Trends in Carbon Emission by Different Types of Automobiles in Tamil Nadu

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ABSTRACT
This research paper explores the trends in carbon emissions from various types of automobiles in Tamil Nadu. It analyses historical data, current trends, and future projections for passenger vehicles, commercial vehicles, two-wheelers, and three-wheelers. The study also examines the impact of government policies, technological advancements, and market shifts on emission patterns. The findings provide insights into the effectiveness of regulatory measures and potential pathways for reducing automotive carbon emissions in Tamil Nadu.

Keywords: Carbon Emissions, Road Transport Sector, Vehicle Population, Passenger Vehicles, Commercial Vehicles, Electric Vehicles (EVs), Sustainable Transportation

INTRODUCTION

Carbon dioxide is emitted into the atmosphere largely for the purpose of producing energy. It was projected that energy demand as well as CO2 emissions will peak in the 2040s due to steadily increasing use of automobiles relying more on diesel and petrol. However, fast electrification may reduce the demand for fossil fuels but the prevailing and new automobiles depend on diesel and petrol still emit CO2 as well as air pollutants such as nitrogen oxides (NOX) and fine particulate matter (PM2.5) (Stated Policy Scenario -STEPS, IEA 2021). At present, transport sector in India accounts for 12 per cent of India's energy related CO2 emissions and the increased demand for automobiles will double the emission of CO2 by 2050. The transport sector accounts for about 50 per cent of the oil demand in India (IEA 2021), next to the US, China, and Russia (IEA 2016), whereas the growth of transport energy demand in the US, China, and Russia is declining while India's transport demand is set to increase, currently a growing economy with a low per capita energy consumption for transport (IEA 2021). The gradual increase in the use of private cars and the expanding use of passenger and trucks due to rapidly increasing population and expanding economy surge a significant rise in carbon emissions. Even if the ambition of India to reach net zero emissions by 2070, it is important to note that India is at present the third largest automobile market, the largest tractor manufacturer, second largest bus manufacturer and third larges heavy trucks manufacturer in the world. As economic growth increases, emissions from transport sector expected to grow even faster even its close linkage to infrastructure development, electrification of vehicles manufacturing and use exist. Hence more emphasis is laid on giving importance to low carbon transport mode in order to achieve sustainable development.

Role Of Transport Sector In Carbon Emissions

The transport sector is one of the significant sources of global energy demand hence an important cause of carbon emissions. The transport sector requires more than half of the total oil demand in India (IEA 2021). Energy use in India's transport sector has increased five times over the last three decades, reaching more than 100 mtoe in 2019. The vehicle population in India has been increasing at an annual rate of 8 to 10 per cent, totalling around 22 crore of which the 2 wheelers account for 74 per cent and passenger cars around 12 per cent of the total. While the total vehicle penetration per thousand population is far less when compared to major developed and even to some developing nations signalling the possibility of more carbon emission in the future owing to the growth of population, urbanisation and economic growth. The road network of India is the largest after the US with 63.86 lakh km of rural-urban roads and national-state highways. The national highways record a compound annual growth rate (CAGR) of 7.25 per cent trailed just by 6.25 per cent of growth by rural roads and 4.27 per cent by urban roads (Economic Survey 2020–21). India imports more than 70 per cent of the crude oil demand because it has limited domestic oil resources, costing the country $150 B in 2022. Within the total petrol and diesel production

in the country, 90 per cent and 70 per cent respectively of the total consumption is diverted towards the transport sector. A large part of the diesel consumption is by the buses and the heavy-duty vehicle segments (39 per cent), while passenger vehicles (cars and utility vehicles) account about (22 per cent). It suggest that energy efficiency and decarbonisation in the transport sector is not only important from the economical but also from the environmental point of view.

Government Policies And Regulations

Realising the importance of reducing carbon emission in the transport sector, government has announced various measures to decarbonise the sector. India has implemented several policies and regulations to control vehicle emissions, such as the Bharat Stage Emission Standards, which set limits for pollutants from internal combustion engine of vehicles.

A. Technological Advancements

Technological advancements in designing vehicles and achieving better fuel efficiency have played a crucial role in reducing emissions. The development of electric and hybrid vehicles, improvements in battery technology, and the implementation of fuel-efficient engine technologies are key factors driving low carbon emissions. The technical advancements in efficient transportation can be achieved by the following methods.

1. Electric Vehicle (EV)

Technology Innovations in battery technology, reduction in battery costs, and advancements in charging infrastructure have facilitated the growth of the EV market.

2. Hybrid Technology

Hybrid vehicles, which combine an internal combustion engine with an electric motor, offer a transitional solution by improving fuel efficiency and reducing emissions.

3. Fuel-Efficient

Engines Developments such as turbocharging, direct fuel injection, and startstop systems have significantly improved the fuel efficiency of internal combustion engines.

