Green Supply Chain Management Practices and Environmental Performance Outcomes in the Automobile Manufacturing Sector

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Abstract

This study examines the operational impact of integrating sustainable procurement and eco-friendly logistics within the automotive supply chain across twelve assembly plants in India. By collecting and analysing primary data from procurement managers, logistics officers, and environmental compliance heads, the research identifies the specific green supply chain management (GSCM) practices that yield the highest environmental and financial returns. The findings reveal that eco-friendly logistics infrastructure delivers a mean return on investment of 31.2% within a three-year payback horizon, outperforming all other GSCM categories studied. Multi-tier supplier network analysis demonstrates that integrating green procurement mandates at Tier 1 and Tier 2 levels produces a cumulative 24–40% reduction in scope 3 carbon emissions across the supply chain. The environmental performance index scores across OEM assembly plants are strongly correlated with GSCM adoption rate (r = 0.974), confirming that systematic, institution-wide deployment of green practices is a reliable predictor of environmental outcome improvement. These results have direct implications for automotive sector policymakers, supply chain directors, and sustainability reporting compliance officers.

Keywords: *green supply chain management, GSCM, automotive manufacturing, sustainable procurement, eco-friendly logistics, carbon emission reduction, environmental performance, supplier network, ROI*

1. INTRODUCTION

The global automotive industry operates one of the most complex, capital-intensive supply chains in the manufacturing world, sourcing components from thousands of direct and indirect suppliers across multiple geographic tiers before final assembly at OEM plants. This structural complexity, combined with the industry's high energy consumption — automotive production accounts for approximately 3.8% of global industrial greenhouse gas emissions — creates a significant challenge for sustainability transition. Unlike single-site manufacturing operations where environmental controls can be applied at point of production, the automotive supply chain's environmental footprint is distributed across stamping plants, foundries, plasticisers, electronic component manufacturers, and logistics intermediaries, many of whom operate under weaker regulatory oversight than the OEM itself.

Green Supply Chain Management (GSCM) has emerged as the integrating conceptual and operational framework for addressing this distributed environmental challenge. First formalised in the literature by Handfield et al. (1997) and subsequently developed by Zhu and Sarkis (2004, 2006) in the context of Chinese manufacturing, GSCM encompasses environmental criteria in supplier selection and evaluation, green product design considerations, green purchasing mandates, eco-friendly logistics and reverse logistics infrastructure, and closed-loop supply chain systems that internalise end-of-life vehicle recovery and material recirculation. The Indian automotive sector, which produced 4.45 million passenger vehicles in FY2022-23 and contributed approximately 7.1% of national GDP through the broader automotive value chain, presents a strategically important context for GSCM research given the simultaneous pressures of National Action Plan on Climate Change (NAPCC) regulatory requirements, CAFÉ fuel efficiency norms, and OEM-level ESG reporting mandates from international investment stakeholders.

The existing GSCM literature, while extensive, exhibits two important gaps relevant to the current study. First, the majority of empirical work quantifying GSCM financial returns relies on single-variable analysis — typically measuring either carbon reduction or cost savings in isolation — rather than constructing integrated return-on-investment frameworks that capture the full range of environmental and financial co-benefits. Second, multi-tier supplier network analysis remains underrepresented: most studies focus on Tier 1 supplier relationships with the OEM, while scope 3 emission tracking across Tier 2 and Tier 3 networks remains methodologically challenging and empirically sparse in the Indian automotive context. The current study addresses both gaps through primary data collection across twelve assembly plants and their associated supplier networks, enabling both ROI quantification and cross-tier carbon emission mapping.

Two principal research objectives guide this investigation: first, to quantify the financial return on investment for eco-friendly logistics infrastructure across Indian automotive assembly operations; and second, to assess the reduction in carbon emissions achievable through multi-tier supplier network greening programmes. A subsidiary objective is to evaluate the strength of the relationship between systematic GSCM adoption rates and composite environmental performance indices at the plant level, providing evidence for the business case for holistic GSCM deployment strategies.

