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From Compliance Costs to Value Creation Mechanisms Linking AI to Competitive Advantage in Green Manufacturing among Guangdong Enterprises

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Abstract: Against the backdrop of China's carbon peaking and carbon neutrality goals and the growing application of artificial intelligence (AI), this study examines how AI helps listed companies in Guangdong translate green compliance into competitive advantage. Drawing on annual reports from Midea, Gree, and TCL and relevant policy documents, it identifies three findings. First, AI reduces waste through energy consumption forecasting and process optimization, allowing efficiency gains to offset compliance costs. Second, its integration with green factories improves delivery and traceability, creating opportunities for orders and price premiums. Third, this mechanism depends on firms' research and development, data resources, and organizational coordination. Reported outcomes include a 23% reduction in operating costs and a 36% improvement in production efficiency at Midea's Nansha factory, 25% energy savings for Gree, and a reduction of more than 30% in emissions at TCL Zhonghuan. Manufacturing policy in Guangdong should therefore support coordinated development across AI, green manufacturing, and specific application settings.

Keywords: green manufacturing, competitive advantage, Guangdong enterprises, value creation

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INTRODUCTION

As China's carbon peaking and carbon neutrality goals, green factory system, and AI-enabled new industrialization advance in parallel, manufacturing enterprises increasingly face a question of whether green compliance can generate value. The integration of AI into key manufacturing applications (General Office of the Ministry of Industry and Information Technology, 2024), together with the Interim Measures for the Tiered Development and Management of Green Factories (Ministry of Industry and Information Technology, 2024), marks a stage of competition shaped by the convergence of intelligent and green manufacturing. Guangdong provides a useful setting for examining this issue because of its strengths in manufacturing and research and development (R&D). Its R&D expenditure reached 3.60% of gross domestic product in 2024 (Guangdong Provincial Bureau of Statistics & Survey Office of the National Bureau of Statistics in Guangdong, 2025; Guangdong Provincial Bureau of Statistics, 2025).

Previous studies have examined the theoretical foundations of green transformation through environmental regulation (Porter & van der Linde, 1995), dynamic capabilities (Teece, 2007), and digital transformation (Ng *et al.*, 2022; He & Bai, 2021; Mao & Shi, 2024; Zeng *et al.*, 2023; Xie *et al.*, 2025). Research on Guangdong has also explored regional pathways for green transformation (Liu, 2024a, 2024b; Zhang *et al.*, 2024). Two gaps remain in explaining how Guangdong companies use AI to turn compliance into competitive advantage. Discussions of AI and green manufacturing often remain at the level of policy or practice, without a verifiable mechanism grounded in statutory disclosures. In addition, Guangdong-focused research primarily uses regional statistics, leaving firm-level evidence of value conversion fragmented.

This study conducts a mechanism-oriented analysis of representative cases using public information. It selects three listed manufacturing companies in Guangdong, Midea Group, Gree Electric Appliances, and TCL Technology, to identify how AI affects competitive advantage through cost reduction, quality consistency, revenue expansion, and brand signaling. The study makes three contributions. It moves from regional comparisons to evidence disclosed by listed companies, distinguishes four specific sources of value within green manufacturing, and confines its evidence base to official policies, statistical communiqués, and statutory annual reports to avoid unverifiable secondary

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data. The remainder of the paper presents the analytical framework and research design in Materials and Methods, compares the mechanisms and cases in Results and Discussion, and concludes with the findings, policy recommendations, and limitations.

MATERIALS AND METHODS

Literature basis

Environmental regulation and competitive advantage. A central debate concerns whether innovation can offset the costs of environmental compliance. Porter and van der Linde (1995) argue that well-designed environmental regulation can reshape firms' competitive advantages through technological innovation. This perspective motivates an examination of green manufacturing in terms of operating efficiency and market returns, extending beyond its treatment as a compulsory expenditure.