B. Technological Advancements Policy Measures

Some key policies have been taken to promote electric vehicle (EV) adoption through incentives and infrastructure development. Key policies include:

1. Bharat Stage Emission Standards: These standards have progressively tightened emission limits, with BS-VI norms being the latest and most stringent.
2. National Electric Mobility Mission Plan (NEMMP) 2020: This plan aims to achieve national fuelsecurity by promoting hybrid and electric vehicles through subsidies, incentives, and infrastructure development.
3. Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) Scheme: This scheme provides financial incentives for the purchase of electric and hybrid vehicles and supports the development of charging infrastructure.

C. Promotional Policy Measures

1. Strengthening Policies for Electrification

The government of India introduced demand incentives to bridge the price gap between Electric Vehicles (EVs) and Internal Combustion Engines (ICEs) vehicles beyond 2024 when Faster Adoption of Manufacturing Vehicles (FAME) expires by having favourable taxation. For cars, demand incentives will go together with by stringent fuel economy standards. Preferential parking and low-emission zones can provide an additional push for EV adoption, without increasing the burden on public budgets.

2. Strengthening Fuel Economy Standards

It becomes necessary for India to establish a fuel economy standards in tune with long term climate goals with regular revisions. It is amply supported by applying penalties for noncompliant automobile manufacturers. Since two-wheelers have large share in vehicle population, introduction of standards will help to move towards electrification. India has proposed fuel consumption standards (FCS) and to implement this from April 2023 for all vehicles, including light, medium, and heavy-duty motor vehicles, which are either manufactured or imported for sale in India.

3. Supporting the Transition of Heavy-Duty Vehicles

Prioritising the deployment of electric buses in India enforce fuel economy regulations. India has set the target of 40 per cent of new buses being electric by 2030. Schemes FAME I and II approved 5595 e-buses just for the public sector, while it is optional in the case of private bus sector. PM-eBus Sewa scheme

announced in 2023 to deploy 10,000 e-buses in the public sector focuses on improving urban connectivity.

4. Scrappage Policy to Accelerate Phase-Out of Polluting Vehicles

Vehicle Scrappage Policy in India implemented in April 2022. Its aim is the phase-out of all old passenger cars and commercial vehicles to reduce air pollution and to increase passenger safety. For the successful implementation of the policy requires setting-up of more testing centres, strengthening incentives to scrap and replace, public campaign, besides having National Clean Air Programme and low emission zones.

5. Access to EV Financing and Reduction the Cost of Financing

India received thirty-six per cent of climate financing flows during the 2015-20 based on 3 rd Biennial Update Report (BUR) of India submitted to the UNFCCC (2021). Out of these 78 per cent was allocated to the electricity to renewables sector and the remaining 22 per cent to the transport sector. EV financing ecosystem is important for the large-scale adoption of EVs. With growing EV adoption, around Rs.45-55 thousand crore will be required to finance EVs by 2026. Currently the financing options available in the market are limited from the consumers' point of view. For the options available, loan terms are starkly unfavourable. And, the EMI burden is higher due to 1-9 per cent higher interest rates and 6-18 months shorter compared to ICE besides an additional repeated capex of battery replacement in every 4-5 years with low financing options.

6. Strengthening the Basis for Transport Policy Making

A better transport policy leads to better transportation. Better anticipation, policy innovation and better proofing are essential prerequisites of a good transport policy. This process helps to identification and preparation for new openings and trials that could appear during implementation. Foresight provides new opportunities for better transportation planning. For instance, preparing a long-term plan to achieve net zero emission goal 2070 depends on a policy explaining collecting and managing road transport-related data to supporting a policy explaining how to achieve it.

7. Strengthen International Engagement and Collaboration

India participates in quite a few international collaborative efforts to reduce carbon emissions in road transport such as the Clean Energy Ministerial Electric Vehicle Initiative and the CALSTART initiative.

LITERATURE REVIEW

The literature on trends in carbon emission by different types of automobiles is limited and therefore some of the important studies have been brought in for the review. This literature evaluation draws outcomes from a few recent studies on carbon emissions in the road transport sector. This exercise helped to understand the nuances of emissions from various types of automobiles, the efficacy of different transportation policies and technologies available to reduce carbon footprints.

Anil Singh et al. (2008) conducted a study on emissions of the road transport sector of India. The study inferred that nearly 27 Mt of CO2 was released in 1980, while the emission level increased to about 105 Mt in 2000. This increase was more than four times during a time span of 20 years

Shashwath Sreedhar et al. (2016) established a computer spreadsheet tool using the Excel platform, labelled as Carbon Footprint Calculator with various modules that correspond to different stages of the roadway construction project to estimate the total kgCO2e for any kind of road transport. This tool is used to estimate the carbon footprints of the pavement systems during the various stages of construction.

