



TOWARD A GREENER FUTURE: INDIA'S ADVANCES IN SUSTAINABLE MANUFACTURING

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ABSTRACT

India is increasingly prioritizing sustainable manufacturing as it seeks to harmonize economic development with environmental responsibility. This study evaluates the country's advancements in implementing green industrial practices aligned with Sustainable Development Goal 9 (SDG-9), which advocates for sustainable industrial growth. The research delves into the significant policies and initiatives that are facilitating the transition to environmentally friendly manufacturing, such as improvements in renewable energy, resource efficiency, and waste minimization. Additionally, it investigates the impact of government incentives, innovations within the industry, and the obstacles encountered in expanding sustainable manufacturing practices. The results underscore both the achievements and shortcomings in India's path toward greener industries, providing suggestions for enhancing progress in the years ahead.

Keywords: Sustainable Industry, Clean Energy, Efficient Resource Use, Sustainable Development Goal 9.

INTRODUCTION:

India is at a crucial point in its industrial development, working to balance swift economic growth with environmental sustainability. As the country aims to reach a \$7 trillion economy by 2030, sustainable manufacturing has become a key element of this change. A 2024 study by PwC India indicated that 93% of Indian manufacturers are focusing on sustainability, with the goal of achieving a 2–3x increase in profits over the next three to five years by adopting Industry 5.0 technologies. The government's dedication to green industrialization is reflected in significant investments and policy measures. Renewable energy investments are expected to rise by 83% to \$16.5 billion in 2024, in line with India's ambitious goal of attaining 500 GW

of renewable energy capacity by 2030. The National Green Hydrogen Mission, launched with a budget of ₹19,744 crore, aims to establish India as a global leader in green hydrogen production, targeting an annual output of 5 million metric tonnes by 2030. In the steel industry, India has implemented a classification system for 'green steel' based on carbon emissions, encouraging the use of cleaner production techniques. Furthermore, the textile sector is experiencing a sustainable transformation, with plans to increase its value to \$350 billion by 2030 while complying with strict environmental standards. These collective efforts highlight India's commitment to embedding sustainability into its manufacturing framework. This paper explores the recent developments, policy structures, and sector-specific initiatives driving India's path toward sustainable manufacturing.

Sustainable manufacturing has become an essential approach for balancing industrial development with environmental protection, especially in rapidly developing nations such as India. As the global economy faces the challenges of climate change, resource scarcity, and environmental harm, there is a growing emphasis on sustainable practices in the industrial sector. This concept encompasses the production of goods through economically viable methods that reduce environmental harm while conserving energy and natural resources. It also involves measures to ensure worker safety and enhance operational efficiency. For India, one of the world's fastest-growing economies, transitioning to sustainable manufacturing is crucial not only for ecological sustainability but also for remaining competitive in global markets that increasingly prioritize environmentally friendly products and processes.

Theoretical Framework:

Sustainable Manufacturing in India Sustainable manufacturing focuses on creating and managing industrial processes that reduce environmental harm, conserve energy and natural resources, and remain economically feasible. In India, this strategy is crucial for tackling issues such as elevated carbon emissions, resource limitations, and the necessity for inclusive economic growth. Key elements of sustainable manufacturing encompass: Energy Efficiency: Adopting technologies and methods that lower energy usage in manufacturing operations. Renewable Energy Integration: Transitioning from fossil fuels to renewable energy options like solar, wind, and green hydrogen. Circular Economy Practices: Encouraging recycling, reuse, and waste minimization to establish closed-loop systems. Green Supply Chains: Applying sustainability principles throughout the supply chain, from raw materials to final products. Policy and Regulatory Support: Creating and enforcing regulations that promote sustainable practices and penalize environmental violations.

Recent Updates and Insights (2024–2025):

- ❖ Growth in Renewable Energy India's renewable energy capacity reached 190.57 GW by March 2024, representing 43.12% of the overall power generation capacity. The government is targeting 500 GW of non-fossil fuel capacity by 2030, in line with its Paris Agreement commitments.
- ❖ National Green Hydrogen Initiative Initiated in January 2023 with a budget of ₹19,744 crore, this initiative aims to produce 5 million tonnes of green hydrogen annually by 2030. It is projected to draw investments of ₹8 lakh crore and generate numerous jobs in the green energy sector.