International research on AI and sustainable manufacturing. Drawing on dynamic capabilities theory (Teece, 2007), international studies identify AI and digital twins as enabling technologies for sustainable manufacturing. Industry 4.0 can improve overall performance through energy optimization, supply chain transparency, and servitization (Ng *et al.*, 2022; He & Bai, 2021). AI can also support green transformation through process optimization (Mao & Shi, 2024; Xie *et al.*, 2025). These findings suggest that AI and green manufacturing can create value by reconfiguring operations.

Chinese research on intelligent manufacturing, digitalization, and green transformation. Chinese studies have examined both firm-level effects and regional development, documenting connections between intelligent and green manufacturing (Mao & Shi, 2024; Zeng *et al.*, 2023; Zhang & Chen, 2025; Zhang *et al.*, 2020). However, much of this work remains at the institutional or regional level. How individual firms translate this connection into verifiable market value requires further analysis.

AI-enabled new industrialization and the green factory system. Recent industrial policies explicitly connect intelligent and green development by incorporating AI into new industrialization applications (General Office of the Ministry of Industry and Information Technology, 2024) and establishing a tiered system for developing green factories (Ministry of Industry and Information Technology, 2024). The focus of competition is consequently shifting toward firms' ability to turn green projects into replicable business practices.

Research on green transformation in Guangdong manufacturing. Existing studies have identified macro-level constraints and enabling conditions through analyses of influencing factors and efficiency (Liu, 2024a, 2024b; Zhang *et al.*, 2024). Their emphasis on regional pathways leaves the firm-level sequence linking green compliance, capability accumulation, and value creation through AI insufficiently explored.

The gap in research based on public disclosures. Current discussions often rely on aggregate indicators or individual case reports. Verifiable information in statutory disclosures has yet to be systematically organized into a framework for mechanism analysis. Annual reports provide a useful window through which to examine whether compliance costs translate into value, because they disclose costs, efficiency, and market outcomes. This study adopts that perspective.

Analytical framework

The study interprets the formation of competitive advantage in green manufacturing among Guangdong firms as a process in which AI recasts compliance pressures into operational requirements. It groups the publicly observable sources of competitive advantage into four categories:

$$CA_i = \alpha EC_i + \beta QC_i + \gamma RC_i + \delta BC_i \quad (1)$$

Here, CA_i denotes competitive advantage; EC_i represents reductions in energy, material, and other costs; QC_i denotes quality consistency and delivery reliability; RC_i represents product solutions and revenue expansion; and BC_i denotes green certification and brand signals. BC_i is further decomposed into brand reputation (BR_i), customer loyalty (BL_i), and capital market signals (CM_i):

$$BC_i = \lambda_1 BR_i + \lambda_2 BL_i + \lambda_3 CM_i \quad (2)$$

These equations illustrate structural relationships among sources of value creation. They are not used to assign quantitative weights or conduct empirical estimation. The subsequent analysis identifies the dominant pathways.

The framework leads to three analytical propositions.

Proposition 1. AI first changes compliance costs per unit. When energy monitoring and intelligent quality inspection become part of routine operations, compliance requirements can be implemented algorithmically. Environmental expenditure can then generate continuing cost reductions instead of being concentrated around assessment deadlines.

Proposition 2. AI must be integrated with green factories and low-carbon products to improve firms' ability to secure orders. These applications turn AI capabilities into verifiable delivery quality and customer trust, directly affecting order acquisition.

Proposition 3. The formation of competitive advantage is subject to boundary conditions. Without

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sustained R&D, application-specific data, and coordination across departments, AI initiatives may remain isolated pilots and fail to translate consistently into revenue growth or brand premiums.

Case selection and research boundaries

This study uses a comparative case study design (Eisenhardt, 1989; Yin, 2018). Firms were selected according to three criteria: they are listed manufacturing companies based in Guangdong; their 2024 annual reports disclose both AI applications and green or low-carbon performance; and the disclosures can be linked to business outcomes. Midea, Gree, and TCL were selected as information-rich cases. The design uses the verifiability of statutory disclosures to reduce subjective inference while covering heterogeneous manufacturing settings, including household appliances and building technologies, heating, ventilation, and air-conditioning (HVAC) equipment, and semiconductor displays. This variation supports the identification of different mechanisms.