Singh, R. (2013) in his study titled "Carbon Emissions from Road Transport in India" explores the historical trends in carbon emissions from road transport. He emphasizes that the correlation between economic growth and rising vehicle ownership, resulted in increased emissions. The paper highlights the urgent need for policy interventions to curb emissions. Sharma, A., et al. (2014) in this study of "Impact of Vehicle Emission Standards on Air Quality in Urban India" assessed the impact of Bharat Stage (BS) emission standards on urban air quality. They find that the implementation of BS-IV standards significantly reduced particulate matter (PM) and nitrogen oxides (NOx) emissions. The authors call for stricter enforcement of emission norms.

Kumar, P. et al. (2015) examines in the paper "Electric Vehicles: A Pathway to Sustainable Transport in India" the potential of electric vehicles (EVs) in reducing carbon emissions. They argue that while EVs have a lower carbon footprint, their environmental benefits depend on the electricity mix. They recommend increasing renewable energy sources to maximize the benefits of EVs.

Verma, S. (2016) discusses various technological innovations in the study titled "Technological Innovations and Their Impact on Vehicle Emissions" that turbocharging and direct fuel injection improve

fuel efficiency and reduce emissions. The paper also covers hybrid and plug-in hybrid technologies as transitional solutions towards full electrification.

Jain, A., and Mehta, R. (2017) in "Policy Measures for Reducing Carbon Emissions from Transport in India" analyse the effectiveness of various policy measures, including the National Electric Mobility Mission Plan (NEMMP) and the FAME scheme. They find that financial incentives and infrastructure development are crucial for the success of these policies.

Chaudhary, N., and Patil, S. (2018) in the study of "Emission Trends from Commercial Vehicles in India" focuses on the commercial vehicle segment, identifying heavy-duty trucks and buses as major contributors to emissions. They suggest that transitioning to electric and alternative fuel vehicles can significantly reduce emissions in this sector.

Rao, K. (2019) in his paper on "Impact of Urbanization on Transportation Emissions in India," explores the relationship between urbanization and emissions from transport. The study finds that rapid urbanization has led to increased vehicle usage and emissions. The author recommends improving public transportation and non-motorized transport infrastructure.

Pandey, M. (2020) "The Role of Public Transportation in Reducing Carbon Emissions" - Pandey investigates how improving public transportation can reduce carbon emissions. The study shows that investment in public transportation infrastructure, such as metro systems and bus rapid transit (BRT), can significantly lower emissions by reducing the number of private vehicles on the road.

Gupta, V., and Singh, T. (2021) in the study on "Assessing the Adoption of Electric Two□Wheelers in India" evaluate the adoption rate of electric two-wheelers and their impact on emissions. They find that government incentives under the FAME scheme have accelerated adoption, but challenges remain in terms of charging infrastructure and consumer awareness.

Deshmukh, A. (2022) in his study on "Future Projections of Carbon Emissions from Road Transport in India" projects future trends in carbon emissions based on current policies and technological advancements. The paper concludes that achieving significant emission reductions will require a combination of stricter emission standards, widespread EV adoption, and renewable energy integration.

The literature review covers historical emission trends, comparative studies and impact assessments. The historical emission trends studies reveal that carbon emissions from automobiles have been rising steadily according to the increased vehicle ownership and economic growth. Whereas comparative studies explains the unique challenges faced by India, such as high population density, diverse vehicle types, and varying levels of infrastructure development. The impact assessments analyses the impact of emissions on air quality and public health, emphasizing the need for stringent emission control measures.

OBJECTIVES

1. To estimate the annual growth of vehicle population in the road transport sector of Tamil Nadu from 2012 to 2023 according to Passenger Vehicles, Commercial Vehicles, Two□wheelers, and Three-Wheelers.
2. To assess the annual increase in total emissions in the road transport sector and the annual increase in emissions in the road transport according to Passenger Vehicles, Commercial Vehicles, Two-wheelers, and Three-Wheelers in Tamil Nadu from 2012 to 2023.
3. To analyse the total carbon emissions in the road transport of Tamil Nadu from 2012 to 2023 according to Passenger Vehicles, Commercial Vehicles, Two-wheelers, and Three□wheelers.
4. To present the major findings of the study with suggestions for the reduction in carbon emission in the road transport sector of India.

METHODOLOGY

The research methodology used in this paper analyses the trends in carbon emissions by drawing secondary data on different types of automobiles in Tamil Nadu. The methodology encompasses data collection, data segmentation, statistical analysis, policy impact assessment, and projection modelling.

Sources of Data

The data used for the study are from secondary sources. These include Ministry of Road Transport and Highways (MoRTH) for the data on vehicle registration, types, and growth trends; Central Pollution Control Board (CPCB) for emission inventories, air quality monitoring data; International Council on Clean Transportation (ICCT) for emission factors for different vehicle categories, policy analysis reports, and technical papers.

