

Review

Advancing the Circular Economy in the Indian Automotive Sector Through Materiality Assessment of Industry Practices and Policy Interventions

Swapnil Gund ^{1,*} , Sandeep G. Thorat ¹ , Sachin Pawar ¹, Prashant Paraye ²  and Anuj Prajapati ³

¹ Department of Mechanical Engineering, MIT Art Design and Technology University, Loni Kalbhor, Pune 412201, India; sandeep.thorat@mituniversity.edu.in (S.G.T.); sachin.pawar@mituniversity.edu.in (S.P.)

² Department of Mechanical Engineering, Plast India International University, Vapi 396193, India; paraye.prashant@gmail.com

³ Department of Computer Science and Engineering, Trinity Institute of Technology and Research, Bhopal 462038, India; anujprajapati482@gmail.com

* Correspondence: swapnil.gund@outlook.com

Abstract

The transition to a circular economy (CE) in the automotive sector is increasingly critical amid rising resource pressures and climate imperatives. In India, this shift is influenced by regulatory initiatives, corporate sustainability goals, and life-cycle-wide environmental challenges. However, current studies remain fragmented, often neglecting the linkages between policy drivers, material issues, and firm-level responses. This study aims to evaluate how CE strategies are operationalized across the Indian automotive value chain using a Drivers–Materiality–Response (DMR) analytical framework. A multiple-case qualitative analysis was conducted involving six major automotive firms and associated ecosystem actors, with data sourced from corporate reports, national policies, and third-party assessments from 2018 to 2024. Semi-structured interviews with 11 industry experts were incorporated to strengthen triangulation, validate firm-level circular economy claims, and support the reliability of the DMR-based interpretation. Findings reveal strong alignment with national CE policies among leading firms, particularly Tata Motors and Mahindra, with comprehensive integration of electrification, battery reuse, zero-waste goals, and digital mobility solutions. However, challenges remain in end-of-life vehicle (ELV) formalization and circularity in downstream systems. The DMR model effectively bridges gaps in existing frameworks by offering a life-cycle-based lens that links Environmental, Social and Governance (ESG), Life Cycle Assessment (LCA), and policy–firm dynamics. The study contributes a scalable diagnostic tool for assessing CE maturity in emerging economies. While limited by reliance on secondary data, the triangulated approach enhances reliability and provides actionable insights for policymakers and industry leaders.



Academic Editors: Michele John and Pedro Simões

Received: 19 March 2026

Revised: 12 May 2026

Accepted: 12 May 2026

Published: 3 July 2026

Copyright: © 2026 by the authors.

Licensee MDPI, Basel, Switzerland.

This article is an open access article distributed under the terms and conditions of the [Creative Commons Attribution \(CC BY\)](https://creativecommons.org/licenses/by/4.0/) license.

Keywords: circular economy; Indian automotive sector; Drivers–Materiality–Response framework; sustainability; lifecycle assessment; policy interventions

1. Introduction

Sustainable development advocates for meeting present needs while ensuring the ability of future generations to meet their own. The Sustainable Development Goals provide a structured and integrative framework that aligns with the automotive industry's objectives of reducing carbon emissions and enhancing resource efficiency [1]. These align

closely with the automotive sector's push to reduce carbon emissions and enhance resource efficiency. Legal pressures, shifting consumer expectations, and the urgency of climate action are driving a major transformation in the automotive industry [2]. Sustainability efforts are now centered on minimizing waste and extending material use through recycling, reuse, and circular manufacturing strategies [3,4]. LCA tools support this by evaluating the environmental impacts of design, production, and end-of-life phases [5,6]. Beyond environmental goals, sustainability in this industry now reflects ESG transparency and market responsiveness [7,8]. Carmakers increasingly integrate CE principles and ethical sourcing to align with both regulatory and societal expectations [9]. The Indian automotive ecosystem, shown in Table 1, is vast and evolving across manufacturing, mobility, recycling, and retrofitting domains. The sector contributes ~7.1% to the nation's Gross Domestic Product (GDP) but also contributes significantly to emissions, pollution, and resource depletion [10,11]. These challenges push firms to adopt greener practices and strengthen ESG compliance under increasing investor scrutiny [12]. Table 1 lists various companies in India across different categories of the automotive and mobility industry. These include automobile manufacturers, shared mobility providers, used vehicle sellers, technology providers, recyclers, and retrofitters.

Table 1. Automotive circular economy landscape in India.

Category	Representative Companies in India	CE Practices	Key Challenges
Automobile manufacturer	Maruti Suzuki, Hyundai, Tata Motors, Mahindra, Toyota	Electric Vehicle (EV) transition, eco-design, recycled material use, zero-waste manufacturing, and battery reuse	High material demand, battery circularity, supply-chain emissions, and ELV responsibility
Shared mobility provider	Ola, Uber, BluSmart, Quick Ride, Zoomcar	Vehicle sharing, higher fleet utilization, fleet electrification, and digital route planning	Charging gaps, maintenance cost, uneven utilization, and policy uncertainty
Used vehicle seller	Cars24, Spinny, OLX Autos, CarDekho	Vehicle resale, refurbishment, reuse, and life extension	Quality verification, warranty issues, informal resale, and emission compliance
Technology provider	KPIT Technologies, Tata Elxsi, Bosch India	Telematics, predictive maintenance, battery management, and digital tracking	Data gaps, digital cost, interoperability issues, and Small and Medium Enterprises (SME) adoption barriers
Recyclers	Mahindra CERO, MSTI, Tata Motors Re.Wi.Re	ELV dismantling, material recovery, scrap reuse, and metal recycling	Informal dismantling, weak traceability, limited infrastructure, and safety concerns
Retrofitters	Maruti Auto Gas, Lovato Gas, BharatMobi, Folks Motor	Compressed Natural Gas (CNG) conversion, EV retrofitting, component reuse, and vehicle life extension	Certification gaps, safety issues, conversion cost, and uneven technical standards

CE in the automotive sector enhances sustainability by promoting recycling, reuse, remanufacturing, and repair. These strategies reduce environmental degradation while supporting industrial competitiveness. Recent studies project that CE integration can maintain

2050 resource consumption at 2015 levels, despite EV growth [13]. Closed-loop recycling of steel and plastics can cut Greenhouse Gases (GHGs) by ~10%, while mobility-sharing models reduce emissions by 4–18% [14]. Integrating Industry 4.0 and lean methodologies improves both quality and sustainability [15]. CE-linked design investments also reduce costs and material demand [16]. However, several barriers persist. These include supply chain fragmentation, informal sector dominance, and inconsistent regulations in developing nations [17]. Challenges also stem from high digital integration costs, lack of workforce skills, and poor data management [15]. Policy frameworks and global standards such as the International Organization for Standardization (ISO) 59000 series provide pathways for addressing these issues [18]. A major challenge is the imbalance of information particularly around reverse logistics and sustainability awareness [19]. This hinders a broad CE transition. The circular car proposes full life cycle circularity from design to end-of-life via strategies such as reduction, reuse, repair, and recovery [20,21]. Effective data governance and LCA are critical for evaluating CE strategies. LCA identifies improvement areas and helps prevent burden shifting [22]. Digital product passports (DPPs) and blockchain enhance traceability and data security, especially in battery remanufacturing [23]. Barriers to CE include limited tech adoption, low scrap utilization, and design challenges due to lightweight materials [24]. Table 2 compares key circularity assessment frameworks in the automotive sector. Models vary in scope from life-cycle-wide approaches to component-specific indicators. While some use fuzzy logic or ontology for Key Performance Indicator (KPI) clarity, others standardize metrics nationally. Together, they provide structured, multi-level tools to evaluate and enhance circular economy performance.

The transition to a CE has become a strategic imperative for India's rapidly expanding automotive sector, which is projected to reach United States Dollar (USD) 1.8 trillion by 2030 [25]. Recent studies highlight that CE adoption significantly enhances firm performance, with green innovation and Corporate Social Responsibility (CSR) acting as mediators in Indian automobile manufacturing firms [26]. Empirical evidence shows that scrap sales used as a proxy for CE engagement positively influence revenue and inventory across 31 Indian automotive firms over 12 years [27]. Yet major barriers persist: technological and environmental constraints are ranked as the most critical impediments to CE practice adoption in regions such as Rajasthan [28,29]. Policy and regulatory gaps remain equally challenging, especially in managing ELV, where India faces ten key structural bottlenecks including informal recycling and inadequate infrastructure [30]. Moreover, firm valuations exhibit a U-shaped relationship with CE investment, indicating that benefits increase only after surpassing a threshold level [31]. At the same time, global recommendations urge automakers to raise recycled plastic content to 20–25% by 2030, pushing for advanced material recovery practices [32]. A DMR-based analytical approach is thus essential to systematically assess industry practices, stakeholder roles, and policy interventions, enabling India's automotive sector to accelerate its CE-driven sustainability transition. Table 2 shows that CE frameworks in the automotive sector have moved from broad life cycle concepts to indicator-based assessment tools. The frameworks mainly focus on material recovery, recyclability, energy use, product lifetime and measurable circularity performance across vehicle design and end-of-life stages.

The comparative analysis highlights diverse DMR models CE goals. Reconfigurable Recycling System (RRS) and closed-loop recycling improve material recovery advancing and automation, while simulation and fuzzy models aid design–recycling integration. Concepts like Design for Disassembly and the circular car encourage life cycle thinking. Though each model has strengths flexibility, emission reduction, or regulatory fit challenges include high costs, complexity, and data needs. Table 3 compares DMR-based models by focus, benefits, and limits.

Table 2. Frameworks for circular economy in automotive sector.

Framework	Key Features	Primary Indicators	Ref.
Circular car Concept	Life-cycle-oriented model emphasizing reduction, reuse, recovery, and recycling	Transition from Internal Combustion Engine Vehicles (ICEs) to Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicle (PHEV) alternatives	[20]
Circularity Assessment Framework	Fuzzy logic and multi-criteria decision-making (MCDM) for CE evaluation	Relative circularity scores; qualitative and quantitative metrics	[33]
Material Circularity Indicator	Evaluates material flow efficiency in vehicle design	Virgin material input, waste generation, and recoverability potential	[21]
Circularity Metrics	Set of tools assessing CE at product and corporate levels	Varies, including input–output ratios, recyclability indices, and reuse rates	[34]
Circularity Micro-Indicators	Tailored indicators for automotive plastic components	23 indicators including sustainable sourcing and end-of-life recovery	[35]
Ontology-Based Circularity Model	Facilitates shared understanding of CE KPIs	Energy consumption, material use, product lifetime, and usage efficiency	[36]
UNI/TS 11820:2022 (Italy)	Standardized national framework for CE monitoring using 71 indicators	Industrial waste, energy efficiency, and IT waste tracking	[37]

Table 3. Comparative analysis of diverse DMR models in CE.

Model	Key Features	Advantages	Challenges	Case Studies	Ref.
Reconfigurable Recycling System (RRS)	Modular, scalable; robotic disassembly	Flexible, automated recycling; efficient recovery	High setup cost; complex integration	Robotic cells for auto parts	[38]
Closed-Loop Material Recycling	Steel/plastic recycling; input–output subsystems	Cuts GHG; efficient resource use	Needs full system integration; quality issues	Auto manufacturing in China	[14]
Multi-Method Simulation Approach	Agent-based + discrete event models	Optimizes reuse/remanufacturing; lowers cost/emissions	Complex setup; heavy data needs	Washing machine case	[39]
System Dynamics Approach	Links design & recycling; material focus	Near-circular recovery; future design insights	Limited scope; life cycle data demands	Aluminum cans	[40]
Design for Disassembly & Recycling	Eco-materials; Design for Disassembly (DFD) principles	Maximizes resource use; lowers pollution	High redesign cost; training needs	Auto recycling in China	[41]
Fuzzy Rule-Based Models	Computer-Aided Design (CAD) recycling link; recyclability prediction	Integrates design/recycling; legal backing	Complex modeling; data intensive	Automotive industry	[42]
Multi-Agent Decision Support	Supports Design for Recycling (DFR); integrates regulations	Better design choices; guided disassembly	Setup complexity; CAD integration	Household appliance model	[43]
Circular car Concept	Full life cycle reduction/reuse/recycling	Higher circularity; boosts sustainability	High cost; needs wide adoption	Conceptual circular car	[20]

However, even with the increasing interest in the CE practices associated with recycling, reuse, and remanufacturing repair practices are still fragmented and focused on technical and environmental benefits. In India, informal players' involvement, fragmentation of the supply chain, and insufficient regulations make large-scale CE application through the entire vehicle life cycle impossible. Existing metrics like circularity indicators, life cycle assessments, and digital product passports are currently not adequately incorporated into companies' strategies. The present study uses DMR approach to evaluate CE practices, identify barriers and enablers, and develop a model that would integrate LCAs and digital measures into the process along with policy–firm cooperation. The proposed DMR approach provides an essential analytical contribution by combining external drivers, materiality in terms of product life cycle with a strategy response from companies at once. Unlike other frameworks that focus on recyclability, flows of materials, efficiencies, and the entire life cycle impacts, DMR analyzes the influence of circular economy pressures on actual industry practices. It makes DMR especially valuable in the context of India because of its uneven implementation of regulations, poor corporate sustainability practices, and downstream circularity. Therefore, DMR creates a structured basis for evaluating policy–industry alignment in circular economy transition.

The manuscript consists of six parts. Section 2 provides details about methodology, data sources, and DMR analysis. Section 3 covers key circularity dimensions such as decarbonization, material circularity, usage, and longevity. Section 4 provides information related to ESG and LCA aspects. Section 5 highlights policy gaps, recommendations, and implications of the research. Section 6 presents conclusion and directions for future research.

2. Methodology

2.1. Scope and Case Selection

This research utilizes a qualitative multi-case method to analyze the incorporation of CE in the automobile industry of India. The study scope focuses specifically on passenger car companies and ecosystem players like recyclers and mobility services that are known for their sustainability efforts between 2018 and 2024. In particular, the criteria for selecting the cases are the following: (i) presence in the Indian market along with transparency in sustainability reporting; (ii) presence of sustainable practices related to CE such as de-carbonization, recovery of resources, and increased longevity of the products; and (iii) consideration of all life cycles of a product starting from sourcing through manufacture, usage, and final disposal stage. Industry companies include Tata Motors, Mahindra & Mahindra, Hyundai, Maruti Suzuki, and Toyota India, as well as recyclers and mobility services connected with them.

2.2. Data Sources

The analysis is based on the secondary data obtained from three sources, which include (i) corporate disclosures (annual reports, ESG reports, technical papers) (Table A1), (ii) policy frameworks (FAME-II, Corporate Average Fuel Efficiency (CAFE) norm, Extended Producer Responsibility (EPR) mandate, and draft ELV policy), and (iii) external third-party sources, such as studies and assessments of the sector. The three sources give a factual perspective on the institutional and firm-based framework. Semi-structured interviews were carried out for eleven experts in different areas such as Original Equipment Manufacturers (OEMs), Tier-I suppliers, Reverse Vehicle Service Facilities (RVSFs), ESG consultancy, governance, procurement, dealer development, and informal dismantlers (Tables A2 and A3). Interviews were utilized in validating the secondary research and obtaining an understanding of the circular economy implementation on ground.