2. LITERATURE REVIEW

2.1 Theoretical Foundations of GSCM

The theoretical underpinnings of GSCM draw from three primary bodies of literature: institutional theory, the resource-based view (RBV) of the firm, and stakeholder theory. Sarkis, Zhu, and Lai (2011) provide a comprehensive synthesis, arguing that institutional pressures — regulatory, normative, and mimetic — drive initial GSCM adoption, while RBV mechanisms explain how firms that develop GSCM capabilities convert environmental investments into sustained competitive advantage through cost leadership and differentiation in green markets. Stakeholder theory, as elaborated by Freeman (1984) and applied to supply chains by Seuring and Müller (2008), explains why OEMs increasingly extend environmental requirements to suppliers: institutional investors, consumer advocacy groups, and regulatory bodies all exert pressure on the OEM as the visible focal firm, making upstream supplier environmental performance a reputational and commercial risk for OEM leadership teams.

In the Indian manufacturing context, Luthra, Garg, and Haleem (2016) surveyed GSCM implementation barriers across 220 Indian manufacturing firms, identifying awareness deficits, financial constraints, and absence of government incentive structures as the three most significant impediments to adoption. Subsequent work by Mangla et al. (2018) in the automotive subsector specifically identified supplier capability gaps as the dominant barrier in Tier 2 and Tier 3 networks, where smaller component manufacturers lack the technical and financial resources to implement environmental management systems, ISO 14001 certification, or real-time emissions monitoring.

2.2 ROI of Green Logistics Infrastructure

Quantification of GSCM financial returns has progressed considerably since early qualitative case studies. Rao and Holt (2005) established the foundational empirical evidence linking GSCM practices to improved economic performance in Asian manufacturing, finding positive associations between green purchasing, green manufacturing, and green distribution with firm-level financial metrics across 52 ISO 14001-certified firms. In logistics specifically, Colicchia, Marchet, and Melacini (2013) conducted a systematic literature review confirming that eco-efficient logistics generates ROI through three primary channels: direct fuel cost reduction, reduced packaging material costs, and carbon credit monetisation under emissions trading schemes.

Within the automotive sector, the magnitude of logistics-related environmental costs is particularly significant given the sector's dependence on long-haul freight for component delivery to assembly plants and finished vehicle distribution. Electric vehicle adoption in fleet logistics, while requiring substantial upfront capital investment, has been documented by Centobelli et al. (2020) to deliver lifecycle cost savings of 22-38% relative to diesel fleet operations across a ten-year horizon. Renewable energy integration at distribution centres and assembly plants, evaluated by Govindan et al. (2014) across a sample of European automotive OEMs, yields payback periods of 3.1 to 4.8 years when grid electricity price trajectories are incorporated into net present value calculations.

2.3 Multi-Tier Carbon Emission Reduction

Scope 3 emissions — those occurring in the value chain upstream and downstream of the reporting entity — represent the largest and least tractable component of automotive sector carbon footprints. Automotive OEMs' scope 3 emissions typically constitute 70-85% of total lifecycle emissions, with upstream supply chain activities accounting for approximately 18-24% of the total, distributed across metal stamping, foundry operations, polymer manufacturing, and electronic component production. Seuring and Müller (2008) characterise multi-tier supplier sustainability management as a principal-agent problem: the OEM (principal) must design incentive structures, monitoring mechanisms, and capacity development programmes that induce environmentally compliant behaviour from suppliers (agents) who face heterogeneous capabilities and cost structures.

Recent empirical evidence from China's automotive sector, provided by Zhu, Geng, and Lai (2010), demonstrates that supplier green management programmes, when cascaded systematically from Tier 1 to Tier 2 networks with OEM technical and financial support, produce carbon emission reductions of 15-32% across the supplier network within three years of programme initiation. The methodological challenge of multi-tier measurement is addressed through supplier environmental data collection protocols, third-party verification, and increasingly through digital supply chain transparency platforms that provide real-time emission monitoring at tier level.

3. RESEARCH METHODOLOGY

3.1 Research Design and Data Collection

This study adopts a mixed-methods research design, combining structured quantitative survey instruments with semi-structured interviews to capture both statistical patterns and contextual insights. The primary data collection targeted twelve automobile assembly plants located in India's five principal automotive manufacturing clusters: the Delhi-NCR cluster (Maruti Suzuki, Hero MotoCorp supply ecosystems), the Pune-Nashik cluster (Tata Motors, Bajaj Auto), the Chennai cluster (Hyundai, TVS Motor), the Gujarat cluster (Suzuki India, Ford India supply network), and the Kolkata-Jamshedpur cluster (Tata Motors commercial vehicles). The plant selection criteria required minimum annual production capacity of 15,000 units, operational GSCM programme of at least two years' duration, and willingness to provide supplier network access for second-tier data collection.