Research Approach

This study examines the driving factors and their relationship with economic growth for the Indian transportation sector using the Logarithmic-Mean Divisia Index (LMDI) - decomposition method and

Tapio decoupling. Transportation-related energy consumption is decomposed into six factors. CO2 emissions data from 2001 to 2020 shows that the emissions from the Indian transportation sector increased from 155.9 Mt to 368.2 Mt. Roadways produce 88 per cent of all CO2 emissions from the transportsector. Energy systems, economic advancement, and population scale the increase in CO2 emissions, whereas energy efficiency and type of fuel influence the reduction in emission in the transport sector. Transport advancement demonstrates both the tendencies intermittently. CO2 emissions from Indian transport sector exhibit a weak decoupling. The increasing demand for vehicles, reliance on conventional fuel, and increase in energy consumption indicate a positive correlation with the increase in the nation's CO2 emissions, while the transition from coal to electric vehicles, hybrid fuel vehicles and the increased use of efficient vehicles offset the increase in emissions. In short, strategic and sustainable transport policy measures of the governments focus on emission free renewable energy. With this approach on the background the present paper aims to study different types of automobiles used for transportation between 2012 and 2023. Keeping this data, the estimation of CO2 emission and the variation over the years has been made. The outcome is useful for policymakers in formulating robust sustainable transportation policies.

Data Segmentation

The collected data was segmented into four primary categories of vehicles:

1. Passenger Vehicles: Including cars, SUVs, and vans.
2. Commercial Vehicles: Including trucks, buses, and light commercial vehicles.
3. Two-Wheelers: Including motorcycles and scooters.
4. Three-Wheelers: Including auto-rickshaws and goods carriers.

Trend Analysis

Historical Emission Trends: Using historical data to identify patterns and growth rates in carbon emissions for each vehicle category.

1. Emission Factors: Applying emission factors sourced from ICCT and CPCB to estimate emissions for different vehicle categories.
2. Fuel Efficiency Trends: Analysing changes in fuel efficiency over time for various vehicle types, considering advancements in technology and changes in fuel types.

Growth Of Vehicle Population And Emissions In The Road Transport Sector In Tamil Nadu

Table 1: Vehicle Population in the Road Transport sector in Tamil Nadu, 2012-2023

Year	Two Wheeler	Three Wheeler	Four Wheeler (cars)	Commercial Vehicles	Passenger Vehicles	Total
2012	1452590 (42.44)	1454602 (42.49)	179881 (5.26)	24093 (0.70)	311505 (9.10)	3422671 (100.00)
2013	1490445 (42.61)	1492458 (42.67)	187159 (5.35)	23369 (0.67)	304685 (8.70)	3498116 (100.00)
2014	1364765 (42.65)	1366779 (42.71)	165243 (5.16)	17581 (0.55)	285433 (8.93)	3199801 (100.0)
2015	1396387 (43.04)	1398402 (43.10)	163546 (5.04)	16972 (0.52)	269048 (8.29)	3244355 (100.00)
2016	1409108 (42.53)	1411124 (42.59)	172045 (5.19)	18031 (0.54)	303132 (9.15)	3313440 (100.00)
2017	1586667 (42.36)	1588684 (42.42)	199427 (5.33)	27162 (0.72)	343591 (9.17)	3745531 (100.00)
2018	1598908 (42.31)	1600926 (42.36)	217609 (5.76)	24069 (0.64)	337876 (8.94)	3779388 (100.00)
2019	1760015 (42.60)	1762034 (42.65)	219540 (5.32)	33788 (0.82)	355691 (8.61)	4131068 (100.00)
2020	1572168 (42.43)	1574188 (42.49)	205002 (5.53)	34356 (0.93)	319528 (8.62)	3705242 (100.00)
2021	1226727 (43.04)	1228748 (43.11)	185493 (6.51)	11173 (0.39)	198201 (6.95)	2850342 (100.00)
2022	1149325 (41.65)	1151347 (41.73)	219745 (7.96)	13274 (0.48)	225564 (8.18)	2759255 (100.00)
2023	1348796 (47.62)	956321 (33.77)	265205 (9.36)	14132 (0.50)	247781 (8.75)	2832235 (100.00)

Source: https://tnsta.gov.in/ Note: Figures in the Parentheses indicate row percentages.

Table 2: Descriptive analysis of registration of vehicles data between 2012 and 2023

	2 - Wheeler	3 - Wheeler	4 - Wheeler	Commercial	Passenger
Mean	1446325.08	1415467.75	198324.5833	22169.81818	295841.2727
Standard Error	48902.8319	63679.9751	8449.338011	2301.028595	14729.51698
Median	1430849	1432863	193293	23369	304685
Standard Deviation	169404.37	220593.904	29269.36545	7631.648483	48852.28116
Range	610690	805713	101659	23183	157490
Count		12	12	11	11
Largest(1)	1760015	1762034	265205	34356	355691
Smallest(1)	1149325	956321	163546	11173	198201

The descriptive analysis of vehicle registration data in Tamil Nadu from 2012 to 2023 reveals significant trends across different vehicle categories that have important implications for carbon emissions. Notably, 2-Wheelers exhibit the highest mean registration numbers at 1,446,325, followed closely by 3-Wheelers at 1,415,467. Despite their lower per-vehicle emissions, the sheer volume of these vehicles results in a substantial cumulative impact on carbon emissions. The high standard deviation and range in these categories indicate considerable year-to-year variability, reflecting fluctuating registration patterns. In contrast, 4Wheelers, with a mean registration of 198,325, show more stable trends but higher per vehicle emissions, making their cumulative impact significant as well.

