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Original Research

Towards Sustainable Development: Measurement and Analysis of Green Development Levels and Obstacles in China's Regional Manufacturing under the Digital Economy

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Abstract

In the context of the digital economy, green development in regional manufacturing is essential for fostering high-quality economic growth and environmental sustainability. This study evaluates the level of green development and identifies obstacles in China's regional manufacturing sector under the digital economy, offering governance strategies accordingly. Using 2022 data from 30 provinces, the entropy method measures green development levels, and the obstacle degree model identifies constraining factors. The results show that: (1) digitization and intelligentization are pivotal for green development, with economic benefits and sustainable development being the primary evaluative criteria. (2) There are significant regional disparities in green and sustainable development scores. High-scoring provinces like Beijing and Guangdong excel across multiple dimensions, while low-scoring provinces such as Gansu and Qinghai lag in digitization, low-carbonization, and intelligentization. (3) Key obstacles to green development include challenges in sustainable development, technology, and innovation. Addressing these issues requires targeted and comprehensive strategies. This research innovates by incorporating digital economy factors into green development evaluations, offering new insights and quantitative analyses for policymakers.

Keywords: Digital economy, green development, sustainable development, China's regional manufacturing, entropy method, obstacle degree mode

Introduction

Amid global environmental challenges and economic growth pressures, green development is crucial for achieving sustainability, combating climate change, preserving ecological balance, and safeguarding human health [1]. Concurrently, the digital economy, driven by ongoing technological advancements, presents opportunities for green technologies, production methods, and product innovations, offering solutions to manufacturing's green transformation challenges [2]. The digital economy enhances resource

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efficiency, reduces energy consumption and pollution, and promotes the shift toward green, intelligent, and sustainable manufacturing practices. As a key player in the global digital economy, China faces the dual challenges of rapid digital growth and green transformation in manufacturing [3]. Consequently, assessing and advancing green development in China's manufacturing sector has garnered significant attention and research. Evaluating green development levels helps identify constraints, develop targeted policies, promote green technological innovation, and upgrade industries, thus achieving balanced economic, environmental, and social benefits. A comprehensive evaluation of the green development level in manufacturing aids in identifying the key factors that constrain green development, formulating targeted policy measures, fostering green technological innovation, and upgrading green industries, thereby achieving a coordinated advancement of economic, environmental, and social benefits.

Recent academic research has extensively studied the impact of the digital economy on industrial structure and green development [4]. At the micro level, the focus is on how the digital economy affects enterprises' digital transformation and organizational restructuring [5]. On the meso and macro levels, research explores how the digital economy drives structural adjustments, shifts manufacturing towards higher segments of the global value chain, and promotes innovation in the service sector [6-8]. Studies also examine how the digital economy contributes to environmental sustainability, green energy consumption, and energy efficiency [9]. Scholars employ various quantitative methods like chromatographic analysis, discriminant analysis, and entropy weighting to assess green development in resource-based cities [10-12]. In conclusion, while there is significant scholarly interest in green development under the digital economy, there are notable shortcomings in assessing green development in regional manufacturing. Current studies often focus on individual provinces or regions, lacking a comprehensive and objective evaluation framework. Evaluation criteria frequently rely on subjective judgments, which compromise the overall comprehensiveness and representativeness of the assessment. This study innovatively integrates digital economy factors into a green development evaluation framework, using 2022 panel data from 30 Chinese provinces. It applies the entropy method to quantify green development levels and the obstacle degree model to identify key influencing factors. The research provides a basis for targeted policy recommendations, facilitating manufacturing's shift towards sustainability and offering new pathways for economic development.

Methods, Data, and Indicators

Research Methods

Measurement Method for Green Development Level in Manufacturing

The entropy method is a highly reliable and precise comprehensive evaluation approach. It determines weights based on the information content reflected by the degree of numerical variation [13]. The specific calculation process is detailed as follows:

(1) Indicator Description

The total number of manufacturing provinces is denoted as n, and the total number of indicators is denoted as m. x_{ij} denotes the *j-th* indicator for the *i-th* province.

