Accelerating Green Manufacturing & Renewable Energy Equipment Production for India s Sustainable Urban Growth

by Jana Publication & Research

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Abstract

India’s rapid urbanization and escalating household consumption have exerted mounting pressure on its industrial energy demand and environmental commitments. To reconcile economic growth with sustainability imperatives, this policy paper examines the twin strategies of green manufacturing and domestic renewable energy (RE) equipment production. The analysis synthesizes Indian case studies, evaluates policy instruments such as the Production-Linked Incentive (PLI) and Perform, Achieve, and Trade (PAT) schemes, and unpacks critical debates around cost competitiveness, self-reliance, and R&D investment.

Key findings reveal that integrating green manufacturing through measures like ***closed-loop water recycling and IoT-enabled predictive maintenance can reduce lifecycle costs and abate up to 30 $MtCO_2$ annually by 2030. Simultaneously, scaling domestic RE equipment production mitigates import bills (potentially saving USD 1.1 billion annually), generates over 1 million jobs, and attracts USD 15 billion in green-manufacturing investments. However, barriers persist: nearly 45% of output from MSMEs faces prohibitive cost premiums; state-level disparities undermine PLI effectiveness; and R&D intensity remains below 0.7% of GDP, far below global leaders.***

Drawing on these insights, the paper advocates for a cohesive policy framework thatextends concessional financing to MSMEs;harmonizes state-level implementation; incentivizes targeted R&D through public–private consortia; and aligns import-duty measures with deployment timelines to prevent supply bottlenecks. An integrated approach is vital to drive India’s transition toward sustainable urban growth.

Aim and Objectives

Aim: To formulate evidence-based policy recommendations that accelerate the adoption of green manufacturing and strengthen domestic renewable energy equipment production, thereby catalyzing India's sustainable urban growth.

Objectives:

- Critically evaluate existing central and state-level incentives for green manufacturing and RE equipment production
- Analyze financial, technological, and regulatory obstacles affecting large scale adoption of green processes and RE component fabrication.
- Estimate potential reductions in GHG emissions, trade-deficit savings, job creation, and GDP growth attributable to integrated policy measures.
- Recommend Policy Options based on secondary literature synthesis

Research Methodology

This study employs a structured secondary-research design complemented by analysis of publicly available datasets.

- Approach: Qualitative method, grounded in literature review of secondary sources and analysis of industry and macro-level energy datasets.
- Scope and Boundaries: Geographical: Exclusive focus on India; no international case studies.
  Time Frame: Literature post-2015; datasets primarily from 2000–2024 to contextualize recent policy shifts.
- Databases & Sources: Academic: Google Scholar
  Policy & Industry: Press Information Bureau, Ministry of New & Renewable Energy (MNRE), CEEW, TERI, EY–Parthenon, Deloitte India.
- Selection Criteria: Relevance: Direct discussion of Indian green-manufacturing policies or RE equipment production.
  Credibility: Peer-reviewed journals, government reports, and leading think-tank publications.
  Recency: Focus on post-2015 to capture evolving policy instruments.
- Data Extraction & Synthesis: Charting key policy features, financial mechanisms, technological enablers, and barriers.

- **Data Sets Used:**

Name of the Dataset	Source	For Further Reference
Household Final Consumption Expenditure in India (in US$, trillion)	World Bank. (2025). Households and NPISHs final consumption expenditure (current US$) [Data set]. World Development Indicators.	https://data.worldbank.org/indicator/NE.CON.PRVT.CD?locations=IN
Industrial Final Energy consumption (in MToe)	International Energy Agency. (2024). Key World Energy Statistics 2024 [Data set]. IEA.	https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances
Industrial Production Growth Rate (in %)	Ministry of Statistics and Programme Implementation. (1990–1999). Index of Industrial Production (Annual Bulletins). Government of India.	http://mospi.gov.in
IPPU Emission (in MT CO2E)	Centre for Science and Environment. (2022). *India and climate change: Achieving emissions intensity reduction targets*.	https://cdn.cseindia.org/userfiles/India-climate-change-Emissions-intensity.pdf
R&D Intensity (in % of GDP share) of India, China and USA	• Department of Science and Technology. (2022). Research and Development Statistics at a Glance: 2021–22. Ministry of Science and Technology, Government of India. • National Science Foundation (NSF). (2023). Science and Engineering Indicators: International Comparisons. National Center for Science and Engineering Statistics • Organisation for Economic Co-operation and Development (OECD). (2023). Main Science and Technology Indicators (MSTI) – R&D Expenditure as Percentage of GDP. • SSTI. (2023, October). U.S. R&D Intensity Reaches Record 3.45% of GDP in 2022. State Science & Technology Institute.	• https://dst.gov.in. • https://ncses.nsf.gov/pubs/nsb20233. • https://stats.oecd.org/. • https://ssti.org/
Cost Premiums and Payback Periods	• TERI. (2021). Green manufacturing in India: Costs, benefits, and policy measures. The Energy and Resources Institute. • EY–Parthenon. (2025). How green manufacturing is reshaping India's industrial landscape [PDF]. Ernst & Young LLP	• https://www.teriin.org/sites/default/files/2021-05/Green-manufacturing-India.pdf • https://assets.ey.com/content/dam/ey-sites/ey-com/en_in/topics/manufacturing/ey-green-manufacturing-report.pdf

PLI-Backed Solar Module Uptake by State	• Press Information Bureau. (2023). PLI schemes attract over USD 15 billion in green-manufacturing investments. Government of India • Deloitte India. (2024). Decarbonisation in Indian manufacturing: State-level readiness and challenges.	• https://pib.gov.in/PressReleasePage.aspx?PRID=1834567. • https://www2.deloitte.com/in/decarbonisation-manufacturing.html

