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Sustainable India: A case study of green industrial development

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Abstract
The research paper though explores that how India is shifting toward green industrialization through renewable energy, sustainable manufacturing, and cleaner mobility solutions. With adoption of green initialization strategies there is significant reduction in carbon emission. For this study five industries have been selected namely Bhadla Solar Park at Rajasthan, Tata Motors for EV Initiative, Wind Energy sector in Tamil Nadu, UltraTech Cement for sustainable cement and Indian Oil Corporation as Biofuel Industry. The findings suggest that the Budha solar park project has reduced carbon emission. Companies such as Tata Motors are encouraging electric mobility through innovation, strategic collaborations and integrations, and expansion of electric vehicle infrastructure. Wind energy development, specifically in Tamil Nadu, reflects the role of favourable policies and private sector participation in promoting renewable energy. In cement industry, UltraTech Cement has adopted energy-efficient and low-carbon technologies to reduce adverse environmental impact. Moreover, initiatives by Indian Oil Corporation in biofuel production, including ethanol blending and 2G ethanol plants, also focuses towards reduce fossil fuel dependence while supporting farmers. Overall, it can be said that these initiatives collectively reflect India's integrated approach toward sustainable and environmentally responsible industrial growth.

Keywords: Sustainable development, green industrialization, environment protection

Introduction
Industrialization has been considered as a key driver of economic growth all over the world. However, industrial development, for a very long time has been associated with excessive resource depletion, environmental degradation and rising carbon emissions. That's why these concerns attracted global attention for sustainable development and thus, the concept of green industrialization has been evolved.
Therefore, green industrialization refers to an approach of developing industries that integrates economic growth with environmental sustainability with efficient resource utilization, reduced emissions, and the adoption of clean technologies. Many developed and developing countries, including Germany and China, even India have adopted green industrialization strategies to have sustainable economic development. Specifically, with regard to India, it is a challenge for sustainable economic development while ensuring environmental protection. To meet this challenge, government has initiated various policies and programmes including renewable energy expansion promotion of electric mobility and adopting sustainable manufacturing practises.

Literature Review
The researcher made efforts to study available existing literature on green industrial development with respect to study the role of renewable energy, sustainable technologies, and environmentally friendly industrial practices in promoting sustainable economic growth in India. Ganesan *et al*., (2014) [4], there is a need integrate the environmental objective with Industrial competitiveness. Kumar *et al*., (2026) [7], Green industrialization requires proper coordinated industrial policies, upgraded technology and support for the organisation targeting towards lower-emission production. Budakoti (2026) [2], provides a technical basis for analysing Bhadla's generation performance, rather than assuming that installed capacity automatically translates into actual output. Nesamalar *et al*., (2017) [10], has conducted a study presenting the relationship between renewable-energy investment, infrastructure and actual generation. They also analysed policy initiatives, installed capacity, power generation and institutional and infrastructure barriers with regard to Tamil Nadu's renewable-energy development. Abdul-Manan *et al*., 2022 [1], conducted a study which helps evaluate Tata Motors' EV initiatives through lifecycle emissions. Ramesh *et al*., (2026) [14], also provides a technical ground for assessing low-carbon cement production. Soam *et al*., (2017) [15] has conducted research for analysing IOC's agricultural-residue-based biofuel initiatives.
The existing literature just provides the study related to individual industries and their contribution to environmental sustainability. However, there is very less literature which brings together different sectors, such as solar energy, wind energy, electric vehicles, sustainable cement and biofuels to explore their role in green industrial development in India. Therefore, the present study provides a broader perspective of these initiatives and their contribution to a sustainable India.

Objectives of the Study
This research paper aims to analyse the following objectives:
- To analyse the environmental contributions of Bhadla Solar Park, Tata Motors' EV initiatives, Tamil Nadu's wind-energy sector, UltraTech Cement and Indian Oil Corporation towards green industrialization of India along with challenges associated with these initiatives.

Research Methodology
The research design for this study is descriptive. A case study approach is adopted to analysing various selected industrial sector adopting green industrial initiatives in India. The data has been primarily collected through

secondary sources including research papers, reports, and other relevant published literature. This study covers solar energy, wind energy, electric vehicles, sustainable cement and biofuels.

Discussions and Findings

1. Analyses of selected Cases

For this study five industries have been selected namely Bhadla Solar Park at Rajasthan, Tata Motors for EV Initiative, Wind Energy sector in Tamil Nadu, UltraTech Cement for sustainable cement and Indian Oil Corporation as Biofuel Industry. Let's discuss all these in their respective contribution towards green industrialization.

