

Green Innovation in Chinese Manufacturing: A Review of Current Issues, Contributions, and Pathways toward Sustainable Practices

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DOI Link: <http://dx.doi.org/10.6007/IJARBSS/v15-i12/27268>

Published Date: 15 December 2025

Abstract

The Chinese manufacturing industry, a cornerstone of global production, faces challenges including resource inefficiency, environmental degradation, and escalating regulatory pressures. Green innovation encompassing advancements in processes, products, technologies, and management practices has emerged as a pivotal strategy to address these issues and promote sustainable development. This study conducts a comprehensive systematic review of the current landscape of green innovation within China's manufacturing sector. Employing bibliometric analysis, we examine the evolution and impact of green innovation, focusing on five key dimensions: environmental performance, economic indicators, policy frameworks, technological innovation, and management systems. Our analysis reveals that while significant progress has been made in adopting green practices, challenges persist, particularly in integrating digital technologies and achieving effective communication across enterprises. Digital-enabled environmental management systems, intelligent manufacturing technologies, policy integration mechanisms, supply chain coordination, and social capital development collectively contribute to enhanced sustainability performance. The findings underscore the necessity for enhanced digital integration, policy support, and collaborative frameworks to overcome existing barriers. This review provides valuable insights for policymakers, industry leaders, and researchers, offering strategic directions to advance green innovation and achieve sustainable performance in China's manufacturing industry.

Keywords: Sustainable Performance, Green Innovation, Issues, Contributions, Chinese Manufacturing

Introduction

China's manufacturing industry has become a cornerstone of global supply chains, contributing significantly to international trade and economic growth (Li et al., 2023a). Now

accounting for nearly 30% of global manufacturing output, China's rapid industrial expansion has also led to considerable environmental degradation, necessitating urgent ecological transformation (Zhang et al., 2022). The nation faces mounting pressure to align its economic trajectory with sustainability goals, particularly after pledging carbon neutrality by 2060. GI offers a vital strategy for balancing economic development with environmental responsibility. As traditional industrial paradigms give way to sustainable models, GI encompassing product, technological, conceptual, and institutional advancements have emerged as a key mechanism for reducing ecological impact while sustaining competitiveness (Li et al., 2023b). Its adoption in Chinese manufacturing is shaped by government policies, market conditions, technological capabilities, and global regulations (Xu, 2022). Policy initiatives such as Made in China 2025 have played a catalytic role in promoting GI and sustainable transformation across manufacturing sectors. Meanwhile, digital transformation serves as a critical enabler, enhancing GI through improved data transparency, internal control systems, and absorptive capacity. Additionally, external forces like the EU's Carbon Border Adjustment Mechanism, set for 2026, are prompting high-carbon sectors to accelerate innovation (Yang et al., 2024). Despite progress, substantial challenges remain, including technological limitations, resource constraints, institutional inertia, and market uncertainty. This review explores how multiple factors influence GI and sustainable performance (SP) in Chinese manufacturing, offering pathways that integrate economic growth with environmental protection. Figure 1 illustrates the development background and strategic orientation of GI.



Figure 1. Green Innovation Development Background and Direction

The paper proceeds as follows: Section 2 details the methodology; Chapter 3 presents bibliometric findings; Chapter 4 analyzes five key innovation dimensions; Chapter 5 discusses contributions and future research; Chapter 6 concludes with recommendations and implications.

Methodology

Green innovation (GI) trajectories in Chinese manufacturing closely align with evolving scholarly publication patterns, citation trends, and keyword dynamics. This systematic review analyzed research outputs from the past five years to identify emerging trends and potential research pathways. The methodological framework integrated citation network analysis with keyword co-occurrence mapping to reveal innovation clusters and their interrelationships in sustainable manufacturing domains (Zhou & Liu, 2024). This approach enables foundational insight into mechanisms driving green transformation in Chinese manufacturing. Temporal

analysis further highlights shifting research priorities, especially those related to digitalization and circular economy strategies (Chen et al., 2024). The sequential process from data extraction to thematic synthesis is shown in Figure 2.