(2) Standardization of Indicators

The formula for standardizing positive indicators is:

$$x'_{ij} = \frac{x_{ij} - x_{ij}^{\min}}{x_{ij}^{\max} - x_{ij}^{\min}}, i = 1, 2, ..., n; j = 1, 2, ..., m \tag{1}$$

The formula for standardizing negative indicators is:

$$x'_{ij} = \frac{x_{ij}^{\max} - x_{ij}}{x_{ij}^{\max} - x_{ij}^{\min}}, i = 1, 2, ..., n; j = 1, 2, ..., m \tag{2}$$

where $x_{ij}^{\max}$ and $x_{ij}^{\min}$ represent the maximum and minimum values of indicators

(3) Non-negative Treatment of Standardized Indicators

To meet the requirements for entropy calculation, the matrix needs to be adjusted by shifting to a non-zero value, typically 0.0001. The revised formulas for standardized indicators are:

For positive indicators:

$$x'_{\theta ij} = \frac{x_{ij} - x_{ij}^{\min}}{x_{ij}^{\max} - x_{ij}^{\min}} + 0.0001, i = 1, 2, ..., n; j = 1, 2, ..., m \tag{3}$$

For negative indicators:

$$x'_{\theta ij} = \frac{x_{ij}^{\max} - x_{ij}}{x_{ij}^{\max} - x_{ij}^{\min}} + 0.0001, i = 1, 2, ..., n; j = 1, 2, ..., m \tag{4}$$

(4) Calculating the Weight of Each Indicator:

1) Weight p_{ij} of each evaluation criterion x_{ij}:

$$p_{ij} = x'_{ij} \Big/ \sum_{i=1}^{n} x'_{ij} \tag{5}$$

2) Calculating the entropy value for each indicator

$$e_j = -\frac{1}{\ln^n} \times \sum_{i=1}^{n} (p_{ij} \times \ln^{p_{ij}}) \quad (6)$$

3) Calculating the Weight of Each Indicator

$$w_j = {1-e_j} \Big/ {\sum_{j=1}^{m} (1-e_j)} \quad (7)$$

(5) Applying the Linear Weighting Method to Calculate the Green Development Level

$$I_i = \sum_{j=1}^{m} (x_{ij} \times w_j) \quad (8)$$

Evaluation of Obstacle Factors in Green Development of Manufacturing

To further elucidate the key barriers to green development, the obstacle degree model is employed to identify and diagnose the obstacles at both the criterion and indicator levels for green development in China's regional manufacturing.

The specific formulas are as follows:

$$M_j = \frac{v_{ij} w_j}{\sum_{j=1}^{m} v_{ij} w_j}$$

$$v_{ij} = 1 - r_{ij}$$

$$A_J = \sum_{j=1}^{m} M_t \quad (9)$$

In the equation: M_j is the obstacle degree of the *j-th* indicator on green development in manufacturing. v_{ij} is the deviation degree, indicating the gap between the indicator j of province i and the development target. W_j is the weight of the indicator j, representing the contribution of the obstacle factor. A_j is the obstacle degree of each criterion layer to green development in the manufacturing.

Research Area and Data Sources

This study examines manufacturing across 30 provinces in mainland China, excluding Hong Kong, Macao, Taiwan, and Tibet. Data are sourced from the 2023 editions of the "China Statistical Yearbook," "China Industrial Statistical Yearbook," "China Science and Technology Statistical Yearbook," "China Energy Statistical Yearbook," "China Tertiary Industry Statistical Yearbook," and "China Population and Employment Statistical Yearbook." These authoritative sources provide a solid and reliable foundation for the research. The study evaluates green development levels in manufacturing across regions and analyzes influencing factors, offering a scientific basis and policy recommendations for advancing green manufacturing and sustainable development.

Construction of Indicator System

Building on relevant literature [14-16], this study integrates advancements in the digital economy with new industrialization to develop a hierarchical evaluation indicator system for green development in manufacturing under the digital economy (see Table 1). This system includes target levels for comprehensive assessment and focuses on five core dimensions: economic benefits, social benefits, innovation drive, industrial development, and sustainable development. It further examines these dimensions through detailed sub-indicators to ensure a thorough evaluation.

