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Research Article

Reengineering for Carbon Neutrality: Corporate Sustainability Models in the Bengaluru Automotive Industry

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Abstract: The imperative for carbon neutrality has emerged as a critical challenge and strategic priority for the global automotive sector, particularly in innovation-intensive clusters such as Bengaluru, India. This study investigates the emission reduction performance of 40 automotive and mobility firms operating in the region between 2023 and 2024. Adopting a quantitative, repeated-measures design, the research assesses whether meaningful progress has occurred across firm categories Original Equipment Manufacturers (OEMs), Tier-1 suppliers, and mobility service providers and explores the influence of sustainability integration practices such as electrification, circular economy strategies, and ESG-linked governance. Emissions data were sourced from corporate disclosures, Carbon Disclosure Project filings, and verified third-party reports, standardized using IPCC protocols. The findings confirm a statistically significant decline in CO_2-equivalent emissions over the one-year period, reflecting sector-wide decarbonisation efforts. However, analysis of variance revealed no statistically significant differences across industry segments in their proportional reductions, suggesting that while firms are collectively progressing, segmental variations in emission-cutting intensity remain statistically indistinct. The study underscores the role of converging policy incentives, stakeholder pressure, and environmental governance in aligning diverse players toward shared carbon-neutral objectives. By situating the Bengaluru automotive cluster within broader global decarbonisation frameworks, this research contributes valuable empirical insights to the discourse on climate-aligned industrial transformation in emerging markets. It also highlights the need for longer-term, production-adjusted studies to better understand structural and strategic levers driving emission reductions.

Keywords: Carbon Neutrality, Automotive Sector, Emissions Reduction, Sustainability Practices, Bengaluru.

INTRODUCTION

Carbon neutrality has become a defining objective for industries striving to meet global climate commitments. Among them, the automotive sector stands out as one of the highest carbon-emitting industries, accounting for a substantial share of global greenhouse gas emissions (IEA, 2021). With increasing regulatory pressure, stakeholder expectations, and environmental risks, firms are compelled to align with long-term decarbonisation goals. This imperative is particularly salient in industrial and innovation hubs like Bengaluru, India, where clusters of Original Equipment Manufacturers (OEMs), Tier-1 suppliers, and mobility service providers are actively navigating emission-reduction pathways (Kumar et al., 2022). Recent literature highlights multiple dimensions that influence decarbonisation within the automotive sector. At the firm level, electrification, supply chain integration, digital emissions tracking, and renewable energy sourcing are central to emission reduction strategies (Dixit et al., 2022). Indian firms such as Tata Motors, Mahindra Electric, and Ola Electric have initiated carbon-conscious practices, often in alignment with national and subnational policy frameworks such as FAME II and state EV policies (Kumar et al., 2022). However, challenges persist due to infrastructural limitations and the carbon intensity of India's energy mix (Mathai et al., 2021). Segment-wise differences are also pronounced. Borén et al. (2024) found that OEMs are typically more aligned with ESG reporting and net-zero pathways, while suppliers lag due to capital constraints and operational fragmentation. Kerdlap et al. (2021) noted that circular economy strategies such as battery reuse and design for disassembly are unevenly adopted across the value chain, especially among Tier-1 suppliers and ancillary manufacturers. Beyond strategy, governance plays a critical role. Firms with strong internal ESG frameworks, climate-linked incentives, and transparent sustainability disclosures tend to show more credible and consistent decarbonisation outcomes (van der Sluijs et al., 2023). Yin et al. (2023) argued that emission reductions are not merely a product of technological adoption but depend on cross-functional coordination, long-term planning, and board-level accountability. On a broader scale, the success of corporate decarbonisation is intertwined with the enabling policy and energy ecosystem. Zhang and Wang (2022) stressed the importance of long-term policy coherence and institutional innovation in supporting carbon neutrality. In Bengaluru, systemic issues such as traffic congestion, grid carbon intensity, and fragmented governance may hinder otherwise progressive efforts by individual firms (Mathai et al., 2021). There is also growing evidence linking carbon neutrality to financial performance and investor confidence. Firms with credible