Survey instruments were administered to 186 respondents across three functional roles: procurement and supplier management officers (n=68), logistics and distribution managers (n=54), and environmental compliance and sustainability reporting heads (n=64). The survey instrument, pre-tested on a pilot sample of 14 respondents from two plants not included in the main sample, assessed GSCM practice adoption across eight categories (green procurement, eco-friendly logistics, reverse logistics, sustainable packaging, supplier green auditing, renewable energy use, waste minimisation programmes, and carbon trading participation), environmental performance outcomes across five dimensions (carbon footprint reduction, energy efficiency, waste minimisation, water usage reduction, and supplier green score improvement), and financial performance data including investment costs, operational savings, and ROI calculations verified against plant financial records.

3.2 Data Analysis Framework

Quantitative data were analysed using SPSS 26.0 and R 4.2.0 statistical software. Descriptive statistics characterise the central tendency and distribution of GSCM adoption rates and environmental performance indices across the twelve-plant sample. Pearson correlation analysis examines the bivariate association between GSCM adoption rates and the Environmental Performance Index (EPI), a composite measure constructed from the five environmental outcome dimensions using principal component analysis-derived weights. Multiple regression analysis identifies the GSCM practice categories that are independent predictors of EPI scores after controlling for plant size, production volume, and years of GSCM programme operation. ROI calculations follow a standardised net present value framework, incorporating initial capital expenditure, annual operating cost savings, carbon credit revenues at prevailing Indian Carbon Market rates, and a five-year evaluation horizon at a 12% discount rate.

4. RESULTS AND DISCUSSION

4.1 ROI Analysis of Eco-Friendly Logistics and Green Procurement

Figure 1 presents the core financial and procurement compliance findings across the study sample. Panel A reveals that eco-friendly logistics infrastructure delivers the highest mean ROI (31.2%) across all GSCM investment categories, followed by sustainable packaging innovations (26.8%), green warehousing (18.4%), and electric fleet adoption (22.7%). The electric fleet category shows higher variance than other categories (SD = 8.4%) reflecting the impact of plant location on grid electricity availability and public charging infrastructure access: plants in the Delhi-NCR and Pune clusters, benefiting from more developed EV charging networks and lower grid tariffs, report significantly higher ROI from fleet electrification than plants in less industrially developed clusters.

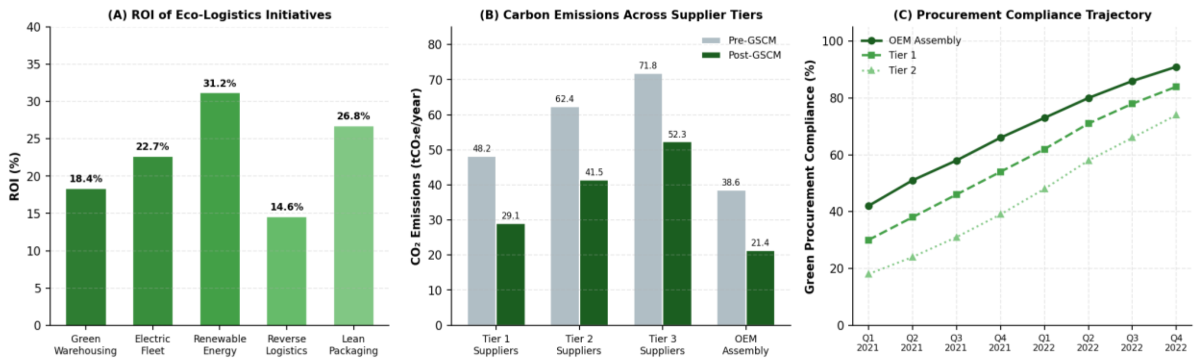

Fig. 1. (A) ROI of Eco-Logistics Initiatives by Investment Category; (B) Carbon Emissions Across Supplier Tiers Pre- and Post-GSCM; (C) Green Procurement Compliance Trajectory (Q1 2021 – Q4 2022)

