CONCEPTUAL ANALYTICAL STUDY

ADHYAYAN Volume 15, Issue 1, 2025 Print ISSN: 2249-1066 Online ISSN: 2455-8656

Driving Sustainability: Exploring the Implementation, Opportunities, and Challenges of Circular Economy Practices in India's Automobile Industry

Atul Sharma*, Ajai Prakash

PhD Research Scholar, Department of Management, Faulty of Management Studies, University of Lucknow.

Abstract

The rapid expansion of India's automobile industry has contributed significantly to economic growth but has also raised concerns over resource depletion, environmental pollution, and waste management. The transition towards a circular economy presents a sustainable alternative to the traditional production model, emphasizing waste reduction, material reuse, remanufacturing, and recycling. This conceptual paper based on the existing literature, explores the implementation, opportunities, and challenges of circular economy practices in India's automobile industry, evaluating the extent to which manufacturers, policymakers, and consumers are adopting sustainable business strategies. The research paper begins by defining the core principles of the circular economy. It examines key initiatives by leading Indian automobile companies such as Tata Motors, Mahindra & Mahindra, and Maruti Suzuki, focusing on their recycling programs, remanufacturing efforts, and end-of-life vehicle (ELV) management. Government policies, including the Vehicle Scrappage Policy, Extended Producer Responsibility (EPR) framework, and the Faster Adoption and Manufacturing of Electric Vehicles (FAME) initiative, are assessed to understand their role in promoting circularity within the industry. This paper identifies significant economic, environmental, and social opportunities emerging from the adoption of circular economy strategies. These include cost savings from material efficiency, the creation of new revenue streams through refurbished vehicle parts, reductions in carbon emissions, and enhanced corporate reputation among environmentally conscious consumers. However, despite these benefits, several barriers hinder widespread adoption. Key challenges include inadequate recycling infrastructure, high initial costs of circular economy innovations, weak regulatory enforcement, and consumer resistance to second-hand and remanufactured automobile products. The study provides insights into how stakeholders can overcome these challenges and accelerate the transition toward a circular automotive ecosystem in India. It highlights the need for stronger policy enforcement, industry collaborations, investment in green technology, and increased consumer awareness. The findings contribute to the broader discourse on sustainable business practices and offer strategic recommendations for policymakers, automobile manufacturers, and supply chain partners to foster a more resilient and resource-efficient automotive sector. Ultimately, this paper underscores that integrating circular economy principles is not just an environmental imperative but also a business opportunity that can drive long-term economic sustainability while reducing the industry's ecological footprint. A collaborative approach involving government intervention, corporate responsibility, and consumer participation will be essential to unlocking the full potential of circular economy practices in India's automobile industry.

Keywords: Circular Economy, Sustainability, Recycling, Reuse.

Adhyayan: A Journal of Management Sciences (2025); DOI: 10.21567/adhyayan.v15i1.11

Introduction

The concept of circular economy has evolved over time, with its origins traced back to pre-1990s. The narrative of circular economy has developed through three distinct periods: pre-1990s, 1990-2010, and 2010-present and beyond, illustrating its historical progression and contemporary implications (Tuladhar et al., 2022). While the circular economy proposition is not a novel concept, it has recently gained prominence in stimulating sustainable consumption and production

Corresponding Author: Atul Sharma, PhD Research Scholar, Department of Management, Faulty of Management Studies, University of Lucknow., e-mail: atulsharmalko15@gmail.com

How to cite this article: Sharma, A., Prakash, A. (2025). Driving Sustainability: Exploring the Implementation, Opportunities, and Challenges of Circular Economy Practices in India's Automobile Industry. Adhyayan: A Journal of Management Sciences, 15(1):70-80.

Source of support: Nil

Conflict of interest: None

ideas, focusing on remanufacturing, refurbishing, and recycling of materials. The circular economy's regenerative systems aim to minimize industrial waste, emissions, and energy leakages through the creation of long-lasting designs that improve resource efficiencies(Mark Anthony Camilleri, 2019). The circular economy has emerged as a key driver in the development of sustainability in the current digital world (Fatimah et al., 2023). It is seen as a way to replace dominant traditional business models based solely on increasing economic value (Dagilienė & Varaniūtė, 2023). However, it's important to note that the concept is still ambiguously defined, and while it is believed to be a satisfactory remedy for expanding environmental pollution and waste overproduction, some premises suggest that rebound effects may offset such social benefits by increasing overall consumption (Bartoszczuk, 2023).

Circular economy is an integrative framework aimed at addressing environmental pollution and resource depletion by reforming manufacturing, production, consumption, and recycling across various economic sectors(Zeng et al., 2022). It presents an alternative to the current linear economic model, with the ambition of positively impacting the environment while contributing to economic growth (Rabta, 2020).

Circular economy aims to create closed-loop systems that minimize emissions, rely on renewable energy, and eliminate waste (Rodias et al., 2020). It encompasses both technical and biological cycles, though the distinction between these is not always clear-cut (Velenturf et al., 2019).

The adoption of CE practices in the Indian automobile sector can lead to improved economic and operational performance (Yu et al., 2022). Industry 4.0 technologies play a significant role in facilitating the transition from a linear to a circular economy model in manufacturing organizations (Sahoo & Jakhar, 2024). These technologies positively influence green procurement and remanufacturing activities, which in turn contribute to better circular economy performance.