- ❖ Adoption of Industry 5.0 A report from PwC India reveals that 93% of Indian manufacturers are adopting Industry 5.0 to enhance sustainability and profitability. More than 50% are investing in sustainable practices, utilizing digital technologies to improve energy efficiency and minimize environmental impact.
- ❖ Green Steel Initiatives India is introducing incentives to encourage green steel production, with the goal of lowering carbon emissions in the steel sector. The proposed policy includes support for renewable energy use in steel manufacturing and requires a specific percentage of green steel in public infrastructure projects.
- ❖ Transformation of the Textile Industry India aims to increase the value of its fashion sector to \$350 billion by 2030 while halving emissions. Initiatives such as the Future Forward Factory project focus on establishing near-net-zero textile facilities, prioritizing energy efficiency and the use of renewable energy.

Literature Review:

- Sustainable manufacturing in India is in its nascent stages, but various industries have begun implementing greener practices. According to Jadhav and Kharpude (2022), sustainable manufacturing in India is primarily characterized by increased energy efficiency, waste reduction, and a shift towards cleaner energy sources. Key sectors like textiles, automotive, and electronics have witnessed a rise in eco-friendly initiatives, such as the use of renewable energy sources, adoption of energy-efficient technologies, and waste management practices that contribute to the circular economy.
- Das and Ghosh (2020) highlight that the Indian manufacturing sector is significantly influenced by global sustainability trends, especially within the context of increasing environmental awareness and regulatory pressure. The authors emphasize that while large corporations have made notable progress, small and medium-sized enterprises (SMEs) face barriers such as high initial investment costs and lack of awareness regarding green technologies.
- Moreover, studies by Gupta and Sharma (2021) indicate that there is increasing policy support from the Indian government, such as the National Manufacturing Policy (NMP) and Swachh Bharat Abhiyan, which focus on cleaner technologies and waste management in manufacturing processes. However, the implementation of these initiatives across industries remains uneven.
- Government Policies and Initiatives: As noted by Bansal (2023), the Indian government plays a critical role in fostering sustainable practices by promoting policies like Make in India and Atmanirbhar Bharat, which focus on resource efficiency and green manufacturing. Additionally, policies like the Perform, Achieve, and Trade (PAT) scheme aim to improve energy efficiency in industries through market-based mechanisms.
- Technological Advancements: The adoption of technologies such as Industry 4.0 and AI-driven solutions is a major driver of sustainability in India. Kumar and Soni (2022) find that automation, the Internet of Things (IoT), and data analytics are enabling companies to optimize energy usage, reduce

emissions, and improve overall efficiency. The rise of green innovations in the automotive and electronics sectors, including electric vehicles (EVs) and solar-powered devices, exemplifies this trend.

- **Consumer Demand and Global Standards:** Singh and Desai (2023) assert that increasing consumer awareness regarding environmental sustainability has pushed manufacturers to adopt greener practices. Companies are aligning their operations with international sustainability standards such as ISO 14001 and the Global Reporting Initiative (GRI), which emphasize transparency and environmental responsibility.
- **Global Trade Agreements and Competition:** With India's integration into global supply chains, international trade agreements now emphasize sustainability. Ravi and Patel (2021) argue that companies in India are increasingly aligning their production processes with global environmental standards to remain competitive in international markets.
- **High Initial Costs:** As noted by Sharma and Reddy (2021), the upfront costs of adopting sustainable technologies, such as energy-efficient machinery or renewable energy systems, remain a significant barrier for many small and medium-sized manufacturers. These enterprises often struggle to access capital and face challenges in justifying the long-term benefits of green investments.
- **Lack of Awareness and Training:** According to Patel and Singh (2020), one of the key challenges in transitioning to sustainable practices is the lack of awareness among Indian manufacturers about the environmental and economic benefits of sustainability. Additionally, there is a shortage of skilled personnel who can implement and manage green manufacturing processes.
- **Weak Recycling Infrastructure:** India's recycling infrastructure is underdeveloped, with a significant gap in the recycling of electronic waste (e-waste), plastics, and other industrial by-products. Singh et al. (2022) note that despite policies promoting recycling, India's limited capacity for managing waste effectively hampers the widespread implementation of circular economy practices in the manufacturing sector.
- **Regulatory Gaps and Implementation Issues:** Rao and Verma (2023) highlight that while India has several sustainability-oriented policies, enforcement and compliance remain inconsistent. The lack of a cohesive framework to monitor and evaluate progress in sustainable manufacturing undermines the effectiveness of government initiatives.
- **Financial Incentives and Support:** To facilitate the transition to sustainable manufacturing, government incentives and subsidies should be provided, especially for SMEs. Financial schemes should be designed to reduce the initial costs of adopting green technologies and make sustainable practices more accessible to smaller manufacturers (Jadhav and Kharpude, 2022).
- **Enhancing Awareness and Training Programs:** Gupta and Sharma (2021) recommend that awareness programs and training workshops be organized at regional levels to educate manufacturers about the

benefits of sustainability. Collaboration with academic institutions and industry experts could help create a knowledge-sharing ecosystem.