Commercial and Passenger vehicles, while lower in number of registrations (22,170 and 295,841 respectively), contribute disproportionately more to emissions due to their size and usage patterns. The analysis highlights that Passenger vehicles have substantial variability in the number of registrations, influenced by economic and policy factors, while Commercial vehicles show more consistent trends. These insights underscore the need for targeted policies to reduce high-emission vehicles by cleaner alternatives, particularly among the 2 and 3-Wheelers which form approximately 85 per cent of the total vehicle registrations. Enhancing fuel efficiency and adopting electric vehicles across all categories could play a critical role in mitigating overall carbon emissions and achieving sustainable environmental goals in Tamil Nadu.

Table 3: Descriptive analysis of CO2 Emission of vehicles data between 2012 and 2023

	2 - Wheeler	3 - Wheeler	4 - Wheeler
Mean	1084.743813	2830.9355	594.97375
Standard Error	36.67712395	127.3599503	25.34801403
Median	1073.13675	2865.726	579.879
Standard Deviation	127.0532843	441.1878096	87.80809635
Range	458.0175	1611.426	304.977
Count	12	12	12
Largest(1)	1320.01125	3524.068	795.615
Smallest(1)	861.99375	1912.642	490.638

The descriptive analysis of CO2 emissions from vehicle data in Tamil Nadu between 2012 and 2023 provides crucial insights into the environmental impact of different vehicle categories. Among the categories, 3-Wheelers exhibit the highest mean CO2 emissions at 2,830.94 units, followed by 2-Wheelers at 1,084.74 units, and 4-Wheelers at 594.97 units. The substantial standard deviation for 3-Wheelers (441.19) and 2-Wheelers (127.05) indicates significant variability in emissions, reflecting diverse usage patterns and vehicle efficiencies over the years. The median values are closely aligned with the means, suggesting a relatively consistent distribution of emissions data within each category.

The range of CO2 emissions further highlights the variability within each category. Three wheelers show

the highest range at 1,611.43 units, indicating a broad spectrum of emission levels across different models or years. In contrast, 4-Wheelers, with a range of 304.98 units, demonstrate more stable emission levels, possibly due to stricter regulatory standards or technological advancements in newer models. The data underscores the need for targeted emission reduction strategies, particularly for 3-Wheelers, which contribute significantly to overall emissions. Enhancing emission controls and promoting cleaner technologies in the high-emission 2 and 3-Wheeler segments could substantially mitigate their environmental impact, aiding Tamil Nadu in achieving its carbon reduction targets.

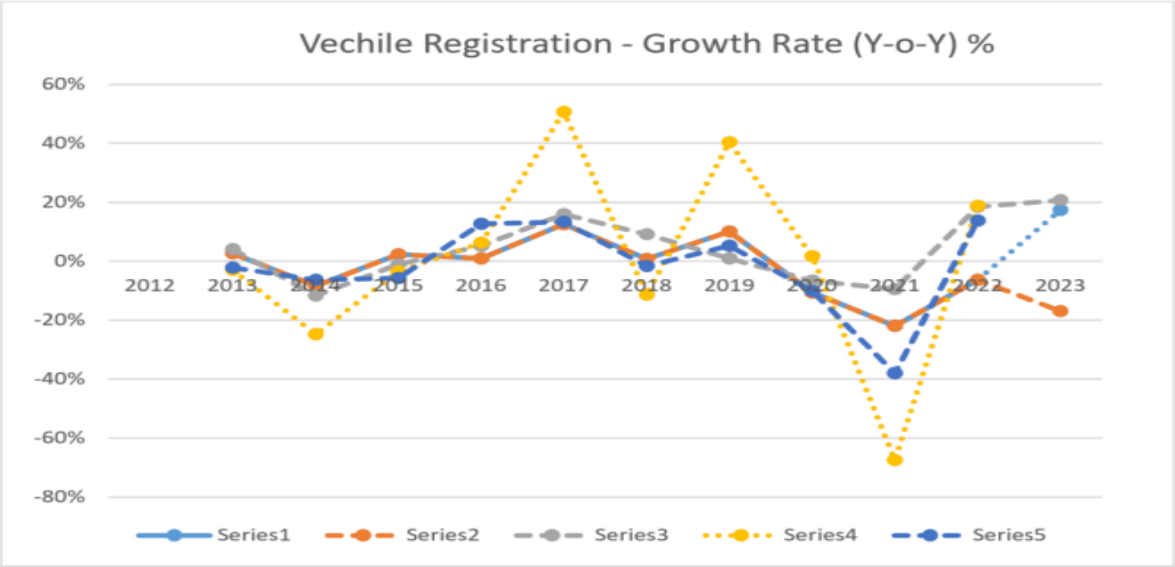


Diagram 1: Annual Growth Rate of Vehicle Registration

A Interpretation of Year-on-Year Registration Growth and CAGR for Vehicle Data (2012 to 2023)
The year-on-year (YoY) registration growth data for various vehicle categories in Tamil Nadu from 2012 to 2023, along with their Compound Annual Growth Rates (CAGR), offers valuable insights into market trends and potential future directions.