Sustainability has become a major concern for organizations in the Indian automobile industry to integrate ecological and societal issues into their business strategies (Luthra et al., 2016). The rising global pressure from stakeholders regarding climate change and its implications for manufacturing has motivated companies to develop greater environmental responsibility and incorporate strategies for ecologically sustainable operations (Mathiyazhagan et al., 2021). This is particularly important for the Indian automotive sector to implement the requirements of the 'Green India Movement' as recommended by governmental decrees. Interestingly, while the automotive industry provides mobility and creates jobs, it also threatens the environment. Consumer pressure, government regulations, and stakeholder demands for a competitive edge have forced the automotive industry to consider their environmental and social impacts in addition to their economic status (Mathivathanan et al., 2018). This has led many automotive industry businesses to adopt Sustainable Supply Chain Management (SSCM) practices.

Objectives of the Study

- To analyze the implementation of circular economy practices in the Indian automobile manufacturers.
- To study the opportunities and challenges in adopting circular economy practices.

Literature Review

Key Circular Economy Theories (Figure 1)

Cradle-to-Cradle (C2C) Theory

Cradle-to-cradle theory is a sustainable design approach that aims to create products and systems with minimal environmental impact by ensuring materials can be continuously reused or recycled. This concept emphasizes the importance of closed-loop systems, where waste is eliminated and resources are perpetually reused (García-Serna et al., 2007). Interestingly, the application of cradle-to-cradle principles extends beyond product design to various industries and processes. For instance, in the fashion industry, it is suggested that retailers shift towards cradle-to-cradle (closed loop) lifecycle supply chains to address sustainability paradoxes and manage post-consumer textile waste more effectively (Rotimi et al., 2021).

Industrial Ecology

Industrial ecology is an emerging framework for environmental management that seeks to transform industrial systems to match their inputs and outputs with planetary and local carrying capacity (Lowe & Evans, 1995). It models urban systems on natural systems to increase efficiency and reduce resource consumption and disposal (Dunn & Steinemann, 1998). The goal is to move from linear to closed-loop systems in all realms of human production and consumption, bringing the industrial world closer to an ecological model. Interestingly, while

industrial ecology aims for collective sustainability, it must also be understood from individual company perspectives in terms of economic and environmental performance (Jacobsen, 2006). The concept integrates principles like renewability of resources, toxicity of emissions, material inputs, product recoverability, and process efficiency (Dewulf & Langenhove, 2004). Industrial symbiosis, a subdiscipline of industrial ecology, focuses on resource optimization among co-located companies, as exemplified by the Kalundborg complex in Denmark (Jacobsen, 2006); (Trokanas et al., 2014).

Regenerative Design

Developed by John T. Lyle, this approach focuses on restoring and improving natural ecosystems through design strategies. This approach goes beyond traditional sustainability practices by focusing on generating net-positive outcomes for the environment, society, and economy. It aligns human consciousness and actions with living systems principles, elevating sustainable development goals to regenerative development goals (Gibbons, 2020).

Regenerative Design represents a significant shift from current sustainable design practices, aiming to generate positive effects on both human and natural systems rather than merely reducing environmental impacts (Dervishaj, 2023). This approach aligns with the concept of 'regenerative sustainability,' which emphasizes a net-positive approach to sustainability and is rooted in the notion of 'procedural sustainability' (Robinson & Cole, 2015).

Performance Economy

The performance economy is a concept that goes beyond traditional interpretations of a circular economy, focusing on the maintenance and exploitation of stock, particularly manufactured capital, rather than linear or circular flows of materials or energy (Stahel, 2016). It represents a complete shift towards servicisation, where revenue is generated from providing services instead of selling goods.

Biomimicry

Biomimicry is an interdisciplinary approach that seeks to emulate nature's time-tested patterns, strategies, and systems to solve human problems and create sustainable solutions (Eldin et al., 2016). It involves studying and transferring principles or mechanisms from nature to address design challenges across various fields, including architecture, engineering, and product innovation (Ilieva et al., 2022).

The Blue Economy

The Blue Economy, introduced by Gunter Pauli, is one of the frameworks that contributes to the Ellen MacArthur Foundation's Circular Economy concept (Blomsma, 2018). It is part of a group of waste and resource management frameworks that aim to address environmental and economic challenges through innovative approaches to resource use and waste management. the Blue Economy concept likely aligns with other emerging approaches such as blue growth strategies and bioeconomy development, particularly in coastal and marine contexts (Albrecht, 2023).

Doughnut Economies

Doughnut Economics is a novel approach to economic development that aims to balance social and environmental sustainability. It provides a framework for operationalizing planetary boundaries and social foundations in societal development (Luukkanen et al., 2021). The model visualizes a "safe and just" space for humanity, represented by a doughnut shape, with social needs forming the inner ring and ecological limits forming the outer ring (Turner & Wills, 2022). This framework challenges traditional growth-focused economic models by emphasizing the need to meet human needs within environmental limits. It offers an alternative lens for considering economic development processes and policies at local, national, and international levels (Warnecke, 2023).