- **Strengthening Recycling Infrastructure:** The development of a robust recycling infrastructure is crucial. This includes improving collection systems, investing in advanced recycling technologies, and incentivizing the recycling of industrial waste (Singh et al., 2022).
- **Policy Coherence and Enforcement:** Ravi and Patel (2021) suggest that India's policy framework should be more integrated and enforced rigorously to ensure the success of sustainable manufacturing practices. A centralized body could be established to monitor the implementation of sustainability guidelines and provide guidance to industries.
- **Promoting Research and Development:** Continuous investment in R&D is essential for driving innovation in sustainable manufacturing. Partnerships between industry players, research institutions, and the government can lead to the development of cost-effective, sustainable manufacturing solutions.

Need for the Study:

As India emerges as one of the largest economies in the world, it faces an urgent need to balance its rapid industrial growth with environmental sustainability. The manufacturing sector, a key contributor to the nation's GDP, is also a major source of resource consumption, carbon emissions, and environmental degradation. As a result, the transition towards sustainable manufacturing has become a crucial aspect of India's broader economic and environmental policies.

In recent years, India's commitment to achieving its climate goals under the Paris Agreement and promoting green growth has spurred policy changes, technological innovations, and industry shifts aimed at making manufacturing more sustainable. However, the practical implementation of these green initiatives is still in its early stages, with several challenges, such as infrastructure limitations, financial constraints, and a lack of awareness, slowing progress.

Given the growing importance of sustainability in India's industrial future, it is essential to examine the current state of sustainable manufacturing practices in the country. By assessing the adoption of environmentally friendly practices, the study will offer valuable insights into the drivers and challenges that hinder or facilitate the transition. Furthermore, identifying best practices, understanding the gaps, and offering actionable recommendations will provide policymakers, industries, and academics with a roadmap for promoting sustainability in India's manufacturing sector.

This study is particularly needed because it will not only provide an overview of the current landscape but will also offer crucial insights that can aid in policy formulation, corporate strategy, and industry-wide collaboration toward a greener future for India.

Objectives of the Study:

1. To assess the current state of sustainable manufacturing practices in India.

2. To identify the key drivers and challenges in the transition to sustainable manufacturing.
3. To provide recommendations for enhancing sustainability in India's manufacturing sector.

Research Methodology:

The study on India's advances in sustainable manufacturing will primarily rely on secondary data. Secondary data refers to information that has been previously collected, processed, and analysed by others, such as government reports, industry studies, academic research, and corporate sustainability reports. This methodology will allow the researcher to obtain a comprehensive view of the current state of sustainable manufacturing in India without the need for primary data collection.

Relevance of Sustainable Manufacturing in India:

The significance of sustainable manufacturing in India is paramount, particularly in light of the country's pressing environmental issues. As the third-largest greenhouse gas emitter worldwide, India must embrace eco-friendly industrial practices to combat climate change (World Resources Institute, 2021). The manufacturing sector, responsible for nearly 17% of the nation's GDP (World Bank, 2020), is a major contributor to emissions, resource depletion, and waste production. Thus, transitioning this sector towards a more sustainable framework is vital for fulfilling India's climate commitments as stated in the Paris Agreement and the Sustainable Development Goals (SDGs), especially SDG 9, which emphasizes the development of resilient infrastructure, the promotion of inclusive and sustainable industrialization, and the encouragement of innovation. Additionally, sustainable manufacturing is increasingly critical for maintaining competitiveness in global trade. Numerous countries are implementing stringent environmental regulations for imports, and consumers in developed markets are increasingly favouring eco-friendly products. By investing in sustainable manufacturing practices, Indian industries can access new markets, improve their brand image, and satisfy the rising demand for green products. This transition also stimulates innovation, as businesses adopt new technologies and processes to minimize their environmental footprint, potentially leading to greater efficiency and profitability.