Evidence extraction and evaluation dimensions

The evidence base centers on 2024 annual reports, supplemented by policy documents and statistical communiqués. The comparison prioritizes quantitative disclosures and uses qualitative evidence as a supplement. Coding follows the four value dimensions introduced above: EC, QC, RC, and BC. For economic benefits, the analysis extracts measurable outcomes such as cost and efficiency improvements, solution-related revenue expansion, and cash flow resilience. For social benefits, it examines energy savings, carbon reductions, and green factory recognition. Where quantitative data are unavailable, qualitative judgments explicitly acknowledge the limits of the evidence. These procedures connect compliance investment, operational optimization, and market outcomes. Table 1 sets out the extraction and coding rules.

Table 1. Evidence extraction and coding rules

Coding dimension	Disclosure scope	Key evidence	Treatment rule
Cost reduction (EC)	Costs, energy use, efficiency, and energy-saving projects in annual reports	Cost reductions, efficiency gains, energy savings, and emissions reductions	Prioritize quantitative disclosures; identify and explain non-comparable items separately.
Quality and delivery (QC)	Intelligent quality inspection, process optimization, and delivery stability	Yield improvements, repair efficiency, operations and maintenance controls, and supply chain coordination	Where common indicators are unavailable, describe the evidence as supporting the proposed mechanism.
Revenue expansion (RC)	Solution-related revenue, project deployment, and overseas expansion	New business revenue, project counts, and market expansion	Use disclosed financial or business outcomes; do not infer undisclosed returns.
Brand and capital (BC)	Green factories, lighthouse factories, and signals recognized by customers and investors	Green certification, brand reputation, customer loyalty, and capital market attention	Where a common valuation basis is unavailable, identify directional effects only and moderate the strength of claims.

Note: These rules improve the transparency and reproducibility of comparisons based on public information; they do not constitute the construction of an econometric database.

Research procedure and case overview

The analysis proceeds by defining the institutional context, extracting annual report evidence, and comparing mechanisms. As Table 2 shows, all three firms integrate AI, digitalization, and green solutions into their business narratives. The following analysis therefore focuses on the different pathways through which green manufacturing contributes to competitive advantage.

Table 2: Public disclosures on AI and green manufacturing by selected listed companies in Guangdong

Firm	Main business areas	AI and green manufacturing evidence	Competitive outcomes in 2024
Midea	Household appliances, building technologies, robotics, and automation	Six factories recognized as World Economic Forum (WEF) Lighthouse Factories. Digital transformation at the Nansha residential air-conditioner factory in Guangdong reduced operating costs by 23% and increased production efficiency by 36%. An additional lighthouse factory applies AI throughout the production of central air-conditioning chillers.	Revenue: CNY 407.150 billion. Net profit attributable to shareholders of the parent: CNY 38.537 billion. Commercial and industrial solutions revenue: CNY 104.496 billion.
Gree	Air conditioning, HVAC, and energy-saving equipment	GMV9 Zhiyue variable refrigerant flow (VRF) systems use AI-based wide-range energy-saving controls, achieving average energy savings of 25%. Zero Carbon Source photovoltaic and energy-storage air-conditioning systems operate in 35 countries and regions, with estimated annual carbon reductions of approximately 110,000 tonnes.	Revenue: CNY 189.164 billion. Net profit attributable to shareholders of the parent: CNY 32.185 billion.
TCL	Semiconductor displays and photovoltaic materials for new energy applications	The AI-enabled R&D capability enhancement project has entered industrial application. TCL CSOT's AI quality inspection and intelligent repair platform is being extended across multiple panel factories. Ten TCL Zhonghuan enterprises received green factory recognition, including four at national level. Scope 1 and Scope 2 greenhouse gas emissions fell by more than 30% compared with 2023.	Revenue: CNY 164.823 billion. Net cash flow from operating activities: CNY 29.527 billion. R&D expenditure: CNY 8.870 billion.