Overview of Indian Automobile Industry

The Indian automobile industry is one of the largest in the world, playing a crucial role in the country's economic growth. It contributes approximately 7.1% to India's GDP and provides employment to millions of people across manufacturing, sales, and service sectors (SIAM, 2023). The industry has seen significant transformations over the years, driven by technological advancements, changing consumer preferences, and government policies.

India is the fourth-largest automobile market globally and is expected to become the third-largest by 2030 (IBEF, 2023). The sector includes passenger vehicles (PVs), commercial vehicles (CVs), two-wheelers, three-wheelers, and electric vehicles (EVs). Two-wheelers dominate the market, accounting for nearly 75% of total vehicle sales, followed by passenger vehicles, which hold around 15% (SIAM, 2023). Companies like Maruti Suzuki, Tata Motors, Mahindra & Mahindra, and Hyundai are key players in the segment

Table 1: Contribution of automobile sector in India's GDP

Metric	*Contribution*
National GDP Contribution	Approximately 7.1%
Manufacturing GDP Contribution	Approximately 46%
Employment Generation	Direct and indirect employment for over 19 million people
Export Share	Accounts for 8% of India's total exports

The Indian automobile sector is a cornerstone of the nation's manufacturing industry, contributing significantly to both the overall Gross Domestic Product (GDP) and the manufacturing GDP (Table 1).

Product-as-a-service (PAAS) Model

Product-as-a-Service (PaaS) is a business model that shifts the focus from selling physical products to providing integrated solutions combining products and services. In this model, manufacturers offer customers access to products through service contracts, often charging for usage rather than ownership (Cohen & Whang, 1997); (Kuo & Wang, 2012).

The PaaS model emphasizes service-based products, where products are designed and innovated as tools to deliver services. This approach replaces traditional

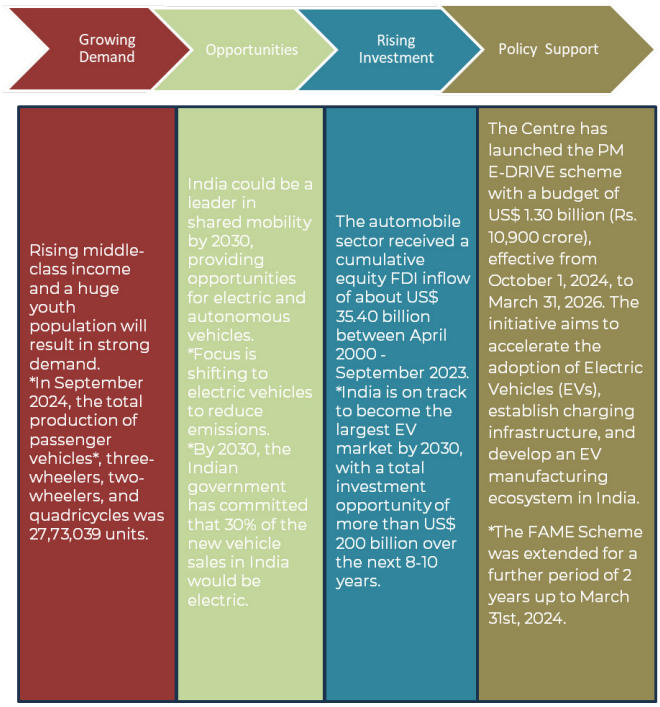

Figure 1: Key circular economy business models

Table 2: Automobile Production Trends

(In Numbers)

Category	*2018-19*					
Passenger Vehicles	40,28,471	3,424,564	30,62,280	36,50,698	45,87,116	49,01,844
Commercial Vehicles	11,12,405	7,56,725	6,24,939	8,05,527	10,35,626	10.66,429
Three Wheelers	12,68,833	1,132,982	6,14,613	7,58,669	8,55,696	9,92,936
Two Wheelers	2,44,99,777	2,10,32,927	18,349,941	1,78,21,111	1,94,59,009	2,14,68,527
Quadricycles	5,388	6,095	3,836	4,061	2,897	5,006
Grand Total	3,09,14,874	2,63,53,293	2,26,55,609	2,30,40,066	2,59,40,344	2,84,34,742

Table 3: Automobile Domestic Sales Trends

(In Numbers)

Category						
Passenger Vehicles	33,77,389	27,73,519	27,11,457	30,69,523	38,90,114	42 18,746
Commercial Vehicles	10,07,311	7,17,593	5,68,559	7,16,566	9,62,468	9,67,878
Three Wheelers	7,01,005	6,37,065	2,19,446	2,61,385	4,88,768	6,91,749
Two Wheelers	2,11,79,847	1,74,16,432	1,51,20,783	1,35,70,008	1,58,62,087	1,79,74,365
Quadricycles	627	942	-12	124	725	725
Grand Total	2,62,66,179	2,15,45,551	1,86,20,233	1,76,17,606	2,12,04,162	2,38,53,463

product-centric thinking with a more holistic view of customer needs and value creation. It allows companies to offer customized solutions that combine products and services, adapting to changing consumer attitudes and expectations for personalized offerings (Guillon et al., 2021) (Table 2).

Application in India

- Ola, Uber, and BluSmart offer ride-hailing services, reducing vehicle ownership and increasing fleet utilization.
- Zoomcar & Revv provide subscription-based car rentals.