2.3. Analytical Framework

Cases were analyzed using a structured DMR framework. Drivers (D) capture external pressures (e.g., regulations, market shifts); materiality (M) identifies life-cycle-critical issues like electrification, resource efficiency, and circularity; and response (R) denotes firm actions such as EV launches, renewable sourcing, battery reuse, and recycling. A two-stage coding process was followed: open coding extracted D/M/R elements from all sources, and axial coding aligned them with life cycle stages. To reduce the risk of self-reporting bias, firm-level claims were verified through source triangulation. Corporate disclosures were compared with ESG/ Business Responsibility and Sustainability Report (BRSR) reports, government sources, policy documents, and third-party studies. Only claims showing consistency across source type or reporting period were used for DMR coding. This process improved the reliability of the firm-level interpretation and strengthened the credibility of the DMR assessment.

To strengthen methodological validation, the coded evidence was cross-checked across corporate disclosures, policy documents, and third-party assessments. A selected 10% subsample was double-coded to check consistency in assigning drivers, materiality, and response categories. The final DMR classification was reviewed against the predefined evaluation criteria of policy alignment, circularity measures, and life cycle coverage.

Each case was evaluated using three criteria policy alignment, circularity measures, and life cycle coverage rated on predefined scales as shown in Table 4. Triangulation ensured reliability, with thematic saturation marking coding completion and a 10% subsample double-coded for consistency. The DMR model bridges gaps found in other circularity tools by linking drivers, material priorities, and firm responses across the full vehicle life cycle. It is particularly suitable for India's context of strategic asymmetry and data gaps, offering a structured, comparative method for assessing CE transitions.

Table 4. Evaluation criteria for automotive circularity.

Criterion	Definition	Key Evidence	Rating
Policy Alignment	Compliance with national frameworks (FAME-II, CAFE, EPR, ELV)	Targets, compliance statements, regulatory investments	Direct/partial/weak
Circularity Measures	Extent of Reduce, Reuse, and Recycle (3R) /closed-loop practices in design & operations	Recycled content, ELV/battery recovery, Zero Waste to Landfill (ZWL)/Zero Liquid Discharge (ZLD), modular design	Strong/moderate/weak
Life Cycle Coverage	Scope of intervention across vehicle life cycles	Evidence from design to end-of-life (ELV/battery)	Comprehensive/moderate/narrow

3. DMR Model and Car Circularity

In this study, the four pillars of automotive circularity were mapped within the DMR structure. Decarbonization, material circularity, utilization and longevity were treated as materiality domains because they represent life-cycle-critical issues for India's automotive CE transition. Materiality was determined through stakeholder impact and life cycle relevance rather than only financial materiality. The selection was guided by ESG/BRSR disclosures, policy priorities, the CE literature, and expert validation. For each pillar, drivers were identified from policy, market, and technology pressures; materiality was linked with life cycle resource and emission concerns; and responses were assessed through firm-level initiatives such as EV adoption, recycling, reuse, telematics, repair, retrofitting, and battery second life practices. The DMR (Drivers–Material–Response) model applies

circular economy principles to the automotive sector by linking circularity drivers such as policy, market, and technology with material issues across the vehicle life cycle design, manufacturing, use, and end-of-life. It aims to reduce resource use, prevent environmental harm, and shift from linear to circular value flows [44]. The circular car concept emphasizes material reuse, decarbonization, and extended life. The DMR model offers a structured approach to embed circularity into decision-making throughout the vehicle life cycle as illustrated in Figure 1.

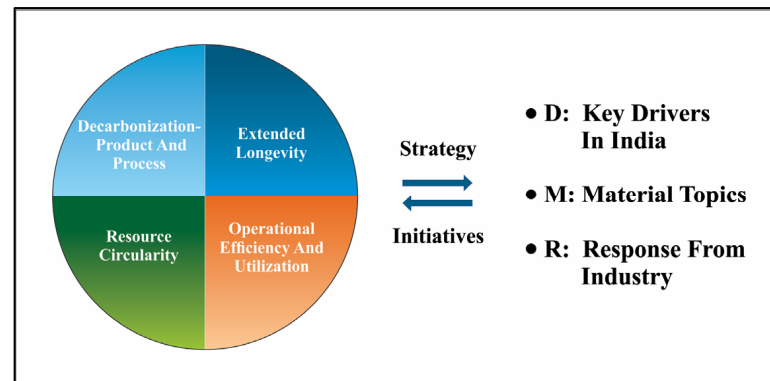


Figure 1. DMR model for circular car.

3.1. Decarbonization as a DMR Pillar

In the DMR structure, decarbonization is driven by emission regulation, fuel-price pressure, EV policy, and corporate net-zero targets. Its materiality is linked with life cycle GHG emissions, energy use, and low-carbon manufacturing. Firm responses include EV expansion, renewable electricity use, fuel-efficiency improvement, green logistics, and zero-waste production practices. Decarbonization in the automotive sector spans product design, manufacturing operations, use phase, and end-of-life treatment. Indian industry priorities reflect this full life cycle view: low-carbon materials, process efficiency, electrification, lightweighting, and alternative fuels are deployed together to align with national climate targets. India is the world's third-largest emitter (~3943 MtCO₂e), and transport contributes roughly 13% of national emissions; consequently, electrification and cleaner fuels are central to the sector's transition [45,46].

Policy Drivers

India has announced net zero by 2070, while the transport sector already emits ~338 Million tonnes of carbon dioxide (MtCO₂) annually and could see emissions double with rising ownership without strong interventions [10]. Instruments such as CAFE-II (2022) push passenger vehicles toward higher efficiency (~20 km/L) and penalize non-compliance, thereby nudging firms toward hybrids, lightweighting, and zero-emission options like BEVs and Fuel Cell Electric Vehicles (FCEVs) [47]. On the demand side, FAME-II (2019) allocates ₹10,000 crore to accelerate EV adoption, charging infrastructure, and Research and Development (R&D), complemented by Section 80EEB income tax deductions for EV loan interest to ease ownership barriers [48,49]. At the same time, high upfront costs, financing gaps, charging constraints, and raw material risks remain salient obstacles [46].

- Zero-emission production—Process decarbonization is advancing through renewable electricity procurement and on-site generation across solar, wind, hydro, and bioenergy [50]. Renewables accounted for ~28.04% (113.226 GW) of India's grid in 2022 and are projected to rise to ~54% by 2030 and ~80% by 2040, trends reinforced by Green Open Access Rules (2022) and Production Linked Incentive (PLI), schemes [51,52]. Electrifying heat and materials handling (e.g., plasma heating, heat pumps, electric

furnaces, forklifts, Automated Guided Vehicles (AGVs) further reduces fossil dependence [53,54]. Efficiency systems AI-based energy management, lean, and Just-in-Time (JIT) cut waste and optimize resources [55–58]. Material circularity practices (e.g., recycling, Zero Waste to Landfill (ZWL)) are themselves powerful levers for emissions reduction via reduced virgin input and landfill diversion, strengthened by closed-loop supply chains and secondary raw materials [59–61].

- Zero-emission vehicles—Over their life cycles, BEVs emit ~50% fewer GHGs than Internal Combustion Engine (ICE) vehicles. Even under high-mineral extraction scenarios, BEVs still show a ~47.5% lower carbon footprint [62]. With cleaner grids, BEVs can reduce life cycle emissions by over 75% [63–65]. Although EV production emits up to 1.5× more than ICE at the factory gate due to battery manufacturing, total life cycle emissions remain significantly lower, especially with clean energy and recycling [66,67]. In 2023, global EV sales hit ~14 million (18% of all car sales), cutting oil use by ~1 million barrels/day. In India, policies and investments are boosting EV adoption in 2- and 3-wheelers, supported by the Zero-Emission Vehicle (ZEV) Roadmap 2030 under the national 2070 net-zero vision [68]. Figure 2 compares the GHG emissions across different life cycle stages, emphasizing the environmental impact of various processes.

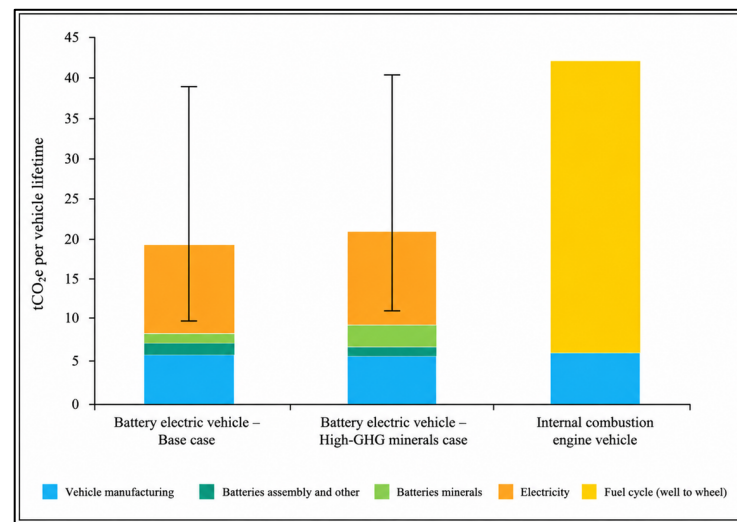


Figure 2. Comparative life cycle GHG emissions (sourced from IEA) [60].

Consumer behavior and fuel prices Volatile fuel prices driven by taxes, crude rates, and currency shifts are pushing buyers toward efficient vehicles, hybrids, and EVs [69]. Awareness and adoption of Compressed Natural Gas (CNG), Liquefied Petroleum Gas (LPG), and biofuels are rising [70], Growth is likely to accelerate with improved batteries, policies, and charging infrastructure, despite ongoing cost and access barriers [71]. Over time, innovation, policy support, and public awareness will drive the shift to cleaner, self-reliant mobility. Table 5 shows how firms respond to sustainability drivers through circularity. Tata Motors leads in EV rollout and renewable energy targets. Mahindra pushes EVs, hydrogen vehicles, and supplier Renewable Energy (RE) adoption. Hyundai advances EVs, renewables, and waste reduction. Maruti Suzuki focuses on logistics, fuel savings, and hybrids. All aim for zero-waste and carbon neutrality, though strategies vary from product design to supply chain efforts together reinforcing circular economy practices in India's auto industry.

Table 5. Company-level initiatives in response to circularity drivers and material concerns.

Company	Initiatives (Response)
Tata Motors [72]	• 70% market share in Four-Wheeler (4W) EV segment, sold 73,844 EVs by Financial Year (FY) 2024. • EVs include Nexon EV, Ace EV, and 1700+ electric buses. • Net-zero target—passenger vehicles by 2040, commercial vehicles by 2045. • 100% RE electricity by 2030; 3% RE in FY 2024. • Zero waste to landfill by 2030. • Promotes low-carbon supply chains via Leadership Group for Industry Transition (LeadIT).
Mahindra [73]	• 200,000 EVs target, “Born Electric” platform. • Developing hydrogen fuel cell and flex-fuel prototypes. • Carbon neutral for Scopes 1 & 2 by 2040 Science Based Targets initiative (SBTi)-approved). • 27% RE usage in FY 2024; target 100% by 2030. • 64% energy productivity increase since 2009. • Zero waste to landfill certification for 59 sites. • 80% of 78 suppliers shifted to RE.
Hyundai [74]	• 34 EV models under “Ambition 2030”; target 2 million EV sales annually by 2030. • Global carbon neutrality by 2045. • 42.1% RE at Chennai plant; RE100 target by 2025. • Manufacturing waste nearly fully recycled. • Compressed air and Light-Emitting Diode (LED) retrofits for energy savings. • Supply chain uses green steel, CNG, and flex-fuel R&D.
Maruti Suzuki [75]	• Shifted vehicle dispatch to 21.5% via rail (from 5% in FY 2014–2015). • Saved ~270 million liters of fuel and 10,000 tons Carbon Dioxide (CO₂) over 10 years. • 35% rail dispatch goal by FY 2030–31. • Testing flex-fuel and hybrid tech.

3.2. Material Circularity as a DMR Pillar

In the DMR structure, material circularity is driven by EPR rules, ELV regulation, resource scarcity, and rising waste pressure. Its materiality is linked with steel, aluminum, plastics, tires, batteries, and critical minerals across the vehicle life cycle. Firm responses include recycling partnerships, authorized dismantling, recycled material use, battery recovery, urban mining, and design-for-recycling practices. Material circularity tackles resource scarcity, waste, and pollution by promoting reduction, reuse, remanufacturing, and quality recycling in the auto sector. Rapid urbanization and weak waste systems worsen fuel, mineral, and water misuse, causing contamination and emissions [76,77]. Circular policies aim to cut virgin material use, recover value from waste, and extend product life through eco-design and EPR frameworks [76,78]. These efforts conserve resources, reduce environmental harm, and support a regenerative, low-waste industrial model.

3.2.1. Policy Drivers and EPR/ELV

India’s updated EPR policy places waste recovery responsibility on producers for categories, like e-waste, batteries, tires, ELVs, plastics, and used oil, as shown in Figure 3. The Battery Waste Management Rules 2022 and 2024 enhance recycling, collection, and traceability duties. Table 6 outlines category-wise targets. Automotive Industry Standard (AIS-129) and upcoming ELV rules mandate design for disassembly, hazardous substance limits, and targets of ~80% recyclability and ~85% recoverability. Steel EPR goals, such as 8% reuse by 2025–26, support closed-loop practices. Reporting from authorized centers and improved dismantling processes aim to tighten traceability and reduce material leakage [79].

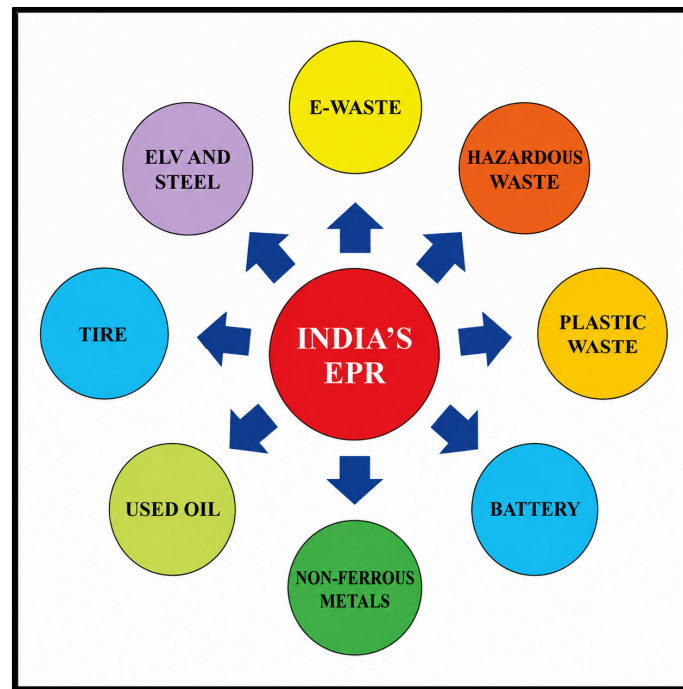


Figure 3. India's EPR framework.

