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# *Evaluation of Green Development Efficiency in the Yangtze River Economic Belt Based on DEA*

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***Keywords:*** Green development; Efficiency evaluation; DEA model

***Abstract:*** This article reviews the current research status of green development both domestically and internationally, including: the connotations and characteristics of green development, the evaluation of green development levels, and the measurement of green development efficiency. By reviewing relevant literature, this paper selects the period from 2011 to 2021 and focuses on the 11 provinces along the Yangtze River Economic Belt to measure the green development efficiency of the region. The conclusions drawn are that the green development in the Yangtze River Economic Belt is showing an upward trend but still faces issues of uneven development, with uneven distribution of green development efficiency. Among these, the green development efficiency of provinces in the middle and lower reaches is higher, followed by those in the downstream provinces, exhibiting a trend of first rising, then declining, and finally rising again. Based on the evaluation of green development efficiency in the Yangtze River Economic Belt, policy implications for its green development are provided: the government should transform its functions and increase investment in science and education to promote more stable green development in the region, driving sustainable development along the Yangtze River Economic Belt.

## 1. Introduction

The Yangtze River Economic Belt plays a significant role in China's regional development. At the Fifth Plenary Session on December 29,2015, it was proposed to implement the five major development concepts of "innovation, coordination, green, openness, and sharing." The concept of "green development" was emphasized more than once, with the term "green" referring to the commitment to "conservation and environmental protection" and "sustainable development." On January 5, 2016, the General Secretary convened a symposium on advancing the development of the Yangtze River Economic Belt, emphasizing that the region should adhere to "major protection, not major development," and follow the path of "ecological priority, green development." In September 2016, the Outline of the Yangtze River Economic Belt Development Plan was released, which reiterated the emphasis on ecological environmental protection and green development in the Yangtze River Economic Belt. On April 26,2018, the General Secretary proposed to accurately grasp five relationships, with the first two focusing on the relationship between green, economy, and development. In November 2020, a symposium on the overall development of the Yangtze River Economic Belt was held, positioning it as the main force for China's development in the new era. Developing the Yangtze River Economic Belt will promote the overall process of green development,

and its role in national development cannot be overlooked. In 2021, the state issued the "Opinions on Fully, Accurately, and Comprehensively Implementing New Development Concepts to Do Well in Carbon Peak and Carbon Neutrality Work," which proposed advancing green development and construction, enhancing the level of opening up to the outside world, and focusing on green development. We must follow the instructions of the General Secretary, with the "14th Five-Year Plan for the Development of the Yangtze River Economic Belt" at its core and the "1+N" framework as the foundation. We need to unite all parties, maintain consistency, and ensure that this mother river, the Yangtze, always remains vibrant. It should play a greater role in supporting and contributing to the high-quality development of the country, serving as a model and leader in this process, becoming a "Yangtze example." The report from the 20th National Congress emphasized the need to adhere to "people-oriented and green development," promoting social progress through the integration of people and nature, and fostering development through the synergy between human efforts and natural resources[1-5].

This paper employs the literature review method, DEA-Malmquist index method, and comparative analysis to gain a deep understanding of green development. Based on national policies and academic research, it measures the efficiency of green development. Using the DEA model, it analyzes specific data on green development in the Yangtze River Economic Belt over the past decade. Eleven provinces are selected for regional and specific analysis to derive the detailed development situation of the Yangtze River Economic Belt, analyzing the reasons and influencing factors. At the end of the article, relevant research results are summarized, and corresponding policy recommendations are provided[6-9].

## 2. Theoretical basis and literature review

### 2.1 Theoretical basis

#### 2.1.1 Theory of sustainable development

In the concept of sustainable development, resources form the foundation. Only in this way can human needs be met. As the economy and society continue to develop, the demand for natural resources is also increasing. However, as people constantly change their methods of resource use, it has led to a severe shortage in resource supply, causing environmental issues. To address this problem, it is necessary to transform the way resources are used and establish the concept of sustainable development. The basic content of the theory of sustainable development includes: (1) pointing out that ecosystems and economic systems are interdependent, constraining, and promoting each other; (2) emphasizing that to achieve the goals of economic and social development, natural resource management must be carried out.

#### 2.1.2 Green economy theory

The green economy refers to promoting economic development by replacing traditional heavy and polluting industries with circular and sustainable concepts. The green economy encompasses "efficiency, harmony, and sustainability," forming a tripartite goal system. It integrates ecological, circular, and sustainable services into a unified structure, establishing a comprehensive development framework for green growth in economic, policy, and social aspects. Years of development history demonstrate that the green economy better adapts to current social progress, achieving sustainability and benefiting human society and global development. The green economy discards traditional development ideas, offering new interpretations of today's sustainable development methods from a fresh perspective. Everything is based on green principles and environmental standards, continuously

recycling resources, reducing energy consumption, conserving resources, and maximizing efficiency within limited resources. Under its influence, the green economy drives the transformation and upgrading of developing countries, making significant contributions to world development. In the transition from traditional to green economies, it achieves structural growth.

### 2.1.3 Circular economy theory

The circular economy and green economy are two inseparable concepts. In simple terms, the circular economy refers to the recyclability of resources and the circulation of socio-economy, involving reuse in input-output processes. The circular economy combines clean energy with waste materials to produce new substances, completing a cycle that integrates "useless" waste to achieve resource recycling. Ecological sustainability is an economic development model based on ecological principles and economic laws. It posits that traditional economics is a linear economy characterized by the unidirectional flow of "resources—products—waste." While this economic model meets human needs, it also exerts significant pressure on the natural environment. The theory of the circular economy advocates for the reuse and regeneration of resources, which saves on resource consumption and investment in economic development. We recognize the importance of developing a circular economy and consider it a crucial economic policy, an important measure for adjusting our economic structure and transforming our economic development model. In the "Eleventh Five-Year Plan," there was also a proposal to develop a circular economy and establish a conservation-oriented, environmentally friendly society as a basic strategy[10-16].