Literature Review

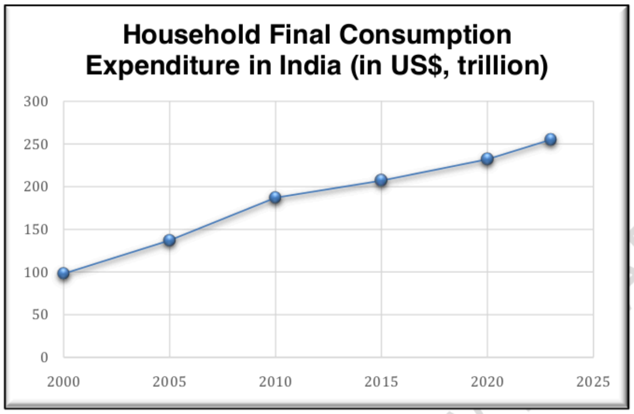
Primary Secondary Research Sources	Summary
EY. (2025). *How green manufacturing is reshaping India's industrial landscape* [PDF]. EY-Parthenon. Retrieved from: https://assets.ey.com/content/dam/ey-sites/ey-com/en_in/topics/manufacturing/ey-green-manufacturing-report.pdf	The report discusses the strategic shift in India's industrial ecosystem towards green manufacturing. Green manufacturing is becoming central to India's industrial competitiveness. Policy support and ESG-focused investment are accelerating the transition. Decarbonisation in manufacturing is essential for meeting climate commitments.
TERI. (2021). *Green manufacturing in India: Costs, benefits, and policy measures*. The Energy and Resources Institute. Retrieved from: https://www.teriin.org/sites/default/files/2021-05/Green-manufacturing-India.pdf	A policy study analyzing economic and environmental implications of green manufacturing. Green manufacturing improves long-term cost efficiency and resource use. Key barriers include high upfront costs and lack of regulatory enforcement. Recommends fiscal incentives and R&D funding.
Council on Energy, Environment and Water. (2024). *Unlocking India's clean-energy manufacturing competitiveness* [Report]. CEEW.	Focuses on India's potential to become a global leader in clean-energy technology manufacturing. India has strong potential in solar PV, battery storage, and green hydrogen. Policy reforms and export competitiveness are essential. Calls for domestic value chain development.
Deloitte. (2024). *Decarbonisation in Indian manufacturing: State-level readiness and challenges*. Deloitte India. Retrieved from: https://www2.deloitte.com/in/decarbonisation-manufacturing.html	Evaluates Indian states' preparedness for decarbonising manufacturing. States vary widely in readiness due to policy, infrastructure, and industry mix. Identifies best practices and challenges in state policy alignment. Encourages a federal-state collaborative model.
The Energy and Resources Institute (TERI). (2021). *Renewable Energy Manufacturing: Opportunities and Challenges.* Retrieved fromhttps://www.teriin.org	Assesses India's RE manufacturing sector and its global positioning. India has untapped potential in RE hardware production. Import dependence is a major concern. Suggests incentives for domestic manufacturing.

Rehman, M. A. A., & Shrivastava, R. L. (2021). A review of green manufacturing in selected Indian SMEs. International Journal of Recent Trends in Engineering & Management, 3(1).	Reviews green initiatives among Indian SMEs. SMEs are crucial for green transition but face financial and technological barriers. Highlights the role of training, credit access, and awareness programs.
Government of India. (2022). *India's updated Nationally Determined Contribution under Paris Agreement*. Ministry of Environment, Forest and Climate Change. Retrieved from https://moef.gov.in/	India's updated climate goals under the Paris Agreement. Pledges include reducing emissions intensity and increasing non-fossil energy capacity.
Sreenu, M., & Mishra, S. (2023). Impact of green finance and fintech on sustainable economic growth: Empirical evidence from India. *Environmental Science and Pollution Research*, *30*(41), 93148–93160. Retrieved from: https://doi.org/10.1007/s11356-023-28071-4	Empirical study linking green finance with sustainable economic growth in India. Focuses on Green finance is significantly associated with improved sustainability metrics. Fintech can improve green investment access and monitoring.

In addition to these sources, other secondary sources contributing to the study based on the studies objectives were also taken into consideration and have been cited across the study for reference.

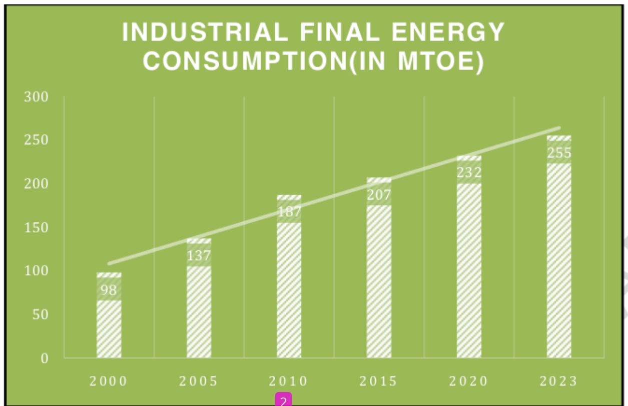
Introduction

With rapid urbanization and a growing population, India's environmental concerns seem to have skyrocketed over the past two decades. As India reconfigures itself to meet its climate commitments, particularly the Paris Agreement targets, many academicians are concerned about an economic slowdown resulting from changes in the country's conventional growth model. Adopting a more sustainable approach to achieve economic growth may be the need of the hour, but it carries a layer of complexity embedded in the choices to make in production and manufacturing in particular. With consumer demand for products peaking due to rapid urbanization and population growth, the country's manufacturing and production need to be fast and efficient without any delays. The graph below illustrates growing household final consumption expenditure in India, highlighting an increasing trend in household purchases of products along with household partial payments for products provided by the government.