While progress has been made, sustainable manufacturing in India continues to encounter numerous obstacles. A significant challenge is the substantial initial investment required for green technology adoption. Small and medium-sized enterprises (SMEs), which are crucial to India's manufacturing landscape, frequently lack the financial means to invest in energy-efficient machinery or renewable energy options. Furthermore, there is a deficiency in awareness and expertise among manufacturers regarding the long-term advantages of sustainable practices, such as cost reductions through energy efficiency and waste minimization. Additionally, regulatory enforcement requires enhancement. Although India has introduced various policies to encourage sustainable industrial practices, their implementation at the local level is often inconsistent due to insufficient monitoring, a lack of compliance incentives, and bureaucratic obstacles that hinder the progress of green initiatives. To foster the adoption of sustainable manufacturing in India, several strategies should be considered. Firstly, stronger government backing is essential, including subsidies, tax breaks, and low-interest loans for businesses investing in green technologies. The government should also initiate awareness campaigns

and offer training programs for manufacturers, particularly SMEs, to educate them on the benefits of sustainable practices and effective implementation methods.

Improving public-private partnerships can significantly advance sustainable manufacturing practices. By fostering collaboration among government entities, industries, and NGOs, we can create innovative and cost-effective solutions for sustainable manufacturing. Furthermore, it is essential to promote research and development initiatives that focus on green technologies to drive innovation and lower the costs associated with sustainable manufacturing. Additionally, implementing stricter regulations and enhancing enforcement mechanisms will ensure adherence to environmental standards. Introducing performance-based incentives, such as tax reductions or recognition awards for companies that achieve sustainability goals, can further encourage the adoption of sustainable practices. Sustainable manufacturing presents both a necessity and an opportunity for India, considering its environmental challenges and the rising global demand for eco-friendly products. Although progress has been made in sectors like automotive, textiles, and green building, there remains significant potential for improvement. By strengthening government support, promoting innovation, and enhancing regulatory enforcement, India can expedite its shift towards sustainable industrialization and make a meaningful contribution to global climate objectives.

RESULTS AND DISCUSSIONS:

1. Current State of Sustainable Manufacturing Practices in India

India has made notable advancements in incorporating sustainability into its manufacturing sector, especially in the last decade. The transition from traditional manufacturing to sustainable practices has been facilitated by governmental initiatives, industry adoption of green technologies, and a growing awareness of environmental impacts. Key observations include:

- **Government Initiatives:** India's government has been at the forefront of encouraging sustainable practices through various policies and schemes like the **National Action Plan on Climate Change (NAPCC)** and **Production-Linked Incentive (PLI) Schemes**. These policies provide financial incentives for industries adopting green technologies, including renewable energy and energy-efficient practices. Several sectors, such as automotive and textiles, have seen substantial investments in cleaner production methods due to these schemes.
- **Technological Integration:** Industry 4.0 technologies, including AI, IoT, and robotics, have become instrumental in enhancing efficiency and reducing waste. A significant portion of Indian manufacturers is integrating technologies like **solar energy**, **smart manufacturing**, and **recycling** to reduce carbon footprints and improve energy efficiency.
- **Circular Economy Adoption:** Industries in India, particularly textiles and electronics, are increasingly adopting circular economy practices. The push for recycling, reuse, and reducing waste has been led by both policy changes and market demand for sustainable products. However, the scope and effectiveness of recycling processes are still at early stages compared to developed nations.

2. Key Drivers and Challenges in the Transition to Sustainable Manufacturing

The transition to sustainable manufacturing in India has been shaped by several drivers and challenges:

Key Drivers

- **Government Policies and Regulations:** Initiatives like the **Atmanirbhar Bharat** and **Make in India** programs emphasize self-sufficiency in sustainable practices, particularly in energy and resource management. The government's clear commitment to achieving **net-zero emissions by 2070** has created a favourable environment for adopting sustainable practices.
- **Private Sector and Industrial Adoption:** Many leading manufacturers, especially in sectors like automotive and electronics, are committing to sustainability as part of their long-term strategy. Companies like **Tata Motors**, **Mahindra & Mahindra**, and **Adani Green Energy** are investing in clean energy and low-carbon technologies.
- **Global Market Demand for Sustainable Products:** Growing international consumer demand for eco-friendly products is a major motivator for Indian industries to adopt sustainable manufacturing practices. Many manufacturers are aligning their operations to meet global sustainability standards, such as the **ISO 14001** for environmental management systems.