## 2.2 Literature review

### 2.2.1 The connotation, characteristics and concept definition of green development

Currently, scholars both domestically and internationally have made some progress in studying the benefits of green development in our country. The main focus is on the following aspects: First, clarifying the connotations and characteristics of green development; Second, evaluating the degree of "green" development; Third, measuring methods for green development efficiency. Since most existing research on green development efficiency is based on single indicators or methods, few studies have addressed the issue of comprehensive measurement using multiple indicators. Therefore, this paper employs the DEA (Data Envelopment Analysis)-Malmquist index method to conduct an empirical analysis of the 11 provinces and cities along the Yangtze River Economic Belt.

(1) The connotation of green development

The connotation of green development is to develop on the basis of respecting nature, so that social and natural development complement each other, and make development more sustainable and sustainable.

Zhen Lin et al. (2013) proposed the dual theory of green development, arguing that the essence of green development is people-oriented sustainable development, emphasizing the unity and harmony between economic growth and environmental protection. Lu Liwen et al. (2016) found that the overall green efficiency of the Yangtze River Economic Belt is relatively low but shows a trend of gradual improvement. Based on this, using the Yangtze River Economic Belt as an example, they studied the differences in urban green comprehensive efficiency at different scales and proposed "oral skills" at various scales. To improve technical capabilities and promote urban innovation, the Yangtze River Economic Belt must break through its current low development efficiency. The Yangtze River Economic Belt is a region with high input and high consumption; to achieve green development in towns in the central and western regions of the Yangtze River Economic Belt, it is necessary to optimize the allocation of resource elements in these areas. The current overall development pattern

of the Yangtze River Economic Belt still focuses primarily on economic output while neglecting the quality of economic operations and social effects. Insufficient "green energy" manifests as issues such as "resource waste" and "environmental pollution," which are key challenges and difficulties in enhancing urban green energy efficiency. It is essential to jointly promote ecological conservation and strengthen environmental supervision and management, which are closely related to improving the green efficiency of the Yangtze River Economic Belt and achieving a model of ecological civilization. Zhu Dajian (2012) emphasized the need for a clear understanding of the current background of green economic development before delving deeper into the discussion of green economics, clarifying three questions: ① Why develop green economics; ② What is the green economy we need; ③ How to promote the development of green economics. Second, scenario simulations were conducted for the "green economy" and the "brown economy," with results showing that the "three-line benefits" of the "green economy" model are much better than those of the "brown economy." In terms of environmental returns from natural capital, in the scenario of green economic development, the degradation of natural capital has been controlled, whereas in the scenario of brown economic development, it will further intensify. Reducing the consumption of natural capital can lower the costs of ecological management and maintenance, while maintaining and enhancing the role of natural capital; it can increase output efficiency with minimal input of natural capital, meeting the requirements for social stability set by human capital; using limited material resources can improve the efficiency of human capital utilization. Fu Baozong et al. (2017) proposed that under the influence of both international and domestic environments, the economic development of provinces along the Yangtze River Economic Belt has entered a "new normal," with increasing downward pressure on the economy, declining industrial growth momentum, and continuously decreasing investment willingness. As the advantage of labor costs gradually diminishes, coupled with significant economic downturn pressures, corporate profits will be greatly affected. Therefore, it is necessary to transform and upgrade traditional manufacturing industries, foster the development of emerging high-end manufacturing; establish regional innovation systems, build the Yangtze River Economic Belt into a national innovation demonstration zone, nurture leading enterprises with core technologies and independent brands, promote the aggregation of innovative elements in enterprises, strengthen the construction of national key laboratories and engineering technology centers, and establish common technology research and development. In industries such as electronics, petrochemicals, steel, automobiles, ships, and equipment manufacturing, brand orientation is emphasized to enhance international competitiveness; expanding production chains and promoting the development of production services to increase productivity. This promotes coordinated development between regions, improves the efficiency of green development, making economic activities more "green" and "ecological." This is an essential part of green development[17-25].

(2) Characteristics of green development

Tang Xiao (2014) pointed out that the construction of ecological civilization in China should be approached from the perspective of an economic-ecological-social composite system. It is necessary to comprehensively examine the development goals of the economy, ecology, and society without any neglect. The notion that environmental protection, social stability, and economic development are mutually exclusive must be broken down. Instead, a comprehensive comparison of these three objectives should be conducted to find ways and methods for achieving a win-win situation in economic development, environmental protection, and social stability. In implementing various directions of green economic development, China should combine its actual conditions, absorb the replicability of different approaches, adapt measures to local conditions, and explore a path of ecological civilization construction that fits China's national conditions. Hu Angang et al. (2014) believe that the characteristics of green development include: emphasizing systematicness, wholeness, and coordination; promoting green development through a green economy. Increasing the proportion

of green economy in social development, using green technology to improve living environments and conditions, and continuously raising the share of green economy in GDP. Replacing heavy industry with low-consumption, low-energy, and low-emission industries; global green development emphasizes collective efforts worldwide; the global climate is deteriorating due to human activities, making global governance and climate change response increasingly important and urgent. Yu Bao-hua et al. (2022) pointed out that green development presents different characteristics in each region, and different aspects need to be coordinated carefully in the development. The green development characteristics of the Yangtze River Economic Belt in China basically show high in the east and low in the west, with a low degree of coupling between the east and the west, which requires the formulation of relevant strategies to strengthen the green guarantee mechanism.