The graph indicates consumer demand in India in terms of HFCE from 2000-2023. Source: World Bank. (2025). *Households and NPISHs final consumption expenditure (current US$)* [Data set]. World Development Indicators. https://data.worldbank.org/indicator/NE.CON.PRVT.CD?locations=IN

Amalgamating sustainable practices in such a mix generates policy dilemmas and requires conscious decision-making from the policymakers of the country. To tackle this dilemma, the concept of green manufacturing was brought into discussion within the Indian context. The concept is fairly recent and promotes a paradigm shift in the manufacturing process, focusing on optimizing resource utilization, minimizing waste generation, and reducing environmental impact throughout the product lifecycle (Gaikwad &Sunnapwar, 2021; Seth et al., 2018). This paradigm shift, however, is not merely based on compliance mechanisms and environmental regulations but rather argues for a structural and mindset change promoting eco-friendly innovation and resource efficiency in the long run (Liu & Ling, 2020). With industrial and manufacturing greenhouse emissions increasing in India at a rate of 4.6% per year (Sreenu & Mishra, 2023), approaches under green manufacturing can act as an interim mitigation, enabling the country to meet its sustainability target without relaxing its manufacturing prowess. It is imperative to note that the need for green manufacturing in India is not only related to GHG emissions but also surging energy demands in the industrial and manufacturing sectors. The graph below depicts the increasing energy consumption of the industrial sector in India.



Industrial Energy Consumption graph of India from 2000-2023. Source: International Energy Agency. (2024). *Key World Energy Statistics 2024* [Data set]. IEA. https://www.iea.org/data-and-statistics/data-product/world-energy-statistics-and-balances

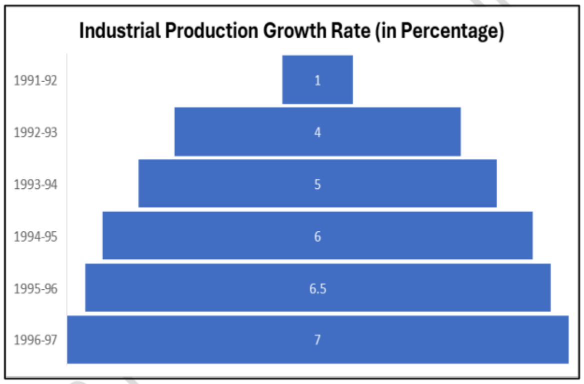
Energy demand of the manufacturing sector in India has grown at a CAGR of more than 5% per annum over the past decade. Hence, the concept of green manufacturing needs to be integrated at an exponential pace in the country's economic and production growth model to fulfill global targets such as the Sustainable Development Goals and Paris Agreement commitments.

Expansion of green manufacturing may resolve the problem partially. However, to scale this expansion across regions of the country, it is imperative to develop complementary technologies to sustain this shift. Herein, the question of renewable energy equipment production comes into the picture. To establish a sustainable industrial ecosystem, domestic production of renewable energy equipment is imperative, as reliance on imports for critical components can expose vulnerabilities in the supply chain, hindering widespread adoption (Alam et al., 2023). Fostering local manufacturing of RE components not only limits foreign dependence but also allows the generation of technologies, keeping in mind the Indian environment and climate vulnerabilities. For example, India's varied rainfall pattern across regions requires modifications in solar panel technology to tackle the cloudburst-induced flash floods. Moreover, domestic RE equipment production promotes the agenda of green manufacturing by employing in-house-developed, energy-efficient technologies that would help manage peaking industrial energy demands.

The political and economic context of the country at present lies in sync with this approach due to the aggressive push towards the sustainability agenda under the current PM Modi-led regime. However, the question remains whether this push is merely ideological or whether there is any concrete development in this regard in terms of policy frameworks, financial instruments, or technological and regulatory shifts. Analyzing these metrics with regard to the two concepts mentioned above forms the crux of this paper and is explored in subsequent sections to assess the feasibility and sustenance of this approach.

Background and Contextual Analysis

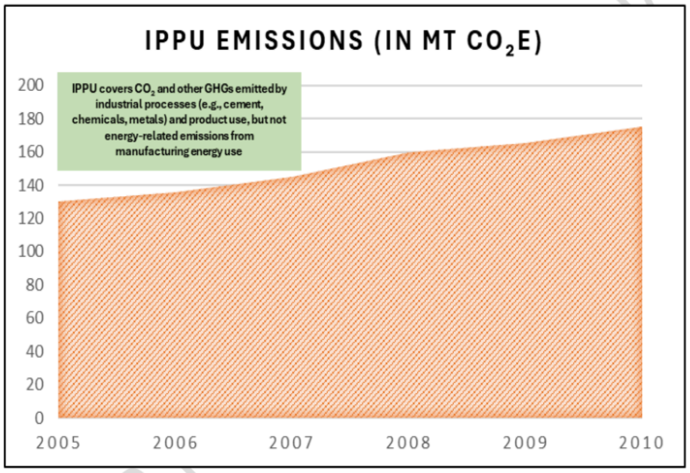
Green manufacturing in India is a fairly new integration, as argued above briefly. The concept may have emerged in the policy landscape in the 1990s but remained in isolation for most of the period, as governments in power at that time felt minimal need for integration. During that time, environmental concerns were not a primary focus within the Indian context. However, rapid industrialization was, due to increased global economic competitiveness.



