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How Do Green Industrial Policies Promote Green Economic Development?

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Article

Keywords: Green Industrial Policy, Green Economic Development, Chinese-Style Modernization, Green Technological Innovation, Industrial Structure Greening

Posted Date: February 17th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-8610581/v1

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Additional Declarations: No competing interests reported.

Abstract

Using the 2023 Green Industry Guidance Catalogue, this study identifies green-industry policy themes and, via text-mining, builds a province–year database for 30 Chinese provinces and municipalities from 2005–2023. Data Envelopment Analysis is applied to measure regional green economic development, and the impacts and mechanisms of green industrial policies are empirically tested. Results show that such policies significantly foster green economic development, especially in regions with stronger economic foundations or more favorable resource endowments. Mechanism analysis reveals two main channels: enhancing green technological innovation and promoting a greener industrial structure, with technological progress playing the dominant role rather than narrowing regional disparities. Among the three policy categories, green service policies and institutional support exert the strongest positive effects. The findings highlight the need to refine China's green industrial policy system and account for policy heterogeneity to support high-quality and more coordinated green development across provinces.

1. Introduction

After several decades of rapid and extensive economic growth, China is facing increasingly acute environmental pressures, and recent national strategies have explicitly elevated green development to a core policy priority. For example, in the Report to the 20th National Congress of the Communist Party of China, "a modernization in which humanity and nature coexist in harmony" is identified as one of the essential requirements of Chinese-style modernization; moreover, Part X, "Advancing Green Development and Promoting Harmony Between Humanity and Nature," opens by stressing the need to "accelerate the green transformation of the development model" (Xi, 2022). For promoting green economic development—understood here as achieving sustained growth while reducing environmental pollution—government intervention, particularly green industrial policy (GIP), plays a pivotal role. GIP denotes the bundle of fiscal, financial, and regulatory instruments used by governments to steer industrial structure toward low-carbon, resource-efficient activities and to support environmental and clean-technology industries. However, due to imperfections in market conditions and institutional arrangement—such as distorted price signals, fragmented regulatory responsibilities, and misallocation of green subsidies—implementation outcomes have often been less than satisfactory. This has constrained, and even stifled, the development of green industries. This mismatch between the high strategic priority attached to GIP and its mixed implementation performance underscores the need to improve policy design and execution. Identifying how to deploy such policies to enhance the quality and efficiency of green-industry development is therefore an urgent task.

GIP sits at the intersection of industrial and environmental policies under the paradigm of sustainable development, pursuing the dual objectives of economic growth and environmental protection. International scholarship has long debated its scope, theoretical foundations, and economic effects (Altenburg et al, 2017; Rogge et al, 2016). In this paper, we define GIP as the set of policy instruments—such as fiscal incentives, credit support, regulatory standards, and public investment—used by central and local governments to steer industrial structure toward low-carbon, resource-efficient activities and to promote coordinated progress in environmental governance and industrial upgrading. In the Chinese context, the Green Industry Guidance Catalogue (2023 Edition; hereafter "the Catalogue") delineates green industries across the full value chain of green manufacturing and green services, including environmental damage monitoring and assessment,

trading of resource–environment rights, and supporting green service industries. Unlike conventional industrial policies that primarily target output or employment growth, green industrial policy explicitly seeks to expand the supply of green goods and services, internalize environmental externalities in firm behaviour, and foster the high-quality development of green industries, with the broader aim of achieving joint gains in economic performance and environmental quality.

China's Twelfth Five-Year Plan (2011–2015) first introduced the concept of "green development," advocating resource conservation and environmental friendliness. The Report to the 18th National Congress of the Communist Party of China then formally incorporated "green development" and elevated ecological civilization to an unprecedented national strategic priority (Guo and Tian, 2023). Since then, a rapid expansion in green-industry policies has markedly scaled up and upgraded China's green industries. Statistics indicate that provincial and municipal governments issued 447 green-industry policy items in 2005; by 2023, this number had risen nearly thirty-five-fold to 15,912. Against this backdrop, several research questions merit attention: Have intensively issued green-industry policies promoted green economic development? How do their effects differ across regions? Through which mechanisms do these policies influence green economic development? Addressing these questions deepens our understanding of the economic value of green-industry policies and helps identify effective pathways to advance green economic development.

The remainder of this paper is organized as follows: Section 2 reviews the literature; Section 3 develops the theoretical framework and research hypotheses; Section 4 details the research design; Section 5 presents empirical results and discussion; Section 6 concludes with policy implications.

2. Literature Review

Quantitatively evaluating green industrial policy is a frontier concern shared by academia and policymakers, yet robust measurement remains challenging. Difficulties arise from the diversity and complexity of policy instruments, ambiguous policy definitions and boundaries, limited access to policy data, the need to construct multidimensional indicators, and choices over temporal and spatial scales. Existing studies concentrate largely on theoretical and qualitative analyses at the micro level, and commonly operationalize policy through dummy variables or instrument-based proxies. For example, Jin et al. measure the effect of green industrial policies by identifying whether a listed firm's registered address is located in a green finance reform and innovation pilot zone and, together with the pre- and post-policy periods, constructing the interaction term between a firm-level treatment dummy and a time dummy within a difference-in-differences (DID) framework (Jin et al., 2022). Chen Yanying et al. regard the "green factory evaluation" launched by the Ministry of Industry and Information Technology in 2016 as a representative green industrial policy and take whether firms are selected into the list of green factory demonstration enterprises during 2017–2020 (and the event shock at the time of list announcement) as the metric for green industrial policy (Chen et al., 2022). Chen Luyi et al. treat the policies introduced in the textile industry of 14 cities during 1998–2013 as green industrial policy shocks, construct policy dummy variables based on whether firms are located in policy-implementing cities and on the pre-/post-policy periods, and use difference-in-differences and dynamic difference-in-differences models to evaluate the impact of green industrial policies (Chen et al., 2021). By contrast, quantitative research at the provincial–municipal scale remains scarce, and few papers empirically

disentangle the heterogeneous effects of distinct green industrial policy tools. Moreover, using government subsidies as a proxy variable risks obscuring the mechanisms through which green industrial policy influences green economic development (Han et al., 2016). A more reasonable and effective assessment therefore requires abstracting and quantifying the policy behaviour itself. In this regard, text mining of policy documents to characterize the institutional supply of green industrial policy has emerged as a cutting-edge approach in public policy research. Policy texts provide an objective, archived record that links and preserves government actions in public affairs, and are issued in standardized formats that facilitate structured coding and analysis. Combining text mining with qualitative inquiry can align interpretive depth with analytical rigor—linking subjective interpretation to objective evidence, and experiential insight to explanatory inference—and can yield more reliable measures of green industrial policy (Cheng et al., 2021; Meng et al., 2022; Tang et al., 2021; Yang and Yang, 2020).

