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Exploring Challenges and Enablers of Sustainable Supply Chains in Indian Automotive SMEs for Enhancing Long-Term Competitiveness

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Abstract: This study explores the contribution of Indian automotive Small and Medium Enterprises (SMEs) in progressing Sustainable Supply Chain Management (SSCM) through the Triple Bottom Line (TBL) framework by focusing on economic, environmental, and social sustainability dimensions. Case studies from top Original Equipment Manufacturers (OEMs) such as Tata Motors, Maruti Suzuki, Mahindra & Mahindra, Ashok Leyland, Eicher Motors, and Hero MotoCorp show how SMEs are involved with green procurement, lean manufacturing, and reverse logistics while challenging barriers of cost, technology, and limited infrastructure. The study highlights both progress and challenges: Maruti Suzuki's supplier policy necessitates ISO 14001 compliance, Mahindra has capitalized on renewable energy, Ashok Leyland has enhanced efficiency through lean production, and Hero MotoCorp reduced emissions by 43% through logistics amendments. Until now many SMEs fight with high initial capital investment and weak digital willingness. The government initiatives, such as FAME and PLI schemes, motivate sustainable practices and electric movement, but uneven implementation still limits SME benefits. The findings propose SMEs' long-term competitiveness depends on innovation, partnerships, and policy support. Creating cooperative ecosystems, prompting Industry 4.0, and enlightening access to financing are essential for qualifying SMEs to change toward sustainable, resilient, and globally competitive supply chains.

1. Introduction

The Indian automotive industry, the fourth largest in the world, is a foundation of Indian economic development, contributing 7.1% to the GDP of the nation and close to half of the country's manufacturing output [1], [2]. Within this automotive sector, Small and Medium Enterprises (SMEs) play a vital role, making about 30% of auto components and acting as Tier 2 and Tier 3 suppliers to domestic and international OEMs [4], [5]. Beyond their economic contribution, SMEs are progressively central to India's shift toward sustainable and technology-driven mobility solutions [3]. The Government of India has implemented initiatives like the Faster Adoption and Manufacturing of Electric Vehicles (FAME) and the

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Production Linked Incentive (PLI) to enhance their role. This kind of scheme offers incentives for investments in electric mobility, advanced technologies, and sustainable manufacturing facilities [4], [5]. Even though these initiatives create opportunities for small and medium-sized enterprises (SMEs), they still encounter substantial challenges. High capital requirements, a limited skilled workforce, and restricted access to Industry 4.0 technologies delay innovation capabilities. Moreover, adherence to emissions, safety, and waste regulations imposes significant challenges on smaller firms [6], [7].

As the cornerstone of the Indian economy, the automobile sector greatly influences GDP, employment, and industrial expansion [7]. Acting as major suppliers of components and subsystems, automotive Small and Medium-sized Enterprises (SMEs) are essential in the supply chain of an industry expected to reach 25 trillion rupees, approximating $300 billion by 2030 [8], [9]. But Indian automotive SMEs are under more pressure to include socially and environmentally conscious practices into their supply chains as worldwide supply chains move toward sustainability-driven operations [10], [11]. In line with national and international regulatory systems and consumer expectations, Sustainable Supply Chain Management (SSCM) is thus becoming increasingly important for long-term competitiveness. SSCM is the application of social, environmental, and financial aspects into supply chain activities to guarantee long-term sustainability [12]. Green procurement, eco design, lean manufacturing, reverse logistics, and carbon footprint lowering are just a few of the several aspects of sustainable supply chains. Under the Companies Act of 2013 and environmental standards set by the Central Pollution Control Board (CPCB), regulatory policies, including Corporate Social Responsibility (CSR) mandates in India, are guiding companies toward SSCM adoption [13]. Nevertheless, despite these laws, financial, technological, and operational difficulties force Indian automotive SMEs to continue slowly towards sustainable supply chains [14], [15].

Since the transportation industry is responsible for almost a quarter of all CO_2 emissions worldwide, and India's automotive industry is a major source of these emissions [16], it is essential to adopt SSCM practices. Although the majority of research focuses on large OEMs, there is insufficient understanding of how SMEs incorporate government incentives, navigate challenges, and attain competitiveness through sustainability [10], [11]. This study fills these gaps by suggesting a complete framework that connects SSCM practices, policies that make them possible, and organizational capabilities to improve the long-term competitiveness of small and medium-sized automotive businesses in India [17], [18].

2. Conceptualizing Sustainable Supply Chains

SSCM ensures factors related to the environment, society, and economy within supply chain processes will lessen their negative impacts while achieving long-term sustainability [19]. SSCM occurs under the framework of the Triple Bottom Line (TBL), where sustainability is defined by an economic aspect, an environmental aspect, and a social responsibility aspect [20]. The recent studies have suggested bi-objective optimization models for green closed-loop supply chains, balancing profit and carbon emission reduction under uncertainty [21]. These models disclose the key trade-offs between economic and environmental goals,

assisting sustainable decision-making. A bi-objective MILP model further proves that improving logistics and transportation can decrease emissions without compromising cost efficiency [22]. Case study outcomes underscore the importance of incorporating environmental factors into supply chain planning. These insights support the significance of our approach and authenticate the integration of sustainability in supply chain design frameworks.

Recent research indicates that enhancing production conditions and process controls can reduce defects and waste by up to 80%. This makes things work better and has less of an effect on the environment without needing to buy new tools [21]. Optimized Automated Guided Vehicle (AGV) scheduling models also reduce delays, waste of resources, and operational costs while increasing energy efficiency and material flow [27]. Two examples of simulation-based methods that have been shown to improve cement bag manufacturing by increasing throughput and cutting down on waste are Discrete Event Simulation (DES) and Adaptive Neuro-Fuzzy Inference System (ANFIS) [23]. Other studies that used Statistical Process Control (SPC) and regression support the idea that preventative maintenance and quality training make processes more stable and use resources better [24]. System dynamics modeling also helps us learn how policies about capacity, processes, and markets affect the supply chain's long-term health [25]. ANFIS, on the other hand, is better than traditional methods at predicting product quality, helping with precise process control, and cutting down on waste [26]. All of these results show that better optimization tools and modeling methods could make supply chain management much stronger.