The graph above illustrates India's industrial production growth rates (based on IIP) from 1991 to 1997, highlighting an increasing trend to meet global economic growth rates. Source: Ministry of Statistics and Programme Implementation. (1990–1999). *Index of Industrial Production* (Annual Bulletins). Government of India.

The introduction of international standards such as ISO 14001 may have triggered discussions in India (Pang & Zhang, 2019), but businesses were barely ready for its universal adoption. Notably, during this time there was also a shift in India's domestic economic policy via the introduction of liberalization reforms, which ushered many industries to shift their business models. Amidst these developments, environmental concerns of manufacturing were nowhere to be considered. Coal consumption in the manufacturing sector was also peaking during this phase, as suggested by increasing trends of coal consumption in iron, steel, and cement industries.

Post this phase, in the early 2000s, the principles of the "4Rs" (reduce, reuse, recycle, remanufacture) were recognized in the Indian manufacturing and industrial setup. There was a shift towards these principles, but growing demand domestically hindered the process of adoption. Additionally, emerging small-scale industries barely had the finances to adopt energy-efficient resources and focus on waste minimization due to high upfront costs and technical constraints (Rehman & Shrivastava, 2021; Singh & Thakar, 2018). Environmental regulations around this principle were devised to enforce punitive measures, but they lacked teeth as industrial emissions during this phase kept rising.



The graph showcases GHG emissions from India's industrial sector as reported under "Industrial Processes and Product Use" (IPPU) in the Government of India's Biennial Update Reports to the UNFCCC. Data are given in million tonnes CO_2 equivalent (Mt CO_2e) for 2005–2010 (the first year for which detailed IPPU breakdown appeared is 2005) Source: https://cdn.cseindia.org/userfiles/India-climate-change-Emissions-intensity.pdf

Similar to green manufacturing, renewable energy equipment production in India also barely had any standing during the 1990s. There were majorly small-scale pilots and research projects focusing on wind, biomass, and small hydro equipment under the observation of the Ministry of Non-Conventional Energy Sources, now known as the Ministry of New and Renewable Energy (Ramachandra, n.d.). Notable advancements were made in biomass gasifier technology with premier research institutes such as IIT at the center. Apart from this, equipment production was limited and heavily reliant on pilot initiatives. Post the introduction of the Electricity Act in 2003, there was some focus on decentralized energy systems as markets opened up for businesses to contribute to RE equipment manufacturing and distribution (Shakti Sustainable

Energy Foundation, 2017). This opening up of markets especially impacted wind turbine production in the country as Suzlon emerged as a global player. However, solar equipment production remained at a nascent stage even during this phase. Hence, it can be argued that renewable energy equipment production had minimal exposure from the 1990s to 2010, with modest developments via pilot and research projects and some expansion of wind turbine production.

The historical background of both concepts appears to be underwhelming within the Indian policy setup. However, as global recognition of environmental concerns gained traction, India also shifted its focus towards these agendas to meet its environmental commitments. The most notable shift in this regard was the announcement made recently by the government to achieve a net zero emission target by 2070 along with a commitment to achieve 500 GW of installed renewable energy capacity by 2030 (Ministry of Power, 2023; Ministry of New and Renewable Energy, 2022). Under this umbrella vision, several transformations have taken place to accelerate the transition towards green manufacturing. Based on the secondary literature review, several key drivers of this transformation can be identified. The table below illustrates the emerging trends in the Indian manufacturing sector accelerating a transition towards green manufacturing.

Trend	Significance
Circular Economy & Material Reuse	Indian manufacturers, especially in textiles, are embedding closed-loop supply chains and digital assessment tools to drive circularity (Das, 2025).
Digitalization & Smart Manufacturing	The integration of IoT, machine learning, and real-time monitoring in "smart factories" has enhanced predictive maintenance and optimized resource use, leading to measurable reductions in energy consumption and emissions (Kadam, Peddinti, & Gupta, 2025).
Green Hydrogen Integration	Advances in electrolyzer technologies and economies of scale are driving down the levelized cost of green hydrogen from USD 4.45/kg in 2024 to an estimated USD 2.45/kg by 2030, positioning heavy industries (e.g., refineries, steel) for deep decarbonization (Jindal, Shrimali, & Tiwary, 2024).
Green Steel Adoption	A national classification for "green steel" based on carbon-intensity thresholds (< 2.2 t CO_2 per tonne) is guiding steelmakers toward low-emission production processes and encouraging investment in cleaner iron-making routes (Reuters, 2024).

Waste Valorization & Resource Recovery	Industrial by-products (e.g., plastic, agro-waste) are increasingly converted into feedstocks via advanced valorization technologies, improving material efficiency and reducing landfill burdens (Council on Energy, Environment and Water, 2023).

The table illustrates key trends driving Green Manufacturing transition in India based on the secondary literature review.

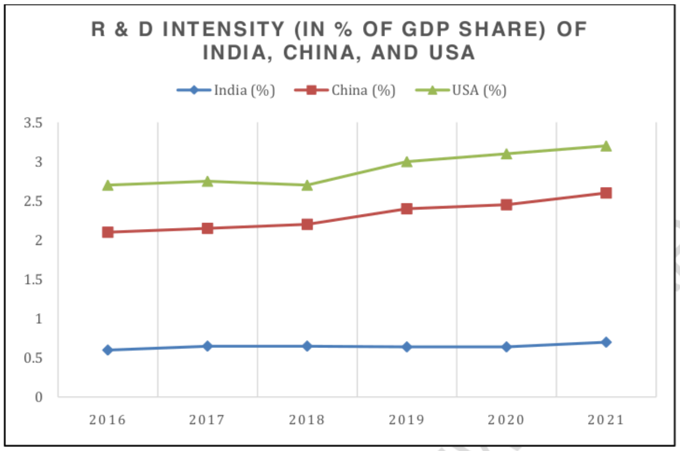
Apart from these trends various policy frameworks and incentives are also driving this change in India. The Production Link Incentive Scheme (PLI), Green Taxation, and PAT compliances are a few policy instruments to note within this context.