(3) Definition of green development concept

"Green development" refers to developing both the economy and ecological civilization. Green development is the inevitable path to achieving sustainable development, a necessary route to break through resource and environmental constraints, and to realize harmonious coexistence between humans and nature. Green development takes the harmonious coexistence of humans and nature as its fundamental concept, uses the reform of the ecological civilization system as its driving force, adopts the new development philosophy of innovation, coordination, greenness, openness, and sharing as its guidance, regards institutional and mechanism innovation as its guarantee, and focuses on building green production and consumption models. Ultimately, it aims to achieve intensive and efficient production space, livable and moderate living space, and clear and beautiful ecological space. The practice of the green development concept requires paying attention to handling a series of relationships, such as development and protection, overall and partial interests, and short-term and long-term considerations, to reduce carbon emissions and pollution. Human history tells us that only by following the path of "green" development and adhering to the "green" path can we achieve sustainable development. Since the 18th National Congress of the Communist Party of China, while promoting economic development, the Central Committee has also given more attention to the construction of ecological civilization, insisting on a civilized development path characterized by productive growth, prosperous living, and sound ecology. The president once stated, "In the new era, we must firmly establish a socialist ecological civilization perspective, promote the coordinated development of humans and nature, achieve harmonious development between humans and nature, and realize harmonious development between humans and nature."

### 2.2.2 Evaluation of green development level

In our country, research on the assessment of green development levels has achieved certain results. However, there are differences in the focus of constructing evaluation indicators. The research achievements from Beijing Normal University (Economics and Resource Management), Southwestern University of Finance and Economics, and the National Bureau of Statistics (National States of Statistics of China) China Economic Conditions Monitoring Center (China and China and National Research and China for China) are the most abundant, and they have published a report titled "China's Green Development Index Report." Many scholars have developed new perspectives and constructed different systems. Xiang Shujian et al. (2013) used green production, consumption, and ecological health to establish a new indicator system as the "China Green Development Index," focusing on the assessment and analysis of key factors in developing a green economy. Cai Shaohong et al. (2021) noted that the development trend of the Yangtze River Economic Belt has changed, with some differences in regional development, mainly manifested as: the level of industrial energy gradually increases along the Yangtze River, while the richness of factors decreases; there is a positive correlation between the levels of green development across regions, leading to spatial spillover effects, resulting in an "island-like, scattered distribution" pattern among regions, but this pattern is gradually

fading; economic development levels, industrial structure upgrading, and environmental regulations are the main driving forces for green development in the Yangtze River Economic Zone, forming a dual driving force. Han Jing et al. (2020) proposed that "green development" is an important approach for economic development and environmental improvement along the Yangtze River Economic Belt, and "green development" is an effective solution to this issue. Wu Chuanqing et al. (2018) found that at present, the economic development, policy support, and technological investment of the Yangtze River Economic Belt have a positive impact on its green development, while differences in regional development levels, population density, industrial development levels, and openness have negative effects. It is essential to balance "protection" with "development."

### 2.2.3 Green development efficiency

The efficiency of green development refers to the economic value added per unit of production factor input over a certain period. It is a comprehensive indicator for measuring resource utilization and environmental protection, encompassing three aspects: social and economic development, resource conservation, and environmental protection. Economic growth should be included in the evaluation system for green development efficiency, which also covers the three major areas of resource conservation and environmental protection. In relevant theoretical research, scholars have conducted extensive and in-depth studies on constructing the indicator system for green development efficiency, such as Song Huafeng et al. (2011), who used data envelopment analysis to construct an evaluation index system for green development efficiency based on economic output. Li Jun et al. (2015) incorporated environmental protection input indicators into the evaluation of green development efficiency, arguing that green development efficiency is a technical efficiency based on ecological and environmental protection, as well as a resource-conserving efficiency[26-30].

### 2.2.4 Measurement of green development efficiency

Research on efficiency primarily comes from foreign scholars. Long ago, foreign scholars began using resource and environmental factors to measure efficiency. Pittman (1983) modified and improved the super-logarithmic productivity index proposed by Caves (1982), introducing environmental factors into the measurement of efficiency for the first time. This perspective has been widely accepted and later developed into two distinctly different measurement methods in subsequent studies. Scholars like coelli (2005) often view environmental pollution as an input, but such a measurement method is inconsistent with the actual production process; it is more reflected in the output stage. Therefore, Kumar (2006) et al. argue that environmental pollution should be seen as a "bad" output. Huang Xiaoyong et al. (2022) concluded that the green development trend in the Yangtze River Economic Belt is gradually increasing, but there are still significant differences within the region, with many cities having room for improvement. They summarized the spatial characteristics of the Yangtze River Economic Belt, noting that economic structure, technological investment, external economy, city size, and green space area have a significant positive impact on the green development efficiency of the Yangtze River Economic Belt. Based on this, efforts should be made to jointly stimulate the potential for green development, vigorously promote green symbiotic development, and focus on creating a new pattern of green development. Cui Dangchen et al. (2022) used the SBM model to evaluate the green development efficiency of the Yellow River Basin, and their results show that there are significant differences among the upper, middle, and lower reaches of the basin. Overall, there is an increasing trend across these regions. The spatial distribution of green development efficiency and economic agglomeration exhibits a "high-high agglomeration" and "low-low agglomeration" pattern, with high-high agglomeration being predominant in the upper reaches, while low-low agglomeration dominates in the middle and upper reaches. The effect of urban

economic agglomeration on green development efficiency follows a "U" -shaped curve, with most urban economic agglomerations not exceeding the turning point. The spatial agglomeration effect of economic activities among the three main regions—upper, middle, and lower reaches—significantly differentiates their green development efficiencies.