Year-on-Year Registration Growth 2-Wheelers and 3-Wheelers
Both 2-Wheelers and 3-Wheelers exhibit similar trends with notable fluctuations. The highest growth occurred in 2017 at 13 per cent, followed by a significant decline in 2021 (- 22 per cent). The trend indicates that economic factors, policy changes, or market conditions likely influenced these fluctuations. The decline in 2021 could be attributed to the COVID‐19 pandemic's impact on the market.

4-Wheelers
4-Wheelers show more pronounced variability, with a peak growth of 16 per cent in 2017 and a significant decline of -10 per cent in 2021. The data reveals a recovery with an 18 per cent increase in 2022 and a substantial 21 per cent increase in 2023, indicating potential market resilience and recovery post-pandemic.

Commercial Vehicles
Commercial vehicle registrations demonstrate the highest variability, with a significant growth peak of 51 per cent in 2017 and a drastic decline of -67 per cent in 2021. The data suggests that commercial vehicle registrations are highly sensitive to economic cycles and regulatory changes. A recovery trend is evident with a 19 per cent increase in 2022.

Passenger Vehicles
Passenger vehicle registrations also show fluctuations, with peaks in 2016 (13 per cent) and a significant decline in 2021 (-38 per cent). The recovery trend is visible with a 14 per cent increase in 2022, indicating market stabilization and potential growth.

Table 4: Compound Annual Growth Rate of Vehicle Registration (CAGR)

	CAGR (2012-2022)
2 - Wheeler	1.234611
3 - Wheeler	1.234196
4 - Wheeler	0.835141
Commercial	1.710016
Passenger	1.337136

B. Compound Annual Growth Rate (CAGR)

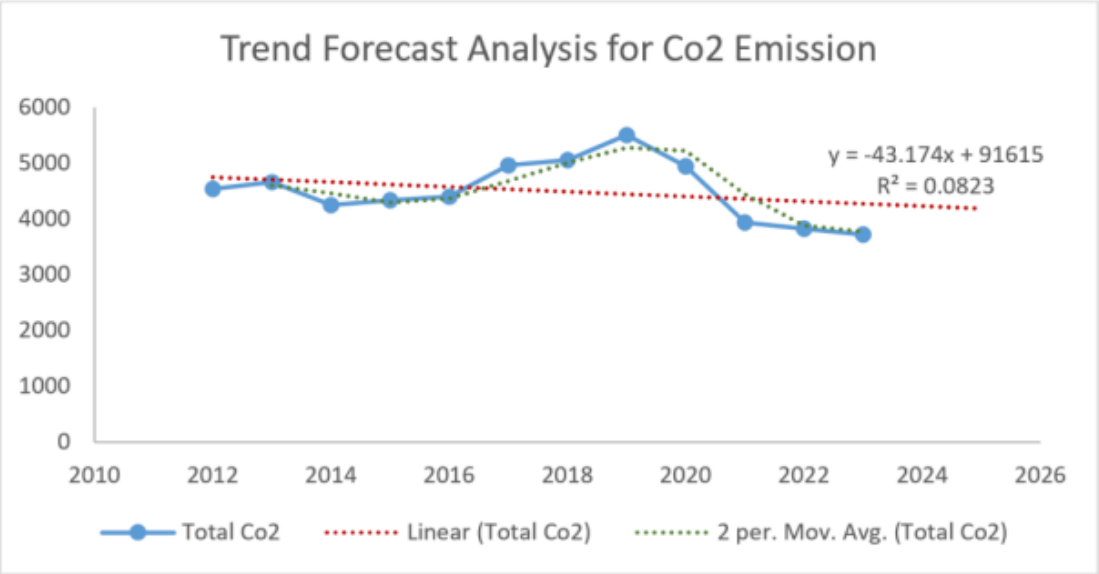
The CAGR values for the analysed period provide a long-term perspective on growth trends:
2-Wheelers and 3-Wheelers: Both categories exhibit a CAGR of approximately 1.23, indicating moderate long-term growth despite yearly fluctuations. 4-Wheelers, Commercial, and Passenger Vehicles: These categories show a CAGR of approximately 0.83, reflecting a slight long-term decline. This decline could be influenced by market saturation, economic conditions, or a shift towards alternative transportation modes. The YoY growth data highlights the volatility and sensitivity of vehicle registrations to external factors such as economic conditions, policy changes, and global events like the COVID-19 pandemic. The moderate CAGR for 2-Wheelers and 3-Wheelers suggests sustained demand, whereas the slight decline in 4-Wheelers, Commercial, and Passenger vehicles may prompt stakeholders to explore strategies to stimulate growth, such as promoting electric vehicles or improving economic incentives. These insights are critical for policymakers and industry stakeholders aiming to understand market dynamics and plan for sustainable growth in the automotive sector in Tamil Nadu.