In terms of renewable energy equipment production, the trends indicating transition towards domestic production emerged relatively slowly. India initially focused on increasing its installed capacity of renewable sources to reduce dependence on fossil fuel-based plants as energy demands peaked in the country. This increase in installed capacity was fulfilled majorly via imports rather than domestic RE equipment production. Solar energy components were barely produced in the country during this time. However, as India's development model transformed with ideologies such as Make in India and Aatmnirbhar Bharat, a renewed push was given towards domestic manufacturing. RE equipment manufacturing benefitted from the same policy vision. The expansion of wind turbine production and rapid scale-up of solar PV manufacturing marked a new phase in RE equipment production in India. In terms of wind turbine production, the local firms started supplying blades and towers both for domestic use and for exports. This resulted in growing the wind turbine production sector at a CAGR of 11% (ResearchAndMarkets, 2025). Similarly, solar PV manufacturing accelerated via vertical integration, process automation, and factory expansion. Imports of Chinese solar modules fell in the country, which were earlier a primary source of increasing installed capacity, by 76% in the financial year 2022-23. Domestic production of solar modules, on the other hand, grew exponentially at a 364% year-on-year rate, highlighting the strengthening of domestic production capacity (Council on Energy, Environment and Water, 2024). A distinct feature of domestic RE equipment production transition in India has been the emergence of green hydrogen equipment production. India has focused on increasing its electrolyser manufacturing capacity by commissioning facilities such as Odisha's Gopalpur Park, indicating its commitment to expanding this new arena. Export diversification and integration of advanced manufacturing technologies have further bolstered this production transition.

The background and contextual analysis, essentially indicate that the two concepts started off slow in India but have gained pace in recent times due to stringent climate conservation practices. However, these recent trends merely reflect the positives instilled because of the recent push provided, gaps in adoption still persist and need to be explored for a holistic understanding.

Problem Statement

The previous sections of the paper clearly indicate the urgency of the adoption of green manufacturing in India for the country to meet its climate commitments. Moreover, as recent trends indicate, there is a shifting focus as well towards green manufacturing, with certain key drivers being introduced. However, these drivers, in absolute terms, fail to categorically integrate green manufacturing within the Indian manufacturing setup. The positioning of small- and medium-scale industries remains a key challenge in this context. Nearly 45% of manufacturing in India is controlled by MSMEs (SIDBI, 2022), and due to high upfront costs and technological constraints, MSMEs in the country fail to integrate green manufacturing processes within their setup. Financial subsidies have been provided to MSMEs, but most of these subsidies are used up by the manufacturers to increase their production capacity rather than being used in adopting green manufacturing procedures. Additionally, MSMEs in the country simply lack the operational bandwidth for integrating green manufacturing in their setup, as most have manual production techniques with some automation along with smaller employee sizes. Apart from MSMEs, India's energy mix within the industrial sector remains another persistent issue. 70% of India's industrial energy mix remains fossil fuel dependent, primarily coal, despite increasing renewable energy capacity in the nation (CEA, 2022). This creates a challenge in terms of energy efficiency, which is a core component of green manufacturing. The dependence on fossil fuel sources to meet energy demands in the industrial sector primarily comes from two factors. First, energy-efficient technologies are almost double in cost. For example, green hydrogen-based steelmaking nearly costs twice as much as traditional methods (TERI, 2021). Secondly, the manufacturing sector's energy demands have peaked so much in the past decade that energy-efficient technologies won't simply fulfil the requirements and would delay production outcomes in the age of mass production. Policy inefficiencies and bureaucratic complexities further puncture the adoption of green manufacturing as different states across the country have their own interpretations and implementation strategies, lacking uniformity and centralization. Notably, OECD data also suggest India's research and development investment in sustainable industrial technologies was less than 0.7% of its GDP in 2021, which is far below in comparison to global leaders such as the USA and China (OECD, 2022).



The line graph depicts R&D intensity of India, China, and USA. R&D intensity does include investments in sustainable industrial technology as its components. Sources: Department of Science and Technology. (2022). *Research and Development Statistics at a Glance: 2021–22*. Ministry of Science and Technology, Government of India. Retrieved from https://dst.gov.in. National Science Foundation (NSF). (2023). *Science and Engineering Indicators: International Comparisons*. National Center for Science and Engineering Statistics. Retrieved from https://ncses.nsf.gov/pubs/nsb20233. Organisation for Economic Co-operation and Development (OECD). (2023). *Main Science and Technology Indicators (MSTI) – R&D Expenditure as Percentage of GDP*. Retrieved from https://stats.oecd.org/. SSTI. (2023, October). *U.S. R&D Intensity Reaches Record 3.45% of GDP in 2022*. State Science & Technology Institute. Retrieved from https://ssti.org/

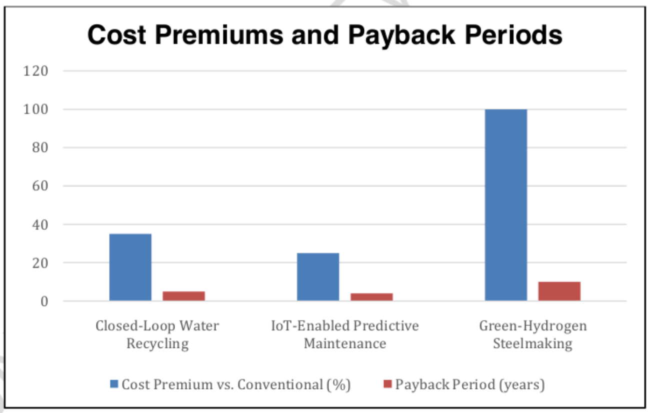
Low investments here illustrate supply chain vulnerabilities and inadequate development of a green manufacturing supportive ecosystem.