In terms of research methods, existing literature mainly falls into two categories: one uses the DEA method to measure green development efficiency; the other employs the Malmquist index method to evaluate green development efficiency. The traditional DEA method involves collecting and organizing input and output data over a certain period, using mathematical models for calculations, which may lead to results that do not align with actual conditions. Therefore, the traditional DEA method has shortcomings in measuring green development efficiency, which to some extent hinders its practical application. The Malmquist index method, on the other hand, involves calculating data for all production factors over a certain period, analyzing their impacts, and quantifying the contributions of each factor to green development efficiency using mathematical methods. In evaluating green development efficiency, the Malmquist index method has significant advantages over traditional DEA methods: first, the Malmquist index can measure regional green development levels and objectively reflect economic growth status; second, it can also reflect changes in technological progress and efficiency across different regions. Based on the evaluation results, trends in green development efficiency can be identified, and policy recommendations can be proposed for reference. Taking the Yangtze River Economic Belt as an example, although many scholars have used the DEA model and Malmquist index method, from these research findings, it is evident that the application scope of the DEA method is relatively limited. It mainly focuses on evaluating the green development efficiency of individual cities or regions, and most of the research results are based on established input-output relationships, primarily using traditional DEA methods to analyze green development efficiency. This has led many scholars to believe that traditional DEA methods struggle with issues of missing or insufficient data information and cannot effectively assess the specific efficiency of green development. Therefore, when using the DEA method to evaluate the green development efficiency of the Yangtze River Economic Belt, both traditional DEA methods and the Malmquist index method were selected for comparative analysis.

## 3. Analysis of green development efficiency in the Yangtze River Economic Belt

This paper primarily employs the DEA-Malmquist index method for analysis, selecting input indicators from three aspects: labor, capital, and energy. Using the Entropy weighting method, an environmental pollution index is constructed based on the emissions of waste, water, and air. This index is then multiplied by the actual regional GDP to form a relative green GDP. The relative GDP serves as the output indicator. By applying the DEA model, this study evaluates the green development efficiency of the 11 provinces along the Yangtze River Economic Belt from 2011 to 2021, analyzing the green development efficiency over the past decade. The analysis is conducted by region (upper, middle, and lower reaches), examining differences and characteristics between regions, followed by a detailed analysis of the green development efficiency of the specific 11 provinces. The study covers the following 11 provinces along the Yangtze River Economic Belt: Shanghai, Jiangsu, Zhejiang, Guizhou, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, and Yunnan.

### 3.1 DEA-Malmquist index method

The green development efficiency levels of cities or regions in the Yangtze River Economic Belt measured by the traditional DEA method do not fully reflect their role in the overall regional economic development. In contrast, the Malmquist index method can measure dynamic conditions. The Malmquist index can be broken down into several specific indicators: technical efficiency (Crste)

and technological progress (Tech). Technical efficiency can be further divided into pure technical efficiency (Vrste) and scale efficiency (Scale); Total Factor Productivity (Tfp) = Technical Efficiency (Crste) * Technological Progress (Tech); Technical Efficiency (Crste) = Pure Technical Efficiency (Vrste) * Scale Efficiency (Scale) , as shown in Table 1.

Table 1 Terms and their meanings

| Noun | Meaning |
|---|---|
| Total factor productivity (Tfp) | A Tfp>1 means that productivity is increasing from period t to period t+1, and vice versa |
| Technical efficiency (Crste) | Crste>1 means that the technical efficiency is improved, and vice versa, it means that the technical efficiency is declining |
| Technological progress (Tech) | A Tech>1 indicates technological progress, while a Tech<1 indicates technological decline |
| Pure technical efficiency (Vrste) | It reflects the impact of comprehensive management and technology improvement on productivity. The value>1 means that technology promotes productivity, and the opposite means that it inhibits productivity |
| Scale efficiency (Scale) | It reflects the impact of production scale expansion on production efficiency. The value>1 means that scale plays a promoting role in productivity, while the value <1 means that scale plays a restraining role |

This study covers the period from 2011 to 2021. Due to the influence of external environmental factors and differences in internal indicators on the results of DEA methods, time series data over a decade were selected for this research period. This decade provides a temporal dimension for the application of the Malmquist index method; provinces and regions with higher levels of economic development should make greater contributions to the development of the Yangtze River Economic Belt. This paper evaluates the green development efficiency of cities or regions in the Yangtze River Economic Belt using the Malmquist index method, primarily to demonstrate the advantages of the Malmquist index method in measuring the green development efficiency of provinces in the Yangtze River Economic Belt, providing a reference for promoting high-quality green development in the region. In summary, this paper builds upon traditional DEA methods and the Malmquist index method, incorporating resource utilization efficiency and environmental protection input efficiency into the DEA model. The improved traditional DEA method is used to measure the green development efficiency of 11 cities or regions in the Yangtze River Economic Belt. The article also employs the entropy weighting method to adjust the weights of the data.

### 3.2 Data sources

Based on this, taking into account the actual situation of the Yangtze River Economic Belt, a new, representative, sustainable, and renewable energy utilization method has been proposed and analyzed. On this basis, three main production factors—labor, capital, and energy—were selected from the perspectives of labor, capital, and energy. Considering environmental pollution, three indicators were chosen: industrial wastewater, industrial sulfur dioxide emissions, and industrial dust emissions. Using the entropy weighting method, an environmental pollution index was constructed for these indicators. The product of the regional gross domestic product and the pollution index was used as the relative green GDP, which replaced the actual GDP as the output factor to measure efficiency. The calculation resulted in the relative green GDP shown in Table 2.