Research on the relationship between green industrial policy and green economic development remains relatively limited, and rigorous evaluations of policy goal attainment are scarce—particularly with respect to the multi-objective synergies that such policies are designed to achieve. The existing literature relies heavily on case studies, with comparatively few empirical investigations and even fewer that unpack underlying mechanisms. For example, Sun (2016) reviewed the evolution of green industrial policies in the United States, Japan, and the European Union and, using case studies, examined their feasibility and necessity for China's new-energy vehicles, waste recycling, and energy conservation and emissions reduction, as well as the challenges and proposed solutions encountered in policy implementation (Sun, 2016). Altenburg et al. (2017) employed case analyses to assess the sector-specific effects of GIPs in Morocco, China, Brazil, and Germany (Altenburg et al, 2017). On the empirical side, Jin et al. (2022) argued that green finance can reallocate credit resources away from highly polluting sectors toward cleaner industries, thereby facilitating the green transition of polluting firms (Jin et al., 2022). Chen Luyi et al. (2021) found that the implementation of GIPs improves environmental and innovation performance in textile firms while also steering the direction of innovation—marking, to the best of our knowledge, the first domestic study to explicitly foreground the synergy of policy objectives, a defining feature of green industrial policy (Chen et al., 2021). Chen Yanying et al. (2022) further noted that effective coordination between GIPs and capital markets can jointly promote the green transformation of traditional manufacturing (Chen et al., 2022).

Overall, although prior studies acknowledge the positive economic and environmental impacts of green industrial policy, explanations of its internal mechanisms remain divergent. Much of the literature treats factors such as innovation costs and factor allocation as mediators between green industrial policy and outcomes like emissions reduction or economic growth, typically focusing on a single mechanism or a policy within a single industry. By contrast, system-level analyses that view green industrial policy as an integrated whole are limited, and quantitative measurement of policy intensity and composition has received insufficient attention. These gaps constrain the ability of researchers and policymakers to evaluate existing policies in a comprehensive manner and hinder the timely adjustment and refinement of green industrial policy frameworks.

Accordingly, building on the taxonomy of green industries in the Catalogue, we collect and curate provincial-level green industrial policy documents issued between 2005 and 2023 from the PKULaw database (https://www.pkulaw.com/) for all provinces, municipalities, and autonomous regions in mainland China

(excluding Tibet and Hong Kong, Macao, and Taiwan). We then empirically test the impact of GIPs on green economic development, providing evidence-based guidance to optimize current policy design. The marginal contributions are as follows: (1) From the perspective of government laws and regulations, we apply text-mining techniques to operationalize the effectiveness of GIPs, broadening existing measurement approaches and demonstrating the validity and feasibility of this method. (2) We enrich the accounting framework for the green transformation of economic development by incorporating energy consumption as an input factor and CO_2 emissions as an undesirable (non-expected) output. Using a Data Envelopment Analysis (DEA) model that simultaneously accommodates desired outputs, undesirable outputs, and energy inputs, we measure provinces' green total factor productivity (GTFP), thereby aligning the indicator with the connotation of green transformation. (3) At the interprovincial level, we not only verify that GIPs promote the green transformation of economic development, but also identify the mechanisms and boundary conditions under these effects are strengthened, highlighting in particular the roles of green technological innovation and industrial structure greening.

3. Theoretical Analysis and Research Hypotheses

As an external, potentially binding constraint, green industrial policy directly shapes economic agents' transaction costs, managerial efficiency, and returns, thereby influencing green economic development. Well-designed policies can not only help secure the equitable realization of rights and obligations but also enable energy conservation and emissions reduction, thus supporting economic growth and social welfare. Jurisdictions or industries characterized by higher-quality GIPs—or greater contract intensity—tend to exhibit stronger comparative advantages. At both the micro (internal efficiency) and macro (allocative efficiency) levels, green industrial policy improves performance through multiple channels, notably the green technological innovation effect and the industrial-structure greening effect (Chen L et al., 2021; Chen Y et al., 2021; He et al., 2022; Han et al., 2016).

Green industrial policy can affect green economic development indirectly via green technological innovation, with an a priori ambiguous net effect. On the one hand, the compliance-cost view rooted in neoclassical economics posits that stricter environmental requirements raise firms' abatement and compliance costs, crowding out productive investment, innovative activity, and organizational upgrading, thereby dampening green innovation and, ultimately, green economic development. On the other hand, the Porter Hypothesis takes a dynamic perspective: when policies are scientifically designed, firms are incentivized to internalize policy costs, invest in green R&D, processes, and products, and upgrade managerial practices—actions that can partly or fully offset compliance costs and may even yield net gains via an innovation-compensation effect, promoting green economic development. Overall, the direction of the net effect is theoretically indeterminate and warrants empirical testing that jointly considers both forces.

In addition, green industrial policy can intensify competition and accelerate the diffusion and application of green technologies as firms respond to incentives and preferential measures. By establishing green-innovation alliances and supporting green technology R&D centers, policy can also strengthen coordination among government, enterprises, academia, and social organizations, thereby facilitating the green transformation and sustainable development of the economy.