In terms of renewable energy equipment production, the problem stems from the systematic approach taken by the country itself. India may have experienced tremendous growth in the total renewable energy capacity, reaching 203.18 GW as of October 2024 (Press Information Bureau, 2024); however, this increased capacity does not indicate increased domestic production. To chase the 2030 target of 500 GW from non-fossil sources, India focused on increasing its installed capacity from whichever method possible rather than strengthening its domestic production to provide that much-required push. Instead, India focused on importing RE components and equipment to meet its demand. This import dependency was most profound in the solar energy sector. As per estimates, India's solar component import bills could grow up to $30 billion by 2030 at current pace, leading to trade deficits and economic disruptions (Global Trade Initiative, 2024). This import dependence stems from insufficient financial incentives and limited access to affordable capital constraining local manufacturers, making them less competitive globally (TERI, 2021). Additionally, India's renewable equipment manufacturing sector faces significant infrastructural deficits, including inadequate research and development (R&D) support, limited innovation ecosystems, and insufficient industrial clusters dedicated to renewable technologies (CSE, 2023).Furthermore, regulatory ambiguity, such as inconsistent implementation of local content requirements and delays in approvals, has hindered investor confidence, discouraging substantial and sustained investment (IEA, 2022).

Discussion and Key Debates

India's ambition to decarbonize its manufacturing sector while maintaining global competitiveness has generated intense debate across four critical dimensions, each marked by sharply contrasting perspectives.

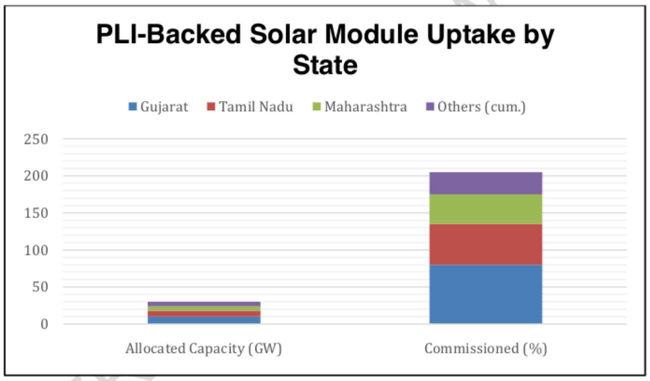
First,cost competitiveness versus long-term sustainability, arguments favouring green manufacturing illustrate examples such as closed-loop water recycling that can reduce net water costs by 35 percent with a five-year payback and, similarly, as per EY's analysis, IoT-enabled predictive maintenance cuts unplanned downtime by 25 percent, highlighting that these lifecycle efficiencies will ultimately outweigh upfront investments (TERI, 2021; EY, 2025).



The graph above indicates cost premium of energy efficient processes against conventional sources along with their cost payback period. Source: TERI. (2021). *Green manufacturing in India: Costs, benefits, and policy measures*. The Energy and Resources Institute. Retrieved from https://www.teriin.org/sites/default/files/2021-05/Green-manufacturing-India.pdf. EY–Parthenon. (2025). *How green manufacturing is reshaping India's industrial landscape* [PDF]. Ernst & Young LLP. Retrieved from https://assets.ey.com/content/dam/ey-sites/ey-com/en_in/topics/manufacturing/ey-green-manufacturing-report.pdf

In contrast, critics point out that nearly half of India's manufacturing output comes from MSMEs, which face capital cost premiums of 20–100 percent for technologies such as green-hydrogen steelmaking and may endure payback periods of up to ten years, which is an economic burden many small firms cannot shoulder without concessional financing (CEEW, 2024).

Second, regarding policy effectiveness, policy advocates of the central government's Production-Linked Incentive (PLI) and Perform, Achieve, and Trade (PAT) schemes highlight their role in mobilizing over USD 15 billion in green-manufacturing investments and driving a 364 percent surge in domestic solar module production in FY 2022–23 (Press Information Bureau, 2023; CEEW, 2024). Yet one can see stark state-level disparities, such as Gujarat having commissioned 80 percent of its PLI-backed capacity, while Maharashtra and Tamil Nadu lag at 40 percent and 55 percent, respectively, blaming regulatory delays, uneven land-approval processes, and inconsistent local-content rules for eroding the scheme's intended impact (Deloitte, 2024).