Table 6. Overview of EPR regulations.

Waste Category	Targets/Obligations	Compliance Mechanism	Ref.
Batteries	EV & portable: 90% by 2026–2027; auto & industrial: 40% by 2029–30; 20–40% recycled content by 2030–31	EPR certificates, online tracking, fines	Battery Waste Management Rules [80–82]
E-Waste	60% in 2024–25, 70% in 2025–26, 80% from 2027 to 2028; importers 100% duty	Recycling obligations, fines for non-compliance	E-Waste Rules [83–85]
Hazardous Waste	40% recycling by 2026–27, 50% by 2030–31; 30% hazardous waste by 2027, 40% by 2032	Online EPR exchange, fines (30–100% of shortfall)	Hazardous Waste Rules [86]
Plastic Waste	Rigid: 50% (2024–25) → 80% (2027–28); flexible: 30% (2024–25) → 60% (2027–28)	Central Pollution Control Board (CPCB) online reporting, recycled content obligation	Plastic Waste Rules [87]
Non-Ferrous Metals	10% (2025–27), 30% (2027–29), 50% (2029–31); 75% after 2031; importers 100% duty	CPCB monitoring, importer responsibility	Draft EPR [88]
Used Oil	5% (2022–23), 10% (2024–25), 20% (2026–27), 50% (2030–31); importers 100% duty	CPCB online tracking, importer full compliance	EPR for Used Oil Rules [87]
Packaging Waste	50% recycling by 2026–27, 80% by 2029–30; recycled content: 70% paper, 50% metal by 2029–30	Centralized CPCB system, fines	Packaging Waste Rules [87]
Tires	35% (2022–23), 70% (2023–24), 100% (2024–25)	Mandatory recycling targets, penalties for violations	Tire Recycling Rules [80]

- A 3R framework enabling technologies—Automotive applications of the (3R) framework promote circularity through resource preservation, longevity, and reduction in environmental impact [89]. Technologies such as those associated with Industry 4.0 (digital twins) enhance manufacturing efficiency while reducing material wastage [4]. Reduction efforts are widespread throughout the value chain, ranging from renewable energy use at factories to minimizing packaging waste [90]. Reuse practices involve high-value assembly components (such as EV batteries and transmissions), which mitigate embodied emissions and preserve rare materials [89]. Concerning recycling, the industry is focusing on creating closed-loop processes for polymers, steel, and aluminum, thanks to innovations in mechanical and chemical recycling that enhance the quality of second-hand materials. For future endeavors, reverse logistics, depolymerization, and design for recycling are expected to increase recovery rates, while investments in eco-design, biomaterials, and recycled feedstock alternatives will strengthen supply chain sustainability and compliance [91,92].
- Design for sustainability—Sustainability-oriented automotive design features recyclability, lightweighting, and modularity. Modularity simplifies repair, reuse, and end-of-life (EOL) dismantling operations. Substitution of materials—for instance, Sheet Molding Compound (SMC) with Polypropylene (PP) in rear door panels and Ethylene Propylene Diene Monomer (EPDM) with plastics in sealing systems—lowers weight and non-recyclable materials [93]. Moreover, recycled materials, including High-Density Polyethylene (HDPE), Polyamide 6/Polyamide 66 (PA6/PA66), PET, and PP, have become common in tanks, engine components, and interiors, with life cycle analysis indicating that recycled Polyethylene Terephthalate (PET) produces only around 2.17 kg CO₂e/kg CO₂ compared to virgin PET [94,95]. Bio-based materials (hemp, flax, Polylactic Acid (PLA), etc.) aid in reducing dependency on petrochemicals, whereas recycled metals, primarily steel and aluminum, lower energy requirements and mining impacts [95]. Lightweighting using innovative materials such as carbon fiber, aluminum, magnesium, and Advanced High-Strength Steel (AHSS) reduces carbon dioxide emissions by ~8–11 g/km and facilitates further weight reductions in tires, brakes, and suspensions [96,97]. In electric vehicles, a 10% weight reduction increases range by approximately 13.7%; combining this with regenerative braking and aerodynamic optimization further improves efficiency [98]. Finally, designing for repair and reuse extends service life and supports ELV principles that emphasize reuse before scrappage [99].
- Urban mining—Recovering resources from anthropogenic stocks buildings, infrastructure, consumer goods, and ELVs offers a scalable complement to virgin extraction [95,100]. Given urban stocks of gold, copper, rare earths, and other materials rival natural deposits, urban mining can reduce ecological damage and supply risk [101,102]. Automotive ELVs yield steel, aluminum, rare earths, and lithium; EV batteries contain high-value metals (e.g., cobalt, lithium) with advanced recycling recovering up to ~95% [101,103]. Such reintegration lowers life cycle emissions and closes loops. Parallel opportunities in construction (“urban ore”) are being unlocked by solvent recovery, depolymerization, Building Information Modeling (BIM), and AI-driven sorting [100,104]. Formalizing recycling, professionalizing value chains, and creating jobs further strengthens social sustainability [101,105].

3.2.2. Automotive 4R Pathways

Automotive circularity can be understood more clearly through four connected pathways: recycling, reuse, remanufacturing, and repair. Recycling focuses on recovering materials from ELVs, production scrap and battery waste. It is important for steel, alu-

minum, plastics, rubber, and critical battery materials because it reduces virgin material demand and landfill burden. However, recycling alone gives limited circular value when materials are downcycled or when informal dismantling causes leakage. The option to reuse generates more circular value since it increases the life span of components or vehicles through minimal processing. Within the Indian context, schemes such as reused cars, second life batteries, and reused components could lower the carbon footprint and postpone the need for virgin materials. The additional benefit from remanufacture lies in the process of restoring the functionality of engines, transmissions, batteries, and other assemblies. This strategy enhances the industrial competitiveness of an organization yet faces challenges such as the absence of standards, warranties, quality issues, and ineffective reverse logistics. The easiest circular strategy is repair, which prolongs the useful life span of products via maintenance, replacement, and refurbishing. The strategy is relevant in India due to the existence of informal repair networks and cost-conscious consumers. However, it requires certification, standardization, and digitalization of services to make the process traceable. The drivers of this process from a DMR viewpoint include policies, material shortages, and cost consciousness. Materiality is reflected in ELV recovery, battery circularity, component longevity, and resource efficiency. Firm responses include authorized recycling facilities, certified used car channels, telematics-based maintenance, second life battery use and design-for-repair practices. Therefore, the Reduce, Reuse, Repair, and Recycle (4R) pathways show that automotive CE should not depend only on recycling. A stronger CE transition requires a hierarchy where repair and reuse preserve product value, remanufacturing restores technical value and recycling recovers material value at the final stage.

3.3. Utilization as a DMR Pillar

In the DMR structure, utilization is driven by mobility demand, digitalization, fleet efficiency, and the need to reduce idle vehicle time. Its materiality is linked with passenger kilometer efficiency, vehicle occupancy, maintenance life, and resource use during operation. Firm responses include telematics, predictive maintenance, shared mobility, connected fleets and data-based service models. Utilization is a key pillar of circular mobility, focusing on maximizing passenger kilometers while minimizing environmental impact. Strategies such as fleet services, ridesharing, subscriptions, and predictive maintenance reduce the number of vehicles needed and improve efficiency per unit of mobility. Lightweighting enhances fuel economy, and Predictive Maintenance (PdM) reduces downtime together boosting resource efficiency and vehicle occupancy across the system [45]. Technological advances, regulations, consumer behavior, and market innovation all drive utilization. Fleet telematics combining Global Positioning System (GPS), diagnostics, and wireless connectivity reduces idle time, theft, and delays. India's telematics market, valued at ₹555 crores in 2021, is expected to grow to ₹3796 crores by 2026, improving fleet productivity and lowering operational costs by 10–15% [106,107].

Predictive features support uptime and early fault detection [108]. AIS-140 mandates telematics in commercial vehicles to improve safety and compliance. Integration with GPS tolling and Electronic VAHAN (Evahan) enhances operational efficiency [109]. In electric mobility, telematics ensures efficient charging and range management, enabling smoother operations [110]. PDM significantly improves utilization efficiency by using AI, Machine Learning (ML), and Internet of Things (IoT) to monitor variables such as engine temperature, vibration, oil viscosity, and battery health [111,112]. Advanced models like Long Short-Term Memory (LSTM) and Gradient Boosting estimate component life and prevent failures [113]. PdM reduces maintenance costs by 20–30%, extends part life by 20–25%, and cuts downtime by up to 30% [114]. Optimized repair scheduling and real-time

diagnostics allow fleet operators to minimize resource waste and improve operational efficiency [115]. Shared mobility models such as ride hailing and car sharing enhance vehicle utilization by lowering costs, reducing congestion, and maximizing usage [116]. Private vehicles remain idle ~95% of the time [117], but platforms like Zoomcar, Rapido, and Quick Ride reduce this by matching demand in real time [118]. These services promote affordable, low-emission transport and align with India's climate goals [119].

Government support, including policies and urban transport investments, enables last-mile connectivity and adoption of shared mobility [120,121]. In India, lightweighting and shared mobility are driven by fuel efficiency and policy support, while globally, cost efficiency and environmental concerns dominate. Fleet telematics and predictive maintenance remain data-limited in both regions. India faces cost barriers and low SME awareness, whereas global markets emphasize innovation and alternative fuels. Industry responses reflect India's policy-driven growth and global lean production strategies. Overall, utilization efficiency strengthens the circular economy by ensuring that vehicles are used more intensively and intelligently during their service life, thus reducing the material and energy footprint per passenger kilometer. Through a combination of shared mobility, predictive maintenance, and telematics-driven fleet management, the automotive sector can achieve higher resource efficiency, improve sustainability outcomes, and support broader climate goals.

3.4. Longevity as a DMR Pillar

In the DMR structure, longevity is driven by affordability, product-life extension, repair demand, and circular mobility policy. Its materiality is linked with vehicle life, component reuse, second life batteries, and reduced need for new production. Firm responses include certified used car programs, retrofitting, repair networks, refurbishment, battery second life use, and life cycle service support. Extended longevity in the automotive sector involves strategies such as modular upgrades, retrofitting, and battery reuse to extend vehicle life and reduce the need for new manufacturing. These practices support sustainability by conserving resources and lowering emissions. Key enablers include vehicle retrofitting, growth in the used car market, and second life battery use. Retrofitting ICE vehicles with EV or CNG/ Bio-Compressed Natural Gas (Bio-CNG) systems under AIS-123 and AIS-024 standards helps older vehicles comply with current emission norms while improving safety and performance [122–124]. This also reduces operational costs, simplifies maintenance, and aids decarbonization efforts [125,126]. Though retrofitting can cost 60–70% of a new vehicle's price, it lowers the total cost of ownership over time, especially for commercial use [127].

Additionally, CNG-converted vehicles show improved environmental performance by lowering non-methane hydrocarbons, despite slight increases in Carbon Monoxide (CO) and Nitrogen Oxides (NOx) emissions [128]. The used car market is similarly evolving due to technological advances, consumer preference shifts, and Original Equipment Manufacturers (OEM)-backed certification programs. It is projected to grow from 5.1 million units in FY 2023 to over 10 million units by FY 2028, with the market value nearly doubling to USD 73 billion [129]. Buyers increasingly upgrade pre-owned vehicles with infotainment and emission-compliant systems, supported by extended warranties and service assurances from OEMs [130,131]. AI-driven evaluation tools now assess vehicle age, usage, and condition to guide resale and retrofitting decisions [132]. Second life battery applications also play a central role in longevity strategies. After initial vehicular use, lithium-ion batteries retain 70–80% capacity and are viable for energy storage in off-grid, rural, or renewable energy systems [133–135]. NITI Aayog estimates 1.6 million metric tons of end-of-life batteries by 2030, potentially yielding 250 GWh in second life capacity [136]. Advanced battery management systems and AI-driven State of Health (SoH) and Remaining Useful Life (RUL) diagnostics now allow for extended battery reuse in various contexts [137].

Second life use reduces reliance on raw material mining, offers up to 40% cost savings, and opens up business models in telecom towers, solar homes, and commercial Uninterruptible Power Supply (UPS) systems [138,139]. The case evidence provides quantitative support for DMR-based interpretation. Firm responses include 73,844 EV sales by Tata Motors, 27% renewable energy use by Mahindra and 42.1% renewable energy use at the Hyundai Chennai plant. Circularity actions also include 92–98% ELV recyclability through Maruti Suzuki Toyotsu India Private Limited (MSTI) and Fleet Edge coverage across more than 600,000 Tata trucks. These indicators show that the DMR-based findings are supported by measurable industry practices rather than descriptive observations alone.

4. Integration of ESG and LCA Frameworks

The automotive sector is shifting toward circularity and sustainability, driven by environmental concerns and tightening regulations. The European Commission now emphasizes recovering critical raw materials Critical Raw Materials (CRMs) from automotive electronics an area overlooked in conventional recycling, which focuses mainly on bulk materials like plastics and metals [140]. Advisory frameworks are emerging to strengthen circularity at both product design and end-of-life stages, aiming for better material recovery and sustainability. Reuse and recycling of end-of-use vehicles can result in savings of energy and materials; in addition, predictive models analyzing the reliability of a vehicle may contribute to cost-effective and sustainable decision-making throughout its life cycle [141].

The ESG approach provides an important mechanism for aligning the practices and strategies of corporations with social objectives. Through addressing environmental hazards, encouraging transparency, and fostering accountability, ESG contributes to sound corporate governance. In addition, it can help companies minimize their exposure to regulatory, legal, and reputational risks [142]. Traditionally, ESG practices were voluntarily adopted by firms. However, recent developments in regulation, particularly in Europe, are moving towards standardizing ESG disclosures and ensuring corporate accountability [143]. While there have been significant improvements in this area, obstacles still stand in the way of implementing ESG policies and practices, especially in developing nations. They include low-quality data availability, weak regulations, technological and financial limitations, and the lack of integration of non-financial indicators. There are multiple advantages to adopting ESG in business models including improved financing possibilities, expanded markets, improved reputation, and more effective risk management [144]. The integration of circular economy thinking in BEV development and life cycles becomes crucial. Advancements in reusing, recycling and repurposing batteries can contribute to the improvement of resource efficiency and sustainability [145].