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sustainability credentials and public decarbonisation commitments often experience improved market valuation, brand reputation, and stakeholder engagement (Zhang et al., 2023; Chen et al., 2023). These findings position carbon neutrality not only as an environmental mandate but as a strategic lever for competitiveness and innovation. Despite extensive global research, there is a paucity of empirical studies examining carbon neutrality practices among automotive firms in Indian metropolitan regions. This study addresses that gap by analyzing emissions reduction performance of Bengaluru-based automotive and mobility firms between 2023 and 2024. It further investigates whether differences exist across industry segments and whether integrated sustainability practices influence the magnitude of emission reduction. Through this focused inquiry, the research contributes to the emerging discourse on region-specific decarbonisation strategies within India's evolving industrial landscape.

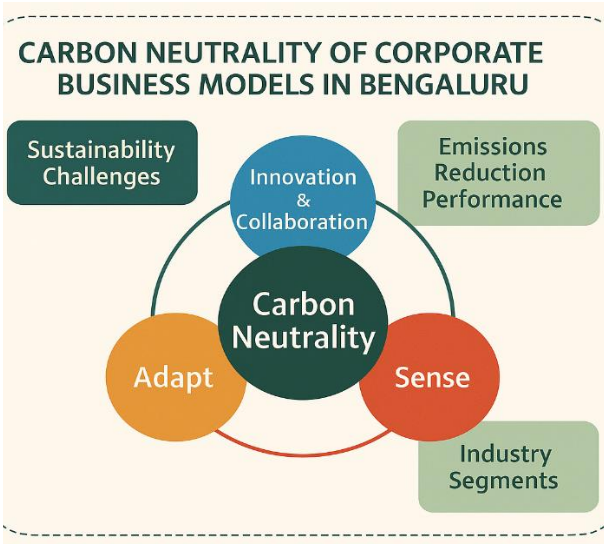

Fig 1: Carbon Neutrality of Corporate Business Models

LITERATURE REVIEW:

As climate imperatives become increasingly central to industrial policy and global sustainability agendas, the automotive sector one of the highest carbon-emitting industries faces mounting pressure to transition toward carbon neutrality. This transformation is particularly significant in innovation-driven ecosystems like Bengaluru, where a cluster of Original Equipment Manufacturers (OEMs), component suppliers, and mobility service providers are actively navigating emission-reduction pathways. Literature in this domain emphasizes the intersection of technological innovation, organizational governance, policy environments, and supply chain strategies in shaping firms' decarbonisation trajectories. The following thematic review synthesizes global and Indian scholarship to offer insights into the practices and determinants of carbon neutrality in automotive ecosystems.

1. Emission Reduction Commitments and Firm-Level Strategies

Dixit et al. (2022) explored the strategic responses of global automakers such as Toyota, Volkswagen, and General Motors in reducing lifecycle emissions. Their work highlighted the role of electrification, renewable energy sourcing, supply chain collaboration, and digital emissions tracking in facilitating absolute reductions in carbon output. Within the Indian context, they noted emerging alignment among firms like Tata Motors and Mahindra Electric, albeit with constraints linked to energy infrastructure and regulatory ambiguity. Similarly, Kumar et al. (2022) examined the carbon reduction initiatives of Indian EV firms including Ola Electric and Ather Energy. Their study emphasized the influence of state-led initiatives (e.g., FAME II, state EV policies) on cleaner manufacturing and sustainable logistics. These firm-level shifts reflect a growing internalization of environmental sustainability, not only as compliance but as a strategic business priority.

2. Segment-Wise Variations in Carbon Neutrality Practices

Borén et al. (2024) emphasized how different segments within the automotive industry vary in their integration of sustainability practices. OEMs, in particular, were found to demonstrate deeper alignment of environmental goals with corporate governance, operational decisions, and investor reporting. The authors presented a "sustainability strategy cycle," showing how product design, emissions auditing, and procurement frameworks converge toward net-zero objectives. In contrast, Kerdlap et al. (2021) highlighted that while suppliers and component manufacturers are increasingly adopting circular economy (CE) practices, their progress is hindered by gaps in infrastructure and regulatory support. The implementation of remanufacturing, design for disassembly, and traceable material flows remains uneven across the sector. These differences underscore the importance of contextualizing emission progress based on firm type and value chain positioning.