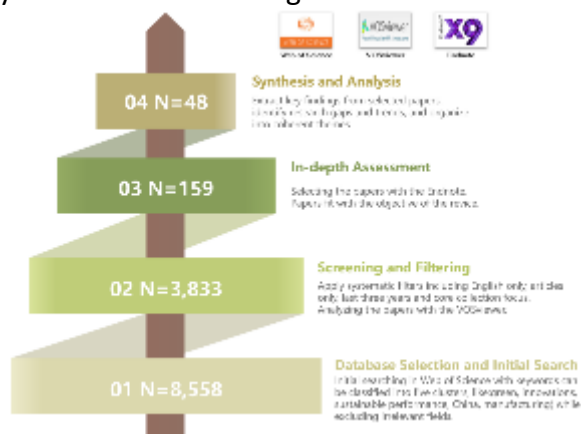


Figure 2. Research Methodology Flowchart

Keyword co-occurrence networks were visualized using VOSviewer, which enables color-coded cluster differentiation and highlights topic interconnections through linking lines. This mapping guided trend identification and refined literature review strategies. Data was extracted from the Web of Science (WoS), chosen for its scientific rigor and coverage, superior to platforms like Scopus (Kasavan et al., 2021). The search strategy incorporated green, innovation, digitalization, manufacturing, and sustainable performance while excluding financial and biological contexts, initially yielding 8,558 records (see Figure 3). Subsequent filtering excluded non-articles, non-English documents, pre-2022 publications, and non-core content, refining the dataset to 3,833 papers. A single-day extraction was performed on April 26, 2025, ensuring temporal consistency. From this corpus, 48 representative articles were selected for deep analysis, forming the basis for examining green manufacturing dynamics (Bai et al., 2022; Lyu et al., 2023). Results are presented in Figure 4.

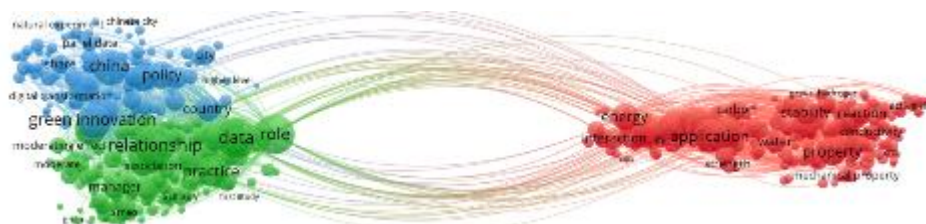


Figure 3. A Co-Occurrence Mapping of Research Hotspots

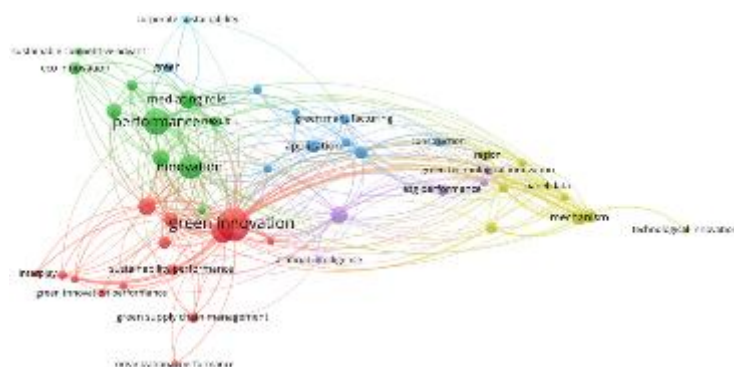


Figure 4. A Co-Occurrence Mapping of Specific Research Hotspots

Academic interest in green manufacturing has surged over the past decade. Figure 5 shows a sharp increase in both publication volume and citation metrics, with 20,765 papers recorded in 2024 over five times the 2015 figure. Although data collection ended in April 2025, the 6,438 publications already registered suggest continued growth. This upward trend reflects global sustainability priorities and China's escalating policy emphasis on green development (Chen et al., 2023).