5. Policy Gap on Automotive Circularity

The Indian government has been actively working towards promoting circular economy (CE) practices within the automotive sector, particularly focusing on electric vehicles (EVs) and end-of-life vehicle (ELV) management. However, the transition towards a fully circular model faces several challenges and requires comprehensive policy interventions. Table 7 shows major Indian policies promoting electric mobility and circular economy practices. The Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) Scheme and National Electric Mobility Mission Plan (NEMMP) drive EV adoption, while Zero Defect Zero Effect (ZED), Make in India, and the Smart Cities Mission emphasize sustainable manufacturing and urban infrastructure. Swachh Bharat and Scrappage Policy enhance waste reduction and recycling. Bharat Stage standards and the Urban Transport Policy reduce environmental impacts. Together, these form a broad framework balancing industrial growth with environmental goals in India's evolving electric vehicle landscape.

The Indian government has been actively involved in promoting CE practices in the automotive sector, especially with EVs and ELV management. Transitioning to a comprehensive circular framework, though, faces a plethora of challenges and requires holistic policy interventions.

Table 7. Key national policies and initiatives supporting electric mobility and circular economy.

Policy/Initiative	Description	Citation
FAME Scheme	Promotes adoption of electric and hybrid vehicles through subsidies and incentives.	[146]
National Electric Mobility Mission Plan (NEMMP)	Promotes electric mobility to reduce greenhouse gas emissions and fossil fuel use.	[146]
Make in India	Encourages local manufacturing, supporting CE principles and resource efficiency.	[147]
ZED	Improves product quality while minimizing environmental impact.	[147]
Smart Cities Mission	Promotes sustainable urban development, efficient waste management, and resource use.	[147]
Swachh Bharat Abhiyan (Clean India Mission)	Nationwide campaign for cleanliness, recycling, and waste management.	[147]
Bharat Stage Emission Standards	Regulates vehicle emissions to reduce air pollutants.	
Draft National Urban Transport Policy	Promotes sustainable, safe, and affordable mobility with biodiesel and green fuels.	[148]

5.1. Effectiveness and Challenges

EPR has certainly been a success story, especially in Europe, as it has facilitated recycling and waste management system organizations. About 35% of electronic waste and 65% of packaging waste are recycled or reused efficiently under EPR programs [149]. Germany is especially noted to be a success story with EPR, simply because of state-of-the-art recycling plants and technological support, although transparency is still a problem [150]. Secondly, EPR has encouraged higher collection rates of waste and stabilization of waste management systems, especially in the case of electronic waste Waste Electrical and Electronic Equipment (WEEE) [151]. Nevertheless, there are some challenges in implementation. These include ambiguous policy definitions, especially in the sphere of compulsory approval from urban local authorities and the registration procedure for recyclers [152].

Another key weakness lies in the insufficient enforcement of individual producer responsibility, which limits upstream measures like eco-design [151]. Legal ambiguities surrounding EPR enforcement also pose risks to its overall impact [153]. The End-of-Life Vehicle (ELV) Directive has been effective in countries like the UK and Sweden, where success is attributed to strong collaboration among producers, coherent policy announcements, and well-integrated policy tools. Nevertheless, success will highly depend on how the policy is implemented at the country level. Merely adopting the policies without proper strategies of implementation may not lead to the required results [154]. In India, the FAME-II strategy is poised for encouraging sustainable mobility based on the principles of the circular economy. While there is not much data about its circular economy impact, its focus on reduction in emissions and resources can be noted. For the full potential of the policy to be realized, proper evaluation frameworks and strategies are required [155].

LCA serves as one of the important methods of incorporating the circular economy into the automobile industry. It involves assessment of the impact of the product throughout its lifetime from raw materials extraction through manufacture, usage, and disposal which has

been referred to as cradle to grave and cradle to cradle approaches [156,157]. Studies show that up to 80% of energy consumption occurs during the vehicle use phase, underscoring the importance of fuel efficiency and alternative fuels [158].

Figure 4 presents a modified sustainable life cycle model that integrates circularity principles across raw material product use and end-of-life stages. It highlights the role of policies regarding energy efficiency and reuse strategies in reducing waste and promoting decarbonized automotive systems.

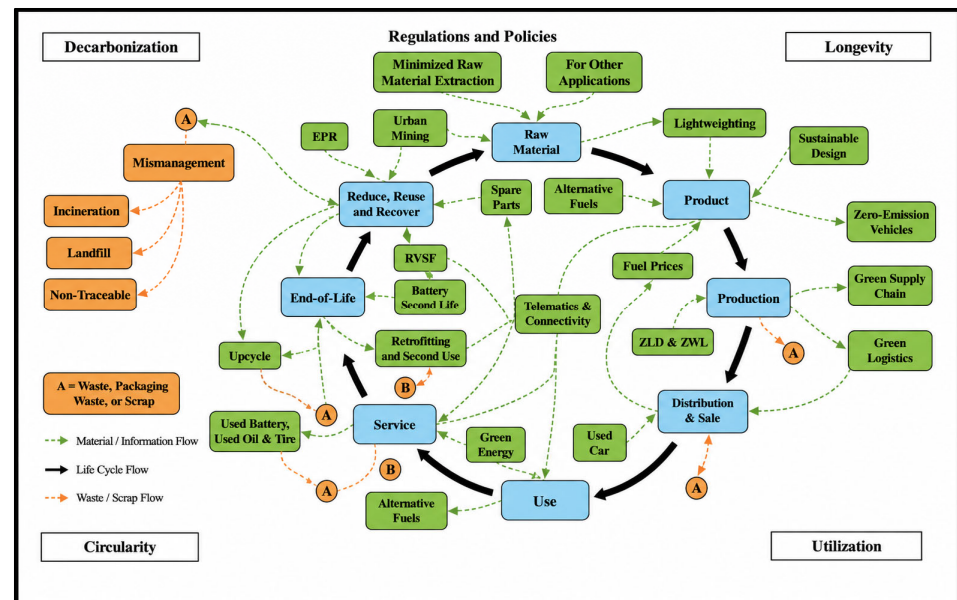


Figure 4. Car circular life cycle model.

In the same way, energy-consuming procedures, such as car painting, have to be optimized in order to decrease their negative impact on the environment. The importance of recycling and reusing (LIBs) is highlighted in order to lessen the burden on the environment and promote circular economy [145,159]. The use of LCAs in analyzing such processes can contribute to better decisions about products and systems. Meanwhile combining LCAs with system dynamics and artificial intelligence-based modeling allows for the assessment of the sustainability of electric vehicle adoption and their life cycles [160]. However, challenges remain, including data inconsistencies, lack of standardized methodologies, and limited integration of socio-economic variables [161,162].

5.2. Suggestions and Recommendations

There are several common barriers that affect the successful implementation of CE policies in India. First, there are no clearly defined policies for CE with conflicting mandates and ambiguous responsibility [152]. Second, the economic viability of CE policies and financial incentives for producers and recyclers and recycling funds are either inadequate or misallocate [155]. In addition, there is limited involvement of stakeholders in developing collaborative CE policy implementation [152]. Among the possible solutions to overcome the existing problems is policy harmonization, especially in regard to EPR frameworks at the European Union (EU) level [150]. Informal recyclers can be integrated into the formal economy, and deposit-refund schemes can encourage proper disposal and recycling of goods [163]. Several initiatives have been taken by the Indian government to promote EVs and reduce CO₂ emissions, such as the National Electric Mobility Mission Plan 2020 (NEMMP 2020) and Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME I&II). Still, lack of subsidies, poor policy planning, and absence of an

EV policy have stalled the process [164]. End-of-life vehicles (ELVs) play a crucial role in achieving the circularity of automotive products. Hence, the Indian government seeks to set up an organized framework of dismantling units, recycling facilities, and a fund management board. With the number of ELVs projected to increase from 8.7 million in 2015 to 21.8 million in 2025, recycling and remanufacturing systems will become imperative [165].

The framework would improve resource recovery and prevent environmental contamination. However, the application of CE activities in the Indian automobile industry, encounters challenges such as the lack of access to quality remanufactured items, infrastructure inadequacies, and consumer ignorance [166]. Moreover, there is uncertainty about the cost of EV charging infrastructure, mainly due to unclear roles and duties among different ministries. Countries such as China and Norway have managed to increase the uptake of electric cars through policy formulation and strong incentives. India needs an appropriate policy approach. Firstly, the nation must formulate an integrated national EV policy that would guide regulation, finance and investments in the EV sector [164]. Secondly, substantial investment in charging facilities needs to be provided, which would facilitate the adoption of electric vehicles in urban and rural areas. Thirdly, the provision of consumer education on environmental and economic benefits of using electric vehicles and adopting CE practices would be vital [167]. Through implementation of these policy pathways, a synergy would emerge, leading to quick transformation of India into a circular and low-carbon economy. Attention should be paid to the informal roadside dismantlers and small-medium enterprises since these players account for a considerable portion of the ELVs dismantled. Through formalization, these entities need to be incorporated into the CE process in phases. By registering, it will be easier to know which players are actively involved in the dismantling process and, thus, eliminate the compliance burden. Basic safety education and dismantling standards at reduced costs would help to minimize unsafe practice. Informal dismantlers may be encouraged to sell their materials to authorized recycling centers through buy-back facilities.

Recent 2025 policy developments show that automotive circularity in India is moving toward stronger traceability, producer responsibility, and sustainability disclosure. The Environment Protection ELVs Rules, 2025 introduced EPR-based obligations for vehicle producers and annual scrapping targets from 2025 to 2026. The rules also require Registered Vehicle Scrapping Facilities (RVSFs) to carry out treatment, depollution, dismantling, segregation and scrapping of ELVs and to route recovered materials to registered recyclers, refurbishers or co-processors. As of January 2025, 84 RVSFs were operational in India, which shows progress but also indicates the need to scale formal scrapping infrastructure. In parallel, Securities and Exchange Board of India (SEBI's) 2025 Business Responsibility and Sustainability Report (BRSR)-related circular introduced green credit disclosure from FY 2024–2025 and made value-chain ESG disclosure voluntary for the top 250 listed entities from FY 2025 to 26, with voluntary assessment or assurance from FY 2026 to 27. Therefore, future policy should integrate ELV traceability, BRSR-linked circularity reporting, material recovery disclosure, informal recycler inclusion, and SME-level compliance support within a unified digital monitoring system. This would improve accountability across formal and informal actors and support a more measurable circular economy transition in the Indian automotive sector.

Formal–Informal Integration in ELV Recycling

Formal–informal integration is a critical issue in India's ELV recycling system because roadside dismantlers still control a large part of vehicle collection, parts recovery, and local repair-linked material circulation. The formal system is now expanding through the Vehicle Scrapping Policy, the Motor Vehicles Rules for Registered Vehicle Scrapping Facilities and

the ELV Rules 2025. As per Press Information Bureau (PIB), 84 RVSFs were operational in India in January 2025 and RVSFs are required to follow proper depollution, dismantling, segregation, scrapping, and transfer of recovered materials to registered recyclers or re-furbishers. This improves traceability, safety, and environmental compliance. The year range has been revised to “2014–2015”. However, the informal sector remains competitive because it provides fast cash recovery, low-cost dismantling, local spare part reuse and strong access to old vehicles. This creates tension between formal recyclers and informal dismantlers. Formal facilities face high compliance cost, land and equipment requirements, documentation burden, and lower material inflow. Informal actors face weak access to registration, training, finance, safety systems, and digital reporting. The main policy barrier is that formalization pathways are still difficult for small dismantlers because compliance systems are designed mainly for organized RVSF operators. Therefore, India should not treat informal actors only as a problem. They can be integrated as registered collection agents, pre-dismantling partners, spare-part recovery units and material aggregators linked with RVSFs. Training, safety certification, buy-back agreements, shared collection points, digital tracking, and simplified compliance support can reduce leakage while protecting livelihoods. Hence, India’s ELV circularity will depend on both Original Equipment Manufacturer (OEM)-led formal infrastructure and structured inclusion of informal dismantlers into the regulated recycling chain.

5.3. Policy Implication

Transitioning to a circular economy (CE) in India’s automotive sector is extremely profitable economically. CE-based business models create employment opportunities in recycling, remanufacturing, and repair, which results in new jobs and inclusive economic growth [168,169]. With enhanced efficiency in the use of resources and reduced waste, CE strategies meet India’s sustainable development goals and realizes long-term economic growth [168,170]. CE practices also enhance Indian automobile manufacturers’ global competitiveness by optimizing production processes, reducing material costs, and maximizing the overall efficiency of resource utilization [166,171]. From an environmental perspective, CE activities significantly reduce the environmental footprint of the automobile industry. CE activities avoid waste generation by recycling, reuse, and remanufacturing of automotive components, thereby avoiding environmental damage [34,169,172]. CE also assists in enhanced resource efficiency through reduced use of virgin sources of material and reduced resource exploitation [168,169,173]. Cleaner technologies and cleaner production techniques also provide improved control over pollution and reduced emissions in the product life cycle [146,174].

In spite of the presence of these advantages, some barriers hindering the extensive application of CE in India exist. Technological barriers, such as limited access to improved technologies and a shortage of skills, are the primary hindrance to implementation. Exorbitant initial investment costs and risks and limited finance deter organizations from adopting circular strategies [175–177]. Gaps created by regulations and policies also hinder official integration of CE principles into the automotive value chain [175,177]. To address these challenges, various policy interventions are proposed. Providing financial incentives in the form of tax relief and subsidies can induce greater business engagement in CE programs [146]. At the same time, greater investment in R&D can enable the development of new technologies and scalable CE processes [171]. There is also a need for a supportive regulatory regime one that regulates CE practices and places recyclable standards upon recycling, resource recovery, and waste management [146,178].

5.4. Discussion

The interview evidence supports the DMR-based findings of this study. Most respondents indicated that circular economy adoption in India is mainly shaped by regulatory pressure, ESG expectations, cost reduction, and material security. These drivers are closely linked with material concerns such as ELV recovery, recycled material use, battery reuse, repair, traceability, and life cycle efficiency. OEMs and Tier-1 suppliers mainly focus on recycling, material efficiency, supplier compliance, and reporting. Dealers and informal actors contribute more directly to repair, reuse, and component recovery. This indicates that recycling continues to dominate the scene, while re-manufacturing and certified reuse remain nascent. From interviews, it is apparent that there is a clear disparity between formal and informal processes. The informal dismantlers and repairers are critical in the process of ELVs dismantling and spare parts recycling. However, their operation is linked to formal ESG and regulatory systems. RVSFs have well-defined disassembly and reporting procedures; however, low inflow levels limit their impact, leading to disparities between reports and material flow. Another issue that respondents indicated is weak policy integration. Policies such as EPR, ELV, BRSR, and FAME contribute to circularity; however, their linkages within the whole life cycle of vehicles are limited. Lack of data, limited tracing, costliness, and lack of standardized metrics are among the main barriers to achieving full integration. Digital technologies like digital product passports, block chain, telematics, and artificial intelligence could help solve some of these issues. Overall, the interviews confirm that India's automotive circular economy is active but fragmented. This supports the need for the DMR framework to connect drivers, material issues, and firm responses.