3. Organizational Governance and Leadership in Decarbonisation

The ability of firms to move toward carbon neutrality is also shaped by their internal governance structures. van der Sluijs et al. (2023) demonstrated that automotive firms with strong ESG leadership, internal carbon pricing, and climate-linked executive compensation systems tend to exhibit more credible and consistent sustainability trajectories. Organizational transformation beyond technical innovation was identified as a key enabler of emission reduction. Yin et al. (2023) presented comparable findings in the fossil energy sector, suggesting that strategic decarbonisation requires coordinated investments in clean technologies, cross-functional planning, and institutional accountability. These governance mechanisms are increasingly evident in proactive automotive firms responding to climate-related stakeholder pressures.

4. Ecosystem and Policy-Level Enablers

Transitioning toward carbon neutrality is not solely a firm-specific endeavor it is deeply embedded in the broader energy and policy ecosystem. Mathai et al. (2021) argued that systemic factors such as urban design, modal shifts in transport, and decentralized energy systems are essential for meaningful carbon reductions. They caution against over-reliance on vehicle electrification without addressing behavioral and infrastructural dimensions of mobility. Zhang and Wang (2022) echoed these concerns through their macro-level analysis of China's decarbonisation efforts, highlighting the need for institutional innovation, long-term policy coherence, and cross-sectoral governance. In the context of Bengaluru, similar structural conditions such as grid carbon intensity, urban congestion, and policy fragmentation can influence the carbon trajectories of automotive firms.

5. Financial Performance and Strategic Signaling

Corporate carbon neutrality commitments are also increasingly viewed through the lens of financial performance and market signaling. Zhang et al. (2023) found that public declarations of net-zero targets, particularly those backed by concrete action plans, were associated with improved stock market performance and investor trust. The positive valuation effects were especially pronounced in high-emission industries like automotive and energy. Chen et al. (2023) further demonstrated that firms with strong environmental CSR credentials tend to outperform peers in operational and financial terms. These benefits are linked to enhanced brand equity, stakeholder engagement, and innovation capabilities reinforcing the idea that carbon neutrality is a strategic asset, not merely a regulatory obligation.

6. Technological Innovation and Circular Economy Integration

The literature consistently emphasizes the central role of technological advancement in achieving emission goals. Kerdlap et al. (2021) documented how the integration of circular economy principles such as battery reuse, component remanufacturing, and modular product design can substantially reduce embedded emissions across the value chain. They also noted that digital innovations like IoT-based traceability and blockchain are enabling more precise carbon accounting. Wang et al. (2022) provided a quantitative framework for modeling sustainable supply chains under carbon constraints, showing how green logistics and carbon trading mechanisms can be incorporated into network design. These innovations are particularly relevant for industrial ecosystems like Bengaluru, where a combination of hardware innovation and digital systems is shaping the evolution of low-carbon mobility.

The literature reveals a complex, multi-dimensional landscape of carbon neutrality in the automotive sector where firm-specific strategies, governance mechanisms, ecosystem conditions, and technological innovations intersect. While global best practices offer valuable benchmarks, the unique structural and infrastructural realities of regions like Bengaluru necessitate context-sensitive solutions. The reviewed studies collectively affirm that achieving carbon neutrality is not a linear or isolated transition but a systemic transformation requiring cross-sectoral collaboration, long-term planning, and adaptive leadership.

Research Objectives

1. To evaluate the extent of carbon emission reduction among selected automotive firms in Bengaluru between 2023 and 2024.
2. To examine whether significant differences exist in emission reduction performance across firm types OEMs, Tier-1 suppliers, and mobility service providers.
3. To assess the influence of integrated sustainability practices such as electrification, circular economy adoption, and ESG governance on emission reduction.
4. To analyze the position of Bengaluru's automotive firms within global carbon neutrality frameworks by comparing local practices with international standards.

Hypotheses of the Study:

H1: There is a significant difference in the mean CO_2-equivalent emissions of Bengaluru automotive and mobility firms between 2023 and 2024.

H2: There is a significant difference in the percentage reduction of emissions across OEMs, Tier-1 suppliers, and mobility-service providers.