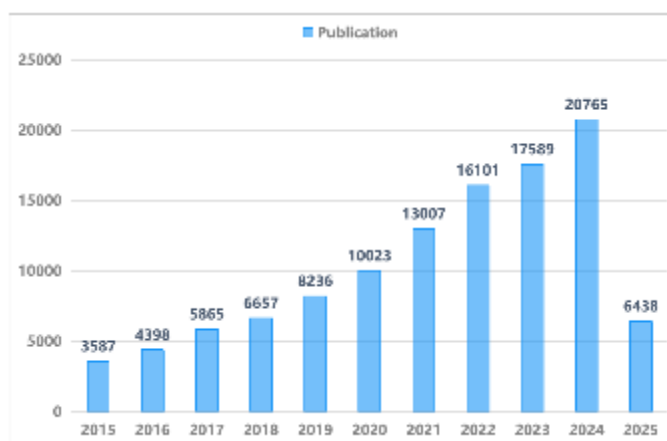


Figure 5. Publication Over Time (The Data were Retrieved on 26th April 2025)

Co-word network analysis (Wang et al., 2022) identified 48 key terms forming five clusters: GI and sustainability (red); environment and products (green); economics and finance (blue); technology (yellow); and ESG and manufacturing firms (purple). "Green innovation," "performance," and "manufacturing" emerged as dominant themes. Overlay visualizations (Figure 6) show new focus areas such as "circular economy," "nexus," and "green transformation," indicating digital integration with sustainability (Li & Wang, 2022; Huang & Chen, 2022).

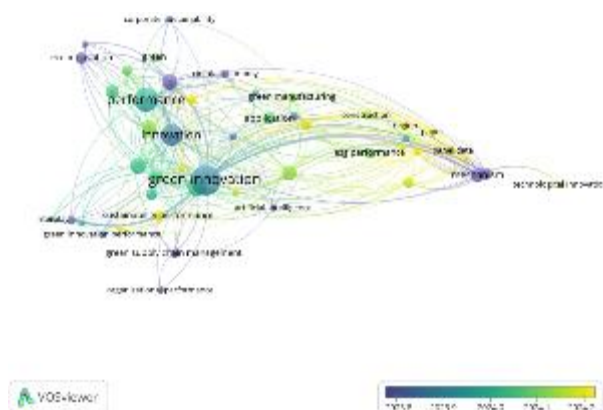


Figure 6. Keyword Overlay Visualization

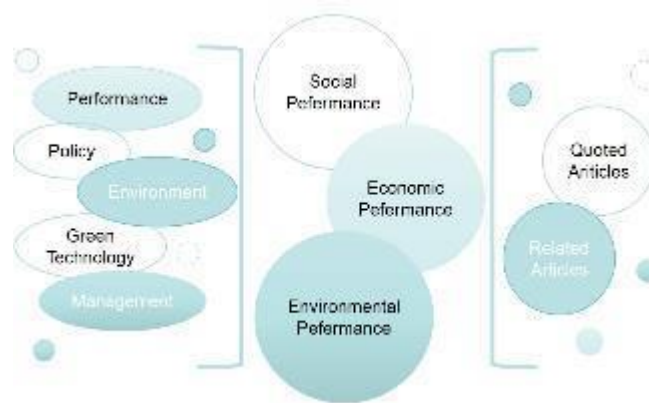


Figure 7. The Theoretical Framework of Induction and Considered Factors

The analytical framework incorporates environmental, economic, and social dimensions based on the Triple Bottom Line (Elkington et al., 2023), supported by life cycle assessment methodologies. Key metrics include energy efficiency, emissions reduction, and ecological impact. Filtering using core terms yielded data across environmental, technological, policy, and managerial domains. Manual verification and citation network analysis, emphasizing studies from 2022–2025, ensured the inclusion of current trends. Figure 7 outlines the integrated analytical model.

