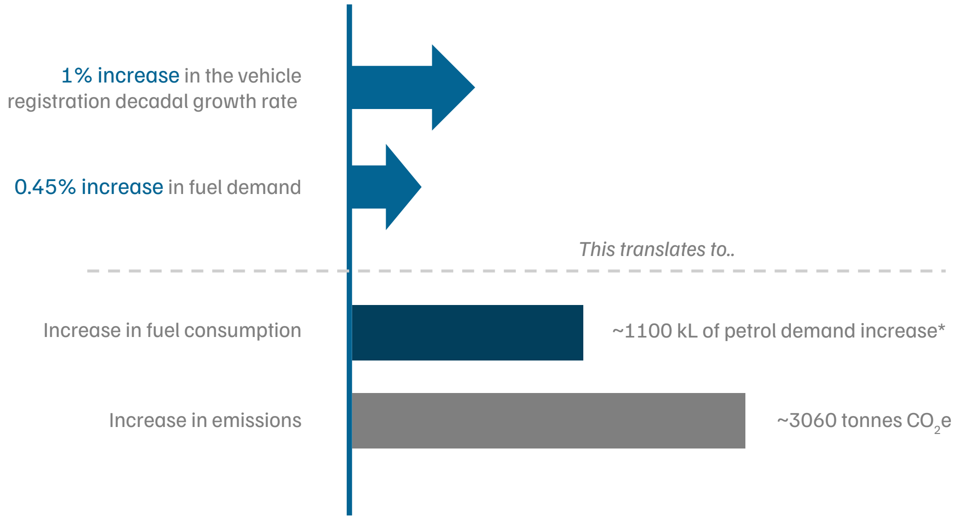
Source: Authors' analysis.

Note: CNG: compressed natural gas; EV: electric vehicle; LNG: liquefied natural gas; LPG: liquefied petroleum gas

5.3 Every 1 per cent increase in vehicle registration decadal growth is associated with a ~0.45 per cent increase in petrol demand and ~3,060 tCO_2e emissions

Scenario 1 (SC 1): Increase in vehicle registration

Figure 18. Every 1% increase in vehicle stock registration leads to an increase of ~1,100 kL in petrol demand and ~0.03 $MtCO_2e$ in emissions



Source: Authors' analysis.

Note: *(i) Conversion unit for multiple fuel types to petrol: diesel (1.11), CNG/LNG (0.68), LPG (1.15), and EV (0.1), as per the energy intensity of fuel in CAFE norms.
(ii) For this study, the decadal growth rate under the BAU scenario is assumed to be 10%.
(iii) BAU: business-as-usual; CAFE: Corporate Average Fuel Economy CNG: compressed natural gas; EV: electric vehicle; LNG: liquefied natural gas; LPG: liquefied petroleum gas

Recent vehicle-registration trends (2021–25) indicate average annual growth of approximately 5 per cent following the pandemic. If this trend continues, ~7,370 additional vehicles are estimated to be added to the fleet by 2030. Based on an average annual emissions intensity of ~1.42 tCO_2e per vehicle, this would generate an additional emissions burden of ~0.01 $MtCO_2e$.

Under the BAU scenario, which assumes a conservative decadal growth rate of 10 per cent (~1 per cent annual growth), projected fuel demand by 2030 would reach ~1,37,200 kL of petrol, ~79,270 kL of diesel, ~322 tonnes of CNG/LNG, ~227 tonnes of LPG, and ~2,996 kWh of electricity, assuming that the vehicle–fuel mix remains unchanged.

However, under increased vehicle registration conditions (SC 1), fuel demand is projected to rise in proportion. Modelling results indicate that every 1 per cent increase in the decadal vehicle registration growth rate could result in a ~0.45 per cent increase in total fuel demand. Similarly, emissions could increase by ~3,060 tCO_2e for every 1 per cent increase in the decadal growth rate.

From a policy perspective, this scenario highlights the importance of managing vehicle-registration growth is an important step towards demand management to reduce emissions. Even a slight increase in vehicle registration can lead to disproportionately large increases in emissions and fuel demand. Therefore, demand-side interventions, such as strengthening public transport accessibility, promoting shared mobility, implementing parking and congestion management policies, and accelerating the adoption of low-emission vehicles, can play an important role in limiting long-term emissions growth.

5.4 Every 1 per cent increase in growth rate in vehicle kilometres travelled due to urban sprawl is associated with a ~0.9 per cent increase in petrol demand and ~6,500 tCO_2e emissions

Scenario 2 (SC 2): Increase in vehicle kilometer travelled

Figure 19. Emissions impact of marginal increases in vehicle kilometres travelled is greater than that of equivalent increase in vehicle registrations

	A 1% increase in...	Increase in fuel demand	Increase in petrol demand	Increase in emission generated
Case 1	Vehicle registrations	0.45%	1,100 kL	3,060 tCO_2ev
		leads to	which translates to	
Case 2	Vehicle kilometres travelled	0.9%	1,161 kL	6,500 tCO_2ev

Source: Authors' analysis.

Note: (i) Conversion unit for multiple fuel types to petrol: diesel (1.11), CNG/LNG (0.68), LPG (1.15), and EV (0.1), as per the energy intensity of fuel in CAFE norms

(ii) For this study, the decadal growth rate under the BAU scenario is assumed to be 10%.

(iii) BAU: business-as-usual; CAFE: Corporate Average Fuel Economy; CNG: compressed natural gas; EV: electric vehicle; LNG: liquefied natural gas; LPG: liquefied petroleum gas

The current jurisdiction of EMC covers ~110 km^2 and generates an average transport emissions intensity of ~5,600 tCO_2e per km^2. As the city expands spatially due to urban development, travel distances are expected to increase, directly influencing fuel consumption and transport emissions even if vehicle ownership follows the BAU trajectory.