Table 2 Calculation results of relative green_GDP of Yangtze River Economic Belt in 2011 and 2021

| Area | 2011 | 2021 |
|---|---|---|
| Chongqing | 13.5 | 82.41 |
| Sichuan | 11.91 | 86.47 |
| Yunnan | 12.19 | 88.28 |
| Guizhou | 12.70 | 94.87 |
| Jiangxi | 10.73 | 84.41 |
| Hubei | 10.23 | 79.07 |
| Hunan | 10.89 | 85.16 |
| Zhejiang | 8.07 | 83.29 |
| Shanghai | 10.61 | 86.21 |
| Jiangsu | 6.53 | 86.71 |
| Anhui | 9.91 | 84.63 |
| mean | 10.66 | 85.58 |

Considering the reliability of data, this paper selects 2011-2021 as the research period, and selects 11 provinces in the Yangtze River Economic Belt composed of Shanghai and Chongqing municipalities for empirical analysis. When analyzing the development efficiency between regions, this paper defines as follows:

Upstream provinces: Guizhou, Yunnan, Sichuan and Chongqing

Midstream provinces: Jiangxi, Anhui, Hunan and Hubei

Downstream provinces: Shanghai, Jiangsu and Zhejiang

The data selected in this paper are all from China Statistical Yearbook 2012-2021.

### 3.3 Analysis of measurement results

#### 3.3.1 Overall overview of the efficiency of green development in the Yangtze River Economic Belt

(1) As shown in Table 3 and Table 4, the provinces along the Yangtze River Economic Belt have achieved good DEA results in green development efficiency, with pure technical efficiency being higher than scale efficiency. The calculation results show that among the 11 provinces of the Yangtze River Economic Belt, Shanghai, Jiangsu, Hunan, Sichuan, Yunnan, and the remaining 7 provinces have a green development efficiency of 1, indicating that existing scale and technological progress have had a positive impact, promoting economic development and green growth. By comparing the two tables and their respective decomposition items, it can be seen that the contribution of scale efficiency is higher than that of pure technical efficiency, suggesting that the current scale investment in the Yangtze River Economic Belt has a positive driving effect on the green development of the 11 provinces. This indicates that over the past decade, the Yangtze River Economic Belt has increased its efforts in scientific innovation, achieving new performance in promoting green development. Comparing Table 2 and Table 3, most provinces saw an improvement in their green development efficiency in 2021, showing a significant increase in development efficiency over the past decade; the provinces that improved include Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, and Hunan, which are downstream and midstream cities, indicating that the improvement in green development efficiency in these mid-to-downstream provinces is better than that in upstream provinces. Of course, there were also provinces that declined in efficiency over the past decade, such as Hunan, where the green development efficiency dropped from 0.707 in 2011 to 0.696; and Hubei, where it fell from 0.733 in 2011 to 0.25. The decline in green efficiency in these provinces is due to severe pollution caused by

heavy industry, which hinders their green development. Economic structural factors are typically studied from two levels: industrial structure and the level of economic openness. The tertiary sector consumes fewer resources and emits less pollution, which can promote green development efficiency. We find that an increase in the share of the tertiary sector can boost green economic growth. Overall, the three dimensions of industrial structure have positive impacts on green economic development, with the improvement of industrial structure softening having the greatest effect.

Table 3 Results of Malmquist index for green development in the Yangtze River Economic Belt in 2021

| Area | Technical efficiency (Crste) | Technical progress (Tech) | Pure technical efficiency (Vrste) | Scale efficiency (Scale) | Total factor productivity (Tfpch) |
|---|---|---|---|---|---|
| Chongqing | 1.00 | 0.99 | 1.00 | 1.00 | 0.99 |
| Sichuan | 1.29 | 0.73 | 1.27 | 1.01 | 0.95 |
| Yunnan | 1.94 | 0.58 | 1.81 | 1.07 | 1.13 |
| Guizhou | 2.27 | 0.58 | 2.06 | 1.09 | 1.32 |
| Jiangxi | 1.46 | 0.67 | 1.43 | 1.02 | 0.98 |
| Hubei | 0.25 | 0.35 | 0.30 | 0.83 | 0.99 |
| Hunan | 0.69 | 0.60 | 1.62 | 1.04 | 1.02 |
| Zhejiang | 1.41 | 0.63 | 1.38 | 1.01 | 0.89 |
| Shanghai | 1.80 | 0.63 | 1.64 | 1.09 | 1.15 |
| Jiangsu | 1.11 | 0.79 | 1.13 | 0.99 | 0.89 |
| Anhui | 1.60 | 0.56 | 1.57 | 1.02 | 0.90 |
| mean | 1.35 | 1.24 | 1.38 | 1.02 | 0.93 |

Table 4 Results of Malmquist index of green development in the Yangtze River Economic Belt in 2011

| Area | Technical efficiency (Crste) | Technical progress (Tech) | Pure technical efficiency (Vrste) | Scale efficiency (Scale) | Total factor productivity (Tfpch) |
|---|---|---|---|---|---|
| Chongqing | 0.703 | 1.021 | 0.969 | 0.726 | 0.718 |
| Sichuan | 0.756 | 1.02 | 0.979 | 0.772 | 0.771 |
| Yunnan | 0.824 | 1.02 | 0.984 | 0.837 | 0.84 |
| Guizhou | 0.744 | 1.05 | 0.973 | 0.765 | 0.782 |
| Jiangxi | 0.68 | 1.024 | 0.972 | 0.70 | 0.696 |
| Hubei | 0.733 | 1.02 | 0.979 | 0.748 | 0.747 |
| Hunan | 0.707 | 1.02 | 0.974 | 0.725 | 0.721 |
| Zhejiang | 0.677 | 1.02 | 0.978 | 0.693 | 0.691 |
| Shanghai | 0.763 | 1.02 | 0.979 | 0.78 | 0.779 |
| Jiangsu | 0.708 | 1.02 | 0.986 | 0.718 | 0.722 |
| Anhui | 0.717 | 1.02 | 0.978 | 0.732 | 0.731 |
| mean | 0.728 | 1.023 | 0.977 | 0.745 | 0.745 |