Research Methodology

This section traces the evolution of green innovation (GI) in China's manufacturing ecosystem using bibliometric analysis. Four core dimensions: product, process, technological, and management innovation, form the foundation of China's socio-technical transition (Wang et al., 2023). Emerging research themes reflect growing integration of digital technologies with circular economy models and increasing attention to climate resilience (Lin et al., 2022). By examining drivers such as policy frameworks, technological enablers, and market dynamics, this review builds a conceptual basis for understanding implementation challenges explored in subsequent chapters. Successful sectoral case studies further highlight transferable strategies that enhance both competitiveness and environmental outcomes (Wei et al., 2024). These innovation dimensions are illustrated in Figure 8.

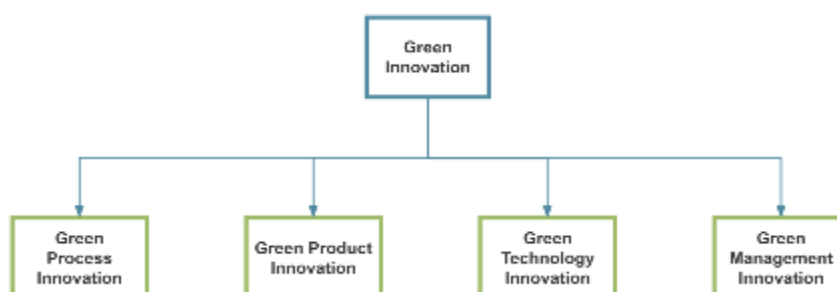


Figure 8. Dimensions of Green Innovation

GI is now recognized as a transformative model that embeds sustainability across production lifecycles, rather than treating environmental concerns as regulatory burdens (Tariq et al., 2021). This paradigm manifests in four key domains. Product innovations like biodegradable materials have reduced material-related impacts by 15–23%, while process innovations using digital automation and energy optimization have lowered energy

consumption by 18-30% (Alex & Mwebaze, 2025). Technological innovation incorporates AI, IoT, and blockchain to enhance monitoring, with AI-driven maintenance reducing waste by 27% (Chen et al., 2022). These technologies complement management innovations; firms with integrated governance structures achieve 3.2 times greater success in adopting green technologies (Zhou & Shan, 2023). Bibliometric analysis shows rapid growth in digital-circular economy studies. Blockchain-based supply chains increased 187% from 2020–2023, improving resource recovery by 34% in electronics manufacturing (Gong et al., 2023). Climate resilience research also rose 213%, shifting focus from isolated tech to system-wide innovation ecosystems. Six identified configurations reveal complex interactions among technologies, institutions, and markets (Wang et al., 2023). Targeted policies have shortened tech adoption cycles by 41% and increased diffusion (Liu & Zhu, 2022). GI momentum is shaped by policy mandates, tech capabilities, and market demands. Goals for peak emissions by 2030 and neutrality by 2060, bolstered by the 14th Five-Year Plan, restructure innovation incentives (Zhang et al., 2023). Regional regulatory variation influences 42% of GI investments. Market drivers include international standards and shifting consumer demand, especially among younger demographics (Yuan et al., 2023). However, challenges persist: 67% of firms cite costs, and 58% face technical shortfalls. Success factors include leadership, cross-functional teams, phased strategies, and supplier collaboration yielding up to 2.7 times stronger outcomes (Su et al., 2023).

Current Issues of Green Innovation

This section identifies key challenges in China's green manufacturing transformation across five dimensions: environmental impacts, economic and social performance, policy frameworks, technological practices, and management strategies derived from bibliometric keyword analysis. As shown in Figure 9, these areas form the foundation for assessing ongoing limitations in green innovation (GI) and inform further exploration of digital green manufacturing development.



Figure 9. Main Research Objectives of Green Innovation

Environmental Impacts

China's shift to green manufacturing has improved environmental performance but revealed persistent gaps. ESG-oriented facilities show reduced carbon intensity, yet total emissions continue rising due to growing output: a "rebound effect" that jeopardizes neutrality targets (Wang et al., 2023). Technological disparities persist, with leading firms outperforming industry averages, indicating unrealized diffusion potential. Water usage has declined in innovative clusters, though withdrawals in water-stressed regions remain high due to overlooked design inefficiencies (Zhang et al., 2022). Material efficiency remains limited by

dependence on conventional inputs over regenerative alternatives (Bai et al., 2022). Industrial symbiosis and remanufacturing efforts are still marginal, hindered by infrastructure bottlenecks and restricted reverse logistics (Geng et al., 2022).