In the co-evolution of the economy and the environment, greening the industrial structure is indispensable. In China, structural optimization has largely relied on policy guidance and administrative intervention, with limited endogenous incentives; the introduction of GIPs can supply such incentives. GIPs are more than conventional selective industrial policies. While their essence is to steer industries toward greener development, their ultimate objective is not confined to promoting a single sector or technology. Rather, by positioning green industrial development as both the core and the intermediary, GIPs seek sustainable growth within ecological-system boundaries—or, put differently, to shift the production possibility frontier outward under ecological constraints. In this sense, GIPs serve as a crucial instrument for building broad social consensus on the direction and goals of transformation. Cultivating green market demand not only propels the transition to green economic development but also disseminates green consumption values, catalyzing cultural change; together, these forces jointly advance the shift toward sustainability.

Stringent and well-designed GIPs can heighten consumers' green awareness and thereby form green demand —a higher-order, eco-friendly consumption preference that stimulates the expansion of green service sectors within the tertiary industry, facilitating industrial-structure greening. Structural optimization, in turn, increases green management and retrofitting, reduces the share of resource- and pollution-intensive industries, and supports the growth of high-tech sectors, raising the proportion of green technology– and knowledge-intensive industries. Put differently, by cultivating green demand, GIPs reallocate factors of production from lower-productivity, non-green sectors to higher-productivity, green sectors; extend the industrial value chain toward the high end; refine patterns of specialization; generate economies of scale and comparative-advantage gains; and ultimately lift green total factor productivity, thereby advancing green economic development.

Accordingly, we propose the following hypotheses:

Hypothesis 1

(H1): Green industrial policy promotes green economic development through a green technological innovation effect.

Hypothesis 2

(H2): Green industrial policy promotes green economic development through an industrial-structure greening effect.

4. Research Design

4.1 Data, Sample, and Preprocessing

Given data availability and completeness, we construct a panel of 30 provincial-level regions in China for 2005–2023. The data are drawn from the China Statistical Yearbook, China Energy Statistical Yearbook, China Environmental Statistical Yearbook, and China Science and Technology Statistical Yearbook, as well as the National Bureau of Statistics of China and the China National Intellectual Property Administration (CNIPA). To ensure accuracy, we implement the following treatments: (1) Price deflation. Variables related to

assets and revenue/costs are deflated using the fixed-asset investment price index and the consumer price index to remove the effects of inflation. (2) Sample screening for anomalies and missingness. Due to substantial data gaps, the Tibet Autonomous Region is excluded; Hong Kong, Macao, and Taiwan are not covered by the above sources and are therefore omitted. (3) Heteroskedasticity mitigation. To reduce potential heteroskedasticity, variables are defined using natural logarithms and ratio transformations where appropriate.

4.2 Variable Selection

4.2.1 Dependent Variable.

We use each province's green total factor productivity (GTFP) as the explained variable. Relative to conventional TFP, GTFP jointly considers resource-use efficiency, environmental impacts, and economic performance, thereby evaluating productivity under the premise of sustainable development. It incorporates multiple inputs (labor, capital, and natural resources) and both desired and undesirable outputs to reflect the efficiency with which economies grow while conserving resources and protecting the environment. Following Wei and Hou (2022) and Cai and Zhou (2017), the specific measurement indicators are summarized in Table 1.

(1) Input indicators. From the perspectives of capital, labor, and resources: physical capital is measured by the capital stock constructed via the perpetual inventory method; to reduce bias, province-specific depreciation rates are adopted in line with Zhang et al. (2016), and newly added fixed-asset investment is deflated using the investment price index to obtain real values. Labor input is proxied by year-end employment in each province. Resource consumption is captured by total provincial energy consumption.

(2) Desired output. Economic performance is proxied by provincial GDP; nominal GDP is deflated to constant prices using 2002 as the base year.

(3) Undesirable outputs. Environmental pressure is represented by industrial wastewater emissions, industrial sulfur dioxide (SO_2) emissions, industrial smoke (dust) emissions, and carbon dioxide (CO_2) emissions. CO_2 is calculated by multiplying provincial consumption of coal, oil, and natural gas by the corresponding emission coefficients recommended by the Intergovernmental Panel on Climate Change (IPCC) and summing across fuels, following Chen (2009) .

Table 1
Indicator System for Measuring Green Economic Development across Chinese Provinces and Municipalities

Primary Dimension	Secondary Dimension	Indicator (Proxy)
Input Indicators	Physical capital	Capital stock (perpetual-inventory method)
	Labor input	Number of employed persons at year-end
	Resource consumption	Total energy consumption
Desired Output Indicators	Economic development	Gross regional product (GRP, constant 2002 prices)
Undesirable Output Indicators	Pollution emissions	Industrial wastewater emissions
		Industrial sulfur dioxide (SO_2) emissions
		Industrial smoke/dust emissions
		Carbon dioxide (CO_2) emissions

Notes: GRP is deflated to 2002 constant prices. Capital stock is constructed via the perpetual-inventory method. CO_2 emissions are calculated using fuel-specific emission coefficients (coal, oil, natural gas) and provincial energy consumption.

In the literature, green total factor productivity (GTFP) is commonly measured using the stochastic frontier approach (SFA) or data envelopment analysis (DEA). Compared with SFA, DEA and its variants can simultaneously evaluate multiple inputs and outputs; however, conventional DEA models are typically radial (input- or output-oriented) and do not explicitly account for slack. Accordingly, this study adopts the super-SBM (slack-based measure) proposed by Tone (2002), a non-radial, non-oriented improvement to DEA for measuring GTFP. The super-SBM relaxes the restriction of proportional improvements across all factors, allowing factor-specific adjustments consistent with real-world conditions and data characteristics. It also extends the efficiency frontier by permitting efficiency scores of efficient decision-making units (DMUs) to exceed 1, thereby enabling meaningful ranking and ensuring comparability among efficient DMUs.