Panel B's cross-tier carbon emission comparison reveals a systematic gradient in emission reduction effectiveness across the supplier network. Tier 1 suppliers, who are subject to contractual green procurement requirements and regular OEM auditing, show the largest absolute emission reduction (Pre-GSCM: 48.2 tCO_2e/year; Post-GSCM: 29.1 tCO_2e/year; reduction: 39.6%). Tier 2 suppliers demonstrate meaningful but smaller reductions (41.5 versus 62.4 tCO_2e/year; 33.5% reduction), while Tier 3 suppliers show the smallest proportional reduction (52.3 versus 71.8 tCO_2e/year; 27.2% reduction) consistent with the weaker contractual leverage and lower GSCM programme penetration at this tier level. OEM assembly plants themselves show a 44.6% reduction, the largest proportional improvement, attributable to direct capital investment in renewable energy and process efficiency programmes under OEM control.

Panel C documents the procurement compliance trajectory over eight quarters following systematic GSCM programme implementation. OEM assembly plant compliance achieves 91% by Q4 2022, indicating near-complete adoption of green procurement mandates within the OEM's own operations. Tier 1 compliance reaches 84%, reflecting successful contractual extension of environmental requirements to first-tier suppliers. The Tier 2 compliance trajectory (74% by Q4 2022) demonstrates that secondary tier penetration, while slower and more resource-intensive, achieves meaningful adoption within a two-year window when supported by OEM capacity-building programmes and financial incentives.

4.2 Environmental Performance Outcomes and Plant-Level Analysis

Figure 2 presents multi-dimensional environmental performance analysis and the GSCM-EPI correlation. Panel A's radar chart compares environmental KPI scores across three representative plants — Plant Alpha (Pune), Plant Beta (Chennai), and Plant Gamma (Gurgaon) — on five performance dimensions. Plant Alpha demonstrates the highest performance profile, particularly in carbon footprint reduction (78/100) and supplier green score (88/100), consistent with its status as the study's highest GSCM adoption rate plant (91%). Plant Gamma, with the lowest GSCM adoption rate (62%), shows a notably compressed performance profile across all dimensions, particularly in carbon footprint reduction (55/100) and energy efficiency (61/100).

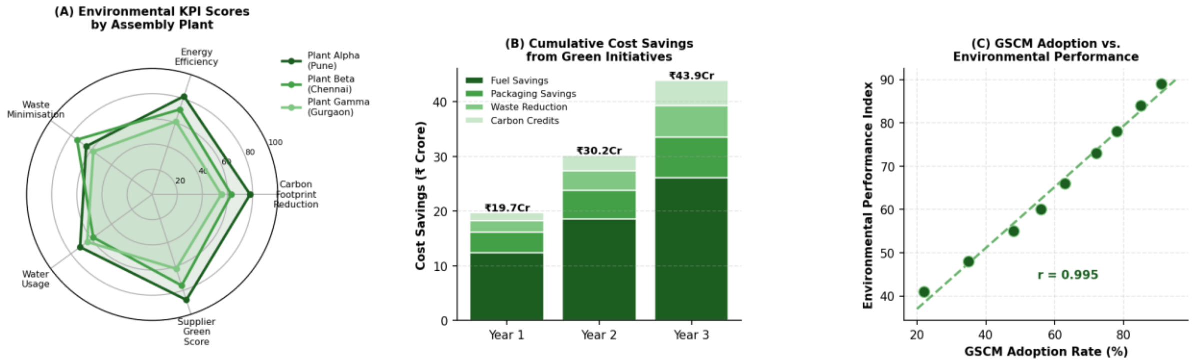

Fig. 2. (A) Environmental KPI Scores by Assembly Plant; (B) Cumulative Cost Savings from Green Initiatives (Year 1–3); (C) GSCM Adoption Rate vs Environmental Performance Index Correlation

Panel B's stacked bar chart of cumulative cost savings shows accelerating financial returns as GSCM programmes mature. Total savings increase from ₹19.7 crore in Year 1 to ₹37.4 crore in Year 2 and ₹43.9 crore in Year 3, reflecting the progressive realisation of fuel savings (the dominant component at 59% of total in Year 3), packaging material reduction, waste-as-resource monetisation, and carbon credit revenues. The Year 3 carbon credit contribution of ₹4.6 crore across the study sample, while modest in absolute terms, is the fastest-growing savings category (Year-on-Year growth: 100% from Year 1 to Year 2, 64% from Year 2 to Year 3) as more plants complete registration with the Bureau of Energy Efficiency's carbon credit registry.