Scenario 2 results indicate that fuel demand is highly sensitive to increases in vehicle-use intensity. When vehicle-registration growth is held constant at the BAU assumption (~10 per cent decadal growth), every 1 per cent increase in annual VKT is associated with a ~0.9 per cent increase in fuel demand. This suggests that urban sprawl and longer travel distances may have a greater influence on emissions than vehicle registration growth alone.

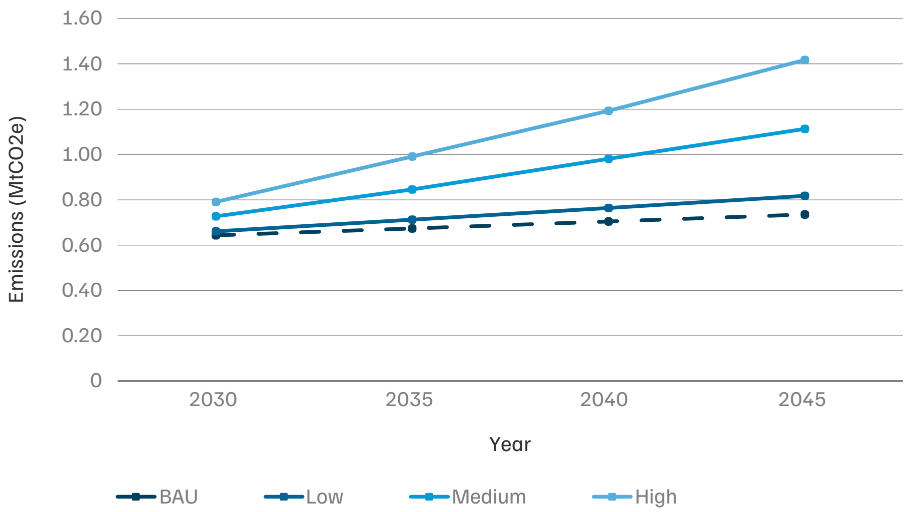
For instance, if emissions under the BAU scenario reach ~0.67 MtCO_2e by 2035, and there is a 10 per cent increase in VKT under SC 2 due to urban sprawl, then emissions could rise to ~0.73 MtCO_2e. Historical evidence from tier-2 cities indicates that VKT has increased by ~13 per cent over the recent years, with extreme cases, such as Kochi, experiencing increases of up to 30 per cent (Narain et al. 2025). If similar trends emerge in Erode due to rapid urban expansion, the resulting increase in emissions could be significantly higher than baseline projections.

Lack of footpath at major junctions in Erode.

5.5 By 2030, transport emissions could range from ~0.66 $MtCO_2e$ to ~0.79 $MtCO_2e$ across different development scenarios and nearly double to ~1.42 $MtCO_2e$ by 2045 under the high-development scenario

Scenario 3 (SC 3): Increase in vehicle ownership and urban sprawl

Figure 20. On-road transport emissions could nearly double by 2045, reaching ~1.42 $MtCO_2e$ under high-growth conditions relative to the 2045 BAU scenario



Source: Authors' analysis.

Note: These are the decadal growth rates

Rate of development	Vehicle registration growth rate (%)	% of VKT increased
Low	10	5
Medium	30	7
High	50	9

Note: BAU: business-as-usual; VKT: vehicle kilometres travelled

Vehicle registration and urban sprawl are closely linked and typically co-evolve in emerging non-metro Indian cities. As urban areas expand spatially and economic activity increases, both vehicle ownership and travel demand tend to increase in parallel. Therefore, this scenario represents a plausible urban development pathway and is critical for understanding long-term on-road transport emissions trajectories.

To better assess the GHG implications of extreme rates of vehicle registration growth and urban expansion, three development cases were modelled under this scenario: (i) low development, (ii) moderate development, and (iii) high development. The decadal growth rates for vehicle registration and VKT were defined to represent different levels of urban development and mobility demand (Figure 20). These cases reflect a realistic range of future development based on recent

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Emissions projections show diverging trajectories, all originating from a common 2025 baseline of ~0.61 $MtCO_2e$. Under the low-development case, emissions increase gradually to ~0.82 $MtCO_2e$ by 2045 (9 per cent increase). The medium-development case reaches ~1.11 $MtCO_2e$ by 2045, while the high-development case results in ~1.42 $MtCO_2e$ in emissions, nearly double the baseline level.

These results highlight the long-term climate risks associated with increasing vehicle registrations and travel demand, particularly in rapidly growing cities such as Erode. They also suggest that demand-management and urban-planning interventions are likely to be as important as technological improvements and fuel transitions in limiting future growth in emissions, especially in emerging tier-2 cities.

5.6 Improving fleet fuel economy by 20–30% could reduce the transport emissions by 17–23% from the business-as-usual scenario by 2030

Scenario 4 (SC 4): Improvement in fuel economy

Fuel-economy improvements across vehicle categories in India have largely been driven by the implementation of Corporate Average Fuel Economy (CAFE) regulations for passenger vehicles. However, the magnitude of efficiency gains varies significantly across vehicle segments due to differences in fuel mix, technology maturity, and operational characteristics.

The current fuel mix shows clear dominance of fuel type by vehicle category. We observe that 2Ws are predominantly petrol-powered, with a gradual shift towards electrification in newer registrations; 3Ws comprise a mix of LPG, CNG and fuel, with limited reliance on petrol; and 4Ws have a relatively balanced mix of petrol and diesel. In contrast, buses, LCVs, and trucks remain diesel-dominated due to higher energy demands, load requirements, and long-distance operating patterns.