Key Challenges

- **High Initial Investment Costs:** One of the primary obstacles to sustainable manufacturing in India is the high initial capital required for the adoption of green technologies and infrastructure. Many small and medium-sized enterprises (SMEs) face difficulty in securing funding for such investments.
- **Technological Gaps and Skill Shortage:** While there has been growth in technological integration, there remains a significant skill gap in the workforce. India's industrial workforce needs continuous upskilling to manage and operate advanced sustainable technologies effectively.
- **Limited Recycling and Waste Management Infrastructure:** Despite the growing interest in a circular economy, India still lacks robust infrastructure for large-scale recycling, particularly in sectors like e-waste and plastics. Inadequate waste management hampers the effective recycling of materials, limiting the circularity of production systems.
- **Regulatory Bottlenecks and Policy Enforcement:** While India's policies support sustainability, inconsistent enforcement of regulations and lack of clear guidelines for industrial operations sometimes hinder progress. Moreover, some policies are still not well-integrated across different industrial sectors, creating confusion and inefficiencies in implementation.

3. Recommendations for Enhancing Sustainability in India's Manufacturing Sector

To further enhance sustainability in India's manufacturing sector, the following recommendations are proposed:

- **Increased Financial Support for SMEs:** The government should provide more targeted financial support for SMEs to invest in green technologies. This could include low-interest loans, grants, and subsidies that help smaller manufacturers transition to sustainable practices without facing crippling financial burdens.
- **Technology Upgradation and Skill Development Programs:** To bridge the technological and skill gaps, the Indian government and private companies should invest in training programs to upskill the workforce. Additionally, there should be incentives for manufacturers to adopt advanced clean technologies, like energy-efficient machinery, automated systems, and waste-to-energy technologies.
- **Improved Waste Management Systems:** Investment in developing comprehensive recycling and waste management infrastructure is critical. This should include establishing centralized recycling hubs for e-waste, plastics, and textiles, with clear policies to incentivize private participation in waste processing.
- **Strengthening Policy Frameworks and Regulations:** The government needs to strengthen the implementation of sustainability regulations and streamline policy frameworks across different sectors. Clearer guidelines and a unified approach to sustainable manufacturing will encourage faster adoption of green technologies.
- **Public-Private Partnerships (PPP):** To overcome financial and infrastructural barriers, public-private partnerships (PPPs) can be used to create synergies in the development of sustainable manufacturing practices. These partnerships could focus on scaling up the adoption of renewable energy, recycling infrastructure, and energy-efficient technologies.
- **Promotion of Circular Economy Practices:** India's manufacturing sector needs more incentives to adopt circular economy principles on a larger scale. This includes creating a regulatory environment that supports the reuse of materials, reducing resource consumption, and facilitating waste reduction practices across industries.

Conclusion

India's manufacturing sector is experiencing a transformative shift toward sustainability, driven by both policy initiatives and a growing awareness of environmental impact. This study has assessed the current state of sustainable manufacturing practices in India, identifying key drivers such as government incentives, technological advancements, and market demand for eco-friendly products. The analysis also highlighted significant challenges, including inadequate recycling infrastructure, limited financial support for small and medium-sized enterprises (SMEs), and the need for more robust policy enforcement.

Key findings from the study indicate that while India has made notable progress in integrating sustainable practices, there remains considerable room for improvement, particularly in areas like energy efficiency, waste management, and circular economy models. The transition to sustainable manufacturing is

further constrained by issues such as inconsistent implementation of green policies, and the lack of widespread industry-level adoption of cutting-edge technologies.

Based on the analysis, the study provides several recommendations to enhance sustainability within India's manufacturing sector. These include increasing government funding for green technologies, fostering public-private partnerships to boost circular economy initiatives, and improving access to finance for SMEs to help them adopt sustainable practices. Additionally, strengthening the infrastructure for recycling and waste management, and promoting a comprehensive framework for corporate sustainability reporting, will be key to supporting a greener future for India's industrial landscape.

In conclusion, while the road to fully sustainable manufacturing in India is complex and challenging, the growing commitment from both government and industry stakeholders presents a promising outlook for the future. With continued effort, strategic investments, and policy reforms, India can position itself as a leader in sustainable manufacturing, contributing significantly to global environmental goals while fostering economic growth and job creation.

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