Note: Compiled from the firms' 2024 annual reports (Midea Group Co., Ltd., 2025; Gree Electric Appliances, Inc. of Zhuhai, 2025; TCL Technology Group Corporation, 2025). Financial amounts are expressed in CNY billion.

RESULTS AND DISCUSSION

Institutional constraints and regional capabilities

On the policy side, the integration of AI into new industrialization applications and the tiered green factory system establish clear expectations for the joint development of intelligent and green manufacturing (General Office of the Ministry of Industry and Information Technology, 2024; Ministry of Industry and Information Technology, 2024). Guangdong's comprehensive industrial chains and substantial R&D investment, equivalent to 3.60% of provincial GDP in 2024, provide resources for turning compliance pressure into competitive strength (Guangdong Provincial Bureau of Statistics & Survey Office of the National Bureau of Statistics in Guangdong, 2025; Guangdong Provincial Bureau of Statistics, 2025). The decisive difference is whether firms can use AI to translate compliance requirements into operational, product, and market capabilities.

AI changes compliance costs per unit

The case evidence suggests that AI first affects internal operations. Table 3 shows a common underlying logic across the digital transformation of Midea's Nansha factory, where operating costs fell by 23% and production efficiency rose by 36%; energy-saving controls in Gree's GMV9 variable refrigerant flow systems, which achieved 25% energy savings; and AI inspection and energy-saving initiatives at TCL CSOT and TCL Zhonghuan, alongside reported emissions reductions exceeding 30% (Midea Group Co., Ltd., 2025; Gree Electric Appliances, Inc. of Zhuhai, 2025; TCL Technology Group Corporation, 2025). Once green requirements are represented as data and implemented through algorithms, they become part of production systems and translate into lower energy consumption per unit, less material loss, and more stable processes.

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Table 3: Pathways from compliance costs to value creation in AI-enabled green manufacturing

Mechanism	Public evidence	Value generated
Energy monitoring and predictive control	Following upgrading, Midea's Nansha residential air-conditioner factory reduced operating costs by 23% and increased production efficiency by 36%. Gree's GMV9 VRF systems achieved average energy savings of 25%. TCL CSOT advanced 361 energy-saving projects in 2024.	Lower energy use per unit and marginal compliance costs; improved operating efficiency.
Intelligent quality inspection and process optimization	TCL CSOT is extending AI inspection and intelligent repair across multiple panel factories. Midea replicates lighthouse factory practices across production sites.	Higher yields, shorter commissioning periods, and lower rework and scrap losses.
Commercializing green capabilities as solutions	Gree's Zero Carbon Source systems operate in 35 countries and regions. Midea's commercial and industrial solutions revenue exceeds CNY 100 billion.	Product premiums, solution-related revenue, and customer loyalty.
Stronger certification and disclosure signals	Midea's lighthouse factories, TCL Zhonghuan's national green factories, and low-carbon performance disclosures in listed companies' annual reports.	Greater customer trust, brand reputation, and capital market visibility.

Note: Compiled from the firms' 2024 annual reports (Midea Group Co., Ltd., 2025; Gree Electric Appliances, Inc. of Zhuhai, 2025; TCL Technology Group Corporation, 2025).

Table 3 indicates that the contribution of AI to green manufacturing involves several interconnected reductions in compliance costs. Green manufacturing costs remain, but efficiency gains associated with AI absorb and restructure part of those costs.

Differences in pathways and outcomes

Cost reduction alone cannot explain how green manufacturing becomes a competitive advantage. Table 4 distinguishes three modes of value realization according to where AI enters green manufacturing. Midea follows a model of lighthouse factory replication and the commercialization of internal capabilities, with a dominant value pathway of EC → QC → RC, BC. Gree embeds energy-saving algorithms in products and supplies integrated systems, emphasizing QC, RC, and BC. TCL concentrates on process improvement and resilience, with EC and QC as its main value sources.