Segment-wise efficiency gains reflect the impacts of regulatory and technology transitions. For 2Ws, BS-VI fuel-injection technologies have improved fuel efficiency in 2Ws by 20–25 per cent (Anup and Deo 2021), while BS-IV to BS-VI transitions have resulted in gains of 10–15 per cent for 3Ws (ECMA n.d.). For 4Ws, CAFE Phase 1 and Phase 2 norms reduced emissions intensity from 130 to 113 g/km CO_2, representing an improvement of ~13 per cent, while Phase III targets a further 19 per cent (BEE 2025). Light commercial vehicles have achieved ~10 per cent CO_2 reductions post BS-VI, with Phase 2 fuel-consumption norms targeting fleet-wide reductions of 30 per cent (Narla et al. 2021). Proposed Phase 2 norms for buses and trucks could improve fuel efficiency by 20–30 per cent in km/L through the adoption of more efficient technologies (Yadav et al. 2023).

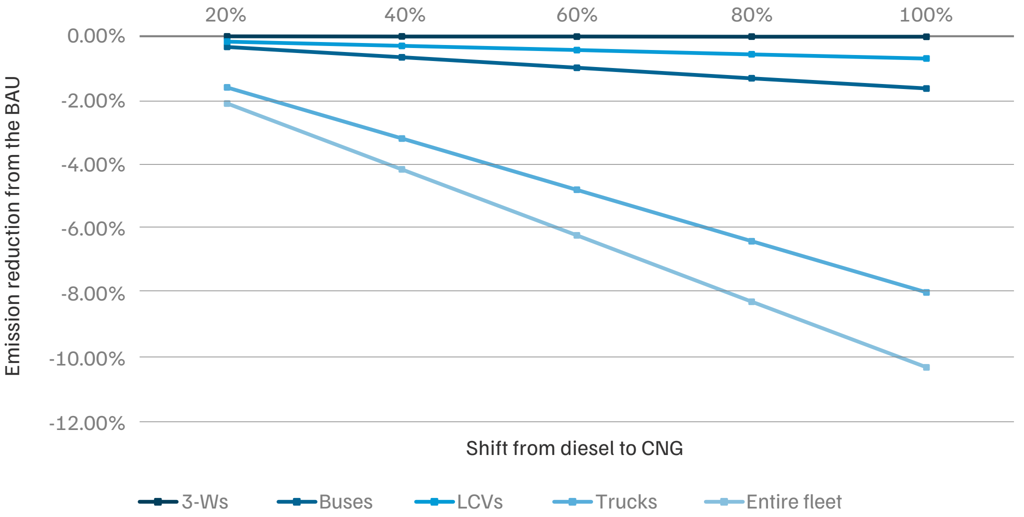
As fuel economy directly influences fuel consumption per kilometre travelled, improvements translate into proportional emission reductions. Based on this relationship, a 20 per cent improvement in fuel efficiency can be considered a conservative case, while a 30 per cent improvement represents an ambitious case. These improvements could reduce emissions by 17–23 per cent relative to the BAU scenario by 2030, depending on operational conditions and better fuel economy.

Peak hour traffic in Erode.

5.7 CNG offers limited, transitional gains (up to ~10 per cent emission reductions from the business-as-usual scenario), but substantial fleet decarbonisation requires prioritising the heavy-duty segment and accelerating electrification

Scenario 5 (SC 5): Shifting from diesel to CNG

Figure 21. Emissions reduction is driven primarily by trucks, while the 3Ws and LCV-CNG transition shows a negligible impact, yielding ~10% reduction at full transition



Source: Authors' analysis.

Note: (i) The BAU scenario projects the 2030 on-road vehicle stock projection assuming a 10 per cent decadal growth rate.

(ii) 3Ws: three-wheelers; BAU: business-as-usual; CNG: compressed natural gas; LCV: light commercial vehicle

The emissions-reduction potential from fuel transition varies considerably across vehicle categories, with the largest benefits concentrated in freight vehicles. The vehicle categories considered for the diesel-to-CNG transition include 3Ws, buses, LCVs, and trucks. Trucks account for the largest share of emissions within these segments (~64 per cent), followed by buses (~20 per cent) and LCVs (~14 per cent) in the commercial and freight segment.

Segment-wise results indicate that increasing transition from diesel to CNG (20–100 per cent) produces markedly different outcomes across vehicle categories in 2030. For 3Ws, the system-level impacts remain negligible, with emission reductions ranging from ~0.001 per cent at 20 per cent penetration to 0.01 per cent at 100 per cent penetration. Similarly, emission reductions for LCVs range from 0.17 per cent to 0.7 per cent. This limited reduction is not a modelling artefact.

Rather, it reflects the interaction of fuel EFs under IPCC's Sixth Assessment Report (AR6) global warming potentials, i.e., the methane GWP of CNG is ~27.2 times higher than of CO_2, and a small difference in reported mileage between diesel and CNG 3Ws.

In contrast, buses show a more substantial impact, with emission reductions ranging from ~0.3 per cent at 20 per cent to 1.62 per cent at 100 per cent penetration. While buses are high-utilisation vehicles, their small fleet size limits their aggregate influence. The most substantial benefits occur in trucks, where emission reductions increase from 1.6 per cent to 8 per cent, through diesel to CNG truck transition from 20 per cent to 100 per cent . As these segments dominate freight activity and fuel consumption, interventions yield disproportionately large emission reductions compared to other fleets.

At an aggregate level, the entire fleet impact scales from 2.1 per cent emission reduction from BAU 2030 (~0.64 $MtCO_2e$) at 20 per cent penetration, to 10 per cent emission reduction at 100 per cent penetration, driven primarily by freight vehicles rather than smaller segments. As such, diesel-to-CNG transitions in trucks and buses should be viewed as a transitional decarbonisation strategy rather than a long-term mitigation pathway, as it can only achieve 8–10 per cent reductions in emissions at 100 per cent fleet transition to CNG.

Electrification should remain the long-term objective, particularly for 3Ws. For trucks, alternative fuels such as CNG may serve as an interim measure, but long-term policy alignment should prioritise zero-emission technologies such as EVs and green hydrogen.