Economic benefits are assessed through indicators such as the proportion of new product revenue, which reflects innovation capability and market competitiveness [17] the profit margin of high-tech enterprises, indicating profitability and economic contribution [18] and capital investment, which measures investment in R&D and equipment upgrades, highlighting sustainability [19].

Social benefits are evaluated by indicators including the employment rate, which reflects the sector's contribution to employment [20] employee quality, indicating the educational and skill levels of the workforce [21] employee productivity, which measures operational efficiency [22] and the ratio of high-tech enterprise employees, reflecting the employment contribution of high-tech sectors [23].

Technology and innovation are measured by the level of digital technology, reflecting technological innovation capability [24] knowledge input, which measures investment in R&D and innovation drive [25] the number of effective patents authorized, indicating technological innovation strength [26] and the ratio of enterprises setting innovation strategy objectives, reflecting strategic management in innovation [27].

Industrial development is assessed by the scale of high-tech industry development, which reflects industrial structure optimization [28] the development level of enterprise e-commerce, indicating market competitiveness and adaptability [29] and the development of strategic emerging industries, which measures industry diversity and sustainability [30].

Sustainable development is represented by indicators such as digitalization, which measures progress in digital transformation and modernization [31] low-carbonization, reflecting efforts in green production and environmental protection [32] and intelligentization, indicating advancements in intelligent manufacturing [33].

Table 1. Evaluation Index System for Green Development in Manufacturing under the Digital Economy.

Primary Indicator	Secondary Indicator	Indicator Explanation		Unit	Attribute
Economic Benefits A)	Proportion of New Product Revenue	New product sales revenue / GDP	A1	%	+
	Profit Margin of High-tech Enterprises	Profit margin of high-tech industries / Manufacturing main business income	A2	%	+
	Capital Investment	R&D Expenditure	A3	ten thousand yuan	+
Social Benefits (B)	Employment Rate	Number of employed / Labor force	B1	%	+
	Employee Quality	Graduates with bachelor's degree or above / Labor force	B2	%	+
	Employee Productivity	Manufacturing main business income / Number of employees	B3	Ten Thousand Yuan / person	+
	Proportion of High-tech Enterprise Employees	Year-end employees of high-tech enterprises / Number of employees	B4	%	+
Technological Innovation (C)	Level of Digital Technology	Number of internet access ports	C1	ten thousand units	+
	Knowledge Investment	Expenditure on new product development	C2	ten thousand yuan	+
	Effective Patents Authorized	Reflects enterprise patent output capability	C3	Piece	+
	Ratio of Enterprises Setting Innovation Goals	Proportion of enterprises setting innovation goals to all enterprises	C4	%	+
Industrial Development(D)	Scale of High-tech Industry Development	Number of high-tech industries / Enterprise units	D1	%	+
	Development of Strategic Emerging Industries	Revenue of software and information technology services / GDP	D2	%	+
	Development Level of E-commerce	Proportion of enterprises engaged in e-commerce activities	D3	%	+
Sustainable Development(E)	Digitization	Number of information transmission, software, and information technology service employees / Number of employees	E1	%	+
	Low carbonization	Production efficiency per ton of energy consumption	E2	Ten Thousand Yuan / ton	+
	Intelligentization	Main business income of electronic information industry manufacturing / Manufacturing main business income indicating the operation of intelligent manufacturing enterprises	E3	%	+

Results and Discussion

Comprehensive Evaluation of Green Development

In the context of the digital economy, this study applies the entropy method to comprehensively assess the performance of each province in green development within manufacturing. It covers 17 key indicators. This approach facilitates a detailed analysis of green development evaluation and provides scientific support for exploring influencing factors and formulating policy recommendations.

Analysis of Factors Influencing Green Development

Table 2's entropy weight analysis reveals that the digitalization indicator has the highest weight (0.132), highlighting its critical role in green development within regional manufacturing. Conversely, employee productivity has the lowest weight (0.017), indicating a minor impact. Dimensional analysis shows that economic benefits and sustainable development are the main drivers of green development, significantly advancing overall progress. Technological innovation, industrial development, and social benefits provide important supplementary roles. Economic benefits are driven by new product revenue proportion,

Table 2. Summarizes the results of entropy method calculations for indicator weights.