C. CO2 Emission Data and Moving Average Analysis

Table 5 summarizes the CO2 emissions data for 2-Wheelers, 3-Wheelers, and 4Wheelers from 2012 to 2023, along with the total CO2 emissions and the 2-year moving average for total emissions.

Table 5: Estimation of CO2 Emission

Year	2 - Wheeler	3 - Wheeler	4 - Wheeler
2012	1089.4425	2909.204	539.643
2013	1117.83375	2984.916	561.477
2014	1023.57375	2733.558	495.729
2015	1047.29025	2796.804	490.638
2016	1056.831	2822.248	516.135
2017	1190.00025	3177.368	598.281
2018	1199.181	3201.852	652.827
2019	1320.01125	3524.068	658.62
2020	1179.126	3148.376	615.006
2021	920.04525	2457.496	556.479
2022	861.99375	2302.694	659.235
2023	1011.597	1912.642	795.615



Interpretation of Trends

1. Overall Decrease in Total CO2 Emissions:

The total CO2 emissions show a general decreasing trend from 2012 (4538.2895 units) to 2023 (3719.854 units), aligning with the negative slope of the linear forecast equation. This decrease may result from various factors, including advancements in vehicle technology, stricter emission regulations, and a potential shift towards more fuel-efficient or alternative fuel vehicles.

2. Category-Specific Trends:

• 2-Wheelers: CO2 emissions exhibit minor fluctuations but generally remain stable, with a slight increase observed in the later years (2022: 861.99375 units to 2023: 1011.597 units).
• 3-Wheelers: Emissions show a decreasing trend, especially after 2019, with a significant drop in 2023 (1912.642 units) compared to previous years.
• 4-Wheelers: Emissions increased over the years, with a notable rise from 2019 (658.62 units) to 2023 (795.615 units), suggesting increased usage or registration of 4-Wheelers.

3. Two-Year Moving Average:

The 2-year moving average provides a smoothed view of the total CO2 emissions, showing a consistent downward trend, peaking in 2019 (5174.070 units) and steadily decreasing to 2023 (3825.932 units). This further confirms the overall reduction in emissions over the observed period.

D. Analysis of Data

Statistical analysis was performed on the collected data to identify trends and correlations in carbon emissions from different vehicle types. Emission factors for different vehicle categories were sourced from ICCT and other relevant databases. The methodology includes:

Passenger Vehicles

Passenger vehicles, including cars and SUVs, are significant contributors to carbon emissions in Tamil Nadu. The trend shows a gradual increase in emissions due to the rising number of vehicles on the road. However, advancements in engine technology and the adoption of Bharat Stage VI (BS-VI) emission norms have started to mitigate this growth.

Trends and Data

Data from MORTH indicates that the number of passenger vehicles has been growing at an annual rate of approximately 8-10 per cent. Despite this growth, the introduction of BS□VI norms in 2020 has led to a noticeable reduction in per-vehicle emissions.

1. Historical Emissions: The historical data shows a steady increase in emissions from passenger vehicles over the past two decades. The trend correlates with economic growth and increased affordability of vehicles.
2. Emission Reduction Technologies: Adoption of advanced technologies such as turbocharging, direct

injection, and hybrid systems has contributed to emission reductions in recent years.
3. Impact of BS-VI Norms: The implementation of BS-VI norms has significantly reduced emissions of NOx and particulate matter, contributing to overall emission reductions.

Impact of Policies
Government policies, such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, have promoted the adoption of cleaner technologies. The impact of these policies is evident in the increasing market share of electric and hybrid vehicles.
1. FAME Scheme: The FAME scheme has provided financial incentives for the purchase of electric and hybrid vehicles, resulting in increased market penetration.
2. Subsidies and Incentives: Various state-level subsidies and incentives have further boosted the adoption of cleaner technologies.
3. Infrastructure Development: Investments in charging infrastructure have facilitated the growth of the electric vehicle market

Commercial Vehicles
Commercial vehicles, such as trucks and buses, have a substantial impact on emissions due to their larger engine sizes and higher fuel consumption. The trend indicates a steady rise in emissions, driven by the expansion of the logistics sector.

Trends and Data
The commercial vehicle segment has been growing at a rate of 5-7 per cent annually. Data shows that heavy-duty trucks and buses are the primary contributors to emissions in this segment.
1. Emission Contributions: Commercial vehicles account for a significant portion of total road transport emissions due to their higher fuel consumption and longer operational hours.
2. Growth in Logistics: The expansion of the logistics sector, driven by ecommerce and economic growth, has led to an increase in the number of commercial vehicles on the road.
3. Fuel Efficiency Improvements: Recent advancements in engine technology and the adoption of alternative fuels have improved the fuel efficiency of commercial vehicles, contributing to emission reductions.