Closed-Loop Recycling Model

Closed-loop recycling (CLR) is a model where materials are recycled and reused within the same production system, aiming to minimize waste and maximize resource efficiency. In chromatography, CLR involves continuously recycling the effluent from a column's outlet back into the feed line until the desired separation is achieved (Kostanyan, 2015). This technique has applications in various fields, including chemical separations and electronic waste management.

Application in India

- Government's Vehicle Scrappage Policy (2021) encourages recycling of old vehicles.
- Tata Steel & JSW Steel supply recycled steel for auto manufacturing.
- Recycling EV batteries (by Tata Chemicals & Attero) reduces lithium waste.

Remanufacturing & Refurbishment Model

Remanufacturing and refurbishment are industrial processes aimed at restoring used products or parts to extend their lifecycle and maintain their value. Remanufacturing involves restoring a product or part to "as-new" quality, while refurbishment restores it to "like-new" quality, though less thoroughly than remanufacturing(Zacharaki et al., 2021). These processes are integral to the circular economy model, which aims to keep products, components, and materials at their highest utility and value at all times (Leino et al., 2016).

Application in India

- Tata Motors & Mahindra offer remanufactured auto parts, reducing production costs & waste.
- E-waste refurbishers like Cashify & Attero extend the lifecycle of EV batteries.

Sharing Economy Model

The sharing economy model is a contemporary business approach that facilitates peer-to-peer exchanges of underutilized assets, often through digital platforms. It aims to increase resource efficiency and create new value for society by enabling collaborative consumption (Grondys, 2019); (Ritter & Schanz, 2019).

Application in India

- Ola, Uber, and Quick Ride promote ride-sharing to reduce traffic & emissions.
- Yulu & Bounce offer shared electric two-wheelers.

Extended Producer Responsibility (EPR) Model

Extended Producer Responsibility (EPR) is an environmental policy approach that extends a producer's responsibility for their products beyond the consumption stage to include the entire product lifecycle, particularly focusing on the post-consumer phase (Cai & Choi, 2021). This policy tool holds producers financially responsible for the collection, recycling, and disposal of their products after use (Gui, 2020). EPR aims to incentivize producers to make environmentally friendly design changes, such as improving product recyclability, reusability, reducing material usage, and downsizing products (Walls, 2006).

Application in India

- Maruti Suzuki's "Take Back" program collects and recycles old cars.
- EPR laws in India require automakers to manage plastic & battery waste responsibly.

Importance of Circular Economy Implementation in the Indian Automobile Sector

Resource Conservation and Cost Efficiency

The Indian automobile industry heavily depends on raw materials such as steel, aluminum, and rare earth metals, which are finite and subject to price fluctuations. By adopting circular economy practices, manufacturers can reduce reliance on virgin materials and focus on recycling and reusing existing resources (Table 3).

Waste Reduction and Environmental Sustainability

India generates a vast amount of automotive waste, including end-of-life vehicles (ELVs), batteries, and tires. If not managed properly, these waste materials can lead to severe environmental pollution. The circular economy encourages efficient dismantling and recycling of ELVs, ensuring that materials such as steel, plastic, and

rubber are reused rather than discarded. The recently introduced Vehicle Scrappage Policy (2021) by the Indian government is a significant step toward promoting sustainable waste management in the sector.

Job Creation and Economic Growth

A shift toward circular practices can create new employment opportunities in sectors such as vehicle refurbishment, battery recycling, and remanufacturing. Studies suggest that circular economy models could generate thousands of new jobs in India's automobile sector, boosting the local economy while promoting sustainability (NITI Aayog, 2021). Companies like Mahindra & Mahindra have already started investing in circular economy initiatives, contributing to employment growth in the green sector.

Compliance with Regulatory Standards

India is increasingly tightening its environmental regulations to meet global sustainability goals. The Bharat Stage (BS) VI emission norms and extended producer responsibility (EPR) policies encourage automakers to adopt greener practices. Implementing a circular economy not only ensures compliance with these regulations but also enhances a company's reputation and market competitiveness.

Consumer Demand for Sustainable Mobility

India is increasingly tightening its environmental regulations to meet global sustainability goals. The Bharat Stage (BS) VI emission norms and extended producer responsibility (EPR) policies encourage automakers to adopt greener practices. Implementing a circular economy not only ensures compliance with these regulations but also enhances a company's reputation and market competitiveness.

Key Circular Economy initiatives of TATA Motors

Tata Motors has been actively integrating circular economy principles into its operations through several key initiatives:

1. TATVA Framework

Launched to embed circularity across the business, the TATVA framework focuses on four main pathways: Materials, Energy, Lifetime, and Utilization. This comprehensive approach aims to optimize resource use and minimize waste throughout the product lifecycle. (Shahkar Abidi & Ketan Thakkar, 2024)

2. Re.Wi.Re (Recycle with Respect) Facilities

To address end-of-life vehicle (ELV) management, Tata Motors has established Re.Wi.Re facilities across various cities, including Pune, Jaipur, Bhubaneshwar, Surat, Chandigarh, and Delhi. These centers utilize eco-friendly recycling methods to dismantle and recycle vehicles responsibly, ensuring minimal environmental impact. (Central Desk, 2024)

3. Tata Prolife

Through the Prolife initiative, Tata Motors refurbishes used vehicle components—such as engines, gearboxes, and power steering systems—to original equipment specifications. This program extends the lifespan of parts, reduces the need for new materials, and offers cost-effective solutions to customers. (TATA Motors, n.d.)