First Layer (Criterion Layer)	Weight	Second Layer (Indicator Layer)	Weigh
Economic Benefits	25.04%	Proportion of revenue from new products	7.69%
		Profit margin of high-tech enterprises	7.82%
		Capital investment	9.53%
Social Benefits	8.88%	Employment rate	2.05%
		Employee quality	3.00%
		Employee productivity	1.65%
		Proportion of employees in high-tech enterprises	2.18%
Technological Innovation	23.67%	Level of digital technology	2.82%
		Investment in knowledge	10.65%
		Number of effective invention patents authorized	8.38%
		Proportion of enterprises setting innovative strategic goals	1.82%
Industrial Development	15.24%	Scale of development in high-tech industries	2.21%
		Development level of e-commerce in enterprises	2.73%
		Development of strategic emerging industries	10.30%
Sustainable Development	27.18%	Digitalization	13.20%
		Low carbonization	5.86%
		Intelligentization	8.12%

high-tech enterprise profit margins, and capital investment, boosting economic growth and competitiveness. Technological innovation is measured by knowledge input and effective patents, essential for industrial upgrading. For sustainable development, digitalization and intelligence reflect leadership in environmental protection and resource efficiency, crucial for sustainability goals. These indicators affect economic growth, competitiveness, and the effectiveness of green development trajectories.

Towards Sustainable Development: Evaluation and Analysis of Green Development Levels

As shown in Table 3, the analysis evaluates the standard values of sustainability dimensions – digitalization, low carbonization, and intelligentization – and the comprehensive green development scores of various provinces. Fig. 1 illustrates each province's performance in these dimensions and their relationship with overall green development scores, highlighting significant performance disparities.

Provinces with high scores, such as Beijing, Guangdong, Jiangsu, and Zhejiang, demonstrate exemplary performance across digitalization, low carbonization, and intelligentization, underscoring their leadership in green development. Beijing, in particular, achieves near-perfect scores across all dimensions, showcasing its comprehensive strengths in the digital economy and green technology. Guangdong excels in intelligentization, reflecting its advanced capabilities in high-tech and smart manufacturing.

Provinces with moderate scores, including Tianjin, Shanghai, Shandong, and Henan, show strong performance in certain dimensions but have room for improvement in others. For example, while Shanghai and Tianjin excel in digitalization and low carbonization, their performance in intelligentization is comparatively weaker. These provinces should address specific shortcomings and implement targeted improvements to achieve a more balanced green development approach.

Provinces with lower scores, such as Gansu, Qinghai, Ningxia, and Xinjiang, exhibit weaknesses across digitalization, low carbonization, and intelligentization. These provinces need increased investment in green technology and environmental conservation, alongside advancements in technological capabilities and enhanced policy frameworks to support sustainable development.

The Identification Results of Green Development Barriers in 30 Mainland Chinese Provinces

Analysis of Individual Indicator Obstacles

Building upon the assessment, the Obstacle Degree Model is used to further identify the primary barriers affecting green development in manufacturing under the digital economy. Given the large number of provinces and indicators studied, this paper focuses on analyzing

Table 3. Scores of sustainable development indicators and green development scores of 30 provinces in Chinese mainland.