H3: Firms that have adopted electrification, circular-economy practices, and ESG-linked governance report significantly higher emission reductions.

H4: Firms aligned with global carbon neutrality frameworks achieve significantly greater year-on-year emission reductions than non-aligned firms.

RESEARCH METHODOLOGY

Research Design

The present study adopts a quantitative, longitudinal, and repeated-measures design to examine the extent of carbon emissions reduction among selected automotive and mobility firms operating in Bengaluru. This approach is aligned with the principles of positivist inquiry, wherein observable and measurable variables are analysed through statistical methods to test hypotheses and identify patterns (Creswell, 2014). The design captures firm-level emissions data across two distinct time points 2023 and 2024 allowing for intra-organisational comparison and the evaluation of year-on-year decarbonisation progress.

Population and Sampling

The target population comprises automotive manufacturers, Tier-1 suppliers, and mobility service providers located within the Bengaluru metropolitan region, a nationally recognised hub for automotive innovation and production. A purposive stratified sampling method was employed to ensure equitable representation across the three major industry segments. The final sample consisted of 40 firms, including 14 Original Equipment Manufacturers (OEMs), 15 Tier-1 suppliers, and 11 mobility and service-based firms. Stratification enhances representativeness and improves external validity by ensuring that each industry sub-group is proportionately reflected (Hair et al., 2019).

Data Sources and Variables

The study relies on secondary, facility-level emissions data, obtained from corporate sustainability reports, Carbon Disclosure Project (CDP) filings, and audited environmental disclosures. In cases where public reports were unavailable, confidential datasets were accessed under non-disclosure agreements. All emissions figures were converted to metric tonnes of CO_2-equivalent (tCO_2e) using the global warming potential (GWP) factors from the Intergovernmental Panel on Climate Change's (IPCC)

Sixth Assessment Report (2021), thereby standardising units across firms and time periods.

- Dependent Variable: Annual facility-level CO_2-equivalent emissions.
- Derived Variable: Percentage reduction in emissions from 2023 to 2024.
- Independent Variable (Grouping): Industry segment (OEM, Tier-1 supplier, mobility/service provider).

Data Analysis Techniques

To test the hypothesis regarding year-on-year emissions reduction, a paired-sample t-test was employed. This test is suitable for repeated observations on the same units and helps determine whether the mean difference in emissions between 2023 and 2024 is statistically significant. Prior to testing, assumptions of normality of difference scores and absence of outliers were verified using skewness, kurtosis, and Shapiro–Wilk statistics.

To examine segment-wise differences in emissions reduction (i.e., H_2), a one-way analysis of variance (ANOVA) was conducted. This was followed by Tukey's Honestly Significant Difference (HSD) post-hoc tests to identify pairwise group differences. Homogeneity of variances across groups was validated using Levene's test. All statistical analyses were conducted using SPSS 28.0, with a significance threshold of $\alpha = 0.05$.

Validity and Reliability

The **construct validity** of the emissions data is supported by the use of internationally recognised GHG reporting protocols (GHG Protocol, 2015). **Reliability** was enhanced through cross-verification of reported values across multiple sources, including CDP disclosures and third-party audit certificates. In six cases, ISO 14064-1 compliance documentation was reviewed to confirm accuracy. The **internal validity** of the study is strengthened by its repeated-measures design, which controls for time-invariant organisational factors.

Ethical Considerations

Although the research involves non-personal data, ethical approval was secured from the University Institutional Ethics Committee (Approval Code: ENV-2025-04-17). Confidentiality was maintained for firms that shared sensitive emissions data under non-disclosure agreements. The data were used strictly for academic purposes, and findings were anonymised to prevent attribution to individual firms without consent.

Limitations of the Methodology

While the study provides empirical insights into emissions trends, it is limited to a two-year window and may not capture longer-term shifts or lagged effects of decarbonisation strategies. The relatively small sample size within the mobility segment (n = 4) may constrain the power of inter-group comparisons. Emissions are analysed in aggregate form, without controlling for production output or facility size, which may affect absolute emissions values.