Table 1 addresses India’s automotive sector, where Original Equipment Manufacturers (OEMs) like Tata Motors and Mahindra & Mahindra have started to incorporate sustainability within their supply chain frameworks via energy- and resource-efficient production processes and sourcing practices [28]. Studies have indicated that Mahindra’s adoption of practices toward green supply chain management, such as sustainable sourcing and renewable energy use, has increased efficiency and reduced overall environmental impact [29]. SMEs are most vital to India’s automotive supply chain; as of now, most SSCM research focuses on large OEMs and multinationals. The limited studies scrutinize how Indian automotive SMEs implement sustainability practices and their influence on competitiveness. Current literature continually necessitates SSCM dimensions like green procurement, lean manufacturing, and reverse logistics in isolation, without analyzing their combined effects. Furthermore, the role of enablers like FAME, PLI, and Industry 4.0, together with barriers such as financial, technological, and cultural challenges, remains underexplored. This study addresses these gaps by suggesting a comprehensive framework connecting SSCM practices, related factors, and competitiveness outcomes for Indian automotive SMEs.

2.1 Key Sustainability Principles in Supply Chains Recorded in the Indian Automotive Industry

Supply chain sustainability is regulated through fundamental principles including resource productivity, waste reduction, transparency, and stakeholder partnership [30]. Indian automotive industry SMEs have difficulties in implementing these principles as they are

restricted by cost issues and limited technological availability [31]. Despite this, companies such as TVS Motors have demonstrated that applying sustainability principles will lead to benefits, such as improved collaboration with suppliers and emissions reductions [32].
Implementation of resource conservation and waste reduction strategies has been shown to create cost savings and compliance with regulations in the automotive SMEs in India. For instance, in the case study of the supply chain of Hero Moto Corp, by mapping and optimizing transportation routes and waste from material usage, the firm was able to reduce carbon footprint and operational costs [33].

2.2 Key Components of Green Procurement and Supplier Collaboration in Sustainable Automotive Supply Chains

Green purchasing is the practice of choosing suppliers based on their environmental performance, sustainability standards compliance, and sustainable practices in sourcing [34]. Organizations like Maruti Suzuki have adopted green purchasing practices that give special consideration to ISO 14001 certified suppliers, which means they must follow environmental management practices [35]. Collaborative supplier relationships can enhance sustainability further by permitting knowledge sharing and innovation. Research on Bajaj Auto's supply chain indicates that collaboration to develop green materials and embrace alternative energy sources in the supply chain had lower environmental footprints, as well as better cost effectiveness [36]. However, Indian SMEs face challenges with supplier collaboration and, as a result, cannot replicate the same sustainable initiatives due to lack of access to the necessary financial and technological resources [37].

2.3 Lean Manufacturing and Eco-Friendly Production

The principles of lean production are about reducing waste, streamlining processes, and improving operational efficiency in a way that meets sustainability objectives [38]. Ashok Leyland and other Indian automobile manufacturers have moved into the arena of lean production techniques that allow for lower energy consumption and better material efficiency [39]. Environmentally friendly production practices, such as the use of biodegradable products and energy-efficient technologies, are increasingly prevalent in India's automotive industry. A case study of Eicher Motors shows how the company's shift to water-based paints and eco-friendly material sourcing has minimized volatile organic compound (VOC) emissions while product quality has been ensured [40]. However, Indian SMEs are discouraged from implementing lean and green manufacturing due to the high capital investment needed and limited technical expertise. However, studies show that government incentives and training programs can enhance SMEs' capacity to implement lean and green production [41].

2.4 Reverse Logistics and Circular Economy Practices in the Indian Automotive Industry

Control of product returns, recycling, remanufacturing, and disposal of the product for the purpose of enhancing sustainability in the supply chain are part of reverse logistics [42]. Indian OEMs like Tata Motors have adopted reverse logistics by developing vehicle take-back programs and remanufacturing initiatives, contributing towards resource conservation

and waste minimization [43]. Circular economy measures are based on the elongation of product life cycles, recycling, and reduction of waste production. An exemplary one is Hero Electric's battery recycling initiative, which gives a second life to electric two-wheeler lithium-ion batteries, thus averting electronic waste and ensuring a sustainable supply chain [44]. Nonetheless, Indian automotive SMEs face enormous reverse logistics challenges due to poor infrastructure, policy support, and customer awareness. Still, an increasing number of SMEs have foregone a competitive edge by engaging in remanufacturing of auto components to reduce costs along with environmental impacts [45].

2.5 Relationship between Sustainability and Competitiveness

Sustainability efforts are a key driver of long-term competitiveness through improved efficiency, reduced costs, and improved brand image [46]. Businesses that integrate sustainability into their supply chain activities are blessed with a competitive edge through compliance with international environmental standards, attracting green consumers, and reducing operational risks [47]. A case study of the green business model of Mahindra & Mahindra shows that the focus of the company on SSCM has turned out to be a source of enhanced profitability and market growth [48]. Through waste reduction, enhanced energy efficiency, and expenditure on green technologies, Mahindra has enhanced its global competitiveness while staying true to its sustainability objectives. Likewise, SMEs that incorporate sustainability practices achieve cost benefits and better market positioning, although financial and operational limitations are an issue [49].

2.6 The Role of Sustainability in Global Supply Chain Integration in the Indian Subcontinent

International supply chain integration calls for adherence to global environmental standards, like the EU End of Life Vehicle (ELV) Directive and ISO 14001 accreditation [50]. Indian auto OEM companies like Tata Motors and Bajaj Auto have been able to integrate supply chain operations in keeping with international sustainability levels to achieve access to the global market in addition to increasing trade competitiveness. Evidence indicates that supply chain sustainability increases global trading opportunities for Indian SMEs as multinational companies are placing additional emphasis on eco-friendly suppliers [51]. However, some SMEs are facing issues with compliance through unawareness and unavailability of funds [14]. Policies such as green finance schemes and interventions can compensate for the shortfall, and SMEs can incorporate sustainability as part of their supply chain management and become competitive in global markets [52].

3. Methodology

The study employs a qualitative case study approach, with data drawn from both primary sources (semi-structured interviews with SME managers, supply chain executives, and policy experts, supplemented by field observations) and secondary sources (company reports, industry publications, and government policy documents) shown in Fig. 1. We picked cases on purpose to show how they are different in size, level of sustainability

maturity, and role in the supply chain. Lucas TVS shows the best ways to do things, Subros shows the problems that mid-sized businesses face, and Hero MotoCorp shows how OEMs can help with sustainability. A comparative analysis of clusters such as Pune, Chennai, and Gurugram identifies facilitators (e.g., FAME and PLI), impediments (e.g., financial constraints, regulations, and technology), and outcomes that influence the competitiveness of SMEs. Data were analyzed using thematic coding, and findings were validated through triangulation of interview insights with secondary evidence.