The comparative evidence shows in Table 8 that previous studies mainly focus on global CE strategies, ELV systems, remanufacturing, circularity indicators, plastics recycling, Life Cycle Assessment (LCA) metrics or Industry 4.0 applications. Most studies are either global, EU-specific, or technology-specific and only limited attention is given to India's mixed formal and informal automotive circularity system. Existing reviews also discuss drivers, barriers, and outcomes separately. The present study extends this literature by linking policy drivers, materiality concerns, and firm-level responses through the DMR framework in the Indian automotive context. This makes the contribution more specific to India's CE transition, ELV formalization, remanufacturing gaps, and policy–industry alignment.

Table 8. Comparative analysis of automotive circular economy studies.

Scope	Objective	Method	Key Findings	Limitations	Ref.
Global EV and Commercial Vehicle (CV)	Identify CE trends	PRISMA SLR	Multiple CE strategies identified	No unified CE evaluation	[179]
Automobile CE outcomes	Assess CE impacts	SLR of 192 studies	CE shows positive outcomes	Limited social dimension	[180]
Automotive CE practices	Map CE understanding	Literature review	CE linked mainly with low-grade recycling	Limited empirical validation	[173]
Global ELV systems	Map ELV bottlenecks	Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Systematic Literature Review (SLR)	Ten bottlenecks identified	ELV-specific focus	[30]
ELV remanufacturing	Build conceptual model	Content analysis	Four themes and three drivers identified	No operational validation	[181]

Table 8. *Cont.*

Scope	Objective	Method	Key Findings	Limitations	Ref.
Global automotive CE	Describe CE strategies	Conceptual analysis	Highlights policy and case examples	High-level discussion	[18]
Automotive CE adoption	Identify barriers	SLR	CE adoption remains fragmented	Limited regional insight	[174]
EU automotive plastics	Identify policy options	Interviews and supply chain analysis	15 barriers and 8 drivers mapped	EU and plastics specific	[182]
EU, Japan, Australia, United States(US)	Assess ELV regulation	CE indicators	Circularity gain up to 17.3%	Indicator focused	[21]
Automotive industry	Identify CE KPIs	EU project output	KPI set proposed	Not a review	[183]
Top 10 OEMs	Assess digital CE	Descriptive analysis	Circularity remains limited	Reporting bias	[90]
US automotive	Build CE framework	Framework and LCA	BEVs reduce non-renewable energy by 47%	US specific	[184]
Indian automotive sector	Evaluate CE using DMR	Qualitative multiple-case analysis	Links drivers, material issues, and firm responses	Secondary data limitation	Present study

6. Conclusions

This study concludes that circular economy transition in the Indian automotive sector is a life cycle governance challenge. It is not limited to firm-level sustainability actions. The DMR framework shows how policy drivers, materiality concerns and firm responses are connected across decarbonization, material circularity, utilization, and longevity. The findings show progress among leading Indian automotive firms in EV adoption, renewable energy use, zero-waste manufacturing, battery reuse, ELV recovery, telematics, and certified life cycle services. However, this progress is uneven. Large OEMs show stronger circularity responses, while downstream systems remain weaker. Informal dismantling, weak traceability, limited remanufacturing, and fragmented reverse logistics still reduce material recovery. Therefore, the findings should be read as evidence from selected leading cases. They should not be treated as a complete representation of the whole Indian automotive sector. Expert interviews and source triangulation improved the reliability of interpretation. Still, wider primary data is needed in future studies. Policy action should now move from broad scrappage promotion to targeted circularity enforcement. India's ELV Rules 2025 provide an important step through EPR-based annual scrapping targets from FY 2025 to 2026.

The formal RVSF system also supports scientific depollution, dismantling and material transfer. These measures should be linked more strongly with fitness testing, deregistration, insurance renewal, resale transfer and verified RVSF routing. Informal dismantlers should be included through registration, training, safety certification, and aggregator linkage with RVSFs. Digital product passports can further improve traceability by recording vehicle identity, material composition, repair history, battery health, dismantling status, and recycling destination. Such digital records can reduce leakage, support EPR verification and improve recovery of steel, aluminum, plastics, tires, batteries, and critical minerals. The expert interviews strengthened the reliability of the study by confirming the gap between reported circularity and actual material flows. They also showed that informal actors, RVSFs, suppliers and OEM functions play different roles in India's circular economy transition. Future research should expand this primary evidence through a larger respondent base and more region-specific field validation. Hence, India's automotive circularity needs

formal infrastructure, informal sector inclusion, producer responsibility, and digital life cycle traceability.

Future Direction

Development of CE practices in the Indian automotive sector requires a research-based, systematic roadmap. It requires technological, regulatory, economic, and social domains. Technological innovation and development are one of the most vital domains for future research. Embracing digital technologies such as blockchain, IoT, and AI can improve tracing of materials, improve efficiency in resource utilization, and improve information exchange along the automotive value chain [185]. Research elaboration on advanced recycling technologies such as bio-metallurgical processes and direct physical recycling is required for environmentally sustainable management of ELVs and lithium-ion batteries [186,187]. Benchmarking CE performance across industries can provide useful information to utilize resources to the fullest and minimize environmental footprint [188].

Policy and regulatory frameworks remain a basis for CE development. Future research needs to be geared toward the formulation of strong legislation acts that allow for effective waste management, recycling mandates, and CE compliance enforcement [175]. As important is the development of incentive systems such as tax credits, rebates, and subsidies to stimulate business participation through CE activities [28,189]. Another necessary area of inquiry is the quantification of CE's fiscal and environmental paybacks. In-depth analyses are required to quantify job creation, cost savings, and investment opportunities that result from CE implementation [168,170]. At the same time, research needs to quantify the effectiveness of CE interventions in terms of carbon emissions reduced, waste reduced, and raw material saved [166]. Consciousness of challenges and hindrances also plays a critical role in strategic CE implementation. Technological constraints such as access to infrastructure and advanced recycling technology need to be addressed through targeted innovation policies [28,177]. Financial constraints can also be addressed through specialized funding systems and risk reduction policies. Moreover, enhancing CE awareness and technical literacy among stakeholders through capacity-building training and education programs is needed [175].

Supply chain sustainability is another area of research. Studies need to examine the application of CE principles to procurement, manufacturing, and logistics with focus on material loop closure [120,187]. Efficient ELV management systems like reuse, remanufacturing, and safe disposal also require systematic evaluation [189].

Author Contributions: S.G.: Writing—Review and Editing, Writing—Original Draft, Validation, Methodology, Formal Analysis, Data Collection, Resources. S.G.T.: Writing—Review and Editing, Supervision. S.P.: Writing—Review and Editing, Supervision. P.P.: Writing—Review and Editing, Visualization, Project Management, Software, A.P.: Writing—Review and Editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: No new data were created or analyzed in this study. Data sharing is not applicable to this article.

Acknowledgments: The authors sincerely acknowledge MIT Art, Design and Technology University, Pune, for providing financial support towards the Article Processing Charges (APC) for the publication of this study.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

CE	Circular Economy
DMR	Drivers–Materiality–Response
ESG	Environmental, Social, and Governance
LCA	Life Cycle Assessment
OEM	Original Equipment Manufacturer
ELV	End-of-Life Vehicle
EV	Electric Vehicle
BEV	Battery Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
ICE	Internal Combustion Engine
GHG	Greenhouse Gas
RE	Renewable Energy
ZWL	Zero Waste to Landfill
ZLD	Zero Liquid Discharge
EPR	Extended Producer Responsibility
BRSR	Business Responsibility and Sustainability Reporting
CAFE	Corporate Average Fuel Economy
FAME	Faster Adoption and Manufacturing of Electric Vehicles
NEMMP	National Electric Mobility Mission Plan
CPCB	Central Pollution Control Board
AIS	Automotive Industry Standards
ESS	Energy Storage System
IoT	Internet of Things
AI	Artificial Intelligence
ML	Machine Learning
KPI	Key Performance Indicator
DPP	Digital Product Passport
RUL	Remaining Useful Life

Appendix A

Table A1. Data Source.

Corporate Disclosure	Report	Year	Assured by
Tata Motors	GROWING RESPONSIBLY—79th Integrated Annual Report 2023–2024	2024	BSR & Co. Limited Liability Partnership (LLP); KPMG Assurance and Consulting Services LLP
Mahindra and Mahindra Limited	Planet Positive—Sustainability Report 2023–2024	2024	Det Norske Veritas (DNV) Business Assurance India Private Limited
Hyundai Motors	Road to Sustainability—2024 Sustainability Report	2024	DNV; Lloyd’s Register Quality Assurance (LRQA); independent auditors
Maruti Suzuki Limited	Annual Integrated Report—2023–2024	2024	DNV Business Assurance India Private Limited
Toyota Kirloskar Motors Pvt. Ltd.	Sustainability Report	2024	RINA SERVICES Società per Azioni (S.p.A.)

Appendix B

Table A2. Semi-structured interview and respondent profile.

Section	Details
Study title	Advancing the Circular Economy in the Indian Automotive Sector through a DMR-Based Analysis.
Purpose	To validate secondary findings and examine practical circular economy implementation in the Indian automotive sector.
Respondents	10 industry experts.
Expert domains	Manufacturing, recycling, repair, remanufacturing, ELV management, ESG practice, and policy-linked practice.
Participant details collected	Name, designation, organization, industry segment, years of experience, and email/contact.
Consent statement	Responses may be used for academic research in summarized form.
Confidentiality	No confidential company data were requested.

Table A3. Semi-structured interview questions.

No.	Interview Question
1	What are the main circular economy practices followed in your automotive industry segment?
2	Which pathway is most active in your work area: recycling, reuse, remanufacturing, repair, or ELV management?
3	What are the main policy-, market-, or material-related drivers pushing circular economy adoption in India?
4	How do EPR, ELV rules, BRSR, ESG disclosure, and FAME-related policies influence circular economy practices?
5	What are the main barriers to circular economy implementation in India's automotive value chain?
6	How important are informal dismantlers, small recyclers, and repair networks in ELV processing?
7	What challenges limit the formalization of informal dismantling, repair, and recycling systems?
8	How reliable are corporate sustainability reports for assessing actual circular economy practices?
9	What evidence should be used to verify firm-level circular economy claims?
10	What is the present status of remanufacturing and certified reuse in India's automotive sector?
11	How can digital tools such as digital product passport, blockchain, telematics, or AI improve circular economy traceability?
12	What policy or industry actions are most needed to improve automotive circularity in India?

References

1. Carlsen, L.; Bruggemann, R. The 17 United Nations' sustainable development goals: A status by 2020. *Int. J. Sustain. Dev. World Ecol.* **2022**, *29*, 219–229. [CrossRef]
2. Dumée, L.F. Circular materials and circular design—Review on challenges towards sustainable manufacturing and recycling. *Circ. Econ. Sustain.* **2022**, *2*, 9–23. [CrossRef] [PubMed]
3. Geissdoerfer, M.; Savaget, P.; Bocken, N.M.P.; Hultink, E.J. The Circular Economy—A new sustainability paradigm? *J. Clean. Prod.* **2017**, *143*, 757–768. [CrossRef]
4. Potting, J.; Hekkert, M.; Worrell, E.; Hanemaaijer, A. *Circular Economy: Measuring Innovation in the Product Chain*; PBL Netherlands Assessment Agency: The Hague, The Netherlands, 2017.
5. Bauer, C.; Hofer, J.; Althaus, H.-J.; Del Duce, A.; Simons, A. The environmental performance of current and future passenger vehicles: Life cycle assessment based on a novel scenario analysis framework. *Appl. Energy* **2015**, *157*, 871–883. [CrossRef]
6. Singh, V.P.; Kumar, A.; Meena, C.S.; Dwivedi, G. (Eds.) *E-Electric Vehicles: Technologies and Challenges*. In *Advances in Manufacturing, Design and Computational Intelligence Techniques*; CRC Press: Boca Raton, FL, USA, 2024.
7. Mamta; Datta, P. The impact of sustainable practices on consumer behaviour in the UK automobile sector. *J. Bus. Retail. Manag. Res.* **2024**, *18*, 19–31. [CrossRef]
8. Panko, M.; Glova, J. The road to social responsibility and esg in the automotive industry: bibliographic analysis (2000–2022). In *Proceedings of the Mezinárodní Masarykova Konference Pro Doktorandy a Mladé Vědecké Pracovníky*, Hradec Králové, Czech Republic, 18–20 December 2023.
9. Ministry of Heavy Industries, Government of India. Automotive Industry. Available online: <https://heavyindustries.gov.in/en/automotive-industry> (accessed on 18 August 2025).
10. Wellbrock, W.; Ludin, D.; Röhrle, L.; Gerstlberger, W. Sustainability in the automotive industry, importance of and impact on automobile interior—Insights from an empirical survey. *Int. J. Corp. Soc. Responsib.* **2020**, *5*, 10. [CrossRef]
11. Tillu, P.G.; Digalwar, A.K.; Singh, S.R.; Reosekar, R.S. Towards sustainable automobile ecosystem in India: Integrated analysis of technical, economic, and ESG dimensions. *Clean. Environ. Syst.* **2024**, *14*, 100210. [CrossRef]
12. Biju, P.; Shalij, P.; Prabhushankar, G. Evaluation of customer requirements and sustainability requirements through the application of fuzzy analytic hierarchy process. *J. Clean. Prod.* **2015**, *108*, 808–817. [CrossRef]
13. Takimoto, H.; Kosai, S.; Watari, T.; Yamasue, E. Circular economy can mitigate rising mining demand from global vehicle electrification. *Resour. Conserv. Recycl.* **2024**, *209*, 107748. [CrossRef]
14. Tong, X.; Gao, J.; Wang, T.; Shi, X. Reducing greenhouse gas emissions in China's automobile manufacturing with circular economy strategies. *Carbon Footpr.* **2025**, *4*, 2. [CrossRef]
15. Shrivastava, A.; Mishra, R.P. Deploying lean six sigma and industry 4.0 framework in an auto motive manufacturing organization for establishing circular economy. *Opsearch* **2025**, 1–32. [CrossRef]
16. Pérez, M.; Lieder, M.; Jeong, Y.; Asif, F.M.A. A simulation-based decision support tool for circular manufacturing systems in the automotive industry using electric machines as a remanufacturing case study. *Int. J. Prod. Res.* **2025**, *63*, 5899–5918. [CrossRef]
17. Ambituuni, A.; Oyinlola, M.; Ajala, O.; Helen, S.; Esfahbodi, A.; Darrow, D. Mechanic Village Business Networks and Circular Economy Practices in the Automotive Industry. *Bus. Strat. Environ.* **2025**, *34*, 3027–3044. [CrossRef]
18. Park, Y.W.; Ryosuke, S. CE Strategy in the Automotive Industry. In *Circular Economy Strategy for SDG Business Management: New Theories and System Techniques*; Springer: Singapore, 2025; pp. 47–62.
19. Sonar, H.; Mukherjee, A.; Gunasekaran, A.; Singh, R.K. Sustainable supply chain management of automotive sector in context to the circular economy: A strategic framework. *Bus. Strat. Environ.* **2022**, *31*, 3635–3648. [CrossRef]
20. Martins, A.V.; Godina, R.; Azevedo, S.G.; Carvalho, H. Towards the development of a model for circularity: The circular car as a case study. *Sustain. Energy Technol. Assess.* **2021**, *45*, 101215. [CrossRef]
21. Soo, V.K.; Doolan, M.; Compston, P.; Duflou, J.R.; Peeters, J.; Umeda, Y. The influence of end-of-life regulation on vehicle material circularity: A comparison of Europe, Japan, Australia and the US. *Resour. Conserv. Recycl.* **2021**, *168*, 105294. [CrossRef]
22. Bjørnbet, M.M.; Vildåsen, S.S. Life cycle assessment to ensure sustainability of circular business models in manufacturing. *Sustainability* **2021**, *13*, 11014. [CrossRef]
23. Berger, K.; Rusch, M.; Pohlmann, A.; Popowicz, M.; Geiger, B.C.; Gursch, H.; Schöggel, J.-P.; Baumgartner, R.J. Confidentiality-preserving data exchange to enable sustainable product management via digital product passports—A conceptualization. *Procedia CIRP* **2023**, *116*, 354–359. [CrossRef]
24. Soo, V.K.; Compston, P.; Doolan, M. Is the Australian automotive recycling industry heading towards a global circular economy?—A case study on vehicle doors. *Procedia CIRP* **2016**, *48*, 10–15. [CrossRef]
25. Seshan, V.; Bandyopadhyay, D.; Sutar, P.S.; Sonawane, S.B.; Rairikar, S.D.; Thipse, S.S.; Gomez, D.J.D.C. Navigating Towards a Sustainable Future: India's Automotive Sector and the Path to Net Zero Emissions. In *Symposium on International Automotive Technology (2026)*; SAE Technical Paper; SAE International: Warrendale, PA, USA, 2026.