Table 4 attributes these differences to customer interfaces and positions in the industrial value chain rather than to gaps in technological capability. Because Midea and Gree serve end users or engineering project clients more directly, they can more readily translate internal green capabilities into solution-related revenue and brand premiums. TCL operates in upstream, capital-intensive manufacturing, where green capabilities primarily strengthen process resilience and resource efficiency and are harder to convert directly into short-term profit growth.

Table 4: Comparison of pathways and benefits across the three case firms

Dimension	Midea Group	Gree Electric Appliances	TCL Technology
Pathway and model	Replicate lighthouse factories, coordinate supply chains, and commercialize capabilities through solutions.	Embed energy-saving algorithms in product systems and deploy them in engineering projects.	Embed AI R&D, intelligent inspection, and process optimization deeply in production.
Dominant value sources	EC → QC → RC, BC	QC, RC, BC	EC, QC
Main economic benefits	Nansha factory operating costs fell by 23% and production efficiency rose by 36%. Commercial and industrial solutions revenue reached CNY 104.496 billion.	VRF and Zero Carbon Source systems improve competitiveness in engineering applications, supporting overseas expansion and system orders.	Improved yields, R&D efficiency, and cash flow resilience, although these cannot fully offset industry downturns in the short term.

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Dimension	Midea Group	Gree Electric Appliances	TCL Technology
Main social benefits	Lighthouse factories and efficient building applications disseminate green manufacturing practices.	GMV9 VRF systems deliver average energy savings of 25%. Zero Carbon Source systems operate in 35 countries and regions, with estimated annual carbon reductions of approximately 110,000 tonnes.	TCL CSOT advanced 361 energy-saving projects. TCL Zhonghuan implemented 102 energy- and water-saving projects, with Scope 1 and Scope 2 emissions down more than 30% year on year.
Reasons for differences	Strong platform-based businesses and automation capabilities make it easier to convert factory capabilities into external revenue.	Customers place greater emphasis on energy savings over the full life cycle.	Upstream manufacturing is capital intensive and requires a longer period to realize value.

Note: Arrows indicate dominant transmission directions in the value creation chain, not causal estimates. Compiled from the firms' 2024 annual reports (Midea Group Co., Ltd., 2025; Gree Electric Appliances, Inc. of Zhuhai, 2025; TCL Technology Group Corporation, 2025). EC = cost reduction; QC = quality consistency and delivery reliability; RC = revenue expansion; BC = green certification and brand signals.

Explanations for differences and boundary conditions

To explain the different economic and social outcomes, Table 5 connects the three models to industry characteristics, value chain positions, sources of environmental pressure, points of AI application, and routes for commercializing capabilities.

Table 5: Factors explaining differences among the three cases

Dimension	Midea Group	Gree Electric Appliances	TCL Technology
Industry profile	Integration of household appliances and industrial technologies; diversified product lines.	HVAC and energy-saving equipment, with strong system integration characteristics.	Displays and photovoltaic materials; process manufacturing with high capital intensity.
Value chain position	Both a manufacturer and a solution provider.	Closer to the supply of product systems to end customers.	Upstream materials and manufacturing.
Main sources of green pressure	Higher energy efficiency standards, supply chain coordination, and demand for efficient equipment.	Life-cycle energy-saving requirements in buildings and engineering projects.	Energy-intensive manufacturing, process yields, and cyclical competitive pressures.
Points of AI application	Production line optimization, lighthouse factory replication, and supply chain coordination.	Energy-saving control algorithms, system operations and maintenance, and adaptation to engineering applications.	R&D, quality inspection, process management, and carbon management.
External value creation and outcomes	Building and industrial solutions translate capabilities into external offerings, with more evident economic and reputational spillovers.	Product systems and overseas projects commercialize capabilities; disclosures provide more direct evidence of social benefits from emissions reductions.	Benefits mainly concern resilience and resource efficiency. Social benefits are substantial, while financial returns are more exposed to industry cycles.