Economic and Social Performance

GI involves a trade-off between initial costs and long-term returns. While green firms show better margins (Przychodzen & Przychodzen, 2015), sectoral variations persist due to differing material costs and capital intensities. Labor markets are reshaped, with technical roles emerging and traditional jobs declining, requiring retraining and educational investment (Che et al., 2024). Community integration remains limited, despite alignment between environmental and economic goals. The digital economy optimizes energy use and reduces emissions, underscoring its role in enhancing social and economic sustainability (Wang et al., 2024).

Policy and Institutional Frameworks

China's regulatory evolution from compliance to innovation-centric governance includes both command-control and market-based tools. The Energy Conservation and Emission Reduction policy applies differentiated targets with flexible execution (Tao et al., 2022), though enforcement varies across regions. Incentives like tax policies under Made in China 2025 promote GI but differ by enterprise type and locality (Yuan et al., 2022). Despite a maturing policy mix including 56 green development guidelines implementation remains uneven. While Porter effects support innovation, crowding-out effects reduce investment in some sectors (Li et al., 2023a). Enforcement of environmental tax policies remains insufficient (Zhang et al., 2022).

Technological Practices

Technology differentiates traditional from green systems. Digital tools improve transparency and coordination, advancing GI (Su et al., 2023). Yet regional adoption disparities persist (Liu et al., 2023). Innovations such as green nanotech and digital twins enhance efficiency and emissions control but face commercial hurdles (Zhang & Li, 2024; Digital Twin Project, 2024). SMEs struggle with limited technological capacity, hindering broad-scale uptake.

Management Strategies

Strategic governance is central to sustainability. Firms with sustainability structures report 34% better outcomes, yet only 25% have such systems. Strategic shifts raise innovation success by 40%, but inertia and short-termism hinder diffusion (Yang et al., 2022). Most firms lack structured green knowledge systems, slowing innovation spread (Shahzad et al., 2021). Internal silos restrict knowledge flow. Supply chain collaboration enhances outcomes, but many manufacturers remain internally focused and lack market feedback loops (Zhang et al., 2023).

Contributions and Future Directions

This section examines the contributions and future prospects of GI in promoting SP across China's manufacturing industry, using five dimensions environmental technologies, policy integration, intelligent manufacturing, supply chain circularity, and social engagement as analytical indicators. As outlined in Figure 10, these interrelated areas demonstrate GI's

expansive role in aligning industrial transformation with broader carbon neutrality goals (Tu et al., 2024; Chen et al., 2024).



Figure 10. Current Green Innovation Contributions in Chinese Manufacturing

Digital-Enabled Environmental Management

Recent digital advancements have transformed China's environmental management systems, significantly reduced ecological footprints while enhanced operational competitiveness. Integrating IoT with monitoring systems has improved resource efficiency, with reductions of 15–28% across sectors (Zhang et al., 2023). AI-driven predictive maintenance has decreased waste by 27% and extended equipment lifespan (Chen et al., 2022). Despite challenges in interoperability and technical skills, these tools offer transformative potential. Digitalization also strengthens GI via improved transparency, absorptive capacity, and control quality (Li et al., 2022). Supported by the Made in China 2025 initiative, such digital systems have bolstered environmental compliance while enhancing global competitiveness (Bai et al., 2022).

Intelligent Manufacturing Technologies

Intelligent manufacturing plays a critical role in China's green transformation. Stronger outcomes are reported in regions with advanced digital infrastructure (Yang et al., 2024). IoT and digital twins have driven 28.9% increases in green transformation by enhancing transparency, enabling pre-emptive impact assessments, and optimizing production (Wei et al., 2024). Productivity gains of 17% and energy savings of 30% have been observed in leading cases. These technologies synergize with industrial policies that encourage environmental integration into modernization strategies (Tian et al., 2023).