1.1 Case Study: Solar Parks – Bhadla Solar Park

Bhadla Solar Park project was started in 2015 in Rajasthan. It is located 220 KMs away from Jodhpur on the Bap-Bhadla. It was developed in phases and completed around 2020 [21]. It is among one of the largest solar power projects in the world, representing India's shift toward clean energy industrialization. It is having capacity over 2245 MW [Rajasthan Renewable Energy Corporation Limited (RRECL)]. It is working on public-private partnership basis. It is spread over 5700 Acres of area. This solar park has reduced estimated 4 million tonnes of carbon dioxide emissions per year [Gold Standard Report]

Table-1: Total 2245 MW capacity of Solar Park have been commissioned in 4 phases at Bhadla, Jodhpur:

Phase	Capacity Commissioned
I. Bhadla Solar Park Phase	In first phase, 65 MW is developed by Rajasthan Solar Park Development Company Limited (a subsidiary of RRECL). 65 MW capacity has been commissioned.
II. Bhadla Solar Park Phase	In second phase, 680 MW is developed by Rajasthan Solar Park Development Company Limited (RSDCL). 680MW capacity has been commissioned.
III. Bhadla Phase	In third phase, 1000MW is developed by M/s Saurya Urja Company of Rajasthan Limited (SURAJ). It is a Joint Venture Company (JVC) between GoR and IL&FS Energy Development Co. Ltd. 1000MW capacity has been commissioned.
IV. Bhadla Phase	In fourth phase, 500MW is developed by M/s Adani Renewable Energy Park Rajasthan Limited. It is a Joint Venture Company (JVC) of GoR & M/s Adani Renewable Energy Park Limited. 500 MW capacity has been commissioned.

Source: Rajasthan Renewable Energy Corporation Limited (RRECL)

Bhadla Solar Park has significant opportunity in renewable energy sector because of its vast land area and high solar irradiance. But it also faces several challenges like land acquisition and infrastructure management; even sometimes its location itself poses a challenge like dust accumulation and sandstorms. Yet Bhadla Solar Park is considered a model for India's renewable energy goals and a significant player in the global clean energy transition.

1.2 Case Study: Electric Mobility – Tata Motors EV Initiative

Electric mobility has emerged as a strong pillar of green industrialization in India. India is promoting electric mobility to reduce pollution along with less dependence on fuel. Among Indian companies, Tata Motors has been playing significant role in promoting electric vehicles (EVs) and sustainable mobility ecosystem. Tata Motors took the initiatives to produce electronic vehicle around 2010 when company introduced electric as well as hybrid vehicles like use of electric buses in Commonwealth Games. Then, from 2017 onwards commercial electronic vehicle expansion has gained momentum. Tata Motors adopted an integrated approach by collaborating with other Tata group companies including collaboration with Tata Motors for charging infrastructure and with the tata chemicals for battery technology and Tata technologies getting innovation support. Tata Nexon, Tiago and punch are key selling models. In Financial Year 2025-26, Tata Motors has sold around 92,120 EV units (Tata Motors Passenger Vehicles Limited Report (2026) [17]. According to Tata group report (November, 2024) [16], that while taking steps toward mass mobility space Tata deployed over 3300 e-buses across 10 cities leading to the reduction of over 1.23 lakh tonnes of CO_2 emissions.

The company also faces several challenges which may include infrastructure, battery supply, and public awareness etc. Yet, by focusing on innovation, collaboration, and the continued expansion of EV adoption across different segments, Tata Motors can remain at the forefront of the electric mobility movement in India.

1.3 Case Study: Wind Energy – Tamil Nadu

Wind energy is a key component of green industrialization initiatives**,** as it promotes sustainable economic growth while reducing adverse environmental impact. It is renewable and clean source of energy as it does not produce greenhouse gas emission. Wind energy is basically involves generating electricity using wind turbines, which convert wind kinetic energy from into electrical power. It reduces dependence on fossil fuels. Countries like India have actively adopted wind energy as part of their green industrialization strategy. Specifically, Tamil Nadu is a leading hub for wind energy in India and it is contributing a significant share to the country's total wind power capacity. Wind energy development in Tamil Nadu started in early 1980s. It took a pace During 1990s with the participation of private sector

Table 2: Tamil Nadu's wind energy capacity and contribution as of 30 June 2026 [9]:

Indicator	Tamil Nadu	India total
Installed wind power capacity	12,273 MW	57,443 MW
Share of national installed capacity	21.36%	100%
Wind electricity generated in FY 2025–26	24,200 million units (MU)	106,699 MU
Share of national wind electricity generation	22.68%	100%

Source: Ministry of New and Renewable Energy (MNRE),

Due to favourable wind conditions and supportive government policies the state has developed large wind farms. According to Ministry of New and Renewable Energy (MNRE), in the year it has generated 22.68% of India Total electricity generated. Development of companies like Suzlon Energy in wind turbine manufacturing sector has also contributing significantly to wind energy sector by providing domestic production capabilities, encouraging technological innovation, and thus, supporting green industrialization initiatives. Yet, there are several challenges still a head like need for repowering of aging wind farms, addressing technological obsolescence, and ensuring reliable supply and energy storage are critical to overcoming.