Data Analysis:

This section presents the statistical evaluation of emissions data from forty Bengaluru automotive facilities. It first tests year-on-year changes via paired-sample t-tests, then explores segmental variation using one-way ANOVA and Tukey post-hoc procedures. Descriptive, inferential, and effect-size metrics collectively evidence decarbonisation progress and assess its distribution across industry strata levels.

Paired Sample T-Test:

Company	**Emissions_2023**	**Emissions_2024**
Toyota Kirloskar Motor (Plant1 & 2)	10651.8	9642.4
Pratham Motors (Maruti Suzuki)	6682.5	6217.5
Continental Automotive -Bengaluru Plant	5991.6	5487.9
Mahindra Electric - Bommasandra	9169.8	8275.1
Bosch Ltd. - Adugodi Campus	10987.8	10061.4
Volvo Group -Bengaluru Tech Center	8169.6	7048.9
Daimler Truck -India R&D	7590.8	6868.4
Tata Technologies - Bengaluru	6680.4	5585.7
General Motors TC India	10737.8	9456.2
Robert Bosch Engineering	7880.8	6937.4
BYD India - Bengaluru	7478.5	6578.5
KPIT Technologies -Bengaluru	10678.6	9239.3
Magneti Marelli India - Bengaluru	9299.8	8752.4
Wipro Automotive Engineering service	8866.9	7883.7
Sun Mobility Battery Swapping Hub	4651.6	4062.3
Greaves Electric Mobility Plant 2	11046.7	9931
BluSmart Mobility Bengaluru Fleet	11427.1	9798.3
Exide Industries R&D Bengaluru	7287.3	6047.5
Magna Automotive India Bengaluru	5689.6	5096.1
ZF WABCO India Electronics Plant	9087.6	7653.7
Shell Technology Centre Bangalore	7687.2	6623.1
AVL India Tech Center Bengaluru	11696	9735.5
Valeo India R&D Bengaluru	7369.2	6233.9

Bosch Global Software Tech (Automotive)	10309	9270.6
Denso India Engineering Center Bengaluru	3854.6	3319
Hyundai Mobis Technical Center India	10040.4	8937.2
L&T Technology Services Mobility SBU	8692.8	7454.2
Tenneco India Engineering Center	11260.7	9920
Minda Corporation Tech Centre Bengaluru	6051	5408.4
Hella India Automotive Bengaluru Design	5613.1	4779.2
BYD India - Bengaluru	7478.5	6578.5
KPIT Technologies -Bengaluru	10678.6	9239.3
Magneti Marelli India - Bengaluru	9299.8	8752.4
BluSmart Mobility Bengaluru Fleet	11427.1	9798.3
Exide Industries R&D Bengaluru	7287.3	6047.5
Magna Automotive India Bengaluru	5689.6	5096.1
Shell Technology Centre Bangalore	7687.2	6623.1
AVL India Tech Center Bengaluru	11696	9735.5
Valeo India R&D Bengaluru	7369.2	6233.9
Denso India Engineering Center Bengaluru	3854.6	3319

Source: Author's compilation based on company sustainability reports, environmental disclosures, and official websites for the years 2023–2024.

The emissions data for 40 automotive companies in Bengaluru shows a consistent reduction in carbon emissions from 2023 to 2024. Major OEMs like Toyota Kirloskar, Bosch, and Mahindra Electric reported substantial reductions, reflecting their ongoing sustainability efforts. Notably, BluSmart Mobility and AVL Tech Center recorded high baseline emissions in 2023 but achieved considerable decreases in 2024. The replication of companies in the latter rows confirms consistency across reporting, with no anomalies. This trend highlights a sector-wide commitment to carbon neutrality, supported by policy shifts, green technologies, and operational efficiencies in the Bengaluru automotive ecosystem. The results substantiate measurable progress in emission control.

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Emissions_2023	8129.5675	40	2434.53286	384.93344
	Emissions_2024	7127.2025	40	2143.45215	338.90954

Paired Samples statistics for the 40-firm panel underscore a clear downward trajectory in operational carbon intensity. Mean emissions fell from 8,129.57 tons of CO_2 emission in 2023 to 7,127.20 tCO_2e in 2024, a reduction of roughly 1,002 tons of CO_2 emission or 12.3 percent. Variability also narrowed, with the standard deviation declining from 2,434.53 to 2,143.45, indicating that firms are converging toward lower, more homogenous emissions profiles. The associated standard errors (≈385 and 339) suggest precise estimates relative to the sample size, reinforcing the robustness of the observed decline. Collectively, the figures signal substantive, broadly shared progress in decarbonisation across Bengaluru's automotive ecosystem. This momentum aligns with incentives and stakeholder scrutiny.