4. Renewable Energy Integration

Demonstrating a commitment to sustainable energy, Tata Motors has installed 109 MW of renewable energy capacity and plans to add approximately 300 MW in the next three years. This initiative aims to achieve 100% renewable electricity usage in operations by 2030, significantly reducing the company's carbon footprint. (TATA Motors, n.d.)

5. REALCAR Project

In partnership with Jaguar Land Rover, Tata Motors has implemented the REALCAR (Recycled Aluminium Car) project. This initiative focuses on creating a closed-loop system for aluminum, recycling materials from end-of-life vehicles into new car production, thereby conserving resources and reducing environmental impact.

Key Circular Economy Initiatives of Mahindra & Mahindra

1. CERO Recycling

In partnership with MSTC, Mahindra established CERO, India's first authorized facility for recycling end-of-life vehicles (ELVs). CERO ensures environmentally friendly dismantling and recycling processes, recovering valuable materials and reducing waste. (Mahindra, n.d.)

2. Waste-to-Energy Conversion

Through its subsidiary, Mahindra Waste to Energy Solutions Limited (MWTESL), the company specialized in converting municipal wet waste into Bio-CNG via bio-methanation. This initiative not only provided a sustainable energy source but also addressed urban waste management challenges. In 2024, MWTESL was acquired by Blue Planet Environmental Solutions, aiming to enhance waste-to-energy solutions and promote circular economy practices. (Blue Planet Environmental Solutions, 2024)

3. Sustainable Manufacturing Practices

Mahindra's automotive manufacturing plants emphasize energy efficiency and resource conservation. Initiatives include installing rooftop solar photovoltaic systems and wind energy solutions to meet a significant portion of their electricity needs. The company also focuses on water conservation through rainwater harvesting, sewage treatment plants, and recycling processes. Waste management protocols ensure that hazardous wastes are recycled or disposed of responsibly, while non-hazardous production waste is maximized for recycling, aligning with circular economy principles. (Udaipur Times, n.d.)

4. Eco-Friendly Product Design

Mahindra incorporates sustainable materials into its vehicles, such as recycled plastics, bio-based fabrics, and polyester fibers derived from PET bottles. These practices reduce dependence on newly sourced materials and support waste reduction. Additionally, the company enhances fuel efficiency through advanced engine designs and aerodynamic improvements, contributing to resource conservation.

5. Tech Mahindra's 4R Policy

Tech Mahindra, a subsidiary of the Mahindra Group, adopts a 4R policy: Reduce, Recover, Reuse, and Recycle. This approach aims to minimize the utilization of natural resources, recover and reuse materials wherever possible, and explore recycling opportunities, thereby promoting a circular economy within its operations. (Tech Mahindra, 2024)

Key Circular Economy Initiatives of Maruti Suzuki

1. Renewable Energy Integration

The company is enhancing its use of renewable energy by installing solar power plants at its facilities. By FY 2024-25, Maruti Suzuki aims to meet over 30% of its power requirements through renewable sources, significantly reducing its carbon footprint.

2. Vehicle Recycling and End-of-Life Management

In collaboration with the Toyota Tsusho Group, Maruti Suzuki established Maruti Suzuki Toyotsu India Private Limited, a joint venture focused on the proper dismantling and recycling of end-of-life vehicles (ELVs). This initiative, operational since October 2021, aims to reduce illegal dumping and environmental pollution by ensuring safe processing of recyclable resources. (Suzuki, n.d.)

3. Sustainable Manufacturing Practices

Maruti Suzuki has implemented the 3R (Reduce, Reuse, Recycle) principle across its operations. The company recycles 100% of metallic scrap generated during vehicle manufacturing and meets nearly 65% of its water requirements through recycling processes. Additionally, over 45% of packaging materials for exporting Knocked Down (KD) kits and components are reused, minimizing waste and promoting resource efficiency.

4. Eco-Friendly Product Design

All vehicles manufactured by Maruti Suzuki are designed to be at least 90% recyclable, ensuring minimal waste at the end of their lifecycle. The company focuses on using sustainable materials and designs that facilitate easy disassembly and recycling, aligning with circular economy principles.

5. Lightweight Vehicle Platforms

Suzuki Motor Corporation, Maruti Suzuki's parent company, is advancing its HEARTECT platform to reduce vehicle weight by an additional 100 kg. This weight reduction enhances fuel efficiency for gasoline and hybrid vehicles and extends the range for electric vehicles, contributing to energy conservation and reduced resource consumption. (HT Auto Desk, 2024)

6. Electric Vehicle (EV) Infrastructure Development

To support the adoption of electric vehicles, Maruti Suzuki plans to install fast charging points every 5 to 10 kilometers in India's top 100 cities. This extensive charging network aims to alleviate consumer concerns about EV infrastructure and promote the transition to sustainable mobility solutions. (HT Auto Desk, 2024)

Opportunities in Circular Economy in the Indian Automobile Sector

Recycling and End-of-Life Management

India generates a significant volume of end-of-life vehicles (ELVs) annually. Establishing a well-structured ELV recycling ecosystem can recover valuable materials such as steel, aluminum, and plastics, reducing the dependency on raw resources. The implementation of the Vehicle Scrappage Policy (2021) (Ministry of Road Transport & Highways azadi ka amrit mahotsav, 2024) is a crucial step in this direction, encouraging systematic recycling and phasing out older, polluting vehicles.