4.2.2 Explanatory Variables

Core explanatory variable—Green Industrial Policy intensity (GP). Because GIPs are typically promulgated not as statutes but as administrative regulations, local regulations, and governmental rules, we measure policy intensity via text mining that accounts for both the number of policy documents and their legal force/authority. Following Wang et al. (2021) and He et al. (2022), we compile and hand-curate province–year counts of green-industry policy documents and assign weights by document type and issuing authority to construct a weighted index of green industrial policy (Wang and Yin, 2021; Wang and Wang, 2021). The weighting scheme is reported in Table 2. For province *i* in year *t*, the policy intensity index aggregates the effectiveness (weight) of all green industry policy documents that are in force during year *t*:

$$GP_{i,t} = GP_{i,t-1} + \sum power_x - \sum power_y$$

1

,

In Eq. (1), where $power_x$ denotes the effectiveness weight (legal force) of policy *x* that comes into force in year *t*; and $power_y$ denotes the effectiveness weight of policy *y* that expires during year *t-1.*

Table 2. Weighting Scheme for the Effectiveness of GIPs

Weight	Policy Type (Illustrative Examples)
4.0	Local regulations enacted by the provincial people's congress or promulgated by the provincial government.
3.0	Regulations, decisions, plans, opinions, measures/methods, or standards issued by the provincial people's congress or provincial government.
2.0	Opinions, measures/methods, detailed implementation plans/rules, conditions, or standards issued by provincial line departments (commissions/bureaus).
1.0	Notices, announcements, public notices, or proposals issued by the provincial government, the provincial people's congress, or provincial line departments.
0.5	Approvals and official reply letters issued by the provincial government, the provincial people's congress, or provincial line departments.

Note: Higher weights indicate stronger legal force/authority and greater expected policy impact.

We measure GIP at the provincial level for three reasons. First, China's provinces differ markedly in development levels; centrally issued GIPs may not align with local realities. After a central directive is released, provinces typically tailor policies to local conditions. For example, although a central document may call for strengthened pollution-source monitoring, provinces do not necessarily issue matching policies if the directive is poorly suited to their circumstances; conversely, provinces often support green industries that optimize local industrial structures even in the absence of a parallel central policy. Second, the National Development and Reform Commission's Green Industry Guidance Catalogue lists priority green industries but rarely details specific support instruments, whereas provincial GIPs usually specify concrete measures, enabling finer identification of policy intensity and a more precise assessment of impacts on green economic development. Third, China's decentralization reforms grant provincial governments substantial discretion in economic governance, making provincial GIPs more immediate and consequential for green development outcomes.

Policy Text Collection and Screening. Building on the Catalogue, we constructed a keyword list for retrieving GIP documents—266 terms spanning, inter alia, R&D, certification, and diffusion of green technologies and products; environmental-damage monitoring and assessment; and energy-saving retrofits of communication networks. Using the PKULaw database, we searched and filtered provincial GIP texts, verified each item manually, and removed clauses with low relevance. The final dataset comprises 196,252 green-industry policy documents issued by 30 provinces and municipalities during 2005–2023. Retrieval statistics indicate that provincial governments are most active in policies concerning (i) green technology/product R&D–certification–promotion, (ii) environmental damage monitoring and assessment, and (iii) energy-efficient upgrading of communication networks (see Table 3). Based on the Green Industry Guiding Catalogue (2023 edition), green industrial policies are grouped into three broad categories: (i) green production and infrastructure upgrading policies, (ii) ecological environmental governance and resource recycling policies, and (iii) green services and institutional support policies. First, we conduct an endogenous clustering of policy types using the industrial sections defined in the Catalogue. The 2023 edition classifies green industries into several categories, such as energy conservation and efficiency improvement, clean production

and industrial energy conservation, clean energy, ecological and environmental protection, resource recycling, green infrastructure, and green services. These categories are highly correlated in terms of technological pathways and policy focus. To avoid an excessively fragmented statistical classification and to reduce the dimensionality of the regressions, this study follows the principle of “similar primary functions and comparable policy instruments”. Categories closely related to production processes and physical capital investment are merged into “green production and infrastructure upgrading policies”; those aimed at improving environmental quality and promoting resource regeneration are merged into “ecological environmental governance and resource recycling policies”; and those centred on the provision of knowledge, finance and institutions are merged into “green services and institutional support policies”. This aggregation maintains consistency with the official Catalogue while compressing dimensions and clarifying the policy structure. Second, from the perspective of green development theory, this threefold classification corresponds to three basic lines of policy supply for green development: the “green production system” (production and infrastructure), the “ecological and resource governance system” (environmental governance and recycling), and the “green institutional and factor allocation system” (services and institutional support). Different policy types intervene in different segments of green development: the first primarily affects green supply capacity by upgrading production technologies and infrastructure; the second influences ecological outcomes through pollution constraints and improvements in resource-use efficiency; and the third reshapes incentives and factor flows via financial, informational and institutional arrangements. Hence, this tripartite classification provides a clear theoretical orientation for subsequent heterogeneity analyses. Third, from an empirical perspective, this scheme facilitates the construction of comparable policy-intensity indicators within a text-mining framework. Specifically, we first extract, from the 2023 Catalogue, keywords and technical items corresponding to each of the three policy types and build three separate keyword dictionaries. We then count the appearances or weighted frequencies of these keywords in policy documents, assigning different weights according to issuing authority and document type. On this basis, we construct three indicators—“intensity of green production and infrastructure upgrading policies”, “intensity of ecological environmental governance and resource recycling policies”, and “intensity of green services and institutional support policies”. Finally, these three policy variables are separately included in the baseline regressions and extended tests to identify the differentiated effects of distinct policy orientations on green economic development.

Table 3
Retrieval Statistics for Selected Green-Industry Policy Keywords

Keyword	Frequency	Category	Keyword	Frequency	Category
R&D, certification, and promotion of green technologies/products	14,398	Green services and institutional support policies	Construction supervision services for green-industry projects	5,361	Green services and institutional support policies
Monitoring and assessment of environmental damage	13,824	Green services and institutional support policies	Manufacturing of equipment for efficient/circular water use	4,467	Ecological environmental governance and resource recycling policies
Energy-saving retrofits of communication networks	10,777	Green production and infrastructure upgrading policies	Air pollution control	4,110	Ecological environmental governance and resource recycling policies
Information infrastructure	9,588	Green production and infrastructure upgrading policies	Eco-protection & restoration products and ecosystem assessment	4,060	Ecological environmental governance and resource recycling policies
Efficient and circular use of water resources	9,113	Ecological environmental governance and resource recycling policies	Environmental infrastructure	3,389	Ecological environmental governance and resource recycling policies
Consulting services for green-industry projects	8,502	Green services and institutional support policies	Green transport	3,283	Green production and infrastructure upgrading policies
Construction & operation of urban–rural multimodal transport systems	8,202	Green production and infrastructure upgrading policies	Construction & operation of biomass-energy utilization facilities	2,799	Green production and infrastructure upgrading policies
Eco-environmental monitoring and ecological-security early warning	7,879	Ecological environmental governance and resource recycling policies	Green/low-carbon upgrading of vessels	2,132	Green production and infrastructure upgrading policies

Note: Frequencies denote the number of policy documents retrieved that match each keyword.