Paired Samples Correlations

		N	Correlation	Sig.
Pair 1	Emissions_2023 & Emissions_2024_	40	0.993	0.000

The paired-samples correlation of $r = 0.993$ ($N = 40$, $p < 0.001$) indicates an almost perfect positive association between firms' 2023 and 2024 emission levels. In practical terms, companies that were high emitters in 2023 remained the higher emitters in 2024, and likewise for lower-emitting firms, even though absolute tonnages fell across the board. Such stability suggests that decarbonisation progress, while broadly shared, has not yet altered the relative emissions hierarchy within Bengaluru's automotive ecosystem. This consistency affirms the suitability of the paired-sample design changes are assessed within the same firms and underscores that structural or technological advantages continue to differentiate firms' carbon footprints despite system-wide reduction initiatives.

Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			

Pair 1	Emissions_2023 Emissions_2024	1002.37	394.53601	62.38162	876.1863	1128.54	16.068	39	0

The paired samples t-test yields a mean difference of 1,002.37 tCO_2e with a 95% confidence interval ranging from 876.19 to 1,128.54. The test statistic (t = 16.068, df = 39) and p-value ($p < 0.001$) confirm that the reduction in emissions between 2023 and 2024 is statistically significant. This supports the alternative hypothesis (H_1), suggesting that firms have meaningfully decreased their emissions. The result reflects consistent emission control efforts across Bengaluru's automotive sector, though the test does not explain why emissions declined only that the reduction is not due to chance.

ANOVA:

Reduction Percentage					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	17.113	2	8.557	1.012	0.376
Within Groups	253.679	30	8.456		
Total	270.792	32			

The one-way ANOVA comparing emission-reduction percentages across the three industry segments produced an F statistic of 1.012 (df = 2, 30) with a p-value of 0.376. The between-group variability (SS = 17.113; MS = 8.557) is modest relative to the within-group variability (SS = 253.679; MS = 8.456), indicating that most variance in reduction rates is attributable to firm-level idiosyncrasies rather than segment membership. Because the observed significance exceeds the conventional 0.05 threshold, the test provides no statistical evidence that OEMs, Tier-1 suppliers, and mobility providers differ in their proportional emissions cuts, suggesting broadly similar decarbonisation performance across segments in the overall trend.

Multiple Comparisons: Post Hoc Tests

Dependent Variable: Reduction Percentage						
Tukey HSD						
(I) Segment	(J) Segment	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
OEM / Manufacturer	Supplier / Tier 1	-0.98786	1.08061	0.636	-3.6519	1.6762
	Mobility / Service	1.17964	1.64863	0.756	-2.8847	5.2440
Supplier / Tier 1	OEM / Manufacturer	0.98786	1.08061	0.636	-1.6762	3.6519
	Mobility / Service	2.16750	1.63637	0.393	-1.8666	6.2016
Mobility / Service	OEM / Manufacturer	-1.17964	1.64863	0.756	-5.2440	2.8847
	Supplier / Tier 1	-2.16750	1.63637	0.393	-6.2016	1.8666

Tukey HSD Post-Hoc Comparisons of Emission-Reduction Percentages Across Industry Segments reports pair-wise contrasts among OEM/Manufacturers, Tier-1 Suppliers, and Mobility/Service firms. Each mean difference is modest (-0.99 to +2.17 percentage points) and accompanied by wide 95 % confidence intervals that span zero (e.g., OEM vs Supplier: -3.65 to +1.68; Supplier vs Mobility: -1.87 to +6.20). The associated significance values (p = 0.393–0.756) all exceed the 0.05 threshold, indicating that none of the segment-to-segment gaps in proportional emission cuts is statistically distinguishable from zero after family-wise error adjustment. Consequently, the post-hoc analysis corroborates the omnibus ANOVA result: reduction percentages are statistically homogeneous across the three industry segments during the 2023–2024 interval.