Province	E1	E2	E3	Comprehensive Green Development Score	Evaluation Analysis
Beijing	1.000	1.000	1.000	0.553	Beijing has the highest comprehensive score, reflecting its leading position in green development.
Tianjin	0.108	0.241	0.163	0.147	Tianjin needs improvement in intelligentization. It is at an upper-middle level.
Hebei	0.018	0.079	0.034	0.103	Hebei needs significant improvement in digitalization and intelligentization.
Shanxi	0.014	0.001	0.012	0.054	Shanxi shows minimal progress in low carbonization, leading to a low comprehensive score.
Inner Mongolia	0.022	0.001	0.005	0.057	Inner Mongolia demonstrates limited progress in low carbonization, resulting in a lower comprehensive score.
Liaoning	0.054	0.070	0.046	0.120	Liaoning shows a moderate comprehensive score, indicating room for improvement.
Jilin	0.027	0.066	0.006	0.139	Jilin performs at a moderate level, resulting in a moderate comprehensive score.
Heilongjiang	0.029	0.017	0.013	0.109	Heilongjiang has a lower comprehensive score, indicating the need for comprehensive improvement in all aspects.
Shanghai	0.442	0.355	0.157	0.281	Shanghai shows a high comprehensive score, reflecting its strong trend in green development.
Jiangsu	0.063	0.308	0.196	0.449	Jiangsu shows a high comprehensive score, demonstrating excellent performance in green development.
Zhejiang	0.081	0.284	0.269	0.334	Zhejiang has a high comprehensive score, indicating strong performance in green development.
Anhui	0.021	0.112	0.156	0.189	Anhui needs improvement in digitalization and low carbonization, achieving a moderate comprehensive score.
Fujian	0.034	0.247	0.245	0.188	Fujian has room for improvement in digitalization, resulting in a moderate comprehensive score.
Jiangxi	0.009	0.228	0.153	0.166	Jiangxi is in a moderately low comprehensive score.
Shandong	0.021	0.114	0.060	0.260	Shandong needs room for improvement, achieving a moderate comprehensive score.
Henan	0.024	0.089	0.048	0.194	Henan needs room for improvement in all aspects, achieving a moderately low comprehensive score.
Hubei	0.038	0.149	0.164	0.174	Hubei needs improvement in digitalization, achieving a moderate comprehensive score.
Hunan	0.011	0.176	0.175	0.148	Hunan performs weak in digitalization, resulting in a moderately low comprehensive score.
Guangdong	0.118	0.405	0.721	0.650	Guangdong is in the highest comprehensive score, reflecting its leading position in green development.
Guangxi	0.005	0.105	0.027	0.078	Guangxi performs resulting in a lower comprehensive score, requiring comprehensive improvement.
Hainan	0.033	0.074	0.003	0.066	Hainan performs resulting in a low comprehensive score, requiring significant improvement.
Chongqing	0.022	0.244	0.182	0.148	Chongqing needs improvement in digitalization, achieving a moderate comprehensive score.
Sichuan	0.043	0.246	0.215	0.176	Sichuan needs improvement in digitalization, achieving a moderate comprehensive score.
Guizhou	0.007	0.016	0.040	0.066	Guizhou is in a low comprehensive score, requiring comprehensive improvement.
Yunnan	0.001	0.083	0.055	0.068	Yunnan is in a lower comprehensive score, requiring comprehensive improvement.
Shaanxi	0.058	0.045	0.121	0.129	Shaanxi needs improvement in low carbonization, achieving a moderate comprehensive score.

→

Gansu	0.008	0.036	0.008	0.053	Gansu shows resulting in a low comprehensive score, requiring comprehensive improvement.
Qinghai	0.024	0.081	0.008	0.054	Qinghai is in a low comprehensive score, requiring comprehensive improvement.
Ningxia	0.013	0.001	0.001	0.057	Ningxia is in a low comprehensive score, requiring comprehensive improvement.
Xinjiang	0.019	0.003	0.026	0.038	Xinjiang is in a low comprehensive score, requiring comprehensive improvement.