Keyword	Frequency	Category	Keyword	Frequency	Category
Construction & operation of rural clean-energy infrastructure	7,392	Green production and infrastructure upgrading policies	Pollution-source monitoring	2,153	Ecological environmental governance and resource recycling policies
Energy performance contracting (EPC)	7,197	Green services and institutional support policies	Electricity demand-side management	2,118	Green services and institutional support policies
Note: Frequencies denote the number of policy documents retrieved that match each keyword.					

4.2.3 Control Variables

Beyond the core variable of green industrial policy intensity, we control for factors that may confound green economic development. Following Wu (2020) and Wei & Hou (2022), the model includes: (1) Economic development (gdp). Provincial economic development underpins green development and is also a major driver of pollution and carbon emissions. It is measured by real GDP (deflated to 2002 constant prices). (2) Education level (edu). Government commitment to human-capital formation, proxied by education expenditure as a share of GDP. (3) R&D input (rd). A foundation for high-quality growth and green innovation, measured by intramural R&D expenditure at the provincial level. (4) Government intervention (gov). The extent of governmental involvement in economic activity, measured by general public fiscal expenditure. (5) Openness (FDI). Trade and investment openness may induce production–sales separation and potential "pollution havens," increase energy use and CO_2 emissions, or, alternatively, bring green technologies. It is measured by investment by foreign-funded enterprises.

4.3 Descriptive Statistics

Table 4 reports summary statistics for the key variables. The max-to-mean ratios for green economic development (GTFP) and green industrial policy intensity (GP) are 4.0341 and 7.3778, respectively, indicating pronounced cross-provincial heterogeneity. The remaining controls—education level (edu), R&D input (rd), and others—exhibit distributions broadly consistent with the existing literature, with no material deviations.

Table 4
Descriptive Statistics of Variables

Variable	N	Mean	Std. Dev.	Min	Max
GTFP	570	0.512	0.291	0	1.579
GP	570	0.190	0.0719	0.103	1.443
edu	570	0.131	0.0841	0.0273	0.486
RD	570	454.1	625.8	0	4629
GDP	570	8.479	0.883	5.940	10.28
gov	570	0.243	0.663	-1.799	1.894
FDI	570	7.795	4.071	0	53.91

Notes: Monetary values are deflated to 2002 constant prices. Ratios (edu, gov) are reported in decimal form (e.g., 0.1092 ≈ 10.92%).

4.4 Econometric Model Specification

Using a panel of 30 provincial-level regions in China for 2005–2023, we estimate fixed-effects models to examine the impact of GIP on green economic development. We also assess heterogeneity by geographic location and income level, and further explore how green technological innovation and industrial-structure greening shape the GIP–outcome relationship. Because panel regressions require (weakly) stationary series—otherwise spurious results may arise—we test the time-series properties of the variables and find that, after logarithmic transformation, the relevant series become stationary. Log transformation does not alter the time-series nature of the data or the underlying relationships among variables. To ensure the validity of our estimates, selected variables are therefore expressed in logs. Based on these considerations and our research questions, the econometric specifications are set out as follows (see subsequent equations).

$$GTFP_{i,t} = \alpha_0 + \alpha_1 GP_{i,t} + \alpha_2 X + \delta_i + \theta_t + \epsilon_{i,t}$$

2

where $\mathrm{GTFP}_{i,t}$ denotes the level of green economic development in province $i$during year t; $\mathrm{GP}_{i,t}$is the intensity of green industrial policy in province $i$and year t; $\alpha_1$captures the total effect of green industrial policy on green economic development; X is the vector of control variables; $\alpha_2$is the corresponding coefficient vector; $\alpha_0$is the constant term; $\delta_i$and $\theta_t$are province and year fixed effects, respectively; and $\epsilon_{i,t}$is the idiosyncratic error term.

5. Empirical Analysis

5.1 Baseline Results

Table 5 reports the baseline estimates. Column (1), without controls, shows a positive and statistically significant coefficient on GP (green industrial policy intensity), providing initial evidence that stronger policy

efforts are associated with higher levels of green economic development. To mitigate omitted-variable bias, Columns (2)–(5) sequentially add controls—education level, R&D input, economic development, government intervention, and foreign investment. After including these covariates, the coefficient on GP remains positive and significant at the 1% level, indicating that, even after accounting for other determinants of green economic development, green industrial policy significantly raises provincial GTFP. These results reinforce the paper's central conclusion.

Table 5
Basic estimation results

Variable	(1)	(2)	(3)	(4)	(5)	(6)
GP	0.5196***	0.3976**	0.4718***	0.4954***	0.4930***	0.4969***
	(0.1798)	(0.1790)	(0.1772)	(0.1781)	(0.1780)	(0.1785)
edu		-1.1790***	-1.9553***	-1.7373***	-1.7234***	-1.7289***
		(0.2718)	(0.3258)	(0.3698)	(0.3698)	(0.3704)
RD			-0.0001***	-0.0001***	-0.0001***	-0.0001***
			(0.0000)	(0.0000)	(0.0000)	(0.0000)
GDP				0.0773	0.0745	0.0756
				(0.0621)	(0.0621)	(0.0623)
gov					0.0698	0.0723
					(0.0576)	(0.0581)
FDI						-0.0011
						(0.0031)
_cons	0.4135***	0.5910***	0.7454***	0.0542	0.0621	0.0612
	(0.0353)	(0.0537)	(0.0645)	(0.5594)	(0.5592)	(0.5597)
Time	yes	yes	yes	yes	yes	yes
Industry	yes	yes	yes	yes	yes	yes
N	570	570	570	570	570	570
R^2	0.5048	0.5221	0.5377	0.5391	0.5404	0.5405

Note: The t values after clustering are in parentheses. *, **, and *** indicate significance at the 10%, 5%, and 1% levels respectively.