Data from FuSS indicate that ~25 per cent of trucks are more than 10 years old and are entirely diesel-powered, making them potential candidates for scrappage-linked or replacement-based transition programmes. In addition, ~82 per cent of truck operations are trans-boundary, with an average daily distance of ~146 km and approximately two trips per day. These operational characteristics make trucks a promising target for near-term adoption of alternative fuels if they are unwilling to transition to EVs.

> Diesel-to-CNG is a transitional pathway; electrification remains the long-term solution.

Overall, while CNG can play a bridging role, durable emission reductions in the transport sector will depend on accelerating electrification rather than relying solely on fossil-fuel substitution.

Why does the CNG transition effect have a negligible impact on LCVs and 3Ws?

According to IPCC EFs and AR6 values, the CNG EF is ~21 per cent lower on an energy basis. However, methane emissions substantially increase the overall CO_2e intensity of CNG. When expressed in fuel-use units, diesel emits ~3.31 kg CO_2e/l, while CNG emits ~2.88 kg CO_2e/kg for LCVs. The difference is therefore relatively modest.

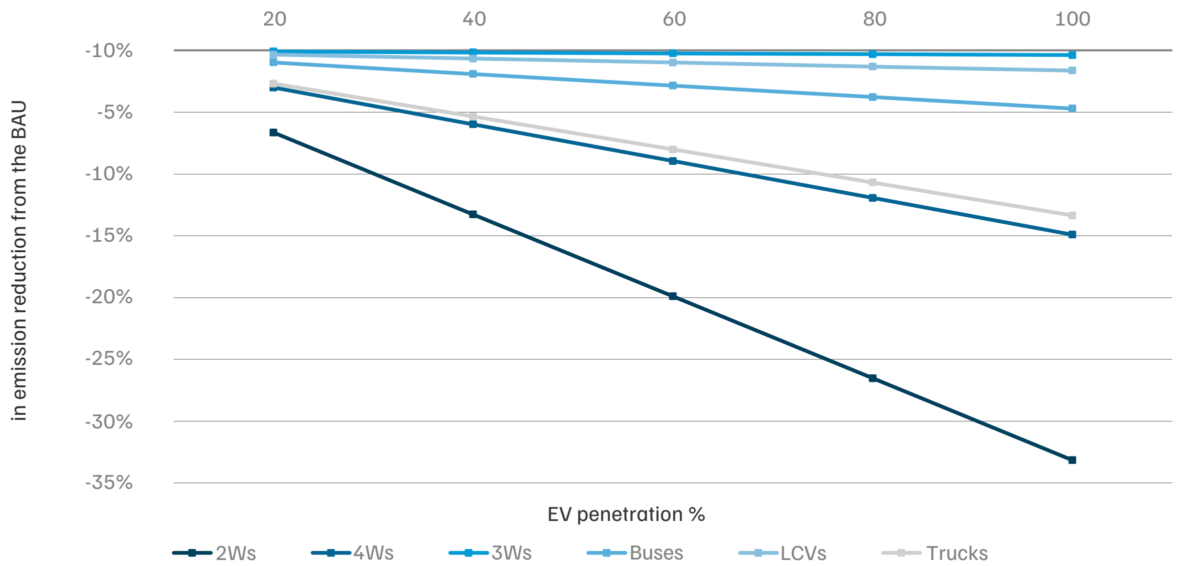
When vehicle mileage is taken into account, per-kilometre emissions become highly dependent on it. For example, diesel-powered LCV-3Ws achieve ~19 km/l compared with ~23 km/kg for CNG vehicles, resulting in emissions of ~0.17 kg CO_2e/km and ~0.14 kg CO_2e/km, respectively. This represents a reduction of ~20 per cent.

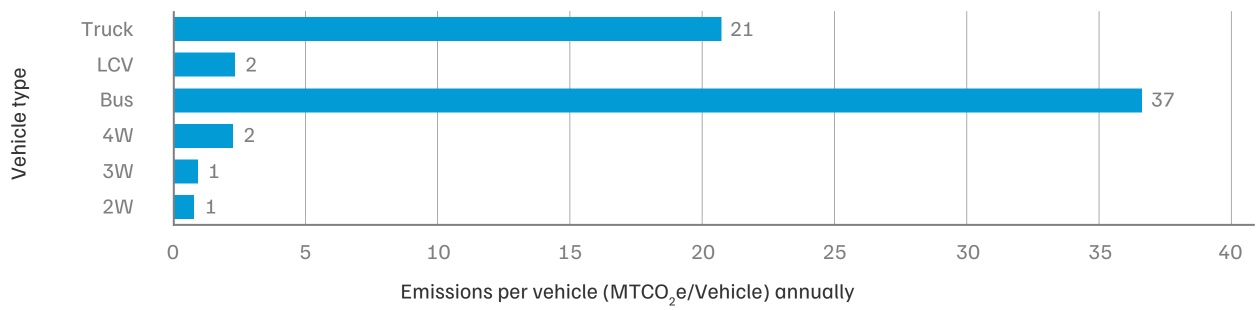
These results suggest that the benefits of fuel switching are highly sensitive to mileage. Under current conditions, efficiency improvements and electrification offer greater emissions-reduction potential for 3Ws and LCVs than diesel-to-CNG transitions.

5.8 Benefits of electrification can be achieved through volume-driven reductions from two-wheeler and four-wheeler vehicles, and intensity-driven emission reductions from heavy-duty freight vehicles

Scenario 6 (SC 6): Shifting to EVs

Figure 22. e2Ws and e4Ws drive aggregate emission reductions, but electrifying high-emission-intensity buses and trucks results in higher marginal abatement on a per-vehicle basis





Source: Authors' analysis.

Note: (i) The BAU scenario projects the 2030 on-road vehicle stock projection assuming a 10 per cent decadal growth rate.