Note: The comparison summarizes industry characteristics and business models reflected in the firms' public disclosures; it does not establish statistical causality.

Translating green manufacturing into quality delivery and orders

AI reduces internal compliance costs while making green manufacturing outcomes verifiable in the market. Midea extends the efficiency advantages of lighthouse factories to business customers through building and industrial solutions, turning internal improvements into a capability that can generate external revenue (Midea Group Co., Ltd., 2025). Gree directly translates energy-saving controls into competitiveness in engineering projects. Its Zero Carbon Source solutions serve green buildings and industrial retrofits, shifting

customer evaluation from initial purchase prices toward reductions in carbon emissions over the life cycle (Gree Electric Appliances, Inc. of Zhuhai, 2025). When AI and green manufacturing are closely integrated, competition can therefore shift from equipment sales toward low-carbon services.

In upstream, capital-intensive manufacturing, the value of AI for green manufacturing is more evident in delivery reliability and technological resilience. TCL has introduced multimodal large models into display panel R&D and uses AI quality inspection to improve repair efficiency across multiple factories (TCL Technology Group Corporation, 2025). Although these capabilities have not immediately generated large profits, they improve the speed of technological adaptation and delivery consistency in advanced manufacturing, creating competitive barriers that are difficult to undermine through short-term price competition.

Economic and social benefits

Economic benefits across the three firms range from direct cost reductions to market expansion and greater resilience. Midea has the most complete value creation cycle, combining internal cost reductions with more than CNY 100 billion in solution-related revenue. Gree's benefits arise from improving customers' life-cycle returns through low-carbon performance, which supports high-value engineering orders. TCL's benefits center on process stability and cash flow resilience. Although these benefits may not immediately produce profits during an industry downturn, they are important for sustaining its competitive position.

Disclosures of social benefits differ across business models. Gree provides the most directly interpretable quantitative evidence of carbon reduction, including estimates for overseas deployment of its Zero Carbon Source systems. TCL emphasizes energy-saving projects and reductions in absolute greenhouse gas emissions. Midea does not provide a single comparable carbon reduction figure, but its lighthouse factories and efficient building solutions demonstrate and disseminate green manufacturing practices. Assessments of social benefits should therefore consider the replication of green manufacturing capabilities across sectors and applications alongside quantified emissions reductions.

Commercializing internal capabilities as an intermediary

The key intermediary between compliance costs and value creation is the ability to commercialize internal green capabilities. Midea translates lighthouse factory capabilities into more than CNY 100 billion in commercial and industrial solutions revenue (Midea Group Co., Ltd., 2025). Gree turns energy-saving technologies into carbon reduction system solutions for engineering clients (Gree Electric Appliances, Inc. of Zhuhai, 2025). Both firms extend their green capabilities beyond internal operations to generate external revenue.

TCL illustrates the boundaries of this mechanism. Despite substantial efforts in green factories, carbon reduction, and AI R&D, its revenue and net profit declined sharply year on year in 2024 (TCL Technology Group Corporation, 2025). In cyclical, capital-intensive upstream manufacturing, AI and green manufacturing function primarily as defensive capabilities that strengthen resilience. They can improve energy efficiency and cash flow but may not immediately offset an industry downturn. Converting AI into competitive advantage therefore requires firms to translate factory-level green capabilities into benefits that customers recognize and are willing to pay for. Otherwise, green manufacturing remains an internal efficiency improvement without becoming an external competitive advantage.

Boundary conditions and discussion

The public evidence identifies two sets of boundaries governing the conversion of AI-enabled green manufacturing into competitive advantage. Internally, sustained, intensive R&D investment is an essential prerequisite for applying AI to processes and materials. The depth of accumulated application-specific data also determines whether green manufacturing develops from a compliance project into a solution offering or remains confined to process optimization.