Remanufacturing and Component Reuse

Automakers can adopt remanufacturing strategies where used parts are restored to like-new conditions. This

process significantly reduces energy consumption and material waste. Several global automobile companies have successfully integrated remanufacturing, and Indian manufacturers can leverage this model to enhance cost efficiency and sustainability.

Sustainable Material Use

The adoption of biodegradable and recyclable materials in vehicle manufacturing can lower environmental footprints. For instance, the use of bioplastics, natural fibers, and recycled metals can reduce raw material extraction and waste generation.

Battery Recycling and Second-life Applications

With the rise of electric vehicles (EVs), battery waste management has become a priority. Developing an efficient lithium-ion battery recycling infrastructure and exploring second-life applications for used EV batteries in energy storage systems can significantly enhance sustainability in the sector.

Extended Producer Responsibility (EPR)

Enforcing EPR regulations can hold automakers accountable for the entire lifecycle of their products, ensuring better waste management and material recovery

Key Challenges in the Circular Economy

Inadequate Infrastructure

The lack of advanced infrastructure for recycling and remanufacturing is a major hurdle. India requires substantial investments in modern facilities and technologies to process and reuse automotive materials effectively.'

Policy and Regulatory Support

There is a need for robust policies and regulations to promote circular economy practices. The absence of clear guidelines and incentives can deter companies from adopting sustainable practices. Government intervention through supportive policies and incentives is crucial for driving the transition.

Economic Viability

Implementing circular economy principles can be economically challenging for businesses. High initial investments in technology and infrastructure, along with uncertain returns, can make it difficult for companies to justify the shift. Financial incentives and support mechanisms are needed to make the transition economically viable.

Consumer Awareness and Participation

Educating consumers about the benefits of the circular economy and encouraging their participation is essential. Without consumer buy-in, initiatives such as recycling programs and remanufactured products may face low adoption rates. Awareness campaigns and incentives can play a vital role in changing consumer behavior.

Complex Supply Chains

The complexity of automotive supply chains can complicate the implementation of circular practices. Coordinating efforts across multiple stakeholders, ensuring product quality, and managing costs are critical challenges that need to be addressed.

Conclusion

The Indian automobile industry stands at a critical juncture where embracing circular economy principles can lead to substantial environmental and economic benefits. The sector has shown promising initiatives in areas such as recycling, remanufacturing, and sustainable material use. The government's Vehicle Scrappage Policy and the push towards electric vehicles demonstrate a growing commitment to sustainability. However, the transition to a fully circular model is hindered by infrastructural limitations, regulatory gaps, economic uncertainties, and limited consumer awareness.

Despite these challenges, the potential for innovation and sustainable growth in the sector remains substantial. The adoption of circular economy practices can not only reduce the industry's environmental footprint but also create new business opportunities, enhance resource efficiency, and contribute to India's broader sustainability goals.

Recommendations

1. Develop robust infrastructure

Invest in advanced recycling and remanufacturing facilities to support end-of-life vehicle management and material recovery.

2. Strengthen policy framework

Implement comprehensive policies and regulations that incentivize circular economy practices and provide clear guidelines for industry stakeholders.

3. Promote research and innovation

Encourage collaboration between industry, academia, and government to develop innovative solutions for sustainable material use and product design.

4. Enhance consumer awareness

Launch educational campaigns to inform consumers about the benefits of circular economy practices and their role in supporting sustainable consumption.

5. Provide financial incentives

Introduce tax benefits, subsidies, or grants to support companies transitioning to circular business models, making the shift economically viable.

6. Establish industry standards

Develop and enforce standards for remanufactured parts and recycled materials to ensure quality and build consumer trust.

7. Foster collaboration

Encourage partnerships within the industry and across sectors to create efficient closed-loop systems and share best practices.

8. Invest in skills development

Train workforce in circular economy principles, remanufacturing techniques, and sustainable design to support the transition.

9. Leverage digital technologies

Utilize Industry 4.0 technologies to optimize resource use, improve traceability, and enhance circular economy performance.

10. Scale up electric vehicle ecosystem

Focus on developing a comprehensive EV battery recycling and second-life application infrastructure to address emerging sustainability challenges.

By addressing these recommendations, the Indian automobile industry can overcome current challenges and capitalize on the opportunities presented by the circular economy, leading to a more sustainable and competitive sector.

References

Albrecht, M. (2023). A Norwegian seaweed utopia? Governmental narratives of coastal communities, upscaling, and the industrial conquering of ocean spaces. *Maritime Studies*, *22*(3), 37. https://doi.org/10.1007/s40152-023-00324-2

Bartoszczuk, P. (2023). Circular economy and its restriction. *Economics and Environment*, *86*(3), 469–482. https://doi.org/10.34659/eis.2023.86.3.650

Blomsma, F. (2018). Collective 'action recipes' in a circular economy – On waste and resource management frameworks and their role in collective change. *Journal of Cleaner Production*, *199*, 969–982. https://doi.org/10.1016/j.jclepro.2018.07.145

Blue Planet Environmental Solutions. (2024, February 15). *Blue Planet Boosts Circular Economy with a majority stake in Mahindra Waste to Energy*.