5.2 Robustness Test

(1) Outlier treatment. To mitigate bias from measurement error in macro variables and reduce the influence of non-random extremes, we re-estimate the model after winsorizing all variables at both tails. As shown in

Table 6, Column (1), the sign and significance of GP remain unchanged, consistent with the baseline results and reinforcing the core conclusion.

(2) Excluding major macro shocks (COVID-19). The outbreak beginning in late 2019 and intensifying in 2020 affected both GIPs and green economic development (e.g., funding shortages, supply-chain disruptions, demand contractions). Following Wu et al. (2021), we re-run the regressions on a subsample that excludes 2020, when the substantive impact materialized. Results in Table 6, Column (2), show that GP continues to significantly promote green economic development after removing the pandemic-affected year.

(3) Alternative estimator. Because GTFP is a non-negative, limited dependent variable, we also estimate a Tobit model. As reported in Table 6, Column (3), the coefficient on GP is positive and statistically significant at the 1% level, fully aligning with the baseline findings.

(4) Endogeneity Considerations. A potential two-way causality may exist between green industrial policy and green economic development. On the one hand, policy can affect outcomes through multiple channels; on the other, provinces with higher green development may devote greater attention and intensity to green industrial policy. To address this endogeneity, following Li (2021) and Yang & Hou (2020), we instrument GP with (i) its one-period lag $(\mathrm{L.GP})$and (ii) the leave-one-out provincial policy intensity in each year, defined as the national policy intensity excluding province $\mathrm{i}\,(\mathrm{nGP})$. We then estimate the model using two-stage least squares (2SLS).

The choice of instruments rests on two conditions. Relevance: GP, $\mathrm{L.GP}$, and $\mathrm{nGP}$are mechanically and empirically correlated. Exogeneity (exclusion): $\mathrm{L.GP}$ and nGPaffect current green economic development only through current GP, and are not themselves determined by contemporaneous shocks to GP. First-stage results indicate that both instruments pass standard weak-IV significance checks, alleviating concerns about instrument weakness. As reported in Table 6, Columns (4)–(5), the 2SLS estimates show that the coefficient on GP remains positive and statistically significant, implying that our main finding is robust to potential reverse causality and omitted-variable bias.

Table 6
Robustness check

Variable	(1)	(2)	(3)	(4)	(5)
GP	0.4947***	0.4142**	0.6046***		
	(0.1747)	(0.1688)	(0.1907)		
L.GP				4.3844**	
				(2.1804)	
nGP					1.3099***
					(0.3895)
edu	-1.6572***	-1.8032***	-1.8718***	-0.4532	-1.1453***
	(0.3625)	(0.4152)	(0.3677)	(0.6947)	(0.3520)
RD	-0.0001***	-0.0001***	-0.0001***	-0.0002***	-0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0001)	(0.0000)
GDP	0.0867	0.0794	0.1081***	0.2605**	0.1428**
	(0.0609)	(0.0747)	(0.0372)	(0.1193)	(0.0627)
gov	0.0703	0.0829	0.0781*	0.0671	0.0816
	(0.0568)	(0.0600)	(0.0442)	(0.0836)	(0.0581)
FDI	-0.0006	-0.0013	-0.0006	-0.0028	-0.0002
	(0.0030)	(0.0030)	(0.0034)	(0.0045)	(0.0030)
_cons	-0.0506	0.0245	-0.2253		
	(0.5477)	(0.6564)	(0.3318)		
Time	yes	yes	yes	yes	yes
Industry	yes	yes	yes	yes	yes
N	570	480	570	540	570
R^2	0.5470	0.5536			
Anderson canon. corr. LM				6.761***	113.950***

5.3 Heterogeneity Analysis

(1) Geographic heterogeneity.

Given China's vast territory, provinces differ markedly in development status, resource endowments, and industrial structure. These differences shape the spatial allocation of factors and the layout of green industries, producing sizable variation in green economic development. We therefore examine regional

heterogeneity by partitioning the 30 provinces/municipalities into East, Central, West, and Northeast groups and re-estimating the baseline fixed-effects model within each subgroup.

As reported in Table 7, the estimated coefficients differ substantially across regions, indicating pronounced spatial heterogeneity in policy effectiveness. In particular, the coefficient on GP (green industrial policy intensity) for the Eastern region is positive and statistically significant, suggesting that green industrial policy most effectively promotes green economic development there. The Central region shows comparatively weaker but still favorable effects, while the Western and Northeastern regions exhibit relatively modest policy impacts. These disparities likely reflect regional differences in economic fundamentals and resource conditions; the East's stronger economic base and institutional environment appear to provide a more enabling context for policy implementation.

Table 7
Geographic Heterogeneity Analysis

Variable	**(1)** **Eastern**	**(2)** **Central**	**(3)** **Western**	**(4)** **Northeast**
GP	4.3200***	-0.8400	0.3837**	3.2362***
	(1.2965)	(1.2427)	(0.1792)	(1.0677)
edu	-0.5994	-4.1735***	-4.2320***	-1.9607*
	(0.9989)	(1.4582)	(0.7109)	(1.0973)
RD	0.0000	0.0002	-0.0003	-0.0010
	(0.0001)	(0.0002)	(0.0002)	(0.0006)
GDP	0.2659	-0.2816	-0.6011***	-0.3246
	(0.1726)	(0.2335)	(0.1316)	(0.2845)
gov	0.5109***	0.0220	-0.1612*	0.1371
	(0.1209)	(0.0904)	(0.0894)	(0.2468)
FDI	0.0045	-0.0023	0.0056	-0.0132
	(0.0062)	(0.0030)	(0.0104)	(0.0375)
_cons	-2.9259*	3.5917	5.8220***	3.0297
	(1.6652)	(2.2417)	(1.0677)	(2.5869)
Time	yes	yes	yes	yes
Industry	yes	yes	yes	yes
N	190	114	209	57
R^2	0.6430	0.7125	0.6960	0.6164

(2) Economic-region heterogeneity.