Table 1: Key Elements of Sustainable Supply Chains in Indian Automotive OEMs and SMEs

Key Element	Description	Indian Automotive Case Study Examples	Reference
Sustainable Supply Chain Management	Integration of environmental, social, and economic aspects in supply chains for long term value creation.	Mahindra & Mahindra's sustainability- driven business model.	[48]
Key Sustainability Principles in Supply Chains	Triple bottom line (People, Planet and Profit), resource efficiency, emissions reduction, and circular economy.	Maruti Suzuki's green manufacturing initiatives.	[35]
Green Procurement & Supplier Collaboration	Sustainable sourcing, supplier audits, and green supplier selection.	Bajaj Auto's supplier sustainability assessment program.	[36]
Lean Manufacturing & Eco-Friendly Production	Waste reduction, energy efficiency, and eco-friendly materials.	Ashok Leyland's lean and green production processes.	[39]
Reverse Logistics & Circular Economy Practices	Product remanufacturing, recycling, and waste recovery strategies.	Tata Motors' remanufacturing and used part recycling initiatives.	[43]
Carbon Footprint Reduction	Strategies to reduce greenhouse gas emissions across the supply chain.	Hero MotoCorp's carbon-neutral supply chain practices.	[33]
ISO 14001 & Environmental Certifications	Compliance with international environmental standards for sustainability.	Maruti Suzuki's ISO 14001 certification and impact on supply chain sustainability.	[35]
Sustainability and Long-Term Competitiveness	How sustainability enhances resilience, profitability, and market positioning.	TVS Motors' sustainability strategies for competitive advantage.	[32]
Global Supply Chain Integration	Meeting global sustainability regulations, green logistics, and ethical sourcing.	Tata Motors' alignment with global environmental and sustainability standards.	[51]
Barriers to Sustainability in SMEs	Financial constraints, lack of technical know-how, and regulatory challenges.	Challenges faced by Indian automotive SMEs in adopting sustainable practices.	[31]
Policy & Government Support	Role of policy frameworks in fostering sustainable supply chains.	Government policies promoting sustainability in India's auto industry.	[41]

Fig. 1: Research Design Approach

The identified gaps contain limited focus on SMEs compared to OEMs, the split action of SSCM practices, lack of appropriate insights on Indian policies, and inadequate clarity on the link between sustainability and competitiveness. Based on these, we now pose four research questions addressing the challenges, enablers, contributions of SSCM practices, and strategic endorsements for SMEs. These additions strengthen the clarity of our study's main contribution, which is to provide a complete framework for Indian automotive SMEs.

Fig. 2 shows the study's conceptual framework, focused on Indian automotive SMEs and their adoption of SSCM practices like green procurement, lean manufacturing, and reverse logistics. These practices are impacted by external challenges (e.g., financial, technological, regulatory) and enablers (e.g., policies, innovation, collaboration). The framework highlights how overcoming challenges and leveraging enablers enables SMEs to enhance long-term competitiveness across Triple Bottom Line dimensions: economic, environmental, and social.

The study now focuses on the Triple Bottom Line (economic, environmental, and social dimensions) to systematically evaluate SSCM outcomes. Also, we included the Resource-Based View (RBV) and Dynamic Capabilities Theory to clarify how SMEs leverage SSCM practices and enabling policies (e.g., FAME, PLI, Industry 4.0) to shape long-term competitiveness. The rationalized framework (Fig. 2) reveals these theoretical linkages, ensuring that the study is firmly grounded in recognized literature.

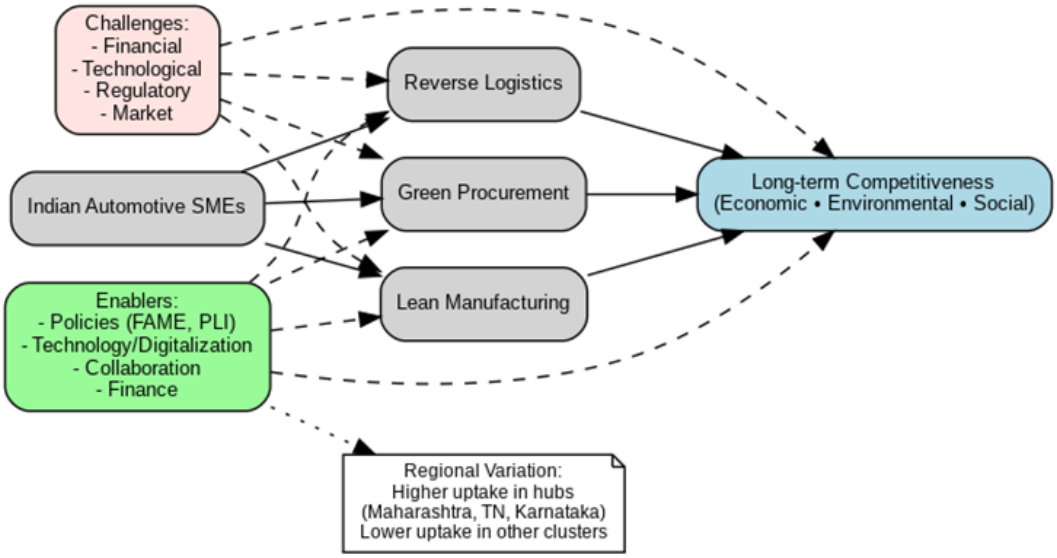

Fig. 2: Conceptual framework of SSCM practices, influencing challenges and enablers, and their link to SMEs' competitiveness

4. Challenges in Implementing Sustainable Supply Chains in Indian Automotive SMEs

The most significant barriers that prevent the small and medium enterprises in the Indian automotive industry from engaging in sustainable supply chain practices, are a raise in awareness and policy push for sustainability, unlike large original equipment manufacturers (OEMs), as addressed in Table 2; aside from that, small and medium enterprises face other unique problems concerning finances, technologies, and market and regulatory concerns that would prevent them from making a shift to green supply chain management (GSCM) and circular economy (CE) practices [53].

4.1 Financial Constraints and Cost Burdens

High costs of green technologies become one of the most serious barriers to developing sustainable supply chains among Indian automotive small and medium enterprises (SMEs). Undergoing an ecological manufacturing revolution, investing in energy-efficient machines, and using sustainable raw materials all require upfront costs that the majority of such SMEs are unable to afford [14]. Apart from that, SMEs are not able to invest in renewable energy, water recycling plants, and carbon offset projects, unlike large OEMs such as Tata Motors and Maruti Suzuki. The organizations that are well off are able to afford it [54].