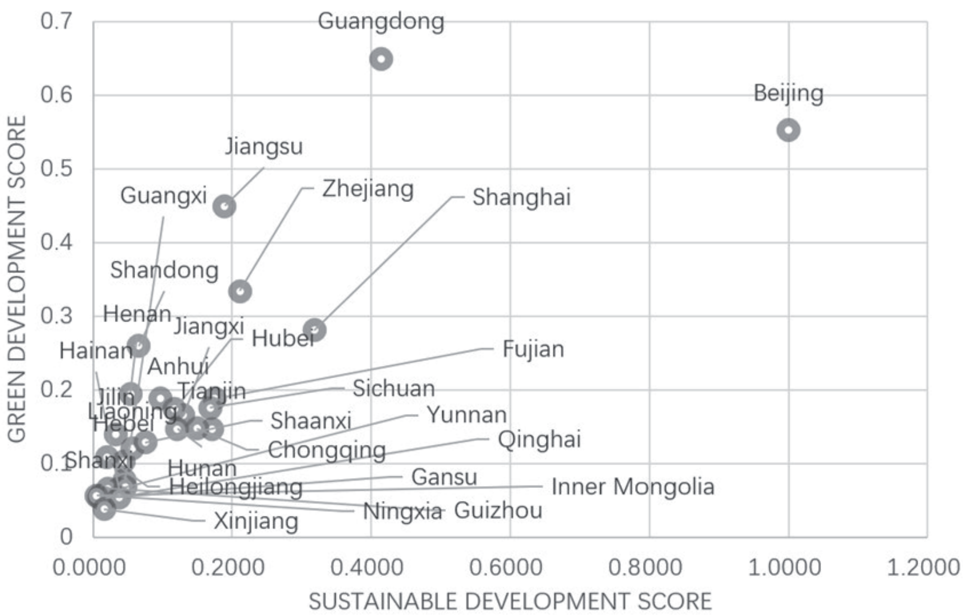

Fig. 1. Manufacturing Scores Trends of Provinces in Sustainable Development and Green Development.

the top five indicators with the highest obstacle degrees across provinces in 2022. Using the obstacle degree calculation formula, the obstacle degrees of various indicators for manufacturing green development across 30 mainland Chinese provinces in 2022 are measured. As shown in Table 4, specific indicators posing significant obstacles to green development in provincial manufacturing in 2022 include digitalization, knowledge input, development of strategic emerging industries, capital investment, and intelligentization. These indicators reflect major weaknesses and challenges in the green development process. Combining the entropy weightings of green development indicators across the 30 provinces, it is found that despite the implementation of multiple policies by these cities, the effectiveness of existing policies remains limited amidst rapid economic and social development. For instance, while some provinces exhibit high levels of digitalization and intelligentization, they still face significant obstacles in the green development process. Therefore, to achieve sustainable economic and environmental development in manufacturing, more comprehensive and targeted measures must be taken to enhance innovation and sustainable development capabilities.

Analysis of Classification Obstacle Indicators

Based on the measurement results from various indicators (Table 5), sustainable development and technology innovation emerge as the primary barriers to green development in China's regional manufacturing industry. They are followed by economic benefits and industrial development. Specifically, the rankings are sustainable development>economic benefits> technology innovation>industrial development>social benefits. This underscores fundamental challenges in achieving green development amid the digital economy's influence. Overall, most provinces face significant obstacles in achieving sustainable development. Whether provinces exhibit higher levels of green manufacturing development, such as Guangdong, Jiangsu, and Zhejiang, or lower levels, like Gansu, Qinghai, and Ningxia, the pressure to achieve sustainable outcomes persists. This highlights critical challenges in environmental protection, resource use, and ecological balance, necessitating enhanced policy support and technological innovation to drive practical advances in green development. Technology innovation plays a pivotal role in promoting green development, evident from the high emphasis placed on it across provinces. This reflects

Table 4. Analysis of Major Obstacles and Obstacle Degrees in Green Development Levels of Manufacturing across 30 Mainland Chinese Provinces in 2022.