(2) As shown in Table 5, the average technical efficiency for the years 2011,2015, and 2019 was greater than 1; the average pure technical efficiency for 2019 was also greater than 1; and the average scale efficiency for both 2011 and 2015 was greater than 1. This indicates that development has been in a continuous growth phase for most of the years. From the table below, it is clear that technological progress has a direct impact on changes in total factor productivity. In other words, technological

progress has made the greatest contribution to the improvement of green development efficiency, while green development still requires further technological refinement. In terms of range, there are also certain differences in development efficiency between upstream, midstream, and downstream sectors. Currently, two types of provinces have shown significant improvements in green development efficiency: one type consists of economically more developed provinces, such as Shanghai and Jiangsu; the other type includes economically less developed cities, such as Hunan and Guizhou. The green development efficiency of the Yangtze River Economic Belt has been steadily increasing year by year, and the Malmquist index decomposition items for most provinces are all greater than 1, indicating that both scale performance and technical efficiency are positively driving its green development.

Table 5 Annual average Malmquist index of green development in the Yangtze River Economic Belt from 2011 to 2021 and its decomposition

| A particular year | Technical efficiency (Crste) | Technical progress (Tech) | Pure technical efficiency (Vrste) | Scale efficiency (Scale) | Total factor productivity (Tfpch) |
|---|---|---|---|---|---|
| 2011 | 0.75 | 1.03 | 0.98 | 0.78 | 0.77 |
| 2012 | 1.38 | 1.14 | 1.02 | 1.35 | 1.57 |
| 2013 | 1.02 | 1.00 | 1.00 | 1.02 | 1.02 |
| 2014 | 0.99 | 0.98 | 1.00 | 0.99 | 0.97 |
| 2015 | 0.83 | 1.39 | 0.97 | 0.86 | 1.15 |
| 2016 | 0.90 | 0.99 | 0.99 | 0.91 | 0.90 |
| 2017 | 1.38 | 0.54 | 1.03 | 1.34 | 0.74 |
| 2018 | 1.03 | 1.02 | 1.00 | 1.03 | 1.05 |
| 2019 | 0.45 | 1.08 | 0.42 | 1.04 | 1.03 |
| 2020 | 1.42 | 0.71 | 1.37 | 1.03 | 0.99 |
| 2021 | 1.01 | 1.17 | 0.97 | 1.03 | 1.01 |

### 3.3.2 Distribution of green development efficiency in the upper, middle and lower reaches

(1) By comparing Tables 6 and 7, it can be seen that scale efficiency better reflects overall green efficiency than pure technical efficiency. In terms of the sub-items of comprehensive green development efficiency, scale efficiency still makes a significant contribution to green development. Moreover, the scale efficiency of downstream provinces is higher than that of midstream provinces and upstream regions, for example, in 2021, the scale efficiencies of upstream, midstream, and downstream regions were 1.04,0.97, and 1.03, respectively, while the pure technical efficiencies were 1.39,1.33, and 1.43, respectively. From the perspective of upstream, midstream, and downstream regions, the trend in scale efficiency is first rising, then falling, and then rising again. The scale efficiency of provinces in the midstream and downstream regions of the Yangtze River Economic Belt is the highest, followed by midstream provinces, then midstream and upstream regions, and finally midstream and upstream regions. The gap in scale efficiency among these three regions first increases and then gradually decreases. In these three regions, the trend in pure technical efficiency is first rising, then falling, and then rising again, with an increase from 2011 to 2014, a decrease from 2014 to 2016, and another increase from 2016 to 2021. It is evident that the scale efficiency in the downstream region is the highest, followed by midstream and upstream regions, but the trend for pure technical efficiency is opposite.

The industrial production efficiency in the upper, middle, and lower reaches of the Yangtze River

Economic Belt generally shows a trend of "first decreasing then increasing." Specifically, this can be divided into three periods: First, from 2011 to 2013, provinces along the upper, middle, and lower reaches of the Yangtze River generally exhibited an upward trend. Among them, the scale efficiency of upstream and midstream provinces increased significantly, with scale efficiencies rising by 31.16% and 43.05% respectively compared to 2011. In contrast, the scale efficiency of downstream provinces improved more slowly, increasing by only 25%. Second, from 2013 to 2016, the scale efficiency of the upper, middle, and lower reaches of the Yangtze River Economic Belt all showed a gradual decline, failing to reach DEA effectiveness. Finally, from 2016 to 2021, the scale efficiency of the Yangtze River Economic Belt experienced some fluctuations, with economic development being affected by the global COVID-19 pandemic. By 2021, the scale efficiencies of the upper, middle, and lower reaches of the Yangtze River provinces were 1.44,1.36, and 1.33, respectively, representing year-on-year increases of 41.17%,32.03%, and 36.68% compared to 2013 , as shown in Figure 1.