However, limited access to green financing further aggravates the case. Due to the lack of necessary credit history and collateral, Indian SMEs often fail to secure sustainability-linked loans or environmental subsidies [55]. Even these schemes, like CGTMSE and SIDBI's Green Financing Programs, might still be in high awareness and low accessibility [56]. Studies conducted among the auto component manufacturers in the Pune and Chennai industrial clusters show that large suppliers receive incentives in sustainability from the OEMs, but SMEs hardly benefit because of the lower bargaining power that they possess [57].

4.2 Technological Barriers

The lack of technological infrastructure has posed yet another major challenge to SMEs in India's automotive supply chain. Advanced digital tracking systems, automation, and predictive analytics are key components for SSCM and are mostly lacking among SMEs [58]. On the other hand, while some leading OEMs such as Mahindra & Mahindra have installed blockchain for supply chain transparency and AI-powered energy management systems, the majority of the SMEs are still engaged in manual and outdated processes [59].

Another major hindrance is the lack of Industry 4.0 readiness. Technologies such as IoT-enabled logistics, big data for sustainable procurement, and robotics-driven green manufacturing are fundamental to achieving sustainability [60]. The implementation costs are a big concern for SMEs, where labor is not skilled and digital literacy is very low [61]. A survey done on auto component SMEs in Gurugram revealed that only 20 percent have incorporated digital monitoring for energy efficiency, while nearly 80 percent continue to consider conventional manual processes [14]. On yet another note, the widening gap in digitalization between OEMs and SMEs is hampering the sustainable innovations in the industry [62].

4.3 Regulatory and Policy Challenges

Compliance with these environmental regulations becomes another great concern for SMEs. In India, the new laws, in fact, the considerable pollution norm of BS VI that places stringent restrictions on exhaust emissions thus far, clear-cut EPR rules, and waste management laws enjoined manufacturers to adopt cleaner production technology and circular economy principles [63]. This said, SMEs have difficulties in understanding, implementing, and financing compliance [64]. Reverse logistics under India's EPR policy requires SMEs to recover used auto parts for recycling, but most lack the technical know-how and the finances to fulfil those requirements. The case study of auto parts-related SMEs in the Nashik and Aurangabad clusters indicates that large firms have sustainability compliance teams, while the SMEs are often left to ad hoc arrangements and have to slog it out to win their cases through bureaucratic quagmires and downright ambiguities in the regulations [65]. In spite of various government incentives for clean energy generation and carbon reduction, policy implementation has not been consistent across the states, which clouds long-term planning for SMEs with uncertainty [66].

4.4 Supply Chain Disruptions and Market Pressures

Whenever something happens in global supply chains, the ripple effects are felt throughout the Indian automotive industry. The SMEs become more exposed to instability and geopolitical threats, as we saw during the COVID era, the global semiconductor shortage, and the escalation in the costs of raw materials [67]. Large OEMs have diversified sourcing strategies, whereas small manufacturers are often dependent on a handful of key suppliers, leaving them with lesser resilience to supply chain shocks [68]. More than that, in the face of all sorts of pressures from MNCs and OEMs to pursue sustainability, SMEs are often incapable of making any such changes themselves [14]. One such example involves the sustainability assessments of Toyota Kirloskar and Honda India, many of which become impossible for the SMEs in automotive hubs in Manesar and Pune to comply with standards [69]. In this context, the power asymmetry between OEMs and SMEs means that costs arising from sustainability will be pushed down to the smaller suppliers, without any financial support or technical assistance [70].

The growing impact of electric vehicles and government backing for green mobility are taking an unprecedented turn on the supply chains as well. Small and medium-sized enterprises specializing in traditional IC engine components now confront declining demand, while the EV supply chain requires new materials, skills, and investments, further marginalizing those small players who cannot quickly adapt [71]. High costs, technology lag, regulatory duty, and external pressures constitute formidable challenges for small manufacturers. While OEMs and corporates are advancing in green logistics, circular economy practices, and digitalization, SMEs struggle to keep up with the advances. Reforms in policy, financial incentives, and stronger integration of OEMs and SMEs are necessary in order to bridge this gap. If not supported, SMEs run the risk of being sidelined in India's sustainable automotive transition.

Table 2: Challenges in Implementing Sustainable Supply Chains in Indian Automotive SMEs

Challenges	Key Elements	Findings from the Indian Automotive Industry	References
Financial Constraints and Cost Burdens	High initial investments in green technologies	Many Indian SMEs struggle with financing energy-efficient production due to high capital costs. E.g., Maruti Suzuki's sustainability report highlights the costly adoption of green manufacturing.	[14], [56], [59]
	Limited access to sustainability financing	SMEs face difficulties securing green loans and rely on traditional financing, which often overlooks environmental initiatives. SIDBI and government green financing policies exist but are underutilized.	[55], [56], [58]
Technological Barriers	Lack of advanced infrastructure and digital adoption	Many SMEs lack the automation and IoT integration needed for smart, green manufacturing. Large OEMs like Mahindra are driving digitalization, but SME adoption is slow.	[59], [61]
	Gaps in Industry 4.0 readiness	Indian auto SMEs lag behind in Industry 4.0 practices, impacting real-time monitoring of sustainability efforts. Toyota and Tata Motors have initiated training programs for suppliers.	[58], [60], [61]
Regulatory and Policy Challenges	Compliance burdens with environmental regulations	Complex pollution control norms, ISO 14001 certifications, and BIS standards add to compliance costs for SMEs. Many lack dedicated ESG compliance teams.	[14], [62], [63]
	Gaps in policy implementation and support	Government policies such as Faster Adoption and Manufacturing of Electric Vehicles (FAME) aim to support sustainability, but implementation challenges remain for SMEs.	[63], [66]
Supply Chain Disruptions and Market Pressures	Volatile demand and global supply chain uncertainties	COVID -19 and geopolitical risks have disrupted supply chains, causing price fluctuations in raw materials. OEMs like Tata Motors and Bajaj Auto faced semiconductor shortages.	[66], [72]
	Pressure from multinational corporations and OEMs	Large MNCs like Hyundai and Toyota impose stringent sustainability norms on Indian SME suppliers, forcing them to adopt green practices despite limited resources.	[14], [69], [70]

5. Enablers of Sustainable Supply Chain Practices in Indian Automotive SMEs

Though Indian automotive SMEs are faced with enormous challenges in practicing sustainable supply chain initiatives, they can still count on various key facilitators in their transition to greener operations. These include government policies and support systems, technological developments, collaboration within the industry, and a host of financial incentives. Such enablers act as mechanisms of sustainable transformation and at the same time help to ensure the viability of enterprises in the long run.