Impact of Policies
The introduction of BS-VI norms and the push for electric buses in urban areas are expected to reduce future emissions. However, the high initial cost of electric commercial vehicles remains a barrier to widespread adoption.
1. BS-VI Norms: The implementation of BS-VI norms has led to significant reductions in NOx and particulate matter emissions from commercial vehicles.
2. Electric Buses: Government initiatives to promote electric buses in urban areas have resulted in increased adoption, particularly in metropolitan cities.
3. Challenges and Barriers: The high cost of electric commercial vehicles and the lack of charging infrastructure in rural areas pose challenges to widespread adoption.

Two-Wheelers
Two-wheelers, including motorcycles and scooters, are the most common mode of transportation in Tamil Nadu. Despite their smaller engines, the sheer volume of two-wheelers results in significant carbon emissions

Trends and Data
Two-wheelers account for nearly 70 per cent of the total vehicle population in Tamil Nadu. The trend shows a consistent increase in emissions, although the adoption of electric two-wheelers is growing rapidly.
1. Historical Emissions: The historical data indicates a steady increase in emissions from two-wheelers, driven by population growth and urbanization.
2. Market Growth: The two-wheeler market has been growing at an annual rate of 6-8 per cent, contributing to increased emissions.
3. Electric Two-Wheelers: The adoption of electric two-wheelers has been growing rapidly, supported by government incentives and increasing consumer awareness.

Impact of Policies

Government incentives for electric two-wheelers, such as subsidies under the FAME scheme, have boosted market adoption. The shift towards electric two-wheelers is a promising trend for reducing emissions in this segment.

1. FAME Scheme: Financial incentives under the FAME scheme have made electric two-wheelers more affordable for consumers.
2. State-Level Incentives: Various state governments have introduced additional subsidies and incentives to promote the adoption of electric two-wheelers.
3. Infrastructure Development: Investments in charging infrastructure have facilitated the growth of the electric two-wheeler market.

Three-Wheelers

Three-wheelers, used primarily for public transportation and goods delivery, contribute to emissions due to their prevalence and older engine technologies.

Trends and Data

Three-wheelers make up about 6-8 per cent of the total vehicle population in Tamil Nadu. Data indicates that emissions from three-wheelers have remained relatively stable, with a slow shift towards cleaner technologies.

Findings

- Significant Increase in Vehicle Population: The number of passenger vehicles and two-wheelers has grown substantially, driven by economic growth and urbanization.
- Reduction in Per-Vehicle Emissions: Technological advancements and stricter regulations have led to a decrease in average emissions per vehicle for all types.
- High Emissions from Commercial Vehicles: Despite improvements, commercial vehicles continue to have the highest average emissions per kilometre.
- Large Contribution of Two-Wheelers: The significant population of two-wheelers results in substantial total emissions, despite their lower per-vehicle emissions.

CONCLUSION

The analysis of carbon emission trends by different types of automobiles in Tamil Nadu from 2012 to 2023 reveals several significant findings. The number of vehicles on Indian roads has increased substantially, with passenger vehicles and two-wheelers showing the highest growth. This surge in vehicle population underscores the growing demand for personal mobility and the expanding logistics and public transport sectors. However, it also presents significant challenges for managing carbon emissions.

Technological advancements and stricter emission standards have led to a reduction in average emissions per vehicle across all categories. Passenger vehicles, commercial vehicles, two-wheelers, and three-wheelers have all seen decreases in per-vehicle emissions, reflecting the positive impact of improved engine efficiency, cleaner technologies, and regulatory measures. Despite these improvements, the overall increase in the number of vehicles has resulted in higher total carbon emissions. This trend indicates that while progress has been made at the individual vehicle level, the sheer volume of vehicles continues to drive up total emissions.

Commercial vehicles remain the highest emitters on a per-kilometer basis, highlighting the need for targeted measures to further reduce emissions in this sector. Additionally, the large population of two-wheelers contributes significantly to total emissions, despite their relatively lower per-vehicle emissions. This suggests that policies aimed at reducing emissions from two-wheelers could have a substantial impact on overall emission levels.

To address these challenges, continued efforts are needed to promote the adoption of cleaner technologies and stricter emission standards. The promotion of electric vehicles (EVs) and the improvement of public transportation infrastructure are critical steps toward achieving sustainable transportation. Incentives for the adoption of EVs and cleaner fuels can further help in reducing the carbon footprint of the transportation sector.

In summary, while there have been positive developments in reducing average vehicle emissions, the growing vehicle population necessitates ongoing and enhanced efforts to achieve significant reductions in total carbon emissions. Future policies should focus on managing the environmental impact of the increasing number of vehicles while promoting sustainable and clean transportation solutions. Only through comprehensive and sustained efforts can Tamil Nadu achieve its goals of reducing carbon emissions and mitigating the impacts of climate change.

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