Province	Index Obstacle Degree									
	1		2		3		4		5	
Beijing	C2	0.2017	A3	0.1876	C3	0.1802	A1	0.1542	A2	0.1338
Tianjin	E1	0.1380	C2	0.1204	A3	0.1062	D1	0.1056	C3	0.0958
Hebei	E1	0.1446	C2	0.1155	D1	0.1121	A3	0.1022	E3	0.0875
Shanxi	E1	0.1375	C2	0.1116	D1	0.1085	A3	0.1001	C3	0.0857
Inner Mongolia	E1	0.1368	C2	0.1121	D1	0.1091	A3	0.1001	E3	0.0857
Liaoning	E1	0.142	C2	0.1175	D1	0.1063	A3	0.1038	E3	0.0881
Jilin	E1	0.1493	C2	0.1224	D1	0.117	A3	0.1098	E3	0.0937
Heilongjiang	E1	0.1437	C2	0.1185	D1	0.1152	A3	0.106	E3	0.0899
Shanghai	C2	0.1289	A3	0.1124	E1	0.1025	C3	0.0959	E3	0.0952
Jiangsu	E1	0.2246	C3	0.126	E3	0.1185	C2	0.1105	D1	0.0788
Zhejiang	E1	0.1823	C2	0.1189	C3	0.1154	A3	0.1048	D1	0.0918
Anhui	E1	0.1592	D1	0.1216	C2	0.1183	A3	0.1039	A2	0.0888
Fujian	E1	0.1571	C2	0.1152	D1	0.1112	A3	0.0978	C3	0.0873
Jiangxi	E1	0.1568	D1	0.122	C2	0.1182	A3	0.1041	C3	0.084
Shandong	E1	0.1744	C2	0.1255	A3	0.1033	E3	0.1031	C3	0.1008
Henan	E1	0.1599	C2	0.1263	D1	0.1244	A3	0.1087	E3	0.0959
Hubei	E1	0.1537	C2	0.1133	D1	0.1105	A3	0.097	C3	0.0966
Hunan	E1	0.1532	C2	0.116	D1	0.1142	A3	0.1007	C3	0.0971
Guangdong	E1	0.3321	C3	0.2196	E2	0.0995	B2	0.0821	E3	0.0647
Guangxi	E1	0.1424	C2	0.1146	D1	0.1076	A3	0.1024	E3	0.0857
Hainan	E1	0.1367	C2	0.1136	D1	0.1097	A3	0.1018	E3	0.0867
Chongqing	E1	0.1515	C2	0.1196	D1	0.1063	A3	0.1048	C3	0.0941
Sichuan	E1	0.1532	C2	0.1169	A3	0.1017	C3	0.1015	D1	0.0981
Guizhou	E1	0.1404	C2	0.1122	D1	0.1068	A3	0.0995	E3	0.0834
Yunnan	E1	0.1416	C2	0.113	D1	0.1098	A3	0.1001	C3	0.0878
Shaanxi	E1	0.1427	C2	0.115	D1	0.1075	A3	0.1008	C3	0.0951
Gansu	E1	0.1383	C2	0.1118	D1	0.1086	A3	0.0999	C3	0.0867
Qinghai	E1	0.1362	C2	0.1124	D1	0.1089	A3	0.1005	C3	0.0881
Ningxia	E1	0.138	C2	0.1121	D1	0.109	A3	0.1001	C3	0.0888
Xinjiang	E1	0.1346	C2	0.1107	D1	0.1068	A3	0.099	C3	0.0844

the urgent need to apply environmental technologies and upgrade industries. While some provinces, such as Inner Mongolia, Jilin, and Liaoning, encounter obstacles related to economic and social benefits, these factors are secondary compared to sustainable development and technology innovation in the overall analysis. Achieving a balance between economic transformation and social engagement remains pivotal. There are notable disparities in the weight of green development barriers among provinces, underscoring the need for tailored strategies that consider local conditions. Certain regions may require more policy support and resource allocation to address specific green development challenges. The study findings reveal common challenges provinces face in transitioning to green practices, alongside significant variations in their green development levels.

Table 5. 2022-Dimensional Indicator Obstacle Degrees of Green Development Levels in Manufacturing across 30 Provinces.