5.1 Government Policies and Support Mechanisms

The Government of India has put forward a number of policies and programs aimed at promoting sustainability in the automotive sector, especially around supporting SMEs. The Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme has directly subsidized and incentivized manufacturers to introduce cleaner vehicle technologies [4]. FAME II has expanded incentives to include electric two-wheelers and three-wheelers along with commercial fleet purchases, fostering an indirect advantage for SMEs involved in manufacturing electric vehicle components [73]. The Production Linked Incentive (PLI) scheme for the automotive sector is designed to encourage companies to invest in newer automotive technologies and offers financial incentives for automakers to do so, including hydrogen fuel cells, battery electric powertrains, and lightweight sustainable materials [5]. In a case study of Tata Motors and its supplier network, the study found that a secondary benefit of the PLI program was to encourage local SMEs to develop EV-specific components to be embedded into an electrified supply chain [74].

The study shows exactly how FAME and PLI schemes are unevenly implemented across states and SME clusters. The automotive hubs like Maharashtra, Tamil Nadu, and Karnataka account for higher FAME acceptance, maintained by strong infrastructure, OEM occurrence, and state guidelines. Large clusters in Uttar Pradesh, Jharkhand, and West Bengal face weaker incentives, poor infrastructure, financial barriers, and sinking commitment. The PLI scheme benefits are focused among larger tier-1 suppliers, though many SMEs fail to meet eligibility edges. By using secondary evidence and case insights, we highlight regional differences and the necessity for targeted SME support. Moreover, pollution regulations and extended producer liability principles in the laws require auto parts manufacturers to apply green practices properly. The Automotive Industry Standards (AIS) 129, which are provisions for battery recycling and reuse, are among the new statutes that pressured SMEs into embracing greener manufacturing practices [75]. Though these guidelines are positive initiatives, policies alone will not address the barriers to implementing their frameworks and processes, as the bureaucratic burden to implementation continues to grow for SMEs, resulting in the inability to enact policies in an effective manner [14] [83].

5.2 Technological Innovations and Digitalization

The advancements in Industry 4.0-related technologies such as the Internet of Things (IoT), artificial intelligence (AI), and blockchain have played a major role in developing

sustainable supply chains. The ability of IoT to enable real-time monitoring of carbon emissions combined with AI-based predictive maintenance results in reduced energy consumption in manufacturing facilities [76]. As a case in point, Bosch India has implemented IoT-focused smart energy management systems, which have improved energy efficiencies across its supply chain network [77]. Blockchain technology is also gaining momentum in ensuring traceability and transparency in the supply chain. Blockchain technology has also gained momentum in offering traceability and transparency in the supply chain. As blockchain offers tamper-proof records of raw material and product life cycles, it offers environmental standard compliance. Case studies of Hero MotoCorp and TVS Motors show that the application of blockchain in tracking the supplier has reduced supply chain waste and improved compliance with sustainability standards [78].

In the EV sector, Ather Energy and Ola Electric built end-to-end digital ecosystems that engage suppliers, manufacturers, and distributors to maximize the use of materials and recycling [79]. These technologies are crucial for SMEs to increase sustainability while competing in the fast-changing market. The implementation of Industry 4.0 in SMEs is uneven. The advanced clusters such as Pune, Chennai, and Bengaluru inspire IoT, automation, and data analytics due to stronger OEM connections and ecosystem support; however, SMEs in less-developed regions depend only on basic digital tools. This indicates varied readiness. Beyond financial constraints, barriers include skill gaps, conflict with organizational change, and restricted awareness of long-term benefits. Insufficient digital infrastructure in some regions further delays the progress. These outcomes highlight the significant diversity of SME digital transformation and underscore the need for policies and capacity-building initiatives that report both financial and non-financial barriers to innovation.

5.3 Collaboration and Industry Partnerships

The involvement of original equipment manufacturers (OEMs) and multinational companies (MNCs) in facilitating the development of sustainability for small and medium-sized enterprises (SMEs) is critical. OEMs such as Maruti Suzuki and Mahindra & Mahindra have collaborated with SME suppliers in the development of green practices through training, capacity-building workshops, and joint sustainability initiatives [80]. An example of the same is Mahindra's Supply Chain Sustainability Initiative, which involves enrolling the suppliers under green procurement, energy efficiency, and emission reduction programs [29] [48]. As a result of such initiatives, the SME suppliers have been able to implement green materials and processes and align themselves with international sustainability norms. Moreover, industry associations like the Automotive Component Manufacturers Association of India (ACMA) have initiated programs to facilitate knowledge transfer and skill development in green manufacturing, lean manufacturing, and reverse logistics [13] [87]. These industry-level initiatives enable SMEs to access the best practices, mentorship, and capital needed for sustainable development.

5.4 Financial and Market Incentives

Availability of green financing and market-oriented incentives for sustainability is essential for SMEs considering environmentally sustainable measures. Banks like the Small

Industries Development Bank of India (SIDBI) and India Exim Bank have come up with green credit programs and low-interest credit facilities for SMEs that are investing in solar power, reduction of waste, and cleaner production technology [45] [75]. A number of case studies show that State Bank of India (SBI) Green Fund financial assistance has enabled SMEs to replace their equipment with energy-efficient ones, lowering costs of operation while improving compliance with sustainability [81]. In addition, foreign investment in green bonds and sustainability-linked loans has also enabled cleaner production adoption by Tier 2 and Tier 3 automotive suppliers. The market-based incentives steered the customer demand toward sustainable automotive products. Companies like MG Motor India and Hyundai India claimed that it was easier to attract customers to EVs and hybrid models, which stimulates the pressure on small and medium enterprises in their supply chain to get low-carbon production methods to remain competitive [37] [75].