Source: Press Information Bureau. (2023). PLI schemes attract over USD 15 billion in green-manufacturing investments. Government of India. Retrieved from https://pib.gov.in/PressReleasePage.aspx?PRID=1834567. Deloitte India. (2024). Decarbonisation in Indian manufacturing: State-level readiness and challenges. Retrieved from https://www2.deloitte.com/in/decarbonisation-manufacturing.html

Thirdly, local manufacturing of renewable energy equipment versus reliance on imported components, and what this means for India's self-reliance (Aatmanirbhar Bharat) and sustainable growth. On one side, the Government of India and many policymakers strongly advocate building a domestic manufacturing base for solar modules, wind turbines, batteries, and other RE components. They argue that dependence on imports, especially from a single source like China is a vulnerability that can lead to supply disruptions and a trade deficit. For instance, India has historically imported the vast majority of solar photovoltaic (PV) cells and modules from China, which contributed to a sizeable outflow of foreign exchange and nearly 100% import dependence in solar value chains a few years ago. In response, the government has enacted measures such as steep basic customs duties (BCD) (since April 2022 a 40% duty on imported solar modules and 25% on solar cells) and an Approved List of Models and Manufacturers (ALMM) policy to mandate use of certified Indian-made panels for certain projects (Ministry of New & Renewable Energy, 2021). Additionally, a major Production-Linked Incentive (PLI) scheme of ₹18,500 crore was launched in 2020–21 to incentivize domestic solar PV manufacturing across the value chain (Ministry of Power, 2023). These interventions have begun to shift the market dynamics. Data indicate a sharp reduction in solar imports and a surge in domestic production in the past two years. However, on the other side of this debate, critics question whether an aggressive localization policy might increase costs and slow down deployment of renewable energy, counterproductively hampering climate and urban sustainability goals in the near term. Some industry analysts warn that imposing import barriers (BCD and ALMM) before domestic manufacturing is fully scaled and cost-competitive could lead to short-term module supply crunches or higher costs for project developers. Indeed, after the ALMM and duties took effect, there were reports of solar project delays and developers seeking deadline extensions, as local manufacturers couldn't immediately supply the needed volume of certain high-efficiency panels (Mercom India, 2022). Thus, one perspective holds that India should not sacrifice speed and affordability of renewables deployment at the altar of self-reliance.

Finally, in the debate over R&D and global benchmarking, observers lament that India's R&D intensity in sustainable-manufacturing technologies stood at only 0.7 percent of GDP in 2021, far below China's 2.4 percent and the USA's 3.1 percent, arguing that this underinvestment hampers breakthrough innovations (OECD, 2022; TERI, 2021). Policymakers, however, contend that India's fiscal constraints necessitate a strategic focus on incremental, near-market innovations, such as modular upgrades and process optimizations that deliver faster commercial returns, advocating for public–private consortia to drive these targeted improvements rather than diffuse frontier research (Ministry of Commerce & Industry, 2022).

Policy Options and Recommendations

Based upon the gaps and problems identified in previous sections along with contentions raised within the section on key debates, several policy alternatives emerge that can be integrated for better adoption of these concepts in India. Below is a summary table of key recommendations emerging across secondary literature sources used in this study based on the gaps analysed.

Recommendation	Literature Evidence
Public–Private R&D Consortia	• Kadam, A., Peddinti, D. R., & Gupta, A. (2025). The evolution of smart factories: Integrating IoT and machine learning in supply chain and manufacturing. Journal of Industry 4.0 Studies, 1(1), 45–62. • Pang, Z., & Zhang, X. (2019). History of green manufacturing frameworks. In The green manufacturing framework: A systematic literature review (pp. 10–20). ScienceDirect. • Organisation for Economic Co-operation and Development. (2022). Main Science and Technology Indicators: R&D expenditure as % of GDP. OECD. • International Energy Agency. (2023). Decarbonisation of manufacturing: Opportunities and insights [Report]. IEA. • Ernst & Young. (2025). How green manufacturing is reshaping India's industrial landscape [PDF]. EY–Parthenon.
Concessional Green Financing	• Council on Energy, Environment and Water. (2023). Unlocking India's circular waste economy potential for sustainability. CEEW. • Small Industries Development Bank of India. (2022). Annual Report 2021–22. • World Bank. (2022). Carbon Border Adjustment Mechanism: Implications for Developing Countries. World Bank. • International Labour Organization. (2018). World Employment Social Outlook: Greening with jobs. ILO. • Ernst & Young. (2025). How green manufacturing is reshaping India's industrial landscape [PDF]. EY–Parthenon.
Centralise State Implementation	• Press Information Bureau. (2023, September 29). India is keen to increase share of manufacturing in GDP from 17 percent to 25 percent: Union Minister Hardeep S. Puri [Press release]. Government of India. • Council on Energy, Environment and Water. (2024). Unlocking India's clean-energy manufacturing competitiveness [Report]. CEEW. • Deloitte India. (2024). Decarbonization in Indian manufacturing: State-level readiness and challenges. Deloitte. • Ministry of Commerce & Industry. (2022). Production Linked Incentive Scheme for High-efficiency Solar PV Modules. Government of India. • Centre for Science and Environment. (2023). State of India's Environment 2023 [In Figures]. CSE.
Third-Party Certification	• International Energy Agency. (2023). Decarbonisation of manufacturing: Opportunities and insights [Report]. IEA. • Ministry of Commerce & Industry. (2022). Production Linked Incentive Scheme for High-efficiency Solar PV Modules. Government of India. • Press Information Bureau. (2023, September 29). PLI schemes help attract US $15 billion into green manufacturing [Press release]. Government of India. • Council on Energy, Environment and Water. (2024). Unlocking India's clean-energy manufacturing competitiveness [Report]. CEEW. • The Energy and Resources Institute. (2021). Green Hydrogen Economy in India: Policy Roadmap for Transition. TERI Press.
Circular-Economy Mandates	• Das, S. K. (2025). Investigating circularity in India's textile industry: Overcoming challenges and leveraging digitization for growth [Preprint]. arXiv. • Council on Energy, Environment and Water. (2023). Unlocking India's circular waste economy potential for sustainability. CEEW. • Seth, D., Rehman, M. A. A., & Shrivastava, R. L. (2021). Green manufacturing drivers and their relationships for small and medium (SME) and large industries. Journal of Cleaner Production, 281, Article 124545. • Pangestu, F., Pujiyanto, S., &Rosyidi, C. N. (2023). Multi-objective cutting parameter optimization model of multi-pass turning in CNC machines for sustainable manufacturing. Materials Today: Proceedings, • Ramachandra, T. V. (n.d.). Renewable energy in India: Historical developments and prospects. Centre for Ecological Sciences, Indian Institute of Science.