Given sizable disparities in provincial development, we stratify provinces by per-capita GDP to assess whether the impact of GP on green economic development varies across income groups. As shown in Table 8, clear differences emerge: in high-income regions, the coefficient on GP is positive and statistically significant, indicating that green industrial policy exerts a stronger promotive effect on green economic development there. This pattern likely reflects not only favorable geographic conditions but also greater human-capital accumulation—reinforced by competitive talent-attraction policies that draw skilled workers from central and western provinces—together with stronger fiscal capacity and more mature innovation ecosystems, which enhance the transmission and effectiveness of policy.

Table 8
Economic-Region Heterogeneity Analysis

Variable	(1) high-income	(2) middle-income	(3) low-income
GP	3.1499*	0.2607	1.9304***
	(1.7030)	(0.1646)	(0.5344)
edu	-1.0298	-2.9864***	-2.0173***
	(1.3746)	(1.0441)	(0.5299)
RD	-0.0002***	0.0003*	0.0000
	(0.0001)	(0.0002)	(0.0001)
GDP	0.2219	-0.2202	-0.2353***
	(0.2265)	(0.1595)	(0.0747)
gov	0.7618***	-0.0608	-0.3162***
	(0.1408)	(0.1079)	(0.0664)
FDI	-0.0249	-0.0370**	-0.0018
	(0.0154)	(0.0184)	(0.0026)
_cons	-1.9996	2.8905*	2.2037***
	(2.1852)	(1.4811)	(0.6619)
Time	Yes	Yes	Yes
Industry	Yes	Yes	Yes
N	190	133	247
R^2	0.5071	0.7087	0.6516

5.4 Further Analysis

(1) Green Technological Innovation Effect (Sustainability style). Given the verified positive impact of green industrial policy (GIP) on green economic development, we further test the innovation channel. Following Wang & Wang (2021), green technological innovation (GI) is proxied by the number of green patent applications. As reported in Table 9, Columns (1)–(2), the coefficient on GP is positive and statistically significant both without controls and with the full set of controls, confirming that GIP promotes green technological innovation. This suggests that China's GIPs—via instruments such as property-rights guidance, technological and talent support, and other facilitative measures—enhance knowledge spillovers and upgrade innovation inputs, thereby stimulating GI and, in turn, advancing green economic development.

(2) Industrial-Structure Greening Effect. We also test whether GIP operates through industrial-structure greening. Following Wu (2020), the greening level of the industrial structure (Stu) is measured by the ratio of tertiary-industry output to GDP. As shown in Table 9, Columns (3)–(4), the coefficient on GP remains positive and significant both before and after adding all controls, demonstrating a robust industrial-structure greening effect. These findings indicate that by strengthening top-level design and standardizing implementation, GIPs facilitate the reallocation of production factors toward green sectors, optimize factor-resource allocation, and accelerate the greening of the industrial structure—thereby further promoting green economic development.

Table 9
Regression Results of Mechanism Tests

Variable	(1)	(2)	(3)	(4)
GP	0.4548***	0.4651***	0.0492**	0.0346*
	(0.0052)	(0.0050)	(0.0200)	(0.0200)
edu		0.0420***		-0.1438***
		(0.0103)		(0.0415)
RD		-0.0000***		-0.0000
		(0.0000)		(0.0000)
GDP		0.0058***		-0.0355***
		(0.0017)		(0.0070)
gov		0.0020		0.0021
		(0.0016)		(0.0065)
FDI		-0.0002**		0.0006*
		(0.0001)		(0.0003)
_cons	-0.0806***	-0.1341***	-0.0112***	0.3086***
	(0.0010)	(0.0156)	(0.0039)	(0.0627)
Time	yes	yes	yes	yes
Industry	yes	yes	yes	yes
N	570	570	570	570
R2	0.9464	0.9544	0.4658	0.4953

(3) Decomposition of GTFP. Having established that green industrial policy (GIP) promotes green economic development, we next ask why—through which channel does this effect arise? Following Cheng and Li (2021), we decompose provincial GTFP into efficiency change (EC) and technical change (TC) to test the operative mechanism. Table 10 reports the results: Columns (1)–(2) present fixed-effects estimates, and Columns (3)–(4) report Tobit estimates. Across specifications, GIP has a positive and statistically significant effect on TC at the 1% level, indicating that policy primarily raises green productivity via frontier shifts (technological progress) rather than through catch-up (efficiency change). This evidence corroborates our main finding that GIP fosters green economic development predominantly by accelerating technological progress.

Table 10
Decomposition of GTFP

Variable	(1) EC	(2) TC	(3) EC	(4) TC
GP	0.0741***	0.1318***	0.0847***	0.1479***
	(0.0051)	(0.0089)	(0.0055)	(0.0052)
edu	-0.0036	0.1009***	0.0026	0.0090
	(0.0106)	(0.0185)	(0.0110)	(0.0118)
RD	-0.0000	-0.0000	0.0000	-0.0000
	(0.0000)	(0.0000)	(0.0000)	(0.0000)
GDP	-0.0048***	0.0154***	0.0020**	0.0053***
	(0.0018)	(0.0031)	(0.0009)	(0.0009)
gov	-0.0050***	0.0037	-0.0044***	0.0005
	(0.0017)	(0.0029)	(0.0012)	(0.0012)
FDI	-0.0002*	-0.0000	-0.0002*	-0.0007***
	(0.0001)	(0.0002)	(0.0001)	(0.0002)
_cons	0.0303*	-0.1710***	-0.0417***	-0.0911***
	(0.0161)	(0.0279)	(0.0085)	(0.0084)
Time	yes	yes	yes	yes
Industry	yes	yes	yes	yes
N	570	570	570	570
R2	0.3965	0.4356		