26. Potharaju, S.; Wukkadada, B.; Nijhawan, G.; Aparaj, S.; Sharma, K.; Lakkimsetty, N.R.; Veerapaneni, M.L.; Behera, A.P. Impact of circular economy adoption on sustainable business performance in Indian automobile manufacturing firms using a DEMATEL, PLS-SEM, and ANN framework. *Discov. Sustain.* **2026**, *7*, 311. [CrossRef]
27. Tejasmayee, P.; Agarwal, B.; Rastogi, S. From waste to wealth: The influence of circular economy on the operational dynamics of Indian automotive firms. *Int. J. Prod. Perform. Manag.* **2026**, *75*, 845–864. [CrossRef]
28. Sharma, M.; Nair, R. Analysis of Barriers to Introducing Circular Economy Practices in the Automotive Industry within Rajasthan, India. *Circ. Econ. Sustain.* **2025**, *5*, 3053–3071. [CrossRef]
29. Sharma, M. Circular Economy Barriers in the Automotive Industries in Rajasthan, India: Modeling through—SEM. *Circ. Econ. Sustain.* **2026**, *6*, 13. [CrossRef]
30. Aggrawal, A.; Das, D.; Kalbar, P.P. A global review of end-of-life vehicle management: India as a model for circular economy in automotive sector. *J. Environ. Manag.* **2025**, *394*, 127386. [CrossRef] [PubMed]
31. Tejasmayee, P.; Agarwal, B.; Rastogi, S.; Rokde, R. Does Circular Economy Effect the Valuation of the Indian Automobile Firms? *Circ. Econ. Sustain.* **2026**, *6*, 60. [CrossRef]
32. Kumar, V.B. Advancing Circular Economy in India's Automotive Sector: Challenges and Sustainable Solutions. In *Symposium on International Automotive Technology (2026)*; SAE Technical Paper; SAE International: Warrendale, PA, USA, 2026.
33. Ahmed, A.A.; Nazzal, M.A.; Darras, B.M.; Deiab, I. A comprehensive multi-level circular economy assessment framework. *Sustain. Prod. Consum.* **2022**, *32*, 700–717. [CrossRef]
34. Janik, A. The analysis of existing indicators, methods and tools for measuring circularity in the context of their future development. In *Proceedings of the SGEM2017 17th International Multidisciplinary Scientific GeoConference*, Albena, Bulgaria, 9 June–5 July 2017; pp. 43–50.
35. Matos, J.; Santos, S.; Simões, C.L.; Martins, C.I.; Simoes, R. Practical application of circularity micro-indicators to automotive plastic parts in an industrial context. *Sustain. Prod. Consum.* **2023**, *43*, 155–167. [CrossRef]
36. Pidikiti, V.S.; Vijaya, A.; Valilai, O.F.; Wicaksono, H. An ontology model to facilitate the semantic interoperability in assessing the circular economy performance of the automotive industry. *Procedia CIRP* **2023**, *120*, 1351–1356. [CrossRef]
37. Amicarelli, V.; Primiceri, M.; Misino, E.; Bux, C. An application of the UNI/TS 11820:2022 on the measurement of circularity in an electrical equipment manufacturing organization in Italy. *J. Clean. Prod.* **2023**, *420*, 138439. [CrossRef]
38. Barwood, M.; Li, J.; Pringle, T.; Rahimifard, S. Utilisation of reconfigurable recycling systems for improved material recovery from e-waste. *Procedia CIRP* **2015**, *29*, 746–751. [CrossRef]
39. Lieder, M.; Asif, F.M.A.; Rashid, A.; Mihelič, A.; Kotnik, S. Towards circular economy implementation in manufacturing systems using a multi-method simulation approach to link design and business strategy. *Int. J. Adv. Manuf. Technol.* **2017**, *93*, 1953–1970. [CrossRef]
40. Soo, V.K.; Compston, P.; Kim, H.C.; Doolan, M. The effects of technological changes on material circularity. *Procedia CIRP* **2021**, *98*, 37–42. [CrossRef]
41. Yu, Y. Research on Recycling-Oriented Automotive Design. In *Future Control and Automation: Proceedings of the 2nd International Conference on Future Control and Automation (ICFCA 2012)-Volume 2*; Springer: Berlin/Heidelberg, Germany, 2012.
42. Van Schaik, A.; Reuter, M.A. The use of fuzzy rule models to link automotive design to recycling rate calculation. *Miner. Eng.* **2007**, *20*, 875–890. [CrossRef]
43. Dostatni, E.; Diakun, J.; Grajewski, D.; Wichniarek, R.; Karwasz, A. Multi-agent system to support decision-making process in design for recycling. *Soft Comput.* **2016**, *20*, 4347–4361. [CrossRef]
44. Urbinati, A.; Chiaroni, D.; Chiesa, V. Towards a new taxonomy of circular economy business models. *J. Clean. Prod.* **2017**, *168*, 487–498. [CrossRef]
45. World Economic Forum; Accenture Strategy. Raising Ambitions: A New Roadmap for the Automotive Circular Economy. Available online: https://www3.weforum.org/docs/WEF_Raising_Ambitions_2020.pdf (accessed on 18 August 2025).
46. Chaturvedi, V.; Ghosh, A.; Garg, A.; Avashia, V.; Vishwanathan, S.S.; Gupta, D.; Sinha, N.K.; Bhushan, C.; Banerjee, S.; Datt, D.; et al. India's pathway to net zero by 2070: Status, challenges, and way forward. *Environ. Res. Lett.* **2024**, *19*, 112501. [CrossRef]
47. Ministry of Road Transport and Highways (MoRTH). Government of India. Available online: <https://morth.gov.in/> (accessed on 18 August 2025).
48. REGD. NO. D. L.-33004/99; FAME India Phase II. Department of Heavy Industries (GOI): New Delhi, India, 2019. Available online: <https://heavyindustries.gov.in/schemes/faster-adoption-and-manufacturing-hybrid-and-electric-vehicles-india-fame-india> (accessed on 18 August 2025).
49. Central Board of Direct Taxes (CBDT), Department of Revenue, Ministry of Finance, Government of India. *Income-Tax Deduction from Salaries Under Section 192 of the Income-Tax Act, 1961 During the Financial Year 2022–23*; Circular No. 01/2023; Government of India: New Delhi, India, 2023. Available online: <https://www.incometaxindia.gov.in/w/circular-no-24/2022-income-tax-deduction-from-salaries-during-the-financial-year-2022-23-under-section-192-of-the-income-tax-act-1961> (accessed on 18 August 2025).
50. Aydogan, H. Electric Vehicles and Renewable Energy. *J. Phys. Conf. Ser.* **2024**, *2777*, 012007. [CrossRef]

51. Debanjan, M.; Karuna, K. An overview of renewable energy scenario in India and its impact on grid inertia and frequency response. *Renew. Sustain. Energy Rev.* **2022**, *168*, 112842. [CrossRef]
52. Ministry of Power, GOI. Electricity (Promoting Renewable Energy through Green Energy Open Access) Rules, 2022. In THE GAZETTE OF INDIA: EXTRAORDINARY. 2022. Available online: [https://www.acma.in/uploads/ciculer-attachement/Electricity%20\(Promoting%20Renewable%20Energy%20through%20Green%20Energy%20Open%20Access\)%20Rules,2022.pdf](https://www.acma.in/uploads/ciculer-attachement/Electricity%20(Promoting%20Renewable%20Energy%20through%20Green%20Energy%20Open%20Access)%20Rules,2022.pdf) (accessed on 18 August 2025).
53. Muñoz-Maldonado, Y.; Correa-Quintana, E.; Ospino-Castro, A. Electrification of industrial processes as an alternative to replace conventional thermal power sources. *Energies* **2023**, *16*, 6894. [CrossRef]
54. Rehman, M.A.; Shrivastava, R. Green manufacturing (GM): Past, present and future (a state of art review). *World Rev. Sci. Technol. Sustain. Dev.* **2013**, *10*, 17–55. [CrossRef]
55. Biswas, P.; Rashid, A.; Biswas, A.; Al Nasim, A.; Chakraborty, S.; Gupta, K.D.; George, R. AI-driven approaches for optimizing power consumption: A comprehensive survey. *Discov. Artif. Intell.* **2024**, *4*, 116. [CrossRef]
56. Jaiswal, S.; Gupta, A.; Kanojiya, S.K. Optimization of energy consumption via artificial intelligence: A study. *SAMRIDDHI J. Phys. Sci. Eng. Technol.* **2016**, *8*, 26–33. [CrossRef]
57. Hąbek, P.; Lavios, J.J.; Grzywa, A. Lean manufacturing practices assessment case study of automotive company. *Prod. Eng. Arch.* **2023**, *29*, 311–318. [CrossRef]
58. Pardi, T. Lean Production in the Automotive Industry: Origin, Diffusion, Paradoxes, and Contradictions of a New Managerial Paradigm. In *The Cambridge International Handbook of Lean Production: Diverging Theories and New Industries Around the World*; Janoski, T., Lepadatu, D., Eds.; Cambridge University Press: Cambridge, UK, 2021; pp. 204–226. [CrossRef]
59. Awasthi, A.K.; Cheela, V.S.; D’aDamo, I.; Iacovidou, E.; Islam, M.R.; Johnson, M.; Miller, T.R.; Parajuly, K.; Parchomenko, A.; Radhakrishnan, L.; et al. Zero waste approach towards a sustainable waste management. *Resour. Environ. Sustain.* **2021**, *3*, 100014. [CrossRef]
60. Karagoz, S.; Aydin, N.; Simic, V. End-of-life vehicle management: A comprehensive review. *J. Mater. Cycles Waste Manag.* **2020**, *22*, 416–442.
61. Petavratzi, E.; Gunn, G. Decarbonising the automotive sector: A primary raw material perspective on targets and timescales. *Miner. Econ.* **2023**, *36*, 545–561. [CrossRef]
62. IEA. *Comparative Life-Cycle Greenhouse Gas Emissions of a Mid-Size BEV and ICE Vehicle*; IEA: Paris, France, 2021. Available online: <https://www.iea.org/data-and-statistics/charts/comparative-life-cycle-greenhouse-gas-emissions-of-a-mid-size-bev-and-ice-vehicle> (accessed on 18 August 2025).
63. Verma, S.; Dwivedi, G.; Verma, P. Life cycle assessment of electric vehicles in comparison to combustion engine vehicles: A review. *Mater. Today Proc.* **2022**, *49*, 217–222. [CrossRef]
64. Veza, I.; Asy’ari, M.Z.; Idris, M.; Epin, V.; Fattah, I.R.; Spraggon, M. Electric vehicle (EV) and driving towards sustainability: Comparison between EV, HEV, PHEV, and ICE vehicles to achieve net zero emissions by 2050 from EV. *Alex. Eng. J.* **2023**, *82*, 459–467. [CrossRef]
65. Kataoka, R.; Ogimoto, K.; Iwafune, Y.; Nishi, T. Does BEV always help to reduce CO₂ emission? impact of charging strategy. *Transp. Res. Part D Transp. Environ.* **2024**, *129*, 104124. [CrossRef]
66. Kurkin, A.; Kryukov, E.; Masleeva, O.; Petukhov, Y.; Gusev, D. Comparative Life Cycle Assessment of Electric and Internal Combustion Engine Vehicles. *Energies* **2024**, *17*, 2747. [CrossRef]
67. Huo, D.; Davies, B.; Li, J.; Alzaghrini, N.; Sun, X.; Meng, F.; Abdul-Manan, A.F.; McKechnie, J.; Posen, I.D.; MacLean, H.L. How do we decarbonize one billion vehicles by 2050? Insights from a comparative life cycle assessment of electrifying light-duty vehicle fleets in the United States, China, and the United Kingdom. *Energy Policy* **2024**, *195*, 114390. [CrossRef]
68. International Assistance Taskforce (IAT). ROADMAP TO 2030. Available online: https://zevtc.org/wp-content/uploads/2024/11/Global-ZEV-Roadmap_2024.pdf (accessed on 18 August 2025).
69. Gabhane, D.; Gabhane, M. Rising prices of petrol and diesel in India since 2014: An analytical study. *PalArch’s J. Archaeol. Egypt/Egyptol.* **2021**, *18*, 2309–2315.
70. Shende, V. Analysis of research in consumer behavior of automobile passenger car customer. *Int. J. Sci. Res. Publ.* **2014**, *4*, 1–8.
71. Vaidya, C.; Department of Economic Affairs, Ministry of Finance, GOI. *Urban Issues, Reforms and Way Forward in India*; Working Paper No. 4/2009-DEA; Department of Economic Affairs, Ministry of Finance, Government of India: New Delhi, India, 2009. Available online: <https://dea.gov.in/publications-working-papers> (accessed on 18 August 2025).
72. Tata Motors Limited (TML). Growing Responsibly. In Tata Motors Limited 79th Integrated Annual Report 2023–24. 2024. Available online: <https://static-assets.tatamotors.com/Production/www-tatamotors-com-NEW/wp-content/uploads/2024/05/tata-motor-IAR-2023-24.pdf> (accessed on 18 August 2025).
73. Mahindra & Mahindra Ltd. Sustainability Report. 2024. Available online: <https://www.mahindra.com/sites/default/files/2024-07/MM-Sustianability-Report-2024.pdf> (accessed on 18 August 2025).