(ii) 2Ws: two-wheelers; 3Ws: three-wheelers; 4Ws: four-wheelers; BAU: business-as-usual; e2Ws: electric two-wheelers; e4Ws: electric four-wheelers; LCV: light commercial vehicle

Achieving a 20 per cent emission reduction (~0.64 $MtCO_2e$ under BAU compared with ~0.51 $MtCO_2e$ under SC 6) requires electrification of 30 per cent of the total vehicle fleet across all segments. This shifts emissions from direct tailpipe emissions (Scope 1) to electricity generation and distribution (Scope 2).

Under the baseline scenario, Scope 1 emissions account for ~85 per cent of total emissions, while Scope 2 contributes only 0.3 per cent and Scope 3 contributes ~14 per cent. Under the 30 per cent fleet-electrification scenario, Scope 1 emissions decline to 74 per cent, while Scope 2 emissions increase to 12 per cent. These findings indicate that vehicle electrification alone will not deliver full decarbonisation benefits unless accompanied by parallel grid decarbonisation.

The segment-wise electrification sensitivity analysis in Figure 22 illustrates the differentiated mitigation potential across vehicle categories. The line graph shows a steep, near-decline in emissions for high-volume, high-intensity segments such as trucks and buses, while low-intensity segments such as 3Ws and LCVs exhibit relatively flat trajectories.

In 2025, fleet composition and its emission contribution highlight clear priority segments for decarbonisation. The 2W segment accounts for 81 per cent of the total fleet and contributes 45 per cent of total emissions. Although per-vehicle emissions are low, the aggregate fleet size makes this segment the largest contributor to overall transport emissions. Shifting 50 per cent of the 2W fleet under the BAU 2030 scenario (~1.25 lakh vehicles) will achieve ~17 per cent of the 0.64 $MtCO_2e$. The 4W segment accounts for 14 per cent of the total fleet and contributes 23 per cent of emissions, reflecting higher per-vehicle emissions.

The heavy-duty segments (trucks and buses) exhibit significantly higher per-vehicle emission intensities. Trucks account for only 1.4 per cent of the fleet but contribute ~21 per cent of total emissions, with annual emissions of 20.7 per vehicle. Buses contribute ~7 per cent of emissions despite accounting for less than 0.3 per cent of the fleet and exhibit the highest emissions intensity (~36.6 tCO_2e. Additionally, LCVs account for ~3 per cent of vehicles and contribute ~4 per cent of emissions. These findings indicate that targeting heavy-duty vehicles can deliver substantial emission reductions.

In contrast, 3Ws account for less than 1 per cent of both fleet share and emissions, with low per-vehicle emissions. Consequently, even complete electrification of this segment would yield only marginal emission reductions (~0.38 per cent relative to BAU). Similarly, full electrification of 3Ws, buses, and LCVs combined would reduce emissions by only ~7 per cent) compared with overall decarbonisation targets.

As of 2025, VAHAN data indicate that EVs constitute only ~2 per cent of the vehicle stock and are concentrated primarily in the 2W, 3W, and 4W segments.

Overall, the analysis highlights two complementary pathways for transport decarbonisation. The first is large-scale electrification of high-volume vehicle segments, such as 2Ws and 4Ws, which deliver fleet-wide emission reductions. The second is targeted transition of high-emission-intensity vehicles, which deliver substantial reductions on a per-vehicle basis. A balanced strategy that addresses both high-volume and high-emission-intensity segments will be critical to achieving state and national net-zero targets by 2070.

Stakeholder discussion at Erode District Collectorate office

6. Discussion and policy implications

The Erode case study demonstrates both the value and the limitations of applying a GPC-compliant, bottom-up inventory to on-road transport. Three broad themes emerge: the absence of a universally accepted benchmark for city-scale transport emissions; the highly uneven distribution of emissions across vehicle and fuel types; and the central role of data quality and institutional readiness in sustaining such inventories and translating them into policy. The developed inventory is sufficiently robust for policy prioritisation and scenario analysis, but should not be interpreted as a precise measure of 'true' emissions. Rather, it represents a structured, transparently documented estimate that can be progressively refined.

The baseline assessment highlights that Erode's on-road transport emissions are shaped by a highly skewed fleet composition, characterised by petrol-powered 2Ws and 4Ws alongside a pronounced dependence on diesel-intensive freight movement. While petrol-powered 2Ws dominate the vehicle stock and contribute substantially to total emissions because of their sheer numbers, the comparatively small segment of commercial diesel vehicles, including LCVs, trucks, and buses, contributes disproportionately to the city's carbon footprint. Their higher average age, greater daily VKT, and lower fuel efficiency significantly increase their emissions intensity. The current fleet also exhibits very low EV penetration, largely concentrated in smaller vehicle categories, reinforcing the dominance of Scope 1 emissions. Together, these findings establish a clear baseline against which future decarbonisation pathways can be assessed.

These findings serve as key takeaways from the baselining exercise, establishing the first foundational step before scenario prospecting. The scenarios are developed to capture travel demand driven by increases in vehicle registrations and VKT, as well as by shifts to cleaner technologies and improved fuel economy. The scenario helps identify emission drivers and test targeted, policy-relevant interventions based on the city's actual emission dynamics.