Developing a green supply chain in Indian automotive SMEs cannot rely on any single strategy but requires a blend of different elements, namely government, technology, industry collaboration, and financial support. While FAME and PLI policies tend to create an impetus toward green manufacturing, they marry the use of IoT, AI, and blockchain technologies for ensuring operational efficiency and environmental compliance in the process. Partnerships with OEMs and MNCs help SMEs become aligned with internationally accepted sustainability standards, while mechanisms of green financing will avail much-needed capital for eco-friendly transformation. To put the pedal to the metal of moving toward sustainability, the stakeholders need to take care of simplification in policy, development in infrastructure, and more financial accessibility so that Indian automotive SMEs can remain competitive on the global green economy platform.

Table 3 elucidates the multidimensional enablers that facilitate the sustainable supply chains in the Indian automotive sector. Government policies like FAME II and PLI promote SME involvement in green manufacturing; technological advances, including IoT, AI, and blockchain, improve the operational efficiency of such manufacturing. OEM collaborations and industry partnerships facilitate supplier training and technical workshops with the help of knowledge transfer and financial support. Other financial incentives, such as green loans and sustainability-linked bonds, are helping SMEs in overcoming the investment hurdle. Together, these enablers would provide long-term competitiveness for Indian automotive SMEs in the global sustainable mobility transition.

Table 3: Enablers of Sustainable Supply Chain Practices in Indian Automotive SMEs

Enabler Category	Key Elements	Case Studies/Examples	References
Government Policies and Support Mechanisms	FAME II subsidies for electric vehicle (EV) adoption	Beneficiaries: Tata Motors, Hero Electric	[4], [73]
	PLI scheme for advanced automotive technologies	Mahindra's green manufacturing expansion	[5], [74]
	AIS 129 battery recycling standards	Implementation by Exide Industries, Amara Raja Batteries	[75]
Technological Innovations and	IoT-based smart energy management	Bosch India's energy-efficient supplier monitoring	[14], [76]

Table 3: Enablers of Sustainable Supply Chain Practices in Indian Automotive SMEs

Enabler Category	Key Elements	Case Studies/Examples	References
Digitalization			
	AI-driven predictive maintenance for energy savings	Used by Maruti Suzuki to optimize factory operations	[76]
	Blockchain for supply chain traceability	Hero MotoCorp & TVS Motors for supplier tracking	[77], [78]
	Digital integration in EV supply chains	Ather Energy's connected EV ecosystem	[79]
Collaboration and Industry Partnerships	OEM-led supplier sustainability programs	Mahindra's supply chain sustainability initiative	[80]
	Industry associations supporting SMEs	ACMA training programs on green manufacturing	[22]
	Joint ventures for skill development	Maruti Suzuki's vendor development initiatives	[13]
Financial and Market Incentives	Green financing schemes by SIDBI and SBI	Loans for SMEs upgrading to eco-friendly machinery	[52], [81]
	International investments in green bonds	India Exim Bank's funding for sustainable suppliers	[44]
	Consumer-driven demand for sustainable vehicles	MG Motor India's market shift towards EVs	

6. Case Studies of Sustainable Supply Chain Practices in Indian Automotive SMEs

6.1 Case Study 1: Successful Sustainability Adoption by an Indian SME

The best case of sustainability adoption in the Indian automobile industry is that of Lucas TVS, a prominent SME dealing in auto electric products. The company has been successful in going green in production by embracing solar power, lean manufacturing systems, and green purchasing practices. Lucas TVS has also installed solar photovoltaic (PV) panels in its factories, which now account for approximately 30% of the total energy used, thereby cutting its carbon footprint significantly [82]. The company has also embraced lean manufacturing practices to reduce waste generation, improve material efficiency, and improve energy efficiency. Its supplier engagement program asks vendors to meet environmentally sustainable procurement standards, and materials are sourced from suppliers who prioritize ecological sustainability [83].

One of the key drivers for their success is that they are aligning with OEMs like Tata Motors and Mahindra & Mahindra, who have very high sustainability standards for suppliers. This way, not only did Lucas TVS gain higher competitiveness, but it has also become an excellent supplier of choice for world markets because they believe in sustainability [84].

6.2 Case Study 2: Challenges Faced and Overcome by a Mid-Sized Automotive Supplier

Subros Limited, an Indian mid-market supplier of automotive thermal products (for ex., radiators & HVAC systems), has encountered a variety of sustainability challenges, including energy consumption, efficiencies in inbound logistics/supply chain & lack of access to green financing. [85]. Conventional fossil fuel-based energy sources were relied upon heavily in Subros operations, resulting in high operational costs as well as carbon emissions. To tackle this situation, the company invested in energy-efficient manufacturing technologies and switched over 20 percent of energy requirements to solar and wind energy [86].

The next major challenge entailed transparency in the supply chain and waste reduction. IoT-based monitoring systems were introduced by the company to monitor material consumption, waste identification, and optimization of logistics routing, all of which helped curtail transportation emissions effectively [18] [71]. Financing was yet another constraint, as many financial institutions were not willing to lend money for sustainability projects. Nevertheless, Subros utilized green financing schemes from the State Bank of India (SBI) and the Small Industries Development Bank of India (SIDBI) to pay for energy-efficient upgrades [87]. The combination of these strategic initiatives has helped the company reduce its carbon footprint by 25 percent over a period of five years and to become more cost efficient, thus meeting the sustainability expectations of leading Indian OEMs such as Maruti Suzuki and Ashok Leyland [80].

6.3 Case Study 3: Lessons Learned from International Benchmarks

While Indian SMEs have transformed, global giants such as Bosch, Toyota, and Volkswagen have raised the bar for SSCM. Indian automobile manufacturers such as Bajaj Auto and TVS Motor Company have embraced best global practices to spur their sustainability performance. Inspired by the lean and green production models of Toyota, Bajaj Auto has been implementing principles of circular economy to reduce waste and recycle materials used in production. Closed-loop water recycling systems were installed by the company, thus achieving ZLD (zero liquid discharge) at its plants [36]. In the same manner, TVS Motor Company adopted Bosch's methodology in supplier sustainability audits. It introduced an OEM-led sustainability program, where suppliers are compelled to follow environmental rules or else face being cut out of the supply chain. This has resulted in the use of green materials, enhanced use of resources, and reduced emissions in its supply base [82], [88].

One of the most important take-home points of international best practices is the requirement of policy-driven incentives in driving adoption of sustainability. Green supply chain programs in Germany and Japan are rewarded with carbon credits and tax benefits, but Indian SMEs are yet to see unambiguous policy direction. It brings into focus the requirement of robust regulation support in India to induce more SMEs to implement sustainable supply chain practices [89]. These case studies reflect the diversified strategy of Indian SMEs towards sustainability. While firms such as Lucas TVS and Subros Limited have overcome difficulties through technological innovations and fiscal innovations, firms such as Bajaj Auto and TVS Motor Company have learned from best practices elsewhere, as

addressed in Table 4. Nonetheless, to bring about mass sustainable change, Indian SMEs need more policy interventions, fiscal incentives, and sectoral coordination.