74. Hyundai Motor Company. 2023 Sustainability Report. 2023. Available online: <https://www.hyundai.com/worldwide/en/company/sustainability> (accessed on 18 August 2025).
75. Suzuki Motor. Annual Integrated Report 2023–24. 2024. Available online: <https://www.marutisuzuki.com/corporate/investors> (accessed on 18 August 2025).
76. Ferronato, N.; Torretta, V. Waste mismanagement in developing countries: A review of global issues. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1060. [CrossRef] [PubMed]
77. Amasuomo, E.; Baird, J. The concept of waste and waste management. *J. Manag. Sustain.* **2016**, *6*, 88. [CrossRef]
78. Ali, A.; Audi, M.; Roussel, Y. Natural resources depletion, renewable energy consumption and environmental degradation: A comparative analysis of developed and developing world. *Int. J. Energy Econ. Policy* **2021**, *11*, 251–260. [CrossRef]
79. Committee, A.I.S. AIS-129: End-of-Life Vehicles; Automotive Research Association of India (ARAI): Pune, India, 2023.
80. Central Pollution Control Board. Battery Waste Management Rules, 2022. The Gazette of India, Extraordinary, Part II, Section 3(ii). 24 August 2022. Available online: <https://gemrecycling.com/wp-content/uploads/2023/04/Battery-Waste-Mgmt-Rules-2022.pdf> (accessed on 18 August 2025).
81. Central Pollution Control Board. Battery Waste Management (Amendment) Rules, 2024. The Gazette of India, Extraordinary, Part II, Section 3(ii). 14 March 2024. Available online: [https://eprbattery.cpcb.gov.in/upload/adminDoc/Battery_Waste_Management_\(Amendment\),_Rules_2024.pdf](https://eprbattery.cpcb.gov.in/upload/adminDoc/Battery_Waste_Management_(Amendment),_Rules_2024.pdf) (accessed on 18 August 2025).
82. Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India. Battery Waste Management (Second Amendment) Rules, 2024. The Gazette of India, Extraordinary, Part II, Section 3(ii). 20 June 2024. Available online: https://moef.gov.in/uploads/pdf-uploads/pdf_67656bdbc41dc6.21368137.pdf (accessed on 18 August 2025).
83. Central Pollution Control Board. E-Waste (Management) Rules, 2022. The Gazette of India, Extraordinary, Part II, Section 3(i). 2 November 2022. Available online: <https://www.mppcb.mp.gov.in/proc/E-Waste-Management-Rules-2022-English.pdf> (accessed on 18 August 2025).
84. Central Pollution Control Board. E-Waste (Second Amendment) Rules, 2023. The Gazette of India, Extraordinary, Part II, Section 3(i). 25 July 2023. Available online: [https://tgpcb.cgg.gov.in/Uploads/PcbDocumentAllUploads/EWaste\(Management\)AmendmentRules2023.pdf](https://tgpcb.cgg.gov.in/Uploads/PcbDocumentAllUploads/EWaste(Management)AmendmentRules2023.pdf) (accessed on 18 August 2025).
85. Central Pollution Control Board. E-Waste (Third Amendment) Rules, 2024. The Gazette of India, Extraordinary, Part II, Section 3(i). 9 March 2024. Available online: <https://www.legitquest.com/act/e-waste-management-amendment-rules-2024/F809#1> (accessed on 18 August 2025).
86. Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India. Hazardous Waste (Ninth Amendment) Rules, 2024. The Gazette of India, Extraordinary, Part II, Section 3(i). 13 March 2024. Available online: <https://cpcb.nic.in/uploads/hwmd/HOWM-Ninth-Amendment-Rules-2024.pdf> (accessed on 18 August 2025).
87. Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India. Plastic Waste Management (Amendment) Rules, 2024. The Gazette of India, Extraordinary, Part II, Section 3(i). 20 August 2024. Available online: <https://socialjustice.gov.in/writereaddata/UploadFile/amend-poa2011.pdf> (accessed on 18 August 2025).
88. Meshram, K.K. The circular economy, 5R framework, and green organic practices: Pillars of sustainable development and zero-waste living. *Discov. Environ.* **2024**, *2*, 147. [CrossRef]
89. Montemayor, H.M.V.; Chanda, R.H. Automotive industry's circularity applications and industry 4.0. *Environ. Chall.* **2023**, *12*, 100725. [CrossRef]
90. Balwan, W.K.; Singh, A.; Kour, S. 5R's of zero waste management to save our green planet: A narrative review. *Eur. J. Biotechnol. Biosci.* **2022**, *10*, 7–11.
91. Jabu, M.A.; Alugongo, A.; Nkomo, N. The Use and Recycling of Natural and Synthetic Fibre-Reinforced Polymeric Composites in the Automotive Industry: A Review. *Int. J. Eng. Trends Technol.* **2024**, *72*, 269–278. [CrossRef]
92. He, X.; Su, D.; Cai, W.; Pehlken, A.; Zhang, G.; Wang, A.; Xiao, J. Influence of material selection and product design on automotive vehicle recyclability. *Sustainability* **2021**, *13*, 3407. [CrossRef]
93. Ravina, M.; Bianco, I.; Ruffino, B.; Minardi, M.; Panepinto, D.; Zanetti, M. Hard-to-recycle plastics in the automotive sector: Economic, environmental and technical analyses of possible actions. *J. Clean. Prod.* **2023**, *394*, 136227. [CrossRef]
94. Sharma, D.S.; Anawade, P.A. Impact of sustainability and performance of automotive supply chain in the context of green innovation: An empirical Study. *Des. Eng.* **2023**, *9*, 13991–13999.
95. Czerwinski, F. Current trends in automotive lightweighting strategies and materials. *Materials* **2021**, *14*, 6631. [CrossRef] [PubMed]
96. Candela, A.; Sandrini, G.; Gadola, M.; Chindamo, D.; Magri, P. Lightweighting in the automotive industry as a measure for energy efficiency: Review of the main materials and methods. *Heliyon* **2024**, *10*, e29728. [CrossRef] [PubMed]
97. Simplay, S.; Haywood, S. *Architecting Next Generation Lightweight Vehicles*; Tata Technologies: Detroit, MI, USA, 2016.
98. Nowakowski, P. Reuse of automotive components from dismantled end of life vehicles. *Transp. Probl.* **2013**, *8*, 17–25.
99. Heisel, F.; Ciobanu, A.; McGranahan, J. Industry and Literature Review of Urban Mining Applications in the United States: Gaps and Drivers for Implementation Towards a Circular Industrialized Construction Economy. *J. Circ. Econ.* **2024**, *2*, 1–18. [CrossRef]

100. Ghisellini, P.; Ncube, A.; Casazza, M.; Passaro, R. Toward circular and socially just urban mining in global societies and cities: Present state and future perspectives. *Front. Sustain. Cities* **2022**, *4*, 930061. [CrossRef]
101. Koutamanis, A.; Van Reijn, B.; Van Bueren, E. Urban mining and buildings: A review of possibilities and limitations. *Resour. Conserv. Recycl.* **2018**, *138*, 32–39. [CrossRef]
102. Seif, R.; Salem, F.Z.; Allam, N.K. E-waste recycled materials as efficient catalysts for renewable energy technologies and better environmental sustainability. *Environ. Dev. Sustain.* **2023**, *26*, 5473–5508. [CrossRef] [PubMed]
103. Erdiaw-Kwasie, M.O.; Abunyewah, M.; Baah, C. A systematic review of the factors—Barriers, drivers, and technologies—Affecting e-waste urban mining: On the circular economy future of developing countries. *J. Clean. Prod.* **2024**, *436*, 140645. [CrossRef]
104. Schlezak, S.L.; Styer, J.E. Inclusive urban mining: An opportunity for engineering education. *Mining* **2023**, *3*, 284–303. [CrossRef]
105. Grant Thornton Bharat LLP. Telematics Ecosystem in India. In Automotive Component Manufacturers Association of India. Available online: https://www.acma.in/uploads/publication/research-studies/3_ACMA_Grant_Thornton_Bharat_White_Paper_on_Telematics_Ecosystem_in_India.pdf (accessed on 18 August 2025).
106. Król, A.; Rokicki, T. Telematics in car fleet management. *Zeszyty Naukowe Szkoły Głównej Gospodarstwa Wiejskiego w Warszawie. Ekon. Organ. Logistyki* **2021**, *6*, 49–57. [CrossRef]
107. Kumar, A.; Kheveria, S. 3C-Enabled Fleet Management: Enhancing Safety, Operational Efficiency, and User Experience. 2020. Available online: <https://www.marketsandmarkets.com/Market-Reports/-fleet-management-systems-market-1020.htm> (accessed on 18 August 2025).
108. Malik, S.; Dhall, R.; Tomar, A.S. InsurTech in insurance. *Int. J. Health Sci.* **2022**, *6*, 5276–5287. [CrossRef]
109. Committee, A.I.S. AIS-140: Intelligent Transportation Systems (ITS)—Requirements for Public Transport Vehicle Operation; Automotive Research Association of India (ARAI): Pune, India, 2026.
110. Brickwork Research. Automotive Telematics Market in India. Available online: <https://www.brickworkratings.com/Research/Automotive%20Telematics%20Market%20in%20India-Sep2024.pdf> (accessed on 18 August 2025).
111. Theissler, A.; Pérez-Velázquez, J.; Kettelgerdes, M.; Elger, G. Predictive maintenance enabled by machine learning: Use cases and challenges in the automotive industry. *Reliab. Eng. Syst. Saf.* **2021**, *215*, 107864. [CrossRef]
112. Solanki, V.K.; Dhall, R. An IoT Based Predictive Connected Car Maintenance Approach. *Int. J. Interact. Multimed. Artif. Intell.* **2017**, *4*, 16–22. [CrossRef]
113. Vasudevan, A.; Gandhimathi, K.; Mohammad, S.I.; Harsavarthini, M.; Raja, N.; Soon, E.E.H.; Abu-Shareha, A.A.; Alshurideh, M.T. Predictive Maintenance for Vehicle Performance using Bidirectional LSTM. *Appl. Math.* **2024**, *18*, 1469–1479. [CrossRef]
114. Aeddula, O.; Frank, M.; Ruvald, R.; Askling, C.J.; Wall, J.; Larsson, T. AI-Driven predictive maintenance for autonomous vehicles for product-service system development. *Procedia CIRP* **2024**, *128*, 84–89. [CrossRef]
115. Mahale, Y.; Kolhar, S.; More, A.S. A comprehensive review on artificial intelligence driven predictive maintenance in vehicles: Technologies, challenges and future research directions. *Discov. Appl. Sci.* **2025**, *7*, 243. [CrossRef]
116. Guyader, H.; Friman, M.; Olsson, L.E. Shared mobility: Evolving practices for sustainability. *Sustainability* **2021**, *13*, 12148. [CrossRef]
117. Vega-Gonzalo, M.; Gomez, J.; Christidis, P.; Vassallo, J.M. The role of shared mobility in reducing perceived private car dependency. *Transp. Res. Part D. Transp. Environ.* **2024**, *126*, 104023. [CrossRef]
118. Krishnan, V.; Hussain, M.E. A Study on Rapido's Strategies to Ensure Success and Sustainability. *IJFANS* **2022**, *11*, 610–612. Available online: <https://www.ijfans.org/uploads/paper/a281795ba4698eddac9d22969ad5c92d.pdf> (accessed on 18 August 2025).
119. KPMG India. The Future of Mobility in Post-COVID-19 India. 2020. Available online: <https://kpmg.com/in/en/home/insights.html> (accessed on 18 August 2025).
120. NITI Aayog; Rocky Mountain Institute; Observer Research Foundation. Moving Forward Together: Enabling Shared Mobility in India 2018. Available online: <https://www.niti.gov.in/sites/default/files/2023-02/Shared-mobility.pdf> (accessed on 18 August 2025).
121. Joshi, R.; Deshpande, P.; Borah, S.; Sharma, M. *Informal and Shared Mobility: Status and Opportunities in India*; Volvo Research and Education Foundation: Gothenburg, Sweden, 2023.
122. AIS-024 (Version 5); Safety and Procedural Requirements for Type Approval of CNG Operated Vehicles (Dedicated, Bi-Fuel & Dual Fuel). The Automotive Research Association of India: Pune, India, 2015.
123. AIS123 Part 3; CMVR Type Approval of Electric Propulsion Kit Intended for Conversion of Vehicles for Pure Electric Operation. The Automotive Research Association of India: Pune, India, 2025.
124. AIS-123 (Part 1) & Amd 1 and 2; CMVR Type Approval of Hybrid Electric System Intended for Retro-fitment on Vehicles of M and N Category having GVW =3500 Kg. The Automotive Research Association of India: Pune, India, 2018.
125. Patel, R.S.; Mishra, A. Scope of Retrofitting ICE Vehicle into E Vehicle in India. *Int. J. Sci. Eng. Technol.* **2023**, *11*, 5.
126. Hoeft, F. Internal combustion engine to electric vehicle retrofitting: Potential customer's needs, public perception and business model implications. *Transp. Res. Interdiscip. Perspect.* **2021**, *9*, 100330. [CrossRef]
127. Das, S.; Gulia, J.; JMK Research & Analytics. *Retrofitment Market EV*; JMK Research: Haryana, India, 2024.