6.1 Interpreting Erode's inventory in the absence of a standardised city-level emission inventory

At present, there is no standardised or official city-scale GHG inventory against which Erode's on-road transport emissions can be directly benchmarked. Different tools and protocols – including national inventories based on the IPCC 2006 guidelines and third-party platforms that use different system boundaries – vary in their allocation rules for trans-boundary trips and in their assumptions about activity data. As a result, the absolute values reported in this study (~0.29 $MtCO_2e$ annually from on-road transport within the EMC boundary) can only be interpreted alongside those of peer cities with similar profiles and, more importantly, that use comparable methodologies and primary and/or secondary datasets. Comparisons with external tools, or even with other GHG inventory approaches for EMC, should therefore be used diagnostically. Instead, the value of this GPC-compliant calculator lies in:

- internal consistency over time, allowing EMC to track changes in emissions as policies and travel patterns evolve;
- the ability to disaggregate emissions by vehicle segment, fuel type, and scope (Scope 1, Scope 2, and Scope 3); and
- transparency of assumptions, which can be updated or refined as improved data become available

6.2 Emissions profile by vehicle and fuel type, and the effectiveness of interventions

The Erode inventory reveals a highly differentiated emission profile. Petrol-powered 2Ws and 4Ws dominate numerically and, because of their large fleet share, contribute significantly to total emissions. However, when emissions are normalised per vehicle, diesel-dominated medium- and heavy-duty vehicles, particularly trucks and buses, emerge as disproportionately high emitters. In 2025, diesel trucks constituted ~1.4 per cent of the on-road fleet but accounted for around 21 per cent of on-road emissions, while buses accounted for only 0.3 per cent of vehicles yet contributed ~7 per cent of emissions.

> Erode requires a dual strategy: targeted action on high-emitting diesel freight and buses, alongside electrification and demand management for two- and four-wheelers.

This has two important implications for policymaking:

- A volume-based approach focused solely on the most numerous vehicle risks, overlooking relatively small but high-impact segments such as heavy-duty trucks, older LCVs, and ageing diesel buses. Targeted interventions in these segments could deliver substantial per-vehicle emission reductions.

- Conversely, managing travel demand and accelerating EV adoption in the 2W and 4W segments remains essential for long-term decarbonisation because these categories account for a substantial share of total emissions even though per-vehicle emissions are relatively low. Measures such as compact land-use planning, improved public transport, and non-motorised transport (NMT) infrastructure will be critical to bending the demand curve for personal vehicle use.

The very low penetration of EVs (~2 per cent of the current vehicle stock, primarily in the 2W segment) and the limited uptake of gaseous fuels, particularly CNG, in freight transport reflect infrastructure gaps as well as the absence of clear regulatory and policy mechanisms to discourage high-emitting vehicle segments and/or fuel types while encouraging the adoption of cleaner technologies.

6.3 Data quality, survey bias, and correction factors

The baseline assessment explicitly addresses a common limitation of city-level emissions inventories, i.e., floating vehicles. Without correction, restricting the stock to vehicles registered in TN33 and TN86 between 2011 and 2025 would substantially underestimate actual on-road activity. The correction factor (2.08 = 1/0.48) applied to account for vehicles registered outside the EMC boundary represents an important step towards aligning the model with observed traffic volumes.

Nevertheless, a few data-quality, completeness, and consistency considerations remain.

Self-reported mileage and trip data: Comparison of self-reported average daily distance travelled (ADT) with calculated ADT (trips × distance per trip) reveals notable discrepancies for some vehicle segments, particularly commercial and freight vehicles. This suggests the presence of recall and recency bias, which are intrinsic and unavoidable in surveys. For buses and LCVs, reported mileage values exceeded typical market standards; therefore, standard market values were used instead.

Incomplete coverage of outbound and pass-through trips: Consistent with GPC guidance, trips whose origin and destination both lie outside the city boundary are excluded from the inventory. For a corridor city such as Erode, located along the Salem–Erode–Tirupur–Coimbatore corridor, this may understate the total traffic burden on the road network and its associated externalities. While this observation supports the case for complementary corridor-level inventories, such analysis falls outside both the scope of the study and EMC’s jurisdiction.

6.4 Institutional readiness and integration with city systems

Developing a GPC-compliant sectoral inventory is only the first step; the larger challenge lies in embedding it within municipal planning processes and data systems.

For Erode, three institutional levers are particularly important. First, EMC can serve as the nodal agency responsible for inventory maintenance, including data collection (VAHAN, FuSS, CMP surveys, traffic counts, and fuel-sales data), quality assurance, and annual updates.

Second, the Integrated Command and Control Centre (ICCC), developed under the Smart Cities Mission, has the potential to function as a central data hub. As additional traffic sensors, automatic number plate recognition (ANPR) cameras, and smart-parking systems are deployed, these systems can complement survey-based approaches and support near-real-time monitoring of vehicle flows, speeds, and congestion patterns.

Third, the inventory should be integrated into existing planning instruments, particularly the master plan and the comprehensive mobility plan (CMP). Over time, this would transform the GHG inventory from a standalone technical product into a decision-support tool for zoning, street design, public transport planning, parking regulation, and infrastructure investment.

6.5 Growth sensitivity and risk of long-term emission lock-in

The scenario analysis demonstrates that emissions are highly sensitive to both vehicle growth and travel distance. The marginal increase in fuel demand associated with VKT growth is approximately twice that associated with vehicle-registration growth. A 1 per cent increase in vehicle registrations and VKT results in approximately 0.45 per cent and 0.9 per cent increases in fuel demand, respectively.

These findings suggest that emissions respond more strongly to changes in travel behaviour and urban form than to vehicle ownership alone. As a rapidly growing tier-2 city, Erode is likely to experience continued spatial expansion driven by economic and trade activity. Without intervention, longer commuting distances and increasingly dispersed land-use patterns could significantly increase transport emissions.

The high-growth case indicates that emissions could rise from ˜0.61 $MTCO_2e$ in 2025 to ˜1.42 $MTCO_2e$ in 2045 in the absence of corrective policy measures. Such a trajectory risks locking the city into fossil-fuel-dependent transport systems for decades. Urban-planning decisions taken during the current decade will therefore have long-term climate implications, reinforcing the need to integrate transport-emissions considerations into master planning, zoning decisions, and infrastructure-investment frameworks.

6.6 Scope-based emissions transition under electrification and grid dependencies

Electrification represents a long-term pathway for reducing transport emissions in Erode. However, its effectiveness depends heavily on the carbon intensity of the electricity grid. Compared with the 2030 BAU scenario, Scope 1 emissions decline, while Scope 2 emissions increase by 30 per cent (0.0018 $MtCO_2e$ under BAU versus 0.056 $MtCO_2e$ under SC 6, assuming 30 per cent fleet electrification).