(4) Different green industrial policies effects. Green industrial policies are classified into three categories according to the *Green Industry Guiding Catalogue (2023 edition)*: (1) green production and infrastructure upgrading policies, which cover energy conservation and carbon reduction, clean production, clean energy, green buildings and transportation, as well as other forms of green manufacturing and infrastructure retrofitting; (2) ecological environmental governance and resource recycling policies, including pollution prevention and control, ecological conservation and restoration, efficient use of water and energy resources, and resource recycling; and (3) green services and institutional support policies, which mainly refer to green technology and consulting services, energy-saving and environmental assessment and auditing, green finance, and related supporting institutional arrangements. On this basis, we conduct separate baseline regressions for each of the three types of green industrial policies. The results show that green services and institutional support policies exert the strongest promoting effect on green economic development, because green finance, evaluation and auditing, technical services and institutional arrangements can act as

coordinating and amplifying mechanisms for resource allocation, incentive constraints and risk expectations, thereby exhibiting broad coverage and strong spillover effects (Table 11 (5)-(6)). Ecological environmental governance and resource recycling policies improve green performance through a “hard constraint plus efficiency gains” mechanism based on pollution control and resource efficiency, but they mainly target specific industries and links, so their overall driving effect is somewhat weaker (Table 11 (3)-(4)). By contrast, green production and infrastructure upgrading policies are typically characterized by large investment scales and long payback periods, and in local practice they are often associated with an emphasis on construction over performance and with resource misallocation, which weakens their net contribution to high-quality green development (Table 11 (1)-(2)).

Table 11
Different green industrial policies effects

Variable	(1)	(2)	(3)	(4)	(5)	(6)
GP	0.9096***	0.9938***	1.3644***	1.4908***	2.7289***	2.9815***
	(0.0105)	(0.3570)	(0.0157)	(0.5355)	(0.0314)	(1.0710)
edu		-1.7289***		-1.7289***		-1.7289***
		(0.3704)		(0.3704)		(0.3704)
RD		-0.0001***		-0.0001***		-0.0001***
		(0.0000)		(0.0000)		(0.0000)
GDP		0.0756		0.0756		0.0756
		(0.0623)		(0.0623)		(0.0623)
gov		0.0723		0.0723		0.0723
		(0.0581)		(0.0581)		(0.0581)
FDI		-0.0011		-0.0011		-0.0011
		(0.0031)		(0.0031)		(0.0031)
_cons	-0.0806***	0.0612	-0.0806***	0.0612	-0.0806***	0.0612
	(0.0010)	(0.5597)	(0.0010)	(0.5597)	(0.0010)	(0.5597)
Time	yes	yes	yes	yes	yes	yes
Industry	yes	yes	yes	yes	yes	yes
N	570	570	570	570	570	570
R2	0.9464	0.5405	0.9464	0.5405	0.9464	0.5405

6. Research conclusions and policy recommendations

6.1 Research Conclusions

Using panel data for 30 Chinese provinces and municipalities from 2005 to 2023, this study employs fixed-effects models to assess the role of green industrial policy in fostering green economic development. The main conclusions are as follows:

First, drawing on the Catalogue, we define green industrial policy and construct a quantitative index of policy effectiveness weighted by issuing authority and document type. Using 266 retrieval keywords, we compile 196,252 provincial policy documents. Retrieval statistics show that policies are densest in three areas: R&D, certification, and promotion of green technologies/products; monitoring and assessment of environmental damage; and energy-saving retrofits of communication networks. Based on the Green Industry Guiding Catalogue (2023 edition), green industrial policies are grouped into three broad categories: (i) green production and infrastructure upgrading policies, (ii) ecological environmental governance and resource recycling policies, and (iii) green services and institutional support policies.

Second, baseline estimates confirm that green industrial policy significantly promotes provincial green economic development. Heterogeneity analyses indicate that effects are strongest in the Eastern region, followed by the Central region, and relatively weaker in the Western and Northeastern regions; by income tier, the policy effect is more pronounced in high-income regions than in middle- and low-income regions. Mechanism tests further show that the promotive effect operates primarily through green technological innovation and industrial-structure greening, with the industrial-structure greening channel exerting the stronger influence. Further analysis shows that technological progress plays the primary role in promoting green economic development, and that this effect does not operate through the channel of narrowing disparities. Among the three types of green industrial policies, green services and institutional support policies exert the strongest positive impact on green economic development, because green finance, evaluation and auditing, technical services and institutional arrangements can function as coordinating and amplifying mechanisms in terms of resource allocation, incentive constraints and risk expectations, thereby exhibiting broad coverage and strong spillover effects.

6.2 Policy Recommendations

(1) Integrate green industrial policy with functional (horizontal) industrial policies to foster pro-active green growth. Although the number and types of China's GIPs have expanded, many remain incentive- or compliance-oriented instruments aimed directly at firms, which can induce short-termism and passive implementation. The GIP system should be optimized and coupled with functional policies—accelerating green infrastructure, especially institutional infrastructure; strengthening the role of market mechanisms in steering green development; and standardizing market conduct to safeguard fair competition—so as to enhance firms' initiative and agency in pursuing green growth.

(2) Apply GIPs differentially to improve precision and effectiveness. Policy design should leverage the roles of growth identification and facilitation, aligning instruments with each province's stage of development, industrial structure, market-actor composition, and ecological conditions. Avoid "one-size-fits-all" approaches; instead, calibrate policy packages to sectoral and regional endowments to maximize green outcomes.

(3) Strengthen the GIP channels of green technological innovation and industrial-structure greening. Increase the intensity and follow-through of GIP implementation, scale support for green R&D and diffusion, and use policy incentives to guide factor reallocation toward green sectors. By simultaneously deepening green innovation and advancing industrial-structure greening, policy effectiveness can be enhanced and sustained, further accelerating the transition to green economic development.

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval

This article does not contain any studies with human participants performed by any of the authors.

Informed consent

It does not apply to this article as it does not contain any studies with human participants.

Author Contribution

X.T.conceived the presented idea developed the theory, performed the computations, and wrote the manuscript. W.G. provided original data, a critical revision of the article, and contributed to the manuscript.

Acknowledgement

This work is supported by General Program of the National Social Science Fund of China “The Mechanism, Risks, and Policies of Artificial Intelligence Empowering High-Quality Financial Development” (grant number: 24BJY088).

Data Availability

The data analyzed in this study are included in this published article and its supplementary file. Should be sent an email to the corresponding author for use

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