Cai, Y.-J., & Choi, T.-M. (2021). Extended Producer Responsibility: A Systematic Review and Innovative Proposals for Improving Sustainability. *IEEE Transactions on Engineering Management*, *68*(1), 272–288. https://doi.org/10.1109/TEM.2019.2914341

Central Desk. (2024, December 3). *Tata Motors Unveils Eco-Friendly Re.Wi.Re Vehicle Scrapping Hub*. Auto World Journal.

Cohen, M. A., & Whang, S. (1997). Competing in Product and Service: A Product Life-Cycle Model. *Management Science*, *43*(4), 535–545. https://doi.org/10.1287/mnsc.43.4.535

Dagilienė, L., & Varaniūtė, V. (2023). Transitioning to a Circular Economy: Paradoxical Tensions of the Circular Business Model. *Organization & Environment*, *36*(4), 559–589. https://doi.org/10.1177/10860266231213108

Dervishaj, A. (2023). From Sustainability to Regeneration: a digital framework with BIM and computational design methods. *Architecture, Structures and Construction*, *3*(3), 315–336. https://doi.org/10.1007/s44150-023-00094-9

Dunn, B. C., & Steinemann, A. (1998). Industrial Ecology for Sustainable Communities. *Journal of Environmental Planning and Management*, *41*(6), 661–672. https://doi.org/10.1080/09640569811353

García-Serna, J., Pérez-Barrigón, L., & Cocero, M. J. (2007). New trends for design towards sustainability in chemical engineering: Green engineering. *Chemical Engineering Journal*, *133*(1–3), 7–30. https://doi.org/10.1016/j.cej.2007.02.028

Gibbons, L. V. (2020). Regenerative—The New Sustainable? *Sustainability*, *12*(13), 5483. https://doi.org/10.3390/su12135483

Grondys, K. (2019). Implementation of the Sharing Economy in the B2B Sector. *Sustainability*, *11*(14), 3976. https://doi.org/10.3390/su11143976

Gui, L. (2020). Recycling Infrastructure Development under Extended Producer Responsibility in Developing Economies. *Production and Operations Management*, *29*(8), 1858–1877. https://doi.org/10.1111/poms.13202

Guillon, D., Ayachi, R., Vareilles, É., Aldanondo, M., Villeneuve, É., & Merlo, C. (2021). Product service system configuration: a generic knowledge-based model for commercial offers. *International Journal of Production Research*, *59*(4), 1021–1040. https://doi.org/10.1080/00207543.2020.1714090

HT Auto Desk. (2024, July 17). *Suzuki unveils sustainability roadmap: Lighter cars, focus on EVs*. Hindustan Times.

Ilieva, L., Ursano, I., Traista, L., Hoffmann, B., & Dahy, H. (2022). Biomimicry as a Sustainable Design Methodology—Introducing the 'Biomimicry for Sustainability'

Framework. *Biomimetics*, *7*(2), 37. https://doi.org/10.3390/biomimetics7020037

Jacobsen, N. B. (2006). Industrial Symbiosis in Kalundborg, Denmark: A Quantitative Assessment of Economic and Environmental Aspects. *Journal of Industrial Ecology*, *10*(1–2), 239–255. https://doi.org/10.1162/108819806775545411

Kostanyan, A. E. (2015). Simple equations to simulate closed-loop recycling liquid–liquid chromatography: Ideal and non-ideal recycling models. *Journal of Chromatography A*, *1423*, 71–78. https://doi.org/10.1016/j.chroma.2015.10.052

Kuo, T. C., & Wang, M. L. (2012). The optimisation of maintenance service levels to support the product service system. *International Journal of Production Research*, *50*(23), 6691–6708. https://doi.org/10.1080/00207543.2011.616916

Leino, M., Pekkarinen, J., & Soukka, R. (2016). The Role of Laser Additive Manufacturing Methods of Metals in Repair, Refurbishment and Remanufacturing – Enabling Circular Economy. *Physics Procedia*, *83*, 752–760. https://doi.org/10.1016/j.phpro.2016.08.077

Lowe, E. A., & Evans, L. K. (1995). Industrial ecology and industrial ecosystems. *Journal of Cleaner Production*, *3*(1–2), 47–53. https://doi.org/10.1016/0959-6526(95)00045-G

Luthra, S., Garg, D., & Haleem, A. (2016). The impacts of critical success factors for implementing green supply chain management towards sustainability: an empirical investigation of Indian automobile industry. *Journal of Cleaner Production*, *121*, 142–158. https://doi.org/10.1016/j.jclepro.2016.01.095

Luukkanen, J., Vehmas, J., & Kaivo-oja, J. (2021). Quantification of Doughnut Economy with the Sustainability Window Method: Analysis of Development in Thailand. *Sustainability*, *13*(2), 847. https://doi.org/10.3390/su13020847

Mahindra. (n.d.). *Planet Positive*. Mahindra.

Mark Anthony Camilleri. (2019). Closing the loop for resource efficiency, sustainable consumption and production: a critical review of the circular economy. *International Journal of Sustainable Development*, *21*(04), 01–17.