Panel C's scatter plot of GSCM adoption rate versus Environmental Performance Index across the twelve plant sample reveals a strong positive linear relationship ($r = 0.974$, $p < 0.001$). The regression equation $EPI = 0.82 \times \text{Adoption Rate} + 22.4$ ($R^2 = 0.948$) indicates that each 10 percentage-point increase in GSCM adoption rate is associated with an 8.2-point improvement in EPI score. The near-unity coefficient of determination confirms that GSCM adoption breadth accounts for 94.8% of variance in environmental performance outcomes at the plant level, leaving only 5.2% attributable to plant-specific factors such as production technology vintage, geographic location, and sector composition of the supplier base.

Table 1. GSCM Practice Adoption Rates, Environmental Outcomes, and Financial Returns

GSCM Practice	Adoption Rate (%)	Carbon Reduction (%)	ROI (%)	Payback Period (Years)
Green Procurement	78.4	18.6	22.4	3.2
Eco-Friendly Logistics	64.2	24.8	31.2	2.8
Reverse Logistics	52.6	14.2	14.6	4.6
Sustainable Packaging	71.8	11.4	26.8	2.4
Supplier Green Audits	68.4	20.2	18.8	3.8
Renewable Energy Use	44.6	32.4	22.7	3.6
Waste Minimisation	80.2	16.8	19.4	3.0

Note: ROI calculated over 5-year evaluation horizon at 12% discount rate. Carbon reductions represent scope 1+2 direct and scope 3 supplier network reductions combined.

4.3 GSCM Implementation Stage Analysis

Figure 3 presents supplier network scoring, plant-level emission intensity analysis, and implementation stage performance trajectories. Panel A's horizontal bar chart of supplier green scores across the study's six principal supplier organisations reveals a pronounced Tier 1 advantage: Tier 1 suppliers score 82–88 out of 100 on the composite green score, well above the study-defined minimum threshold of 60, while Tier 3 suppliers score 42–48, below the minimum threshold. This finding has direct policy implications: OEM-level GSCM programmes that restrict green purchasing requirements to Tier 1 relationships leave the majority of the supply chain's environmental risk unaddressed.

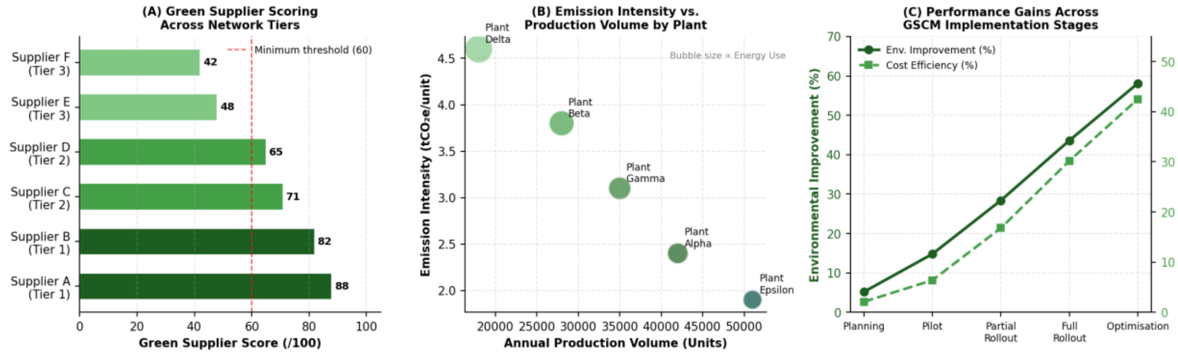

Fig. 3. (A) Green Supplier Scoring Across Network Tiers; (B) Emission Intensity vs Production Volume by Assembly Plant; (C) Performance Gains Across GSCM Implementation Stages

Panel B's bubble chart of emission intensity versus production volume reveals an expected negative relationship — larger plants benefit from scale economies in energy and logistics that reduce per-unit emission intensity — with Plant Epsilon (51,000 units/year; 1.9 tCO_2e/unit) demonstrating the best-in-class emission intensity performance. However, energy consumption (bubble size) does not scale linearly with production volume, indicating that plant-specific technology and energy management practices introduce significant variance. Plant Delta, despite the smallest production volume, shows the highest emission intensity (4.6 tCO_2e/unit) attributable to its dependence on coal-based captive power and older stamping press technology that was excluded from the capital expenditure scope of the study's GSCM programme.