Policy Integration and Market Mechanisms

China's environmental governance has evolved from regulatory mandates to market-integrated mechanisms. Policies like the Environmental Protection Tax Law encourage GI, with regulations now mediating intelligent manufacturing upgrades (Chen et al., 2022). Carbon trading pilots have strengthened green cooperation across cities through industrial restructuring and digital finance (Liu et al., 2022). These efforts are reinforced by policy frameworks like Made in China 2025, which align sustainability with modernization. Synergistic coordination between incentives and regulations has proven critical to transformation success.

Supply Chain Integration and Circular Practices

GI now extends across supply chains. Collaborative supplier programs significantly reduce upstream impacts. Digital platforms enhance traceability and resource recovery, particularly in electronics manufacturing (Wang et al., 2022). Industry 4.0 technologies, such as AI, IoT, and cloud computing, support modular design and circular flows, improving resource efficiency and lowering costs (Yang et al., 2022; Hao et al., 2023). Empirical evidence confirms that circular models simultaneously reduce environmental burdens and strengthen competitiveness.

Social Integration and Human Capital

Social factors underpin sustainable manufacturing. Enterprises implementing digital skill transition programs report 75% success in reskilling workers for green roles, helping mitigate job displacement. Online training platforms enhance technical capabilities and green awareness, boosting innovation capacity (Zhang & Li, 2023). Community engagement platforms improve implementation success by fostering stakeholder feedback and support (Khattak et al., 2022). Firms with integrated sustainability governance perform 34% better environmentally. Together, technological and social strategies foster a robust foundation for long-term sustainability.

Future Outlook

China is poised to become a global GI leader. AI applications are reshaping emission control and energy efficiency, offering system-wide optimization tools (Wang et al., 2024). The robotics sector enables high-precision manufacturing at lower costs, reducing material waste (Yang et al., 2022). Concurrently, China's regulatory architecture is evolving, with emissions trading and circular economy laws increasingly influencing industry behavior (Du et al., 2021). Crucially, convergence between GI and digital technology is intensifying. Studies show that integrated applications outperform isolated tools in environmental metrics (Wei et al., 2024). This creates potential for systemic transformation, not just incremental gains. As China scales this convergence, its leadership in global sustainable development will likely grow, offering lessons and raising competitive pressures for other major economies.

Conclusions

China's traditional manufacturing sector faces persistent challenges resource scarcity, environmental degradation, and increasing international competition that hinder sustainable development. In alignment with global sustainability goals, scientific and technological innovations have emerged as key drivers of transformation. Inconsistent adoption of digital and GIs across industrial sectors, due to fragmented knowledge exchange and lack of systematic review, has limited widespread impact. This review, through bibliometric analysis and literature synthesis, identifies five core pillars of GI in Chinese manufacturing: environmental performance, economic indicators, policy frameworks, technological innovation, and management systems. These dimensions were systematically analyzed to construct a comprehensive understanding of the current GI landscape. Recent global trends emphasize using existing technologies to achieve industrial sustainability, with manufacturing standing as a practical example. In China, carbon reduction and renewable energy adoption are essential strategies to address environmental challenges while preserving economic competitiveness. Product innovation, including eco-material use and lifecycle design, enhances sustainability outcomes. Process optimization contributes through supply chain

efficiencies, reducing resource use, costs, and labor inputs. The integration of digital, intelligent, and automated technologies fosters transformative pathways toward sustainable industrial development. These innovations must be embedded in institutionalized management systems to prevent fragmented efforts and ensure consistent execution. IoT-enabled data collection enhances decision-making for sustainability governance. Nonetheless, technical and operational limitations remain. Future research should incorporate real-world feedback, refine evaluation frameworks for specific needs, and emphasize scenario analysis, risk assessment, and knowledge-sharing mechanisms to support the continued evolution of GI.

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