Table 4: Sustainable Supply Chain Practices in Indian Automotive OEMs and SMEs

Category	Company	Sustainable Supply Chain Initiative	Key Element	Reference
Four-Wheeler Manufacturers	Tata Motors	Adoption of EV supply chains, localization of battery production, and integration of green logistics	Electric vehicle (EV) production, sustainable logistics	[74], [90]
	Mahindra & Mahindra	Implementation of a circular economy in vehicle manufacturing, use of recycled materials in production	Recycled materials, circular economy adoption	[29], [48]
	Maruti Suzuki	Supplier sustainability audits, integration of solar energy in production plants	Sustainable energy integration, supplier monitoring	[35]
Cargo & Commercial Vehicle Manufacturers	Ashok Leyland	Transition to alternative fuel vehicles (AFVs), fleet electrification for cargo logistics	Green logistics, alternative fuels	[91]
	Eicher Motors (Volvo Eicher Commercial Vehicles)	Deployment of fuel-efficient engines, supply chain decarbonization programs	Fuel efficiency, supply chain emissions reduction	[92]
Two-Wheeler Manufacturers	TVS Motor Company	Partnered with global firms to implement sustainable supplier programs and use biodegradable materials in production.	Sustainable supplier collaboration, green material adoption	[88], [93]
	Bajaj Auto	Zero liquid discharge (ZLD) water recycling, green energy adoption in production plants	Wastewater management, renewable energy adoption	[36]
Major Equipment & Auto Component Suppliers	Lucas TVS	Green procurement policies, adoption of solar energy for manufacturing	Renewable energy, sustainable procurement	[82]
	Bosch India	Deployment of energy-efficient automation systems, adoption of Industry 4.0 for real-time monitoring of energy usage	Smart manufacturing, energy efficiency	[94]
	Subros Limited	Integration of IoT-based	IoT-based waste	[95]

Table 4: Sustainable Supply Chain Practices in Indian Automotive OEMs and SMEs

Category	Company	Sustainable Supply Chain Initiative	Key Element	Reference
		tracking for waste reduction, utilization of SIDBI green financing for sustainability projects	management, green financing	

- Tata Motors, Mahindra & Mahindra, and Maruti Suzuki are three of the four OEMs that are actively considering electric vehicles, green logistics, and supplier sustainability audits.
- Trucking and logistics vehicle manufacturers like Ashok Leyland and Eicher Motors are investing in alternative fuels and fuel-efficient technologies to reduce emissions.
- Two-wheeler producers such as TVS Motor Company and Bajaj Auto have adopted sustainable supplier initiatives, biodegradable material use, and zero liquid discharge practices.
- Major automobile component suppliers such as Lucas TVS, Bosch India, and Subros Limited are embracing renewable energy, smart manufacturing, and IoT-based sustainability monitoring in their supply chain operations.

6.4 Comparative insights from Lucas TVS, Subros, and global benchmarks:

The sustainability strategies, process improvements, resource efficiency projects, ecosystem collaborations, policy alignment, and challenges faced by the three examples are all explained in Table 5. Global leaders like Toyota, Bosch, and Volkswagen show how to use new ideas like the circular economy, carbon neutrality, and Industry 4.0 integration. Lucas TVS is an example of a company that is committed to renewable energy and lean manufacturing. Subros is a mid-sized supplier that is overcoming big problems by making small improvements and getting green financing. The lessons show that Indian small and medium-sized businesses need to stop focusing on compliance and start working on sustainability projects that are connected to the rest of the world.

Table 5: Comparative Insights from Case Studies:

Dimension	Lucas TVS	Subros	Global Benchmarks	Lessons Learned
Sustainability Strategy	Lean manufacturing, renewable energy incorporation	Energy efficiency, emission reduction	Circular economy, carbon detachment goals	Shift from compliance to strategic sustainability
Process Improvements	Waste reduction, Kaizen, 5S practices	Energy-efficient HVAC, IoT for logistics	AI, automation, Industry 4.0	Implement incremental automation and AI.

Table 5: Comparative Insights from Case Studies:

Dimension	Lucas TVS	Subros	Global Benchmarks	Lessons Learned
Resource Efficiency	Material efficiency, reduced waste	Refrigerant management, waste heat recovery	Closed-loop supply chains	Quick and Easy Wins
Collaborations & Ecosystem	Cluster-based partnerships with OEMs	OEM compliance partnerships	Global supplier integration	Extend OEM-SME collaboration.
Policy/Regulatory Alignment	Aligned with national energy policies	Emission standards, refrigerant rules	ISO 14001, ESG frameworks	Move to practical global standards alignment.
Barriers Faced	High automation costs, skill gaps	Limited digitalization, fossil fuel dependence	High upfront investment offset by incentives	Policy support and capacity building are needed.

7. Future Trends and Strategic Recommendations

7.1 Future of Indian Automotive SMEs: Projected Growth of Sustainability-Driven Supply Chains

It is expected that the Indian automotive sector, especially SMEs, will be substantially impacted by sustainability pressures, government initiatives, and international climate actions. By 2030, EV penetration in India is projected to reach close to 30%, necessitating a restructuring of supply chains to accommodate battery manufacturing and use of lightweight materials as well as green logistics [96], [97]. OEMs like Tata Motors and Mahindra Electric have already started providing training for suppliers to comply with their sustainability agenda [29], [74]. Additionally, Maruti Suzuki has a goal to cut its carbon footprint by 50% by 2040, which will have a direct effect on its supply chain, forcing SMEs to adopt more sustainable production methods [98].

7.2 Emerging Trends in Green Automotive Manufacturing

The Indian automotive industry has stood on shifting carbon-neutral manufacturing plants, with companies like Ashok Leyland investing in hydrogen fuel cell technology and zero-emission vehicles [99], [100]. TVS Motor Company has also drawn a sustainability roadmap that includes biodegradable parts and renewable materials in its manufacturing processes [101]. The process of moving from IC engines towards hybrid and battery powertrains will require light materials, energy-efficient equipment for their manufacture, and circular economy principles by recycling and remanufacturing the waste generated from their production [58] [104].