Table 6 Pure technical efficiency of provinces in the upper, middle and lower reaches of the Yangtze River Economic Belt from 2011 to 2021

| | Ensemble | Lower reaches | Middle reaches | Head waters |
|---|---|---|---|---|
| 2011 | 0.98 | 0.98 | 0.97 | 0.96 |
| 2012 | 1.02 | 1.03 | 1.02 | 1.00 |
| 2013 | 1.00 | 0.99 | 1.00 | 0.99 |
| 2014 | 1.00 | 0.99 | 0.99 | 1.00 |
| 2015 | 0.97 | 0.97 | 0.96 | 0.96 |
| 2016 | 0.99 | 0.97 | 0.98 | 0.98 |
| 2017 | 1.03 | 1.00 | 1.01 | 1.02 |
| 2018 | 1.00 | 1.00 | 1.00 | 1.00 |
| 2019 | 0.42 | 0.24 | 0.47 | 0.46 |
| 2020 | 1.37 | 1.38 | 1.23 | 1.53 |
| 2021 | 1.38 | 1.43 | 1.33 | 1.39 |

Table 7 Pure scale efficiency of provinces in the upper, middle and lower reaches of the Yangtze River Economic Belt from 2011 to 2021

| | Ensemble | Lower reaches | Middle reaches | Head waters |
|---|---|---|---|---|
| 2011 | 0.76 | 0.72 | 0.72 | 0.77 |
| 2012 | 1.35 | 1.79 | 1.46 | 1.15 |
| 2013 | 1.02 | 0.90 | 1.03 | 1.01 |
| 2014 | 0.99 | 0.95 | 0.98 | 1.00 |
| 2015 | 0.86 | 0.94 | 0.84 | 0.84 |
| 2016 | 0.91 | 0.82 | 0.90 | 0.93 |
| 2017 | 1.34 | 1.35 | 1.25 | 1.12 |
| 2018 | 1.03 | 1.06 | 1.00 | 1.07 |
| 2019 | 1.04 | 1.11 | 1.10 | 1.14 |
| 2020 | 1.03 | 1.03 | 0.97 | 1.04 |
| 2021 | 1.37 | 1.44 | 1.36 | 1.33 |

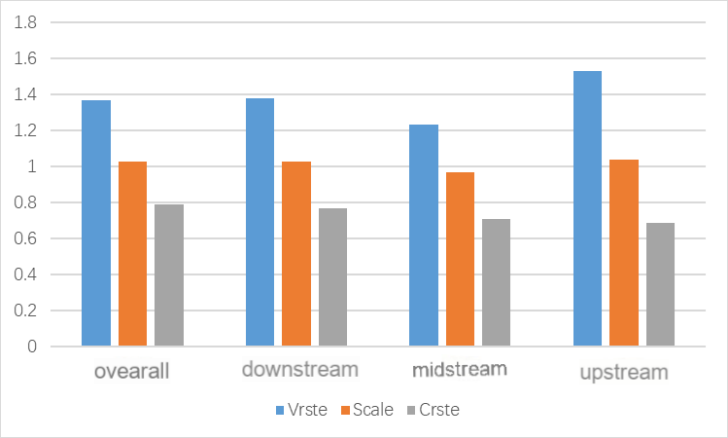


Figure 1 Comparison of green development efficiency by provinces in the upper, middle and lower reaches of the Yangtze River Economic Belt in 2021

(2) According to the above results and Table 8, it can be seen that the trend of total factor productivity over this decade has been to rise, then fall, and rise again. In 2011, the upstream region had higher total factor productivity compared to the midstream and downstream regions, with specific values of 0.77,0.73, and 0.72, respectively, all indicating low efficiency. After 2011, differences in total factor productivity began to emerge among upstream, midstream, and downstream regions. Based on the absolute differences, this change can be divided into three stages. Firstly, from 2011 to 2013, the gap in TFP between upstream, midstream, and downstream regions gradually widened, especially with a slight increase in TFP in the downstream region. However, there was an improvement in TFP in both upstream and midstream provinces, which further widened the gap in TFP. Due to the annual improvement in technical efficiency, total factor productivity and scale efficiency also increased, indicating that technological progress is positively correlated with the input of scale returns, thereby promoting the improvement of total factor productivity and driving the development of green economy. Secondly, during 2013 to 2016, the gap in TFP across regions remained largely unchanged, primarily characterized by significant increases in TFP in the upstream, midstream, and downstream provinces. However, it should be noted that the contribution rate of technical efficiency decreased year by year, suggesting a weakening of China's ability to utilize new technologies during this period. Finally, from 2016 to 2021, the gap in TFP between the upstream, midstream, and downstream regions continuously narrowed. The reason for this is that while total factor productivity in upstream provinces continued to improve, it declined in midstream and downstream cities. Under the combined influence of these two factors, the gap between them became increasingly smaller. In 2021, the total factor productivity in the downstream, midstream, and upstream regions was 1.06,0.99, and 1.01, respectively, with upstream provinces surpassing midstream provinces' total factor productivity for the first time under green development. However, overall, the Tfp levels of provinces in the Yangtze River Economic Belt are highest in the midstream provinces and higher than those of the midstream provinces, generally close to the Tfp levels of the midstream provinces. The efficiency of green development is mainly reflected in two aspects: "green" and "development," thus there is an inherent connection between "green" and "development." The improvement in scale efficiency indicates that current scale inputs are driving the green economic development. Overall, there is a positive correlation among scale efficiency, pure technical efficiency, and total factor productivity, meaning that the increase in scale returns and technological efficiency boosts the overall green development efficiency of the Yangtze River Economic Belt , as shown in Figure 2.