Mathivathanan, D., Kannan, D., & Haq, A. N. (2018). Sustainable supply chain management practices in Indian automotive industry: A multi-stakeholder view. *Resources, Conservation and Recycling*, *128*, 284–305. https://doi.org/10.1016/j.resconrec.2017.01.003

Mathiyazhagan, K., Agarwal, V., Appolloni, A., Saikouk, T., & Gnanavelbabu, A. (2021). Integrating lean and agile practices for achieving global sustainability goals in Indian manufacturing industries. *Technological Forecasting and Social Change*, *171*, 120982. https://doi.org/10.1016/j.techfore.2021.120982

Ministry of Road Transport & Highways azadi ka amrit mahotsav. (2024, November 28). *Vehicle Scrappage Policy*. Press Information Bureau (PIB).

Rabta, B. (2020). An Economic Order Quantity inventory model for a product with a circular economy indicator. *Computers & Industrial Engineering*, *140*, 106215. https://doi.org/10.1016/j.cie.2019.106215

Ritter, M., & Schanz, H. (2019). The sharing economy: A comprehensive business model framework. *Journal of Cleaner Production*, *213*, 320–331. https://doi.org/10.1016/j.jclepro.2018.12.154

Robinson, J., & Cole, R. J. (2015). Theoretical underpinnings of regenerative sustainability. *Building Research & Information*, *43*(2), 133–143. https://doi.org/10.1080/09613218.2014.979082

Rodias, E., Aivazidou, E., Achillas, C., Aidonis, D., & Bochtis, D. (2020). Water-Energy-Nutrients Synergies in the Agrifood Sector: A Circular Economy Framework. *Energies*, *14*(1), 159. https://doi.org/10.3390/en14010159

Rotimi, E. O. O., Topple, C., & Hopkins, J. (2021). Towards A Conceptual Framework of Sustainable Practices of Post-consumer Textile Waste at Garment End of Lifecycle: A Systematic Literature Review Approach. *Sustainability*, *13*(5), 2965. https://doi.org/10.3390/su13052965

Sahoo, S., & Jakhar, S. K. (2024). Industry 4.0 deployment for circular economy performance—Understanding the role of green procurement and remanufacturing activities. *Business Strategy and the Environment*, *33*(2), 1144–1160. https://doi.org/10.1002/bse.3542

Shahkar Abidi, & Ketan Thakkar. (2024, May 31). *Tata Motors reiterates commitment to circularity with "TATVA" framework*. Autocar Professional.

Stahel, W. R. , & C. R. (2016). Stocks and flows in the performance economy. *Taking Stock of Industrial Ecology*, 137–158.

Suzuki. (n.d.). *Resource Circulation*.

TATA Motors. (n.d.). *Planet resilience Towards impact neutrality*. TATA Motors.

Tech Mahindra. (2024). *Environmental Policy*.

Trokanas, N., Cecelja, F., & Raafat, T. (2014). Semantic input/output matching for waste processing in industrial symbiosis. *Computers & Chemical Engineering*, *66*, 259–268. https://doi.org/10.1016/j.compchemeng.2014.02.010

Tuladhar, A., Iatridis, K., & Dimov, D. (2022). History and evolution of the circular economy and circular economy business models. In *Circular Economy and Sustainability* (pp. 87–106). Elsevier. https://doi.org/10.1016/B978-0-12-819817-9.00031-4

Turner, R. A., & Wills, J. (2022). Downscaling doughnut economics for sustainability governance. *Current Opinion in Environmental Sustainability*, *56*, 101180. https://doi.org/10.1016/j.cosust.2022.101180

Udaipur Times. (n.d.). *Exploring Mahindra's Sustainability Initiatives in the Auto Industry*. Udaipur Times.

Velenturf, A. P. M., Archer, S. A., Gomes, H. I., Christgen, B., Lag-Brotons, A. J., & Purnell, P. (2019). Circular economy and the matter of integrated resources. *Science of The Total Environment*, *689*, 963–969. https://doi.org/10.1016/j.

scitotenv.2019.06.449

Walls, M. (2006). Extended Producer Responsibility and Product Design: Economic Theory and Selected Case Studies. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.901661

Warnecke, T. (2023). Operationalizing the Doughnut Economy: An Institutional Perspective. *Journal of Economic Issues*, *57*(2), 643–653. https://doi.org/10.1080/00213624.2023.2202570

Yu, Z., Khan, S. A. R., & Umar, M. (2022). Circular economy practices and industry 4.0 technologies: A strategic move of automobile industry. *Business Strategy and the Environment*, *31*(3), 796–809. https://doi.org/10.1002/bse.2918

Zacharaki, A., Vafeiadis, T., Kolokas, N., Vaxevani, A., Xu, Y., Peschl, M., Ioannidis, D., & Tzovaras, D. (2021). RECLAIM: Toward a New Era of Refurbishment and Remanufacturing of Industrial Equipment. *Frontiers in Artificial Intelligence*, *3*. https://doi.org/10.3389/frai.2020.570562

Zeng, X., Ogunseitan, O. A., Nakamura, S., Suh, S., Kral, U., Li, J., & Geng, Y. (2022). Reshaping global policies for circular economy. *Circular Economy*, *1*(1), 100003. https://doi.org/10.1016/j.cec.2022.100003