Province	Economic Benefits (%)	Social Benefits (%)	Technology & Innovation (%)	Industrial Development (%)	Sustainable Development (%)
Beijing	47.56	4.14	44.83	3.46	0
Tianjin	27.38	4.09	26.4	15.16	26.97
Hebei	25.32	7.17	22.58	15.71	29.22
Shanxi	25.83	6.48	23.56	15.71	28.43
Inner Mongolia	25.92	6.24	23.95	15.45	28.45
Liaoning	26.49	6.04	22.8	15.46	29.2
Jilin	28.25	5.03	19.54	16.52	30.66
Heilongjiang	27.81	5.51	20.36	16.5	29.82
Shanghai	28.69	6.3	26.85	13.14	25.02
Jiangsu	10.64	8.29	26.45	12.94	41.68
Zhejiang	19.22	7.87	25.78	13.67	33.45
Anhui	25.54	7.29	20.74	15.65	30.79
Fujian	24.75	6.53	24.5	15.53	28.69
Jiangxi	24.78	6.51	24.17	15.19	29.36
Shandong	21.32	7.76	24.44	11.72	34.76
Henan	27.13	7.6	15.35	17.71	32.21
Hubei	24.94	6.59	23.66	15.19	29.62
Hunan	24.65	7.13	24.29	15.1	28.83
Guangdong	1.32	13.68	23.93	11.43	49.63
Guangxi	26.44	7.48	22.63	14.96	28.5
Hainan	26.76	5.94	24.45	14.7	28.15
Chongqing	26.34	6.43	25.02	14.06	28.15
Sichuan	26.13	7.54	24.24	13.67	28.41
Guizhou	26.22	7.23	23.23	14.77	28.56
Yunnan	25.66	7.5	23.42	15.27	28.15
Shaanxi	26.27	5.71	24.42	14.71	28.89
Gansu	26.19	6.91	23.33	15.28	28.3
Qinghai	26.16	7.2	24.28	14.54	27.83
Ningxia	26.24	6.32	23.57	15.25	28.62
Xinjiang	25.98	6.89	23.75	15.63	27.76

Conclusions and Recommendations

Conclusions

This study has developed a comprehensive evaluation framework for green development within the context of the digital economy. It offers quantitative insights into green manufacturing levels across provinces and identifies critical barriers. Key findings are:

(1) Primary Drivers of Green Development in Regional Manufacturing in China

The study highlights digitization and intelligentization as significant drivers of green development. Digitization indicators are weighted highest, emphasizing their crucial role in enhancing green development and achieving sustainability. Advancing digital transformation and intelligentization are essential pathways for realizing green development in the digital economy. Key factors such as the proportion of new product revenue, profitability of high-tech enterprises, capital investment, knowledge input, and effective patent authorizations significantly drive economic growth and market competitiveness, thereby advancing green development.

(2) Green Development Levels from a Sustainable Development Perspective

Economic benefits and sustainable development are central to evaluating green development in manufacturing. Indicators like the profitability of high-tech enterprises, the proportion of new product revenue, and metrics of digitization and intelligentization directly influence green development levels. High-scoring provinces, such as Beijing, Guangdong, Jiangsu, and Zhejiang, demonstrate exceptional performance in these areas, showcasing their leadership in green development and success in promoting economic growth, market competitiveness, and sustainability.

(3) Regional Disparities and Principal Challenges

Significant regional disparities exist in green development levels. High-scoring provinces excel in digitization, low-carbon initiatives, and intelligentization, while lower-scoring provinces lag in these areas. Major challenges include sustainable development and technological innovation, particularly in environmental protection technologies and industrial upgrading. These barriers highlight regional disparities in green development, revealing deficiencies in environmental protection, resource utilization, and ecological balance in certain provinces.

Recommendations

Based on this analysis, we propose the following policy recommendations:

(1) Promote Digitization and Intelligent Transformation

Recognizing the pivotal role of digitization and intelligentization in advancing green development within regional manufacturing, governments should prioritize policies that support the adoption of digital technologies and smart manufacturing practices. This includes making substantial investments in digital infrastructure to enhance production efficiency and resource utilization, thereby reducing environmental impacts and facilitating the transition of industries towards environmentally sustainable practices.

(2) Enhance the Innovation Environment and Policy Support

Encourage and support research and development (R&D) investments and protect intellectual property for high-tech enterprises. Policies such as tax incentives and targeted funding for research projects should foster technological innovations in green technologies and environmental conservation. Additionally, strengthen technology transfer platforms to expedite the application and dissemination of technological advancements, thereby enhancing industry-wide innovation capabilities and global competitiveness.

(3) Establish Mechanisms for Regional Collaboration and Knowledge Sharing

Promote collaboration and knowledge exchange among provinces in green development. Establish robust platforms for interregional cooperation and information sharing to facilitate coordinated policy efforts and best practices in adopting green technologies and implementing environmental policies. These initiatives are essential for addressing regional disparities in environmental protection, resource utilization, and ecological balance.

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Conflict of Interest

The authors declare no conflict of interest.

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