Table 8 Total factor productivity of the upper, middle and lower reaches of the Yangtze River Economic Belt from 2011 to 2021

| Tfp | Ensemble | Lower reaches | Middle reaches | Head waters |
|---|---|---|---|---|
| 2011 | 0.74 | 0.73 | 0.72 | 0.77 |
| 2012 | 0.82 | 0.79 | 0.82 | 0.85 |
| 2013 | 0.99 | 0.90 | 1.04 | 1.02 |
| 2014 | 0.97 | 0.94 | 0.97 | 0.99 |
| 2015 | 0.99 | 0.98 | 0.99 | 1.02 |
| 2016 | 0.91 | 0.90 | 0.90 | 0.93 |
| 2017 | 0.97 | 0.97 | 0.95 | 0.99 |
| 2018 | 1.05 | 1.09 | 1.03 | 1.05 |
| 2019 | 1.03 | 1.10 | 0.99 | 1.01 |
| 2020 | 0.93 | 0.98 | 0.73 | 1.10 |
| 2021 | 1.02 | 1.06 | 0.99 | 1.01 |

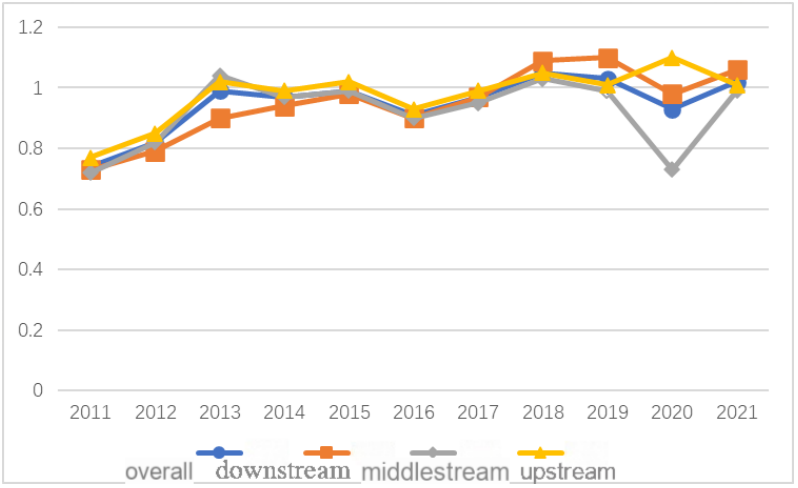


Figure 2 Comparison of total factor productivity in the upper, middle and lower reaches of the Yangtze River Economic Belt from 2011 to 2021

### 3.3.3 Distribution of green development efficiency by province

(1) According to the measurement results in Tables 9, 10, 11, the Malmquist efficiency index for 11 provinces and cities from 2011 to 2021 is generally greater than or close to 1, with an average value of 1.14. In terms of regions, Jiangsu has seen the largest growth in green development, while Yunnan has experienced the smallest growth. From the decomposition index, technical efficiency has a significant impact on industrial green development TFP. As shown in the tables, Guizhou, Zhejiang, Jiangsu, and Yunnan all have relatively high technical efficiencies, whereas Gansu's technical efficiency and technological progress are relatively low and need further improvement. The pace of technological progress is accelerating across the country, but the rate of pure technical efficiency improvement is slower. The economic development levels in Yunnan, Jiangxi, Hunan, and Hubei are relatively low, indicating that their economic development needs to be improved.

Table 9 Annual average development efficiency Malmquist index and its decomposition of 11 provinces in the Yangtze River Economic Belt from 2011 to 2021

| Area | Technical efficiency (Crste) | Technical progress (Tech) | Pure technical efficiency (Vrste) | Scale efficiency (Scale) | Total factor productivity (Tfpch) |
|---|---|---|---|---|---|
| Chongqing | 1.02 | 1.84 | 1.00 | 1.02 | 1.87 |
| Sichuan | 0.95 | 1.68 | 0.95 | 1.01 | 1.59 |
| Yunnan | 1.04 | 1.43 | 1.01 | 1.01 | 1.48 |
| Guizhou | 1.06 | 1.72 | 1.04 | 1.01 | 1.82 |
| Jiangxi | 1.01 | 1.55 | 0.98 | 1.04 | 1.56 |
| Hubei | 0.98 | 1.72 | 0.93 | 1.03 | 1.68 |
| Hunan | 1.02 | 1.57 | 0.99 | 1.03 | 1.60 |
| Zhejiang | 1.04 | 1.20 | 0.96 | 1.08 | 1.24 |
| Shanghai | 1.03 | 1.95 | 0.99 | 1.03 | 2.00 |
| Jiangsu | 1.04 | 1.62 | 0.94 | 1.11 | 1.68 |
| Anhui | 1.02 | 1.85 | 0.98 | 1.04 | 1.88 |

Table 10 Pure technical efficiency of provinces in the Yangtze River Economic Belt from 2011 to 2021

| | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| Chongqing | 0.96 | 1.01 | 1.00 | 1.00 | 0.96 |
| Sichuan | 0.97 | 1.01 | 1.00 | 1.00 | 0.96 |
| Yunnan | 0.98 | 1.00 | 1.00 | 1.00 | 0.96 |
| Guizhou | 0.97 | 1.01 | 0.99 | 1.00 | 0.96 |
| Jiangxi | 0.97 | 1.04 | 1.00 | 1.00 | 0.97 |
| Hubei | 0.97 | 1.02 | 1.01 | 0.99 | 0.95 |
| Hunan | 0.97 | 1.02 | 1.00 | 1.00 | 0.95 |
| Zhejiang | 0.98 | 1.04 | 0.99 | 0.99 | 0.97 |
| Shanghai | 0.98 | 1.03 | 0.99 | 1.00 | 0.97 |
| Jiangsu | 0.99 | 1.03 | 0.99 | 0.99 | 0.98 |
| Anhui | 0.97 | 1.03 | 1.00 | 1.00 | 0.97 |

Table 11 Continued Pure technical efficiency of provinces in the Yangtze River Economic Belt from 2011 to 2021

| | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|
| Chongqing | 0.99 | 1.05 | 1.00 | 1.00 | 1.00 | 1.00 |
| Sichuan | 0.98 | 1.00 | 1.01 | 0.25 | 1.27 | 1.25 |
| Yunnan | 0.99 | 1.04 | 0.99 | 0.29 | 1.81 | 1.33 |
| Guizhou | 0.99 | 1.01 | 1.01 | 0.33 | 2.06 | 1.35 |
| Jiangxi | 0.97 | 1.02 | 0.99 | 0.