7.3 Driving Sustainable Supply Chains with AI, Automation, and Renewable Energy

Artificial intelligence (AI) and machine learning-based predictive analytics are highly invaluable in enhancing energy efficiency, demand forecasting, and waste elimination, which ultimately improves supply chain sustainability. Bosch India has adopted AI-based quality control and blockchain for traceability as a strategy to enhance its sustainable procurement practices [94]. Furthermore, Eicher Motors utilizes automation and robotics on its production lines to improve energy consumption and precision in using eco-friendly materials [102]. Another important consideration in future supply chains is the integration of renewables into operations. For example, Bajaj Auto has applied solar panels in its manufacturing sites and improved its dependence on non-renewable power sources, forming a 35% reduction in the past five years [103]. Lucas TVS, one of the leading suppliers, has switched to 100% green energy procurement and, on a level, can be a useful model for SMEs thinking about how to integrate renewable power in their manufacturing process [82].

7.4 Shift towards Circular Economy Models

The shift from a linear supply chain (take, make, dispose) towards a circular economy (reduce, reuse, recycle) is gaining traction in the Indian automotive sector. Mahindra & Mahindra has utilized remanufacturing of vehicle parts while lowering raw material consumption and extending the life of products [104]. Tata Motors has laid the groundwork for the recycling of batteries. Another very important upcoming trend captures reverse logistics, where a manufacturer creates a closed loop in the recovery of the end-of-life vehicle, or ELV, for material recovery and reuse. Under "Take Back," an initiative adopted by Maruti Suzuki, customers can present their ELVs to the company for proper dismantling into parts before waste generation to ensure that resources are efficiently used while minimizing waste [105].

7.5 Strengthening Government-Industry Collaboration for Long-Term Competitiveness

To enhance the adoption of sustainability, it is imperative to take a multi-stakeholder opportunity with government, industry, and SMEs. Although the FAME II scheme, the Production Linked Incentive program, and the Scrappage Policy have built a good policy base, more work is needed for accessibility for SMEs [106], [107]. Companies like Ashok Leyland and TVS Motor Company have asked the government to provide subsidies on green-sourced raw materials and low-interest loans for green technology upgrades [108].

Collaborations with public research and development organizations give SMEs the opportunity for partnership towards technological assimilation and knowledge sharing. Maruti Suzuki Centre of Excellence in Green Manufacturing has also collaborated with industry experts and government policymakers in creating training modules for SMEs on resource-efficient manufacturing practices [98].

7.6 Enhancing Financial Support and Regulatory Clarity

One of the major problems that small and medium enterprises (SMEs) encounter while pursuing sustainability in the supply chain is the huge initial investment cost towards green technologies, energy-saving machinery, and waste treatment plants. SIDBI and other banks

are suggested to launch focused green loan schemes and low-cost credit facilities to SMEs that are looking to switch to a more sustainable practice [52], [109]. Regulatory clarity is another one that is critical. Most SMEs are unable to keep up with changing environmental regulations, and policy implementation is delayed. A sustainability compliance mechanism, specific to automotive SMEs, can bridge this gap. Eicher Motors has highlighted the importance of industry-specific guidelines for environmental performance to allow SMEs to have clear, actionable roadmaps for embracing sustainability [110].

The Indian automotive sector, particularly SMEs, is on the threshold of radical change led by sustainability imperatives. Green auto production growth forecast, new technology such as AI and renewable energy, and application of the circular economy will define the future of the supply chain. Stronger policy interventions, cooperation between government and industry, and tax incentives are wanted more for sustained competition. Indian automotive companies, such as Tata Motors, Mahindra & Mahindra, Maruti Suzuki, Ashok Leyland, TVS Motors, and Bajaj Auto, have been leading by example in sustainability for SMEs.

7. Conclusions

The study defines the dynamic role of SSCM in the automotive sector in India, especially focusing on the critical role that is being undertaken by Small and Medium-sized Enterprises (SMEs) to achieve long-term sustainability. The study illustrates the driving force for SSCM is the Triple Bottom Line (TBL) approach with dimensions that are economic, environmental, and social responsibility. The major outcomes from leading OEMs such as Mahindra & Mahindra, Tata Motors, and Maruti Suzuki highlight their initial efforts in adopting lean manufacturing, reverse logistics, and green procurement. For example, Lucas TVS reduced energy costs by 30% through the implementation of solar power. Hero MotoCorp attained a 43% reduction in emissions by shifting from air to truck-based logistics. Likewise, Subros Ltd. reduced carbon emissions by 25% in five years by engaging IoT-based energy monitoring systems. These cases show the tangible benefits of SSCM practices for both large and small enterprises in the Indian automotive sector.

Lean concepts in manufacturing have become more prevalent in the industry, demonstrated through Ashok Leyland and Eicher Motors improving material efficiency and reducing volatile organic compound (VOC) emissions through green manufacturing practices. However, the high cost of capital and technical skills needed are huge barriers for SMEs. Governmental incentives and special training schemes play a vital role in overcoming such a gap. Reverse logistics and circular economy initiatives are also on the rise. Tata Motors' take-back schemes for vehicles and Hero Electric's take-back schemes for batteries are classic examples of best practices for resource conservation. But SMEs are lagging behind due to weak infrastructure and policy backing.

Empirical studies show that the adoption of sustainable supply chain practices has economic and environmental benefits. Logistics route optimization and waste management by Hero MotoCorp have resulted in substantial decreases in carbon footprints and operational costs. The study also indicates that India's Faster Adoption and Manufacturing of Hybrid and

Electric Vehicles (FAME) Policy and the Production Linked Incentive (PLI) Scheme have offered financial incentives to the small and medium-sized enterprises (SMEs) in the automotive domain, thus enabling investment in sustainability and innovation. Even with all the above influences, there are still a few challenges that need to be addressed. There are limited budgets; there are disruptions of supply chains; and the regulatory complexities commonly render scaling the sustainable operations for SMEs rather difficult. Accessing Industry 4.0 technologies like automation, AI, and IoT remains a challenge due to high implementation costs.

Competitiveness for Indian automotive SMEs in the coming times will depend on their ability to adopt new technologies for the enhancement of international partnerships and diversify in foreign markets. Better policy interventions and strategic collaborations with international OEMs would also be important, as would establishing a framework that promotes sustainability-oriented investments. With the government playing a facilitating role in this transition, technology capability building, and nurturing cooperative strategies, Indian automotive SMEs can look forward to a resilient, sustainable, and competitive future.

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