1.4 Case Study: Sustainable Cement – UltraTech Cement

The cement industry is one of the largest industrial sectors which is contributing in carbon emissions. However, UltraTech Cement company has taken significant steps for adopting sustainable industrial practices toward green industrialization. These initiatives were initialised around 2004-05 and gradually company shifted towards adoption of green technologies and significantly expanded sustainable practices after 2010. Company adopted green industrial practices like use of energy-efficient technologies, reduction in energy consumption per unit of output, use of waste materials (industrial waste, biomass), reduction in dependence on fossil fuels, installation of waste heat recovery system, conversion of waste heat into usable energy, installation of zero liquid discharge systems and rainwater harvesting system. Because of these green initiatives, company has become among the lowest carbon footprint cement producers globally and large-scale adoption of waste heat recovery systems and able to produce blended cement.

Table 3: Green industrial practices Data reported for FY 2024–25

Criteria	Initiatives taken
Investment	More than ₹680 crore invested in energy-conservation equipment and capital schemes.
Capacity	1 GW of renewable energy capacity commissioned and operationalised for captive use and recovering waste heat to reduce emissions.
Carbon emission	Avoided Scope 1 emissions of 16,78,175 tonnes of CO_2 through waste heat recovery.
Waste Processed	8,769 tonnes of industrial waste and 6.75 lakh tonnes of agro-waste co-processed as alternative fuels. 14.12 lakh tonnes of municipal solid waste co-processed as alternative fuel. 44.15 million tonnes of recycled and alternative raw materials utilised in cement production.
Water Management	In water management, the company implemented zero liquid discharge at all of its cement manufacturing units and bulk terminals which results in 116.8 million kilolitres of water harvested across plants, mines and communities.

Source: UltraTech Cement Limited. (2025) [6]. Integrated and Sustainability Report 2024–25

Although UltraTech cement is having a dominant position in the sustainable cement industry yet it also faces several challenges like pricing pressures, competition, and the need for cost optimization. It also faces and acquisition and regulatory approvals, which could hamper its expansion plans. But despite of these challenges, the company has set ambitious targets to reduce its carbon footprint, including a 27% reduction in emissions and a 69% reduction in emissions by 2032. UltraTech aims to achieve carbon-neutral concrete by 2050 and has committed to using 100% renewable electricity by 2050.

1.5 Case Study: Biofuel Industry – Indian Oil Corporation

The biofuel industry contributing significantly in green industrialization by reducing dependence on fossil fuels and promoting sustainable energy initiatives. The countries like India facing huge challenges in biofuel industry like rising demand of fuel, environmental pollution and more dependence on crude oil imports. Therefore, to address these challenges Government of India is promoting biofuel as a cleaner alternative energy source. In early 2000s [20], Indian Oil Corporation (IOC) has taken initiatives in this regard by developing and promoting biofuels such as ethanol and biodiesel. Ethanol Blending Programme (EBP) started by IOC in 2003 helped in reducing carbon emissions and gradually expanded this programme to biofuel production and distribution over the time which utilizes non-edible oils and waste materials, thus, encouraging environmentally friendly fuel alternatives. Moreover, second-generation (2G) Ethanol plants enabled the conversion of agriculture waste into fuel which again help reducing stubble burning and ultimately less environment pollution. Along with this company also collaborated with farmers for procuring the agricultural residue which also creates additional income opportunities for the farmer.

Table 4: Official data and sources for IndianOil's biofuel initiatives

Indicator	Officially reported data	Source
2G ethanol plant capacity	100 kilolitres per day (KLPD) at Panipat	IndianOil Annual Report 2024–25
Agricultural residue used	Approximately 2 lakh tonnes of rice straw annually	Press Information Bureau (PIB), 8 August 2022 [11]
Ethanol production capacity	Approximately 3 crore litres annually	
Greenhouse-gas reduction	Estimated reduction of approximately 3 lakh tonnes of CO_2-equivalent emissions annually	
Farmer participation	More than 1.2 lakh metric tonnes of biomass collected during the 2023 and 2024 Kharif seasons through depots in Karnal and Panipat	IndianOil Annual Report 2024–25
Ethanol blending	IndianOil reported 17.20% ethanol blending in FY 2024–25 in its natural-capital disclosure	IndianOil Annual Report 2024–25

Indian Oil Corporation (IOC) is collaborating with other industries like Praj industries to strengthen its biofuels production capacities (IOC report 6 July, 2023). This partnership will result into leveraging India's agriculture surplus to produce indigenous biofuels. However, this sector also faces several challenges like balancing food security with biofuel ambitions, diverting edible crops to biofuel production, which could lead to food inflation and nutritional security threats.

Conclusion

Overall, this study explores that green industrialization in India is steadily getting momentum through the combined efforts of government support, proactive corporate strategies, and continuous technological advancements. Green industrialization initiatives not only fostering reducing carbon emissions and environmental degradation but at the same time it is also promoting sustainable economic growth, enhancing energy security, and encouraging innovation. Thus, green industrialization is emerging as a key driving force for achieving long-term environmental sustainability and inclusive development of India in long run.

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