The adoption of EVs shifts emissions from tailpipe combustion to electricity generation; therefore, achieving overall mitigation benefits requires continued grid decarbonisation. Tamil Nadu's *Electric Vehicles Policy* promotes EV adoption across 2Ws, 3Ws, 4Ws, buses, and commercial fleets through demand incentives and tax waivers. The policy also supports public and private investment in charging infrastructure through energy tariffs and green tariffs (GoTN 2019).

Similarly, the *Tamil Nadu State Action Plan on Climate Change* (TNSAPCC) identifies transport electrification and renewable energy expansion as priority strategies for emission reductions. Aligning Erode's transport strategy with these state-level priorities could improve access to funding, technical support, and policy coordination. Ultimately, the effectiveness of transport electrification will depend on coordination among transport planning, electricity distribution planning, and state-level renewable energy deployment.

6.7 Implementation challenges and financial constraints

Although the scenario modelling demonstrates significant emissions-reduction potential, implementation feasibility ultimately depends on institutional capacity, financial resources, and stakeholder consensus.

First, fiscal constraints at the municipal level limit EMC's ability to finance large-scale fleet electrification, electric bus procurement, or pilot programmes involving e2Ws and e3Ws independently. Erode Municipal Corporation could strengthen its own-source revenues through measures such as rationalised parking fees, improved property tax collection, and land value capture mechanisms linked to major infrastructure investments. In addition, the city can leverage state and national schemes and explore public–private partnerships (PPPs) to support charging infrastructure, depot electrification, and coordinated information, education, and communication (IEC) campaigns to improve EV awareness.

Second, freight operators may be reluctant to adopt cleaner technologies because of high upfront costs and operational uncertainty. This challenge could be addressed through targeted financial instruments, including scrappage-linked incentives, interest subventions for EV and CNG trucks, phased low-emission zones in commercial areas (time-based or cordon-based), and demonstration projects to build confidence among operators.

Third, regulatory authority over key transport-sector interventions is distributed across multiple levels of government. Strengthening coordination among EMC, the Directorate of Town and Country Planning (DTCP), the Tamil Nadu State Transport Corporation (TNSTC), and the Tamil Nadu Electricity Board will therefore be critical to aligning vehicle policy, charging-infrastructure deployment, and land-use planning.

6.8 Policy recommendations

Based on the current baseline results and the GPC-compliant calculator's design, the following actions are recommended in the near term:

Management for vehicle ownership and vehicle kilometres travelled growth

Policy recommendation	Key actions	Stakeholders
Manage vehicle ownership growth through integrated demand-side transport planning	• Draft parking pricing reforms and differential pricing for the older vehicle segment • Link major public and commercial project approvals to public transport accessibility	EMC, DTCP, traffic police
Prevent VKT-driven emission growth through integrated land-use planning with transport safeguards	• Mandate mobility impact GHG assessments for new developments • Promote mixed-use zoning • Prioritise bus and shared mobility penetration in newly added municipal areas, starting with assessing existing bus network coverage	EMC (planning wing), DTCP
Embed climate in transport planning through the CMP and master plans	• Require GHG impact note for new transport projects • Utilise the emissions calculator to assess CMP interventions, such as new bus corridors, NMT improvements, parking management, and travel demand management measures	EMC, DTCP, and CMP/master plan in-charge

Note: CMP: comprehensive mobility plan; DTCP: Directorate of Town and Country Planning; EMC: Erode Municipal Corporation; GHG: greenhouse gas; NMT: non-motorised transport; VKT: vehicle kilometres travelled

Freight and high-intensity segment transition by super-emitters

Heavy-duty diesel vehicles contribute disproportionately to transport emissions despite representing a small share of the fleet. Therefore, prioritising interventions for older diesel trucks and buses offers the opportunity for near-term emission reductions. The following recommendations focus on accelerating the transition of this high-emitting vehicle segment.

Policy recommendation	Key actions	Stakeholders
Implement a targeted diesel freight transition programme	• Identify >10-year-old truck profile • Provide scrappage-linked incentives • Identify green freight access zones and preferential loading areas as transition incentives	EMC, RTOs, TNSTC, state transport department
Strengthen regional freight coordination for green freight corridors	• Coordinate with district authority on Salem–Erode–Tiruppur–Coimbatore freight corridor for green corridor planning	State transport department, district collectors
Develop a transitional fuel strategy for CNG/ LNG for high-VKT trucks	• Provide scrappage, retrofit, and replacement schemes wherever applicable	State transport department, oil marketing companies (OMCs)

Note: CNG: compressed natural gas; EMC: Erode Municipal Corporation; LNG: liquefied natural gas; OMC: oil marketing company; RTO: regional transport office; TNSTC: Tamil Nadu State Transport Corporation; VKT: vehicle kilometres travelled

Electrification and energy grid alignment for volume- and intensity-based decarbonisation

Policy recommendation	Key actions	Stakeholders
Accelerate adoption for high-volume segments for existing fleets (2Ws, 4W)	• Link demand incentives for 2Ws, 3Ws, 4Ws, and LCVs with scrappage of existing fleet	State transport department
Public transport decarbonisation	• Implement phased bus electrification by mandating EVs for public fleets • Target state schemes and PPP models for deploying depot charging infrastructure	TNSTC, TNPCB, TANGEDCO, EMC
Implement charging rollout in alignment with Tamil Nadu's EV Policy (2023)	• Integrate PPP models in charging infrastructure • Deploy utility-enabled EV connections • Lower standardised tariffs and provide green tariffs • Integrate solar + energy storage facilities at bus depots • Promote slow-charging infrastructure at homes and workplaces to align with user charging behaviour in the case of the personal vehicle segment (2W and 4W)	TANGEDCO, Tamil Nadu Electricity Board