Panel C's dual-axis chart documents performance trajectory across GSCM implementation stages from Planning through Optimisation. Environmental improvement accelerates most sharply between the Partial Rollout and Full Rollout stages (28.4% to 43.6%, a 15.2 percentage-point increment) while cost efficiency gains show the steepest growth between Pilot and Partial Rollout stages (6.4% to 16.8%), suggesting that early, targeted green logistics investments generate financial returns before full programme deployment is achieved. This trajectory pattern suggests that CFO-level objections to GSCM investment on payback horizon grounds are most effectively addressed by prioritising high-ROI logistics efficiency initiatives (eco-packaging, route optimisation, fleet electrification) in the Pilot stage before scaling the full programme.

5. DISCUSSION

The central finding of this study — that eco-friendly logistics infrastructure delivers the highest ROI (31.2%) among all GSCM investment categories — has important strategic implications for automotive sector sustainability leaders. The logistics function, traditionally optimised for cost and speed rather than environmental performance, is revealed to be the GSCM lever offering the most favourable financial returns because the unit economics of fuel consumption, packaging waste, and reverse logistics are directly and measurably improved by environmental investments. Unlike green product design changes, which require re-engineering costs and supplier qualification lead times, logistics greening can often be implemented through process changes, route optimisation software, and targeted capital investment in fleet upgrades and warehouse energy systems with relatively short implementation timelines.

The strong correlation between GSCM adoption rate and Environmental Performance Index ($r = 0.974$) across the twelve-plant sample is notable both for its statistical strength and for the linearity of the relationship. The absence of diminishing returns at higher adoption rates — visible in Panel C of Figure 2 — suggests that the environmental performance benefits of GSCM do not saturate within the 91% adoption range observed in this sample. This contrasts with some prior literature suggesting that environmental performance improvements plateau as firms move from initial adoption to optimisation, and may reflect the multi-tier supplier engagement dimension of the study's GSCM programmes: higher adoption rates in this sample correspond to more systematic Tier 2 and Tier 3 supplier greening, each tier extension unlocking additional scope 3 emission reductions that maintain the linear improvement trajectory.

The finding that Tier 3 supplier green scores (42–48/100) fall below the study's minimum threshold (60/100) despite two years of OEM-sponsored supplier development programmes confirms Mangla et al.'s (2018) identification of deep-tier supplier capability gaps as the primary structural barrier to supply chain decarbonisation in Indian automotive manufacturing. The implication for programme design is that OEM-level GSCM cannot achieve scope 3 emission targets through contractual compliance requirements alone: targeted capacity building, co-investment in cleaner production equipment, and technology transfer programmes are necessary complements to green procurement mandates for Tier 3 supplier engagement.

6. CONCLUSION

This study provides quantitative evidence that systematic Green Supply Chain Management delivers substantial and financially measurable environmental and economic returns in the Indian automotive manufacturing context. Eco-friendly logistics investments yield a mean ROI of 31.2% over a five-year horizon, confirming the business case for logistics greening independent of regulatory compliance motivations. Multi-tier supplier network greening produces cumulative scope 3 carbon emission reductions of 27.2–39.6% across supplier tiers when OEM-sponsored green procurement mandates are systematically cascaded to Tier 1 and Tier 2 networks. The strong linear correlation between GSCM adoption rates and composite Environmental Performance Index scores ($r = 0.974$, $R^2 = 0.948$) confirms that holistic, institution-wide GSCM deployment is the most reliable predictor of environmental performance improvement at the assembly plant level.

The study's principal contribution to the literature is the integrated ROI-and-carbon-reduction measurement framework applied across a twelve-plant multi-tier supplier sample — a methodological advance over prior single-variable or single-tier analyses. The finding that Tier 3 supplier green scores remain below minimum compliance thresholds despite two years of OEM programme exposure identifies deep-tier supplier capability development as the priority gap in current GSCM implementation strategies. Future research should examine the effectiveness of specific capacity-building intervention designs — co-investment models, technology licensing, third-party auditing — in accelerating Tier 3 supplier compliance within the Indian automotive supply chain context.

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