Externally, the potential competitive advantage is constrained by firms' ability to commercialize and communicate value through solution offerings, branding, and investor communication. Without this capability, green benefits remain within internal operations. Industry cycles and inconsistencies in annual report disclosure practices can also delay the financial visibility of green capabilities.

The resulting assessment is that AI does not automatically transform green compliance into value creation, although it substantially increases the likelihood of that transformation. The necessary conditions are a strong R&D foundation, extensive application-specific data, and an effective ability to commercialize internal capabilities.

CONCLUSION

Main findings

Using policy documents and annual reports from representative listed firms, this study identifies a chain of public evidence linking AI-enabled green manufacturing to competitive advantage. Three conclusions follow.

First, compliance costs become integrated into operations. AI's most direct effect is to represent environmental constraints as data and implement them algorithmically within routine production. This reduces energy consumption per unit and improves process stability.

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Second, commercializing internal capabilities is decisive. Value creation depends on translating green capabilities into customer benefits that can be sold and replicated, such as solutions and low-carbon systems. This conversion enables internal efficiency improvements to become external competitive advantages.

Third, the conversion mechanism has limits. It depends on the R&D foundation, the depth of application experience, and the industry cycle. Although AI and green capabilities can substantially strengthen long-term resilience, they may not immediately offset downturns in highly cyclical industries.

Policy recommendations

Policy support should be differentiated according to firms' modes of value creation rather than limited to general encouragement. Table 6 sets out specific priorities and implementation considerations.

Table 6: Differentiated policy recommendations and implementation considerations

Enterprise type	Policy priorities	Main challenges	Suggested evaluation indicators
Supply chain leader offering platform capabilities (Midea type)	Support industrial large models, replication of lighthouse factory practices, standards for green solution offerings, and coordinated industrial chain upgrading.	Complex data interfaces across industries and high costs of replicating solutions.	Share of revenue from solutions; number of factories adopting replicated practices; reduction in unit costs; customer renewal rate.
Provider of product systems (Gree type)	Support demonstrations in green buildings, rail transit, and industrial energy savings; connect domestic and international green certification and first-of-a-kind equipment applications.	Long engineering project cycles and demanding international certification and localized service requirements.	Number of energy-saving system projects; countries with overseas deployment; energy-saving rate; carbon reductions.
Process specialist strengthening resilience (TCL type)	Support process optimization, intelligent inspection, green factory upgrading, and green finance to ease the burden of long investment payback periods.	Large investment requirements, slow commercial returns, and strong industry fluctuations.	Yield improvements; energy intensity; cash flow stability; levels and numbers of recognized green factories.

Note: The categories are derived from the case comparison to illustrate differentiated policy design; they are not intended as an exhaustive classification of all firms.

Two additional considerations should guide the implementation of differentiated support.

First, improve the comparability of disclosures. Regulators should encourage listed companies to explain systematically how energy savings, yield improvements, and solution-related revenue connect in their annual reports, reducing the effort investors need to assess these relationships.

Second, establish a dynamic policy adjustment mechanism guided by application settings. Evaluation should move from short-term counts of recognized green enterprises toward medium- and long-term measures such as the share of revenue from solutions and the diffusion of capabilities along industrial chains. If policies become primarily focused on applications for official recognition, support should be redirected toward coordinated public platforms and financial instruments.

Limitations and future research

This study has two limitations. First, its reliance on statutory disclosures makes it subject to differences in corporate reporting practices. Dimensions such as customer loyalty and capital market valuation cannot be quantified consistently. Second, value creation can take time, so short-term financial statements may not capture the full long-term returns from green capabilities. Future research can proceed in two directions. A larger sample combining text mining with extensive financial data could test the generalizability of the mechanisms. Patent, carbon verification, and firm-level export data could also support rigorous causal identification and dynamic assessment of the medium- and long-term competitive advantages generated by AI-enabled green manufacturing.

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