128. Agarwal, S. Cost-Benefit Analysis of converting vintage cars into EVs in India. *IOSR J. Environ. Sci. Toxicol. Food Technol.* **2024**, *18*, 11–22. [CrossRef]
129. Indian Blue Book. *The Booming Indian Used Car Market: A Glimpse into the Future*; car&bike (Mahindra First Choice): Mumbai, India, 2024; Available online: <https://images.carandbike.com/data/IBB-Final-Report.pdf> (accessed on 18 August 2025).
130. Shankar, S.K.C. A study on consumer behavior towards Pre-Owned cars in India. *PARIPEX—Indian J. Res.* **2016**, *5*, 200–203.
131. Kumar, P.; Manish, A.; Kaushal, V. Is India's Used Car Market larger than previously thought? *J. Technol.* **2023**, *11*, 87–91.
132. Sun, Y.; Ying, L.; Zhang, J. Analysis of the Impact of Fintech on Small and Medium-sized Enterprises. In *2022 7th International Conference on Financial Innovation and Economic Development (ICFIED 2022)*; Atlantis Press: Dordrecht, The Netherlands, 2022; pp. 822–826.
133. Casals, L.C.; Amante García, B.; Canal, C. Second life batteries lifespan: Rest of useful life and environmental analysis. *J. Environ. Manag.* **2019**, *232*, 354–363. [CrossRef] [PubMed]
134. Song, H.; Chen, H.; Wang, Y.; Sun, X.-E. An Overview About Second-Life Battery Utilization for Energy Storage: Key Challenges and Solutions. *Energies* **2024**, *17*, 6163. [CrossRef]
135. Rustamkhon, M.; Alawadi, A.H.; Abbas, A.H.; Jayashree; Santhi, G.; Kumar, J.R.R. Second-Life Applications of Electric Vehicle Batteries in Energy Storage. In *E3S Web of Conferences*; EDP Sciences: Les Ulis, France, 2024; p. 02011.
136. Gattu, A.; Agrawal, A.; Chatterjee, A.; Mittal, D.; Khan, M.S.; Bagdia, R.; Singh, R.; Khan, S.M.; Singh, V. *Advanced Chemistry Cell Battery Reuse and Recycling Market in India*; NITI Aayog and Green Growth Equity Fund Technical Cooperation Facility: New Delhi, India, 2022. Available online: https://www.niti.gov.in/sites/default/files/2022-07/ACC-battery-reuse-and-recycling-market-in-India_Niti-Aayog_UK.pdf (accessed on 18 August 2025).
137. Etxandi-Santolaya, M.; Casals, L.C.; Corchero, C. Extending the electric vehicle battery first life: Performance beyond the current end of life threshold. *Heliyon* **2024**, *10*, e26066. [CrossRef] [PubMed]
138. Vu, F.; Rahic, M.; Chirumalla, K. Exploring second life applications for electric vehicle batteries. In *SPS2020*; IOS Press: Amsterdam, The Netherlands, 2020; pp. 273–284.
139. Iqbal, H.; Sarwar, S.; Kirli, D.; Shek, J.K.H.; Kiprakis, A.E. A survey of second-life batteries based on techno-economic perspective and applications-based analysis. *Carbon Neutrality* **2023**, *2*, 8. [CrossRef]
140. Fontana, A.; Rossi, L.; Nika, J.; Dell'AMBrogio, S.; Sorlini, M.; Pachon, E.R.; Rosa, P.; van Schaik, A.; Reuter, M. Enhancing the Sustainability of the Electronics in the Automotive Sector in the Context of Circular Economy Through a Decision-Making Framework. 2024 Electronics Goes Green 2024+ (EGG). In *2024 Electronics Goes Green 2024+(EGG)*; IEEE: New York, NY, USA, 2024.
141. Verna, E.; Puttero, S.; Saluto, P.; Guelfi, S.; Galetto, M. Integrating economic analysis and reliability assessment for sustainable management in the Italian used car market. *Chall. Sustain.* **2025**, *13*, 193–206. [CrossRef]
142. Hoai, B.T.M.; Khang, D.S. ESG Factors and Rating and Green Economy. In *Corporate Governance, Organizational Ethics, and Prevention Strategies Against Financial Crime*; Springer: Cham, Switzerland, 2025; pp. 177–201.
143. van Langen, S.K.; Patil, R.A.; Ramakrishna, S. Insights from ESG evaluation for circularity assessment. In *Circularity Assessment: Macro to Nano: Accountability Towards Sustainability*; Springer: Singapore, 2023; pp. 15–34.
144. Tarczynska-Luniewska, M.; Maciukaite-Zviniene, S.; Nareswari, N.; Ciptomulyono, U. Analysing the complexity of ESG integration in emerging economies: An examination of key challenges. In *Exploring ESG Challenges and Opportunities: Navigating Towards a Better Future*; Emerald Publishing Limited: Leeds, UK, 2024; pp. 41–60.
145. Picatoste, A.; Justel, D.; Mendoza, J.M.F. Exploring the applicability of circular design criteria for electric vehicle batteries. *Procedia CIRP* **2022**, *109*, 107–112. [CrossRef]
146. Patil, N.N.; Saurabh, S.; Bhardwaj, R.; Gawhade, R.; Gadve, D.; Amancharla, N.C. Overview of Indian Government Policies, Regulations and Automotive Company Strategies toward Net-zero Emissions. In *Proceedings of the KSAE/SAE 2025 Powertrain, Energy & Lubricants Conference & Exhibition, Busan, Republic of Korea, 22–25 June 2025*; SAE Technical Paper.
147. Modak, P. Circular economy practices in India. In *An Introduction to Circular Economy*; Springer: Singapore, 2021; pp. 555–575.
148. Singh, V.P.; Kumar, A.; Meena, C.S.; Dwivedi, G. (Eds.) *Energy Efficient Vehicles: Technologies and Challenges*; Advances in Manufacturing, Design and Computational Intelligence Techniques; CRC Press: Boca Raton, FL, USA, 2024; Available online: <https://www.routledge.com/Advances-in-Manufacturing-Design-and-Computational-Intelligence-Techniques/book-series/CRCAIMDCIT> (accessed on 18 August 2025).
149. Kunz, N.; Mayers, K.; Van Wassenhove, L.N. Stakeholder views on extended producer responsibility and the circular economy. *Calif. Manag. Rev.* **2018**, *60*, 45–70. [CrossRef]
150. Pruess, J.T.; Garrett, R.D. Potential effectiveness of extended producer responsibility: An ex-ante policy impact analysis for plastic packaging waste in Belgium, France, and Germany. *Resour. Conserv. Recycl.* **2025**, *219*, 108297. [CrossRef]
151. Compagnoni, M. Is Extended Producer Responsibility living up to expectations? A systematic literature review focusing on electronic waste. *J. Clean. Prod.* **2022**, *367*, 133101. [CrossRef]
152. Gupta, D.; Dash, S. Challenges of implementing extended producer responsibility for plastic-waste management: Lessons from India. *Soc. Responsib. J.* **2023**, *19*, 1595–1612. [CrossRef]

153. Steenmans, K. Perceived legal risks of extended producer responsibility. *Rev. Eur. Comp. Int. Environ. Law.* **2025**, *34*, 337–351. [\[CrossRef\]](#)
154. Manomaivibool, P. Network management and environmental effectiveness: The management of end-of-life vehicles in the United Kingdom and in Sweden. *J. Clean. Prod.* **2008**, *16*, 2006–2017. [\[CrossRef\]](#)
155. Kuo, T.-C.; Hsu, N.-Y.; Wattimena, R.; Hong, I.-H.; Chao, C.-J.; Herlianto, J. Toward a circular economy: A system dynamic model of recycling framework for aseptic paper packaging waste in Indonesia. *J. Clean. Prod.* **2021**, *301*, 126901. [\[CrossRef\]](#)
156. Ledakowicz, S.; Ziemińska-Stolarska, A. The role of life cycle assessment in the implementation of 1 circular economy in sustainable future. *Chem. Process Eng. New Front.* **2023**, *44*, e37. [\[CrossRef\]](#)
157. Stanciulescu, V.; Fleming, J.S. Life Cycle Assessment of Transportation Fuels and GHGenius. In *2006 IEEE EIC Climate Change Conference*; IEEE: New York, NY, USA, 2006.
158. Papasavva, S. Addressing Environmental Issues for the Automotive Industry. *MRS Proc.* **2005**, *895*, 107. [\[CrossRef\]](#)
159. Schulz-Mönnighoff, M.; Bey, N.; Nørregaard, P.U.; Niero, M. Integration of energy flow modelling in life cycle assessment of electric vehicle battery repurposing: Evaluation of multi-use cases and comparison of circular business models. *Resour. Conserv. Recycl.* **2021**, *174*, 105773. [\[CrossRef\]](#)
160. Cai, B.; Liu, Y. Automotive industry development versus environment and policy: An integration of system dynamics and life cycle assessment. *Int. Rev. Econ. Financ.* **2025**, *103*, 104382. [\[CrossRef\]](#)
161. Khandelwal, N.; Behera, S.K.; Kumar, A.; Gedam, V.V. Life Cycle Assessment and Circular Economy in Emerging Green and Sustainable Energy Sectors: A Critical Review. *Sustain. Energy Technol. Assess.* **2025**, *81*, 104436. [\[CrossRef\]](#)
162. Song, J.; Cui, G.; Han, Y.; Yao, X.; Shen, X.; Wang, Y. Review on environmental impacts of various types of power batteries using LCA. *Environ. Dev. Sustain.* **2025**, *27*, 1–25. [\[CrossRef\]](#)
163. Ezeudu, O.B. Harnessing the drivers and barriers to implementation of extended producer responsibility for circular economy in Nigeria. *Circ. Econ. Sustain.* **2024**, *4*, 1461–1486. [\[CrossRef\]](#)
164. Sarath, K.; Banerjee, R. Evolution of electric mobility policy in India: A historical analysis. In *Infrastructure Development—Theory, Practice and Policy*; Routledge: Abingdon, UK, 2022; pp. 142–156.
165. Venkatesan, M.; Annamalai, V. An institutional framework to address end-of-life vehicle recycling problem in India. In *Proceedings of the Symposium on International Automotive Technology 2017*, Pune, India, 18–21 January 2017; SAE Technical Paper.
166. Agrawal, R.; Wankhede, V.A.; Kumar, A.; Luthra, S. Analysing the roadblocks of circular economy adoption in the automobile sector: Reducing waste and environmental perspectives. *Bus. Strat. Environ.* **2021**, *30*, 1051–1066. [\[CrossRef\]](#)
167. Gayathiri, B.; Ahamed, S.B.I. Assessing Consumer Perceptions of Electric Vehicles in India Through the Lens of the Theory of Planned Behavior. *J. Inst. Eng. India Ser. A* **2025**, *106*, 155–174. [\[CrossRef\]](#)
168. Vijai; Wisetsri, W. Circular economy for sustainable development in India. In *Global Sustainability: Trends, Challenges & Case Studies*; Springer: Cham, Switzerland, 2024; pp. 61–87.
169. Imre, G.; Remsei, S. Towards Sustainability in the Automotive Industry—Circular Economic Practices of the Audi Group. *Chem. Eng. Trans.* **2023**, *107*, 211–216.
170. Srivastava, B.; Sowmya, S. Designing sustainable supply chains in India to create a circular economy. In *Handbook of Research on Designing Sustainable Supply Chains to Achieve a Circular Economy*; IGI Global: Hershey, PA, USA, 2023; pp. 538–553.
171. Nag, U.; Sharma, S.K.; Govindan, K. Investigating drivers of circular supply chain with product-service system in automotive firms of an emerging economy. *J. Clean. Prod.* **2021**, *319*, 128629. [\[CrossRef\]](#)
172. Jones, J.W.; Verma, B.P.; Nokes, S.; Verma, L.; Zazueta, F.; Rider, A. Toward circular food and agricultural systems. *Resour. Mag.* **2020**, *27*, 15–17.
173. Prochatzki, G.; Mayer, R.; Haenel, J.; Schmidt, A.; Götze, U.; Ulber, M.; Fischer, A.; Arnold, M.G. A critical review of the current state of circular economy in the automotive sector. *J. Clean. Prod.* **2023**, *425*, 138787. [\[CrossRef\]](#)
174. Du, B.; Bryson, J.R.; Qamar, A. Aspiring towards automotive circularity: A critical review and research agenda. *J. Environ. Manag.* **2025**, *380*, 125150. [\[CrossRef\]](#) [\[PubMed\]](#)
175. Molla, A.H.; Shams, H.; Harun, Z.; Ab Rahman, M.N.; Hishamuddin, H. An assessment of drivers and barriers to implementation of circular economy in the end-of-life vehicle recycling sector in India. *Sustainability* **2022**, *14*, 13084. [\[CrossRef\]](#)
176. Agyemang, M.; Kusi-Sarpong, S.; Khan, S.A.; Mani, V.; Tahaur Rehman, S.; Kusi-Sarpong, H. Drivers and barriers to circular economy implementation: An explorative study in Pakistan's automobile industry. *Manag. Decis.* **2019**, *57*, 971–994.
177. Sharma, M.; Jain, N.L.; Yashpal. Barriers Impacting the Circular Economy in Indian Manufacturing Industries: Modeling Through a Smartpls4-SEM Approach. *J. Inst. Eng. India Ser. C* **2025**, *106*, 991–1007. [\[CrossRef\]](#)
178. Saidani, M.; Kendall, A.; Yannou, B.; Leroy, Y.; Cluzel, F. Management of the end-of-life of light and heavy vehicles in the U.S.: Comparison with the European union in a circular economy perspective. *J. Mater. Cycles Waste Manag.* **2019**, *21*, 1449–1461. [\[CrossRef\]](#)
179. Kifor, C.V.; Grigore, N.A. Circular economy approaches for electrical and conventional vehicles. *Sustainability* **2023**, *15*, 6140. [\[CrossRef\]](#)

180. He, Z.; Sun, L.; Hijioka, Y.; Nakajima, K.; Fujii, M. Systematic review of circular economy strategy outcomes in the automobile industry. *Resour. Conserv. Recycl.* **2023**, *198*, 107203. [[CrossRef](#)]
181. Chong, J.Y.; Saman, M.Z.M.; Ngadiman, N.H.A. Sustainable remanufacturing management approaches and applications model in end-of-life vehicles: A critical review and classification. *J. Remanuf.* **2024**, *14*, 169–184. [[CrossRef](#)]
182. Baldassarre, B.; Maury, T.; Tazi, N.; Mathieux, F.; Sala, S. Increasing plastic circularity in the automotive sector: Supply chain analysis and policy options from the European Union (EU). *Resour. Conserv. Recycl.* **2025**, *218*, 108216. [[CrossRef](#)]
183. Kanellou, E.; Alexakis, K.; Kapsalis, P.; Kokkinakos, P.; Askounis, D. The DigiPrime KPIs' framework for a circular economy transition in the automotive industry. *Procedia Manuf.* **2021**, *54*, 302–307. [[CrossRef](#)]
184. Esteva, L.C.A.; Kasliwal, A.; Kinzler, M.S.; Kim, H.C.; Keoleian, G.A. Circular economy framework for automobiles: Closing energy and material loops. *J. Ind. Ecol.* **2021**, *25*, 877–889. [[CrossRef](#)]
185. Teena Bagga, N.K. Achieving Environment Sustainability in Automobile Sector: Application of Circular Economy in India. *Int. J. Environ. Sci.* **2021**, *7*, 1–6.
186. Kumar, N.; Mishra, A.; Kumar, D. Recovery of valuable metals from spent lithium-ion battery: Technologies, sustainability, and challenges in India. *Miner. Eng.* **2025**, *227*, 109312. [[CrossRef](#)]
187. Kumar, P.; Singh, R.K.; Paul, J.; Sinha, O. Analyzing challenges for sustainable supply chain of electric vehicle batteries using a hybrid approach of Delphi and Best-Worst Method. *Resour. Conserv. Recycl.* **2021**, *175*, 105879. [[CrossRef](#)]
188. Gopan, S.N.; Balaji, M. Comparative Studies on Adoption of Circular Economy Practices Across Indian Manufacturers. In *International Conference on Recent Advances in Industrial and Systems Engineering*; Springer: Singapore, 2023.
189. Suman, D.; Rajak, S. Assessing the key enablers for circular economy adoption for industrial symbiosis: Evidence from an Indian automotive component manufacturing industry. *Environ. Dev. Sustain.* **2025**, *27*, 1–33. [[CrossRef](#)]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.