Note: 2W: two-wheeler; 3W: three-wheeler; 4W: four-wheeler; EV: electric vehicle; LCV: light commercial vehicle; PPP: public–private partnership; TANGEDCO: Tamil Nadu Generation and Distribution Corporation Limited; TNPCB: Tamil Nadu Pollution Control Board; TNSTC: Tamil Nadu State Transport Corporation

Improvement in fuel efficiency and vehicle emissions intensity

Policy recommendation	Key actions	Stakeholders
Improve fleet fuel efficiency through BS-VI compliance or state targets	• Inspect city cordon points and high congestion zones periodically to identify non-compliant vehicles, and implement phased restrictions on pre-BS-VI vehicles • Link state permits for a minimum fleet efficiency standards over time for heavy duty vehicles	Traffic police, RTOs, TNPCB
Reduce emissions intensity in the commercial fleet through a retrofit and upgrade programme	• Pilot CNG retrofits for buses and trucks where technically feasible	State transport department

Note: BS-VI: Bharat Stage VI; CNG: compressed natural gas; LCV: light commercial vehicle; RTO: regional transport office; TNPCB: Tamil Nadu Pollution Control Board

Data, governance, and institutional capacity

Policy recommendation	Key actions	Stakeholders
Institutionalise emissions tracking through an annual GHG inventory mandate	• Notify EMC as custodian of the city GHG calculator • Update VAHAN and periodic fuel station data annually and mandatorily. • Publish and submit emissions reports to the state transport agency	State transport department, EMC, RTO, OMCs
Ensure methodological continuity on GHG inventory through SOPs	• Document data sources, correction factors, and assumptions so updates remain consistent despite staff turnover	EMC
Reduce survey dependence by integrating ICCC and traffic feeds	• Use ANPR for real-time traffic counts to monitor travel demand behaviour and patterns • Install real-time AQI sensors at major junctions for real-time monitoring	ICCC (EMC)
Improve data quality through data-sharing partnerships	• Form an MoU with the RTO, OMCs, and fleet operators to access anonymised activity data	EMC, TNSTC, state transport department, OMCs
Multi-level coordination by constituting state-city decarbonisation taskforce	• Align with Tamil Nadu net-zero pathways/policies • Set targets for 2030 and conduct multi-departmental quarterly review meetings	EMC, TNSTC, TANGEDCO

Note: EMC: Erode Municipal Corporation; GHG: greenhouse gas; ICCC: Integrated Command and Control Centre; MoU: memorandum of understanding; OMC: oil marketing company; RTO: regional transport office; SOP: standard operating procedure; TANGEDCO: Tamil Nadu Generation and Distribution Corporation Limited; TNSTC: Tamil Nadu State Transport Corporation

Acronyms

2/3/4W	two/three/four-wheeler
2AT	two-axle trucks
3AT	three-axle trucks
3W-P	three-wheeler private
3W-S	three-wheeler shared
4W-C	four-wheeler commercial
AADT	annual average distance travelled
ADT	average daily distance
AFOLU	agricultural, forestry, and other land use
ANPR	automatic number plate recognition
AQI	air quality index
AR6	Sixth Assessment Report
ASIF	Activity–Share–Intensity–Fuel
BAU	business-as-usual
BEI/MEI	baseline emissions inventory / monitoring emissions inventory
BS	Bharat Stage
CAFE	Corporate Average Fuel Efficiency (or Economy)
CF	correction factors
CH_4	Methane
CJV	car/jeep/van
CMP	comprehensive mobility plan
CNG	compressed natural gas
CO	carbon monoxide
COP	Conference of the Parties
CRF	common reporting framework

CVC	classified volume count
DCAP	district climate action plan
DTCP	Directorate of Town and Country Planning
EDGAR	Emissions Database for Global Atmospheric Research
EF	emission factor
EIA	Energy Information Administration
EMC	Erode Municipal Corporation
EV	electric vehicle
FuSS	Fuel Station User Survey
GDP	gross domestic product
GHG	greenhouse gas
GoI	Government of India
GoTN	Government of Tamil Nadu
GPC	*Global Protocol for Community-Scale Greenhouse Gas Emission Inventories*
IB/OB/TB	in-boundary/out-boundary/trans-boundary
ICCC	Integrated Command and Control Centre
IEC	information, education, and communication
IPCC	Intergovernmental Panel on Climate Change
IPPU	industrial processes and product use
ISDGC	*International Standards for Determining Greenhouse Gas Emissions for Cities*
LCV	light commercial vehicle
LNG	liquefied natural gas
LPG	liquefied petroleum gas
LULUC	land use and land-use change
MAV	multi-axle vehicle
MHDV	medium and heavy-duty vehicles
MJ	megajoules
MoU	memorandum of understanding

MRIO	multi-region input–output
N_2O	nitrous oxide
NDC	nationally determined contributions
NMT	non-motorised transport
NOx	nitrogen oxides
OD	origin destination
OMC	oil marketing company
PM2.5	particulate matter (2.5 microns)
PM E-DRIVE	*PM Electric Drive Revolution in Innovative Vehicle Enhancement*
PPP	public–private partnership
PT	public transport
PUC	Pollution Under Control
RTO	regional transport office
SD	standard deviation
SOP	standard operating procedure
SPUR	spatially prioritised urban region
T&D	transmission and distribution
TANGEDCO	Tamil Nadu Generation and Distribution Corporation Limited
TJ	terajoules
TNCCM	*Tamil Nadu Climate Change Mission*
TNGCC	Tamil Nadu Green Climate Company
TNSAPCC	*Tamil Nadu State Action Plan on Climate Change*
TNSTC	Tamil Nadu State Transport Corporation
t/$MtCO_2e$	tonnes/million tonnes carbon dioxide equivalent
VKT	vehicle kilometres travelled
WRI	World Resources Institute

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Trucks parked at fuel station near Erode Lorry Association.

Image: CEEW

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