Detailed Policy Recommendations:

1. Leverage SIDBI's refinancing window and a dedicated "Green Manufacturing Fund" to offer sub-5% interest loans for energy-efficient retrofits, water-recycling installations, and renewable-equipment fabrication lines.
   This recommendation can successfully be implemented by drawing on successful CEEW models for circular-economy financing (CEEW, 2023).
2. Academics argue for creating public-private sector specific research and development consortia by bringing together academia, large OEMs, and SMEsto co-fund pilot projects in advanced materials, circular-economy processes, and Industry 4.0 digitization.

The ratios of this co-investment shall be done as per OECD recommended best practices (OECD, 2022).

3. Centralize State Implementation by constituting an inter-state Green Manufacturing Council under the Ministry of Commerce & Industry to align incentive disbursement, quality-certification standards, and skill-training to reduce policy fragmentation of PLI and PAT across states.
4. Third Party Certification by requiring ISO 50001 and equivalent third-party energyaudit certifications for all factories above 10 MW load, with outcomes tied to lower tariff brackets under thePATscheme.
   Use insights from IEA's decarbonization roadmap that argues for third part audits (International Energy Agency, 2023)
5. Circular Economy Mandates for core sectors argues for mandating minimum recycled-content thresholds (e.g., 20% post-consumer polymer in packaging or 15% scrap steel content) for industries such as textiles, food and automotive.

Contribution towards India's Sustainable Growth

The significance of green manufacturing and RE equipment production in India's sustainable urban growth hinges upon a multitude of factors, such as devising comprehensive policy frameworks, increased financial investments, capacity building, and systemic integration. The trends and gaps illustrated above fundamentally highlight how these two concepts can act detrimental to India's sustainable urban growth. Based upon synthesis of secondary literature and analysis presented in previous sections, several overlapping themes emerge that are imperative to note in order to understand the urgency of integrating green manufacturing and RE equipment production in India's industrial ecosystem.

- Primarily, the integration of these two concepts would be pivotal for reducing India's GHG emissions from the industrial sector. For example, recycling raw materials and usage of captive renewable power in manufacturing can lower grid emission intensities by up to 40% for each unit of output produced (especially in the case of RE equipment production) (IEA, 2023). Substantiating the same, IEA models indicate energy-efficient green factories by 2030 can abate up to approximately 30 million tonnes of CO_2 annually within the Indian context, which is equivalent to removing more than six million petrol cars from roads (IEA, 2023).

- In addition to this, green manufacturing and RE equipment production can also act as a toolkit for trade deficit mitigation. Increasing domestic solar module capacity can save up to USD 1.1 billion in imports each year, preventing global supply chain disruptions along with providing energy security domestically (PV Tech, 2025). Scaling up semiconductor manufacturing can further narrow trade deficits by lowering reliance on critical mineral imports.

- Accelerated renewable-equipment production and green manufacturing can act as engines of job creation. In 2023, India's renewable-energy sector directly employed around 1.02 million people across generation, manufacturing, and operations (India Renewable Energy Jobs Council, 2024). Solar PV alone accounted for some 318,600 positions in module and cell manufacturing as well as system installation (IRENA, 2023). Projections by the International Renewable Energy Agency indicate that under ambitious deployment scenarios, the sector could sustain over 1.5 million jobs by 2027 (IRENA, 2024).

- Finally, green manufacturing and RE equipment production are pivotal for securing investments and assuring GDP growth for India's sustainable urban growth. According to EY, greening hard-to-abate industries (steel, cement, oil & gas) through adoption of low-carbon processes and renewable inputs could unlock a US $7 trillion economy by 2030, adding an estimated 2–3 percent to annual GDP growth (EY, 2025). Furthermore, Production-Linked Incentive (PLI) schemes targeting green-manufacturing sectors have mobilized over US $15 billion in private and public investment between FY 2022–23 and FY 2024–25, bolstering domestic capacity in solar modules, batteries, and electrolyzers. This infusion is estimated to have contributed approximately 0.5 percentage points to India's real GDP growth in FY 2024–25 by catalysing factory creation, technology transfers, and upstream supply-chain development (Press Information Bureau, 2023)

Conclusion

This policy paperillustrates that synergizing green manufacturing with robust domestic RE equipment production offers a multifaceted pathway to India's sustainable urban growth. Lifecycle efficiencies from resource-optimized manufacturing, coupled with a surge in indigenous production of solar modules, wind turbines, and electrolyzers, can collectively abate emissions, shore up energy security, and bolster economic resilience. Yet, realizing these potential hinges on alleviating cost-barriers for MSMEs, harmonizing state-level policy execution, and ramping up R&D investment to at least match global benchmarks.

A recalibrated policy architecture: featuring concessional financing for small enterprises, performance-linked incentives synchronized across states, and public–private R&D partnershipswill not only catalyse green-technology adoption but also guard against short-term trade-off between self-reliance and deployment speed. By operationalizing these recommendations, India can unlock substantial environmental, social, and economic dividends: cutting up to 30 $MtCO_2$ annually, saving over USD 1 billion in import costs, creating more than 1.5 million jobs, and contributing up to 3 percentage points in GDP growth by 2030. This integrated strategy is imperative to ensure that India's urban expansion is both prosperous and planet-positive.

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