

Vehicular Greenhouse Gas Emissions and Spatial Temporal Traffic Patterns in Gorakhpur City

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Abstract

The rapid urbanisation and the consequent increase in private vehicle ownership have contributed to increased air pollution and GHG emissions in developing Indian cities. This study estimates and analyses the vehicular emissions of CO₂e, CH₄ and N₂O from traffic in Gorakhpur, Uttar Pradesh. Field traffic volume assessment was carried out for a period of seven days at two different locations, Point A (College Gate, institutional zone with heavy traffic) and Point B (Ranidihiya Area, mixed residential-commercial zone) on a high-resolution basis. Different types of vehicles were two wheelers, gasoline, diesel, CNG, auto-rickshaws and HMTVs. Emissions were calculated using standardised emission factors from the IPCC Fourth Assessment Report and translated into CO₂e to assess overall environmental effects. The empirical results show that emissions vary significantly in space and time. Point A had significantly higher aggregate emission levels due to localised weekend economic activity and traffic, with a steep peak on Sundays (~ 377 kg/hr). On the contrary, a more constant and stable weekly emission profile was observed at Point B, with moderate increases in the middle of the week. Two-wheelers contributed the maximum to the total emission share (~ 43% to 44%) at both the sites due to their overwhelming statistical dominance in the traffic stream and not due to their individual emission intensity. Furthermore, a large part of emissions came from passenger cars. The paper stresses that a correct climate audit must take into account high GWP gases CH₄ and N₂O in CO₂e matrices. The results of this study provide a useful baseline for infrastructure design, cleaner fuel transition regulation, and localised traffic management strategies in growing urban areas.

1. Introduction

Global atmospheric greenhouse gas emissions are largely generated by transportation. The transport sector, an important component of socioeconomic development, remains a significant contributor to anthropogenic climate change and environmental degradation worldwide. Massive quantities of greenhouse gases (GHGs) and localised air pollution from the global road transport infrastructure are released by burning fossil fuels. These emissions trap thermal radiation in the Earth's atmosphere that exacerbates global warming (Sims et al., 2014; Krausmann et al., 2018; Wang et al., 2019; Zhang et al., 2023). India's transport sector accounts for about 13% to 14% of the country's total energy-related emissions and is the third largest emitter of greenhouse gases in the country (MoEFCC, 2021). Road transport is the biggest culprit in this area, contributing to an unbelievable 90% of all emissions related to transportation.

India is undergoing a massive transformation in the structural dynamics of vehicle pollution due to the rapid economic growth, burgeoning population and extensive urbanization in the country (Ramachandra et al., 2008; Verma et al., 2021). As metropolitan borders expand and disposable incomes grow, the desire for mobility is growing exponentially. In many rapidly growing mid-sized urban areas, also known as Tier-2 cities, public transport infrastructure development has lagged behind population growth historically (Qi et al., 2018; Qian, 2024). As a result, the urban people obviously like to have their own private vehicles, particularly two wheelers and small passenger cars, then to use public transport. This

geometric evolution of the vehicle population causes severe traffic congestion, long idling, low average transit speeds, and frequent stop-and-go driving during peak morning and evening commuting hours (Lipman et al., 2002; Goel et al., 2015; Lehtoranta et al., 2019). These operating inefficiencies increase tailpipe emission intensities and significantly increase fuel consumption rates.

Vehicle exhaust contains greenhouse gases and air pollutants that are not greenhouse gases. Carbon dioxide (CO_2) is the most common greenhouse gas produced when hydrocarbon fuels like petrol, diesel and compressed natural gas (CNG) are completely burned. Tracking CO_2 alone is not sufficient for full climate effect evaluations (Lipman, et al. 2002). Secondary greenhouse gases are methane (CH_4) and nitrous oxide (N_2O) generated by incomplete combustion of fuel and chemical reactions in catalytic emission control systems (Lin, Y. C., et al. 2021). These trace gases are far more powerful at trapping heat than CO_2 , though they are emitted in smaller absolute quantities. CH_4 and N_2O have high Global Warming Potentials (GWPs) over a typical 100-year time horizon, being tens to hundreds of times more potent than CO_2 on a per mass basis (Shine et al. 2005; Hirano et al., 2020; Hertwich 2021). There are also particular environmental trade-offs with fuel transitions. Although the extensive use of CNG as a greener alternative reduces CO_2 and particulate matter significantly, it also brings the problem of “methane slip” the emissions of unburned CH_4 due to fugitive losses or poor vehicle maintenance (Chen et al., 2012; Andrade et al., 2018; Trivedi et al., 2020). Meanwhile, non-GHG emissions including carbon monoxide (CO), nitrogen oxides (NO_x) and particulate matter (PM_{10} , $\text{PM}_{2.5}$) significantly deteriorate local air quality, resulting in urban haze and severe respiratory vulnerabilities (Boyчук et al., 2014; Peng et al., 2020). Extensive research has been carried out on emission profiles of megacities such as Delhi, Mumbai, and Bengaluru (Guttikunda et al., 2013; Arora et al., 2023) however, empirical field data is lacking for emerging Tier-2 urban areas.