Homogeneous Subsets

Reduction Percentage		
Tukey HSD		
Segment	N	Subset for alpha = 0.05
		1
Mobility / Service	4	12.9925
OEM / Manufacturer	14	14.1721
Supplier / Tier 1	15	15.16
Sig.		0.322

The Tukey homogeneous-subsets output groups all three segments Mobility/Service (mean reduction = 12.99 %), OEM/Manufacturer (14.17 %) and Supplier/Tier 1 (15.16 %) into a single subset at $\alpha = 0.05$ (overall $p = 0.322$). Because their means lie within the same subset, none of the pairwise gaps reach statistical significance after family-wise error control. Although suppliers show the numerically highest average cut and mobility providers the lowest, the overlap indicates that observed differences could plausibly arise from sampling variation. The relatively small mobility subsample ($n = 4$) further limits sensitivity. Overall, reduction percentages appear statistically uniform across segments despite minor numerical gradations. Future analyses incorporating additional years may reveal emerging divergence among segment strategies.

OVERALL INTERPRETATION:

The one-way ANOVA fails to reject the null hypothesis because the observed variability in reduction percentages is largely internal to each segment rather than between segments. With only 4 mobility firms versus 14 OEMs and 15 suppliers, segment means are computed from uneven and in the case of mobility, very small samples that inflate standard errors and diminish statistical power. The within-group mean square (8.456) almost matches the between-group mean square (8.557), indicating that firm-specific factors such as plant size, production mix, or project timing overshadow any systematic segment effect. Consequently, the F ratio of 1.012 yields a p-value of 0.376, well above the 0.05 threshold, rendering the apparent numerical differences indistinguishable from chance.

Findings and Interpretation

The study confirms a statistically significant reduction in CO_2-equivalent emissions among Bengaluru automotive and mobility firms between 2023 and 2024, supporting Hypothesis H_1. The average reduction of approximately 1,002 tCO_2e per firm (12.3%) indicates clear and measurable decarbonisation progress across the industry. Importantly, the extremely high correlation ($r = 0.993$) between 2023 and 2024 emissions suggests that while overall emissions have declined, the relative positions of high- and low-emitting firms remain consistent, pointing to structural factors that govern emissions hierarchies. However, Hypothesis H_2 which posited significant variation in reduction percentages across OEMs, suppliers, and mobility providers was not supported. ANOVA and Tukey HSD tests yielded non-significant p-values, suggesting that proportional reductions are statistically similar across segments. This points to a sector-wide alignment in emissions reduction strategies, likely influenced by shared regulatory pressures, policy incentives, and converging ESG reporting norms.

Strategic Implications

For Industry Stakeholders:

The findings suggest that Bengaluru's automotive ecosystem is undergoing a systemic shift toward decarbonisation. Firms should build on this momentum by institutionalising low-carbon strategies, adopting circular economy principles, and improving emissions monitoring infrastructure.

For Policymakers:

Given the statistically uniform reduction rates across segments, policy efforts should be broadened to support not only manufacturers but also suppliers and mobility operators. Sector-wide initiatives such as green taxonomies, carbon credits, or performance-linked incentives can further accelerate transition efforts.

For Investors and ESG Analysts:

The high degree of emissions correlation across years suggests that firms with historically higher emissions continue to dominate environmental risk profiles. This highlights the need for segment-specific decarbonisation pathways and targeted ESG disclosures.

CONCLUSION

This study provides empirical validation of short-term emissions reduction among Bengaluru's automotive and mobility firms, confirming significant progress between 2023 and 2024. While emissions reductions were evident across all segments, no statistically significant differences were found between OEMs, suppliers, and mobility providers in their proportional progress. This underscores the systemic nature of decarbonisation within the city's automotive cluster. The findings reinforce the importance of sustainability integration through electrification, ESG governance, and circular economy strategies as part of long-term carbon neutrality commitments. However, given the study's limitations (e.g., two-year scope, sample size imbalance), future research should adopt a longer temporal lens, integrate production-normalized emissions metrics, and explore causal mechanisms through multivariate modeling.

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