The traffic in the regional economic centres such as Gorakhpur, Uttar Pradesh is growing at a fast pace without any corresponding changes in the geometry of the roads leading to structural localized atmospheric exposures (Bera et al., 2024). This work addresses this critical research gap by deriving a localized emission inventory for the city of Gorakhpur based on real-time empirical traffic volume surveys. The aggregate radiative forcing impact of multi-fuel vehicular flows using the standard CO_2 equivalent (CO_2e) framework from the recommendations of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2019; CPCB, 2020). The main objectives are to identify the most contributing vehicle segments, spatial and temporal mapping of emissions in residential and institutional areas, and to design targeted sustainable urban transportation programs.

2. Study area and Methodology

Gorakhpur is a rapidly growing Tier-2 city in the north-eastern sub-region of the state of Uttar Pradesh, India. The traffic monitoring campaign was based on two geographically distant field observation sites selected for data collection to obtain highly representative and regionally contrasting traffic dynamics. Point A (MMMUT Main Gate): This is a busy, densely populated institutional and business hub situated at

26.7314N, 83.4331E. It is characterised by narrow road widths, high pedestrian-vehicle interaction and high susceptibility to stop-and-go traffic behaviour during peak commuting hours each day. Point B (Ranidihiya Area): 26.7412N, 83.4415E This is a high-density residential and retail feeder route. It also accommodates more fluid, continuous-flow traffic situations with less concentrated pedestrian friction, because it is located within a mixed residential-commercial-transit route.

The vehicle greenhouse gas emission inventory was developed for the selected Gorakhpur corridors based on the 2006 IPCC Guidelines in a systematic bottom-up framework. We assessed a high-resolution, field-based activity data and emission-factor approach to map tailpipe outputs at targeted highway bottlenecks, although alternative methodology tracking paths such as land-use zoning grids or regional energy-balance datasets were assessed. The scope of this study is limited to direct tailpipe combustion activities that occur within the geographic boundaries of the selected intersections and only considers scope 1 emissions. The aggregate engineering approach is implemented in five stages: Vehicular Source Stream Delineation: The transport flow is segmented into six distinct engine-fuel types viz. gasoline two-wheelers, diesel cars, alternative CNG passenger units, three-wheeled CNG auto-rickshaws and diesel-fueled heavy motor vehicles (HMs). Empirical Activity Data Quantification: Simultaneous manual field vehicle counts over a continuous 7-day life span at synchronised morning, afternoon and evening observation sessions. EF_{ij} (Emission Factor Selection): The engine types were assigned to the IPCC AR4 emission values, adjusted for Indian road conditions, and standardized with country-specific validation baselines. Mass Emission Calculation Hourly mass profiles of CO_2 , CH_4 and N_2O are isolated by multiplying recorded vehicle volumes by standard pollutant metrics over a set unit distance factor ($D = 1 \text{ km}$) (Eskander et al., 2020; FSI 2021).

In order to adequately incorporate weekday-weekend variations, simultaneous empirical traffic volume surveys were implemented at both observation stations over continuous, uninterrupted seven-day periods (Monday to Sunday). To reduce human error and eliminate time variation discrepancies, synchronous counts were performed at fixed cross-sections across three stratified diurnal time blocks. Morning Peak Block Captures concentrated workplace, school and commercial opening commute streams between 9:00–10:00 AM in the morning. The off-peak block in the afternoon, 12:00 to 1:00 PM, is measuring baseline traffic patterns which are moderate and localised. Evening Peak Block (04:00 to 05:00 PM): Commercial store traffic and high-volume return home trips are captured. The main traffic count was done manually using a very accurate method and then double checked by a digital mobile tally counter app that enabled the classification of vehicles in real time and instantaneously.

2.1. Classification System for Vehicles

Based on vehicle size, weight and primary fuel usage patterns the mixed traffic stream seen during the field surveys was divided into six different structural categories: (i) Two-Wheelers (Bikes): These include scooters and motorcycles, which are fundamentally expected to run consistently on petrol. (ii) Four-wheelers (petrol cars): These are light-duty passenger cars that run on petrol. (iii) Four-wheelers (Diesel Cars): Light-duty vehicles with compression ignition that run on diesel. (iv) Four-wheelers (CNG Cars):

Compressed natural gas-powered light passenger cars that have been constructed or modified. (v) Three-Wheelers (Auto CNG): CNG-powered rickshaws used for intermediate public transportation. (vi) Heavy Motor Vehicles (HMTVs): This broad group includes public and private buses, agricultural tractors, and diesel-powered medium and heavy-duty trucks that operate inside urban freight boundaries (FSI 2021).

2.2. Mathematical Analysis

An analytical modelling framework was used to measure the absolute pollution load produced per unit of time. By multiplying classified hourly vehicle counts by standardised mileage-scaled emission factors across a uniform baseline trip distance matrix, the mathematical formulation calculates individual petrol masses (Kumar et al., 2014; IPCC 2019).

$$E_{ij} = V_j \times EF_{ij} \times D \quad (1)$$

where V_j is the empirical field vehicle count for class j during the 60 minute observation interval; EF_{ij} is the standardised empirical emission factor for gas i relative to vehicle class j (expressed in kg/km or g/km); D is the standardised unit travel distance vector, consistently maintained at 1 km across all structural calculations to maintain spatial consistency; and E_{ij} is the absolute mass emission of a specific target gas pollutant i (e.g., CO_2 , CH_4 , N_2O) generated by vehicle class j (CPCB 2020; Agency 2023).

Bulk emissions of CH_4 and N_2O were combined into a Carbon Dioxide equivalent framework to unify the multi-gas thermodynamic effects of separate vehicle streams into a single, structurally auditable climate metric. The precise 100-year timescale is lifted directly from the IPCC Fourth Assessment Report of GWP for Methane and Nitrous Oxide mass emissions were folded into a Carbon Dioxide equivalent framework to aggregate distinct vehicular streams multi-gas thermodynamic effects into a single climate metric amenable to structural audit. The conversions use the precise 100-year timescale GWP coefficients directly from the IPCC Fourth Assessment Report. The GWP multipliers are 25 for CH_4 and 298 for N_2O . The unified algebraic equation utilized for the calculation of the aggregate hourly carbon footprint is modelled as (IPCC 2007 & 2019):

$$CO_2e = CO_2 + ((CH_4) \times 25) + ((N_2O) \times 298) \quad (2)$$

The mathematical model makes use of an extremely rigorous, standardised dataset of emission factors that was taken from the IPCC's authoritative regulatory frameworks and validated against local conditions. Table 1 shows the empirical inputs used throughout the primary computation engine.

Table 1
Standardized Multi-Fuel Vehicular Emission Factors Sourced from IPCC Guidelines (IPCC 2007)

Vehicle Class (j)	Fuel Type Base	CO ₂ Factor (kg/km)	CH ₄ Factor (g/km)	N ₂ O Factor (g/km)
Two-Wheeler (Bike)	Petrol	0.05	0.01	0.005
Petrol Car	Gasoline	0.02	0.02	0.015
Diesel Car	Diesel	0.01	0.01	0.020
CNG Car	CNG	0.05	0.05	0.010
Auto CNG	CNG	0.04	0.04	0.008
HMV	Diesel	0.02	0.02	0.030

3. Results and Discussion

3.1 Variations in Vehicle Composition by Location and Day

The empirical field data collected over a seven-day period at both the studied intersections, shows a large structural domination of personalized transport solutions. According to the raw vehicle data sheet, the volumetric density requirement is highest for two-wheelers (bikes) in the active traffic stream, followed by gasoline passenger cars and CNG autorickshaws. The diurnal study shows a strong correlation between traffic peaks and local corporate, commercial and institutional schedules. Point A (College Gate) shows dramatic, concentrated volumetric spikes throughout the morning peak block (09:00 AM–10:00 AM) and evening return block (04:00 PM–05:00 PM) driven only by institutional commuting cycles. For example, on the first day of monitoring (Monday), the morning stream at Point A recorded 2,160 cyclists and 518 passenger automobiles in one 60-minute period. In contrast, Point B (Ranidihiya Area) exhibited a more dispersed and fluid diurnal profile. At point B, the off-peak afternoon block (12:00PM-1:00PM) had a baseline traffic density that was markedly higher than at point A, suggesting that transit activity was still taking place across residential-commercial networks, even if morning and evening commute volumes remained high.

3.2 Sectoral Contribution to Carbon Footprint

Table 2
 Vehicular Segment Percentage Contribution to Total CO₂ Emissions at
 Points A and B

Two-wheelers	Point A (College Gate)	Point B (Ranidihiya Area)
	43.1%	44.1%
Petrol Cars	22.7%	23.7%
Diesel Cars	13.0%	12.6%
Auto CNG	7.8%	7.4%
HMVs	7.3%	6.6%
CNG Cars	6.2%	5.7%

The matrices of percentage distribution were used to study the baseline CO₂ contributions to identify the exact environmental burden exerted by each vehicle category. A comparison of the mathematical results for Monday to Sunday commutes in a grouped bar chart the behavioural pattern of both geographical research points is the same:

At Point A (College Gate), peak was observed in the graph for two-wheelers, which also contributed the highest single share of carbon emissions (43.1%), followed by gasoline vehicles (22.7%) and diesel vehicles (13.0%). Gaseous fuel systems CNG automobiles, Auto CNG and diesel-powered HMVs occupied the lower distributions (6.2%, 7.8% and 7.3% respectively) as shown in Fig. 1 and Table 2.

At Point B (Ranidihiya Area): The structural dominance of two-wheelers was replicated with a dominating 44.1% of the localized share of emission. Diesel cars had a 12.6% share, with petrol cars a close second at 23.7%. The other smaller margins (5.7%, 7.4% and 6.6% respectively) were from the combined gaseous options and HMVs.

This diagnostic dissection highlights an important environmental paradox: despite their significantly lower engine displacement and lower stand-alone emission factor (0.5 kg/km CO₂) than a passenger car or an HMV, the magnitude of the statistical volume of two-wheelers in the urban stream makes them the main source of aggregate urban carbon loads as shown in Fig. 1. This over-height of the two-wheeler bars at both research sites visually underscores this disproportionate influence.

Table 3
Comparative Spatial-Temporal Distribution of Vehicular CO₂ Emissions at Points
A and B

Monday	Point A (College Gate) kg/hr	Point B (Ranidihiya Area) kg/hr
	290	275
Tuesday	285	280
Wednesday	270	295
Thursday	265	300
Friday	260	230
Saturday	310	250
Sunday	320	210

Spatial-temporal bar graphs of integrated weekly average CO_{2e} distributions reveal clear behavioural differences between the two study areas. Table 3 shows the most interesting result is from the Sunday monitoring at point A, where the weekly average emission increases to the absolute maximum of 320 kg/hr (and with some specific peaks in the afternoon, up to 377.659 kg/hr). This huge weekend rush is only at Point A (College Gate) and is much higher than the Sunday emission load at Point B. The pattern indicates that the institutional core is the site of major weekend commercial traffic, shopping transit, and leisure-related congestion. Conversely, Point B (Ranidihiya) is a clear winner for output on Wednesdays and Thursdays, showing its highest emission intensities during the mid-week active phases. Such a crossover is typical for residential-commercial zones, which are highly consistent and stable, with regular household logistics and commercial goods maintaining a steady carbon output over the typical workweek, only to sharply drop on Fridays (230 kg/hr) as shows in Fig. 2.

3.3 Equivalent CO_{2e} analysis

Table 4
Underlying Baseline Emission Data for Modelling Verification

Monday	Raw CO ₂ Mass (kg/hr)	Integrated CO ₂ e (kg/hr)
	250.85	257.78
Tuesday	240.00	246.50
Wednesday	260.00	271.20
Thursday	245.00	251.80
Friday	235.00	241.50
Saturday	220.00	226.00
Sunday	210.00	215.50

Figure 3 shows the grouped bar chart of the difference between raw CO₂ mass and integrated CO₂e metrics is an important indicator of real environmental damage. The mathematical difference between each pair of side-by-side bars shows the unmasked heat-trapping effect of trace gases (CH₄ and N₂O) multiplied by their high IPCC global warming potentials (25 and 298, respectively). The trend analysis clearly indicates that the climate impact of the fleet is always underestimated by CO₂ values alone. When plugged into the CO₂e engine, the integrated CO₂e columns consistently outperformed their raw CO₂ counterparts because the aggregate valuation moves upward across all tracking days. For example, the baseline CO₂ bar of 250.85 kg/hr is inflated to an absolute climatic impact profile bar of 257.78 kg/hr of CO₂e during the Monday morning peak at Point A as shown in Table 4. The height difference grows dynamically with the number of diesel-powered heavy vehicles or with older, poorly maintained CNG systems which are prone to methane slip (as is evident from the mid-week columns). Such very visible expansion between the paired bars highlights that CO₂e tracking is an essential prerequisite for accurate urban environmental auditing as normal carbon bars alone can hide a significant percentage of the true radiative force. This vertical gap is the crucial additional contribution of non-CO₂ trace gases (CH₄ and N₂O), which accounts for their high global warming index values. A bigger gap indicates incomplete combustion cycles or volatile operational windows, including high idle periods, and frequent deceleration phases during peak hours. The lower the variance, the more consistent the fuel to air combustion properties. The real carbon footprint reveals real ecological risk patterns by shifting the analytical focus from simple volumetric outputs to full radiative forcing equivalents.

Temporal tracking of aggregated CO₂e load reveals structural patterns of each site and local traffic behaviours. Point A (College Gate) has a steady trend layout during work-week indices. Then on Sunday it immediately and dramatically spikes up to a peak of 322.23 kg/hr. Structural congestion due to leisure travel, absence of local flow limitations and the increase of shopping-bound transits nearby important institutional crossings, highlight this intense weekend escalation. On the other hand, Point B (Ranidihiya Area) has a more balanced baseline with a visible midweek expansion on Wednesday and Thursday before dropping on its lowest index on Friday (213.54 kg/hr). This constant profile is typical of the

normal work-bound transit flows of a main arterial corridor. The analysis reveals that focusing only on unweighted metrics or raw counts of vehicles fails to capture the temporal anomalies that are central to contemporary urban planning.

4. Conclusion

The empirical data showed that institutional zones are critical bottlenecks and have volatile, high amplitude emission spikes during morning and evening peak hours and weekends, due to the highly synchronized commuter movements. On the other hand, the mixed residential corridors have a more uniform, predictable and stabilized daily carbon footprint. It is important to note from a volumetric perspective that motorized two-wheelers form the single largest contributor to urban transport carbon load with a massive 43% to 44% share of total emissions. This is driven entirely by the overwhelming numerical dominance of motorized two-wheelers in the active fleet as opposed to individual engine intensity. Moreover, it demonstrates that relying solely on raw CO₂ figures results in a significant systematic underestimation in environmental accounting. Therefore, incorporating secondary trace gases such as CH₄ and N₂O through a comprehensive global warming potential-based CO₂e matrix is computationally crucial to accurately represent the actual radiative forcing effects of highly heterogeneous urban transport streams. This forecasted growth, municipal policies must aggressively encourage fleet electrification through targeted localized purchase subsidies, dense battery swapping networks, and zero-emission zones for the hyper-dominant two-wheeler segment. Comprehensive approach that includes both emissions tracking and targeted urban planning is essential for mitigating the environmental impact of transportation in Gorakhpur.

Declarations

Ethical Approval Not applicable

Consent to Participate Not applicable.

Consent to Publish the authors has consented to the submission of the manuscript to the journal.

Author Contribution *Ashutosh Kumar Yadav* contributed to the study methodology, data collection, data analysis, original manuscript preparation. *Krishna Kumar Singh* Supervision methodology, manuscript preparation and Resource provided.

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Data availability all data generated and analyzed during this study are included in this published article.

Competing interest, the authors have no relevant financial or non-financial interests to disclose

References

1. Agency IE. CO₂ Emissions from Fuel Combustion: Database Documentation. Paris: International Energy Agency; 2023.
2. Andrade JCS, Dameno A, erez P, de Andres Almeida J, Lumbreras JM, J. Implementing city-level carbon accounting: a comparison between Madrid and London. *J Clean Prod.* 2018;172:795–804. <https://doi.org/10.1016/J.JCLEPRO.2017.10.163>.
3. Arora T, Reddy CS, Sharma R, Kilaparathi SD, Gupta L. Greenhouse gas emissions of Delhi, India: A trend analysis of sources and sinks for 2017–2021. *Urban Clim.* 2023;51:101634.
4. Bera OP, Venkatesh U, Pal GK, Shastri S, Chakraborty S, Grover A, Joshi HS. Assessing the impact of the National Clean Air Programme in Uttar Pradesh's non-attainment cities: a prophet model time series analysis. Volume 30. *The Lancet Regional Health - Southeast Asia*; 2024. p. 100486.
5. Boychuk K, Bun R. Regional spatial inventories (cadastres) of GHG emissions in the energy sector: accounting for uncertainty. *Clim Chang.* 2014;124(3):561–74. <https://doi.org/10.1007/S10584-013-1040-9/METRICS>.
6. Chen S, Chen B. Network environ perspective for urban metabolism and carbon emissions: a case study of Vienna. *Austria Environ Sci Technol.* 2012;46(8):4498–506. <https://doi.org/10.1021/ES204662K>.
7. Central Pollution Control Board (CPCB). Status of Vehicles and Air Quality Profile in Indian Cities. New Delhi: Ministry of Environment, Forest and Climate Change; 2020.
8. Eskander SMSU, Fankhauser S. Reduction in greenhouse gas emissions from national climate legislation. *Nat Clim Chang.* 2020;10(8):750–6. <https://doi.org/10.1038/s41558-020-0831-z>.
9. Forest Survey of India. (2021). Forest & Tree Resources in States and Union Territories. New Delhi. Accessed: apr. 2026.
10. Guttikunda SK, Kopakka RV, Dasari S, Robinson J. Receptor model-based source apportionment of particulate pollution in Hyderabad, India. *Environ Monit Assess.* 2013;185:5585–93.
11. Goel R, Guttikunda SK. Evolution of on-road vehicle populations and emissions in Indian cities (1985–2030). *Atmos Environ.* 2015;111:45–55.
12. Hertwich EG. Increased carbon footprint of materials production driven by rise in investments. *Nat Geosci.* 2021;14(3):151–5. <https://doi.org/10.1038/s41561-021-00690-8>.
13. Hirano Y, Ihara T, Hara M, Honjo K. Estimation of direct and indirect household CO₂ emissions in 49 Japanese cities with consideration of regional conditions. *Sustainability.* 2020;12(11):4678. <https://doi.org/10.3390/SU12114678>.
14. IPCC. Fourth Assessment Report (AR4): Climate Change 2007: The Physical Science Basis. Geneva: Intergovernmental Panel on Climate Change; 2007.
15. IPCC. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Task Force on National Greenhouse Gas Inventories; 2019.

16. Kumar A, Sharma MP. GHG emission and carbon sequestration potential from MSW of Indian metro cities. *Urban Clim.* 2014;8:30–41. <https://doi.org/10.1016/J.UCLIM.2014.03.002>.
17. Krausmann F, Lauk C, Haas W, Wiedenhofer D. From resource extraction to outflows of wastes and emissions: the socioeconomic metabolism of the global economy, 1900–2015. *Glob Environ Chang.* 2018;52:131–40. <https://doi.org/10.1016/J.GLOENVCHA.2018.07.003>.
18. Lipman TE, Delucchi MA. Emissions of nitrous oxide and methane from conventional and alternative fuel motor vehicles. *Clim Change.* 2002;53(4):477–516.
19. Lin YC. Role of vehicular catalytic converter temperature in emission of pollutants: An assessment based on isotopic analysis of CO₂ and N₂O. *Environ Sci Technol.* 2021;55(7):4430–8.
20. Lehtoranta K, Aakko-Saksa P, Murtonen T, Vesala H, Ntziachristos L, Ronkko T, Karjalainen P, Kuittinen N, Timonen H. Particulate Mass and Nonvolatile Particle Number Emissions from Marine Engines Using Low-Sulfur Fuels, Natural Gas, or Scrubbers. Volume 53. *Environmental Science & Technology*; 2019. pp. 3315–22. 6.
21. Ministry of Environment, Forest and Climate Change (MoEFCC). India: Third Biennial Update Report to the United Nations Framework Convention on Climate Change. Government of India; 2021.
22. Peng W, Yang J, Corbin J, Trivanovic U, Lobo P, Kirchen P, Rogak S, Gagne S, Miller JW, Cocker D. Comprehensive analysis of the air quality impacts of switching a marine vessel from diesel fuel to natural gas. *Environ Pollut.* 2020;266:115404.
23. Qian LH. An empirical study on the relationship between urbanization, transportation infrastructure, industrialization and environmental degradation in China, India and Indonesia. *Environment, Development and Sustainability*; 2024.
24. Qi C, Wang Q, Ma X, Ye L, Yang D, Hong J. Inventory, environmental impact, and economic burden of GHG emission at the city level: case study of Jinan. *China J Clean Prod.* 2018;192:236–43. <https://doi.org/10.1016/J.JCLEPRO.2018.04.259>.
25. Ramachandra TV, Shwetmala B. Emissions from India's transport sector: Statewise synthesis. *Atmos Environ.* 2009;43(34):5510–7.
26. Shine KP. Alternatives to the global warming potential for comparing climate impacts of emissions of greenhouse gases. *Clim Change.* 2005;68(3):281–302.
27. Sims R. Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2014.
28. Verma A, Harsha V, Subramanian GH. (2021). Evolution of urban transportation policies in India: A review and analysis. *Transp Developing Economies*, 7(2), Article 26.
29. Trivedi S, Prasad R, Mishra A, Kalam A, Yadav P. Current scenario of CNG vehicular pollution and their possible abatement technologies: an overview. *Environ Sci Pollut Res.* 2020;27(32):39977–40000.
30. Wang J, Rodrigues JFD, Hu M, Behrens P, Tukker A. The evolution of Chinese industrial CO₂ emissions 2000–2050: a review and meta-analysis of historical drivers, projections and policy goals.

31. Zhang B, Yin S, Lu X, Wang S, Xu Y. (2023). Development of City-Scale Air Pollutants and Greenhouse Gases Emission Inventory and Mitigation Strategies Assessment: A Case in Zhengzhou, Central China. <https://doi.org/10.1016/j.uclim.2023.101419>

Figures

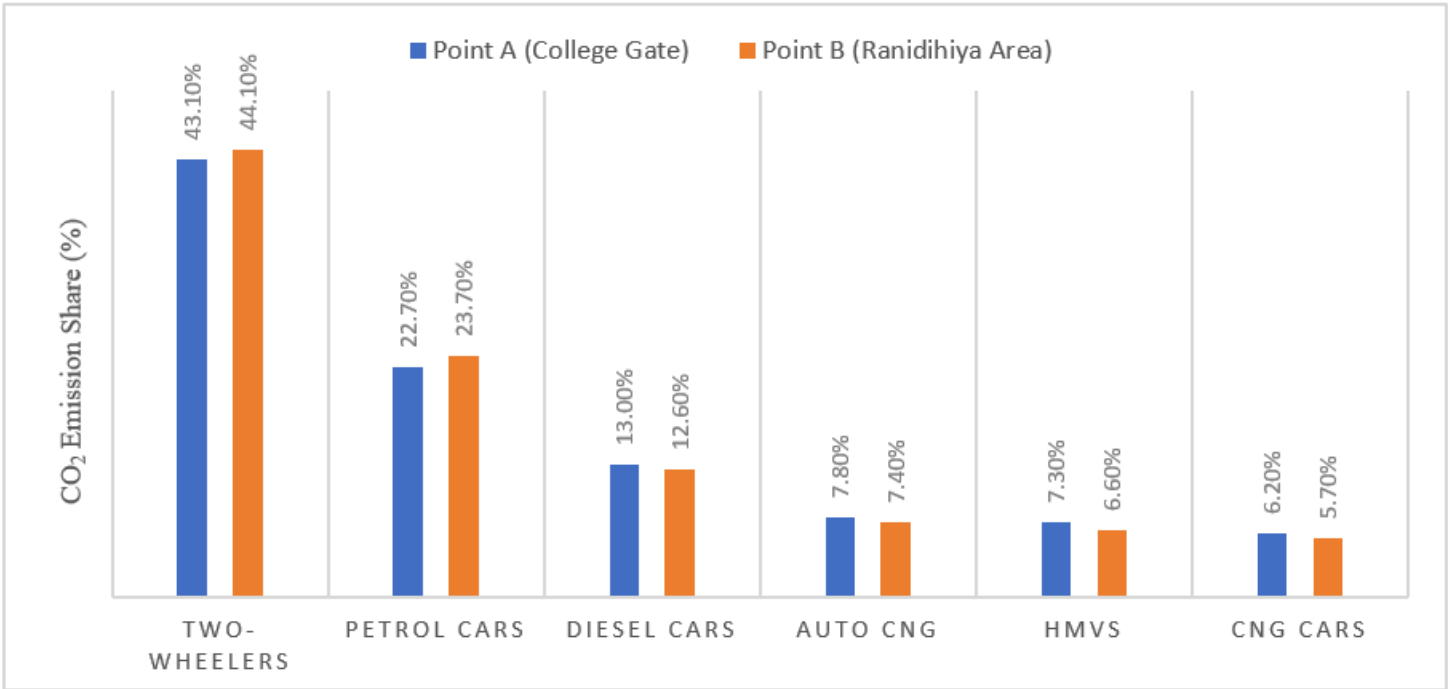


Figure 1

Different vehicular emission share for point A and Point B

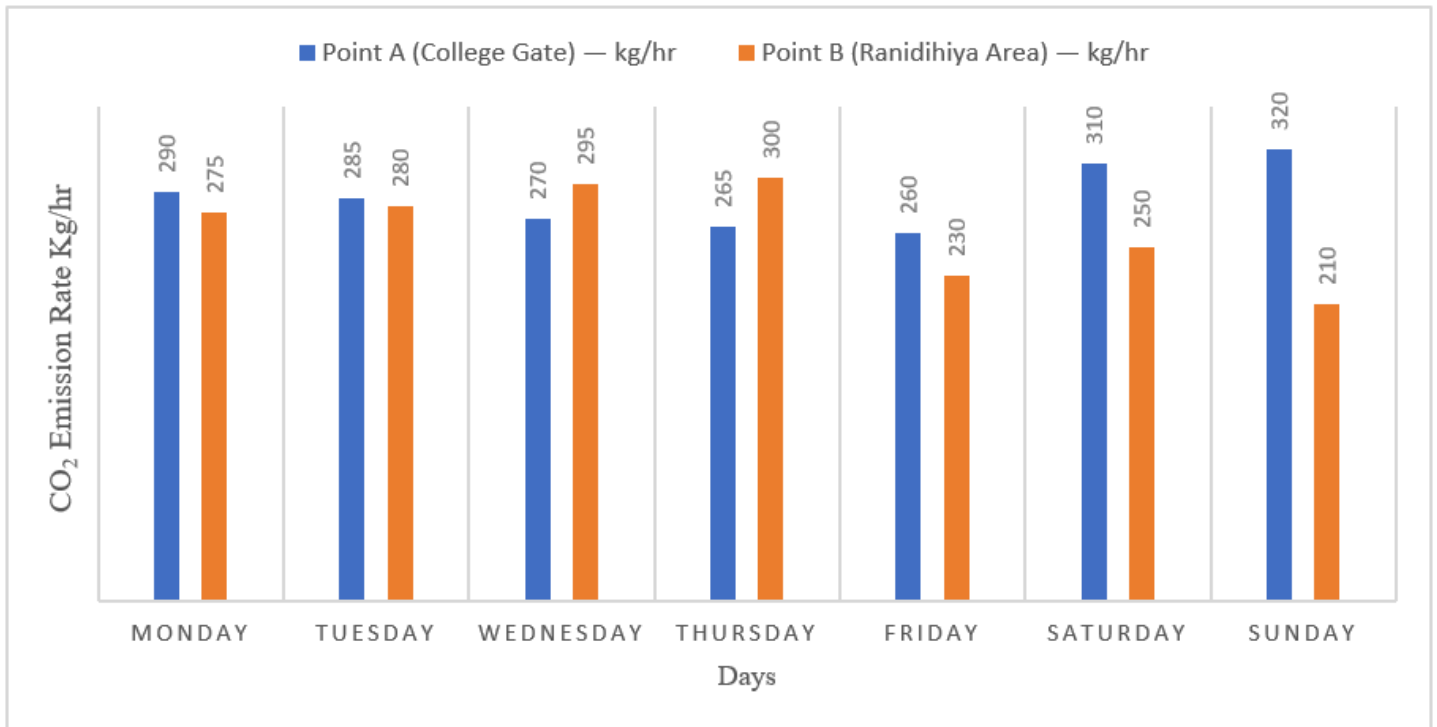


Figure 2

Weekly CO₂ emission rate for point A and Point B

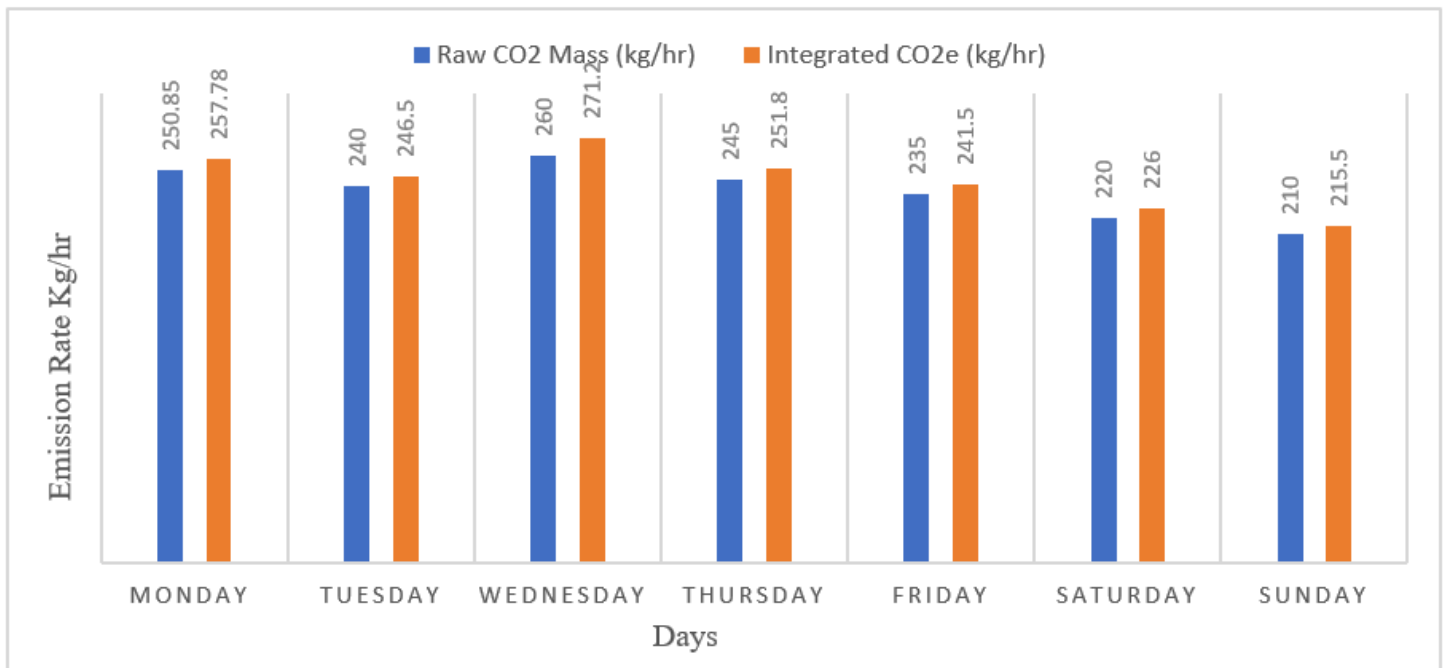


Figure 3

Weekly CO₂ and CO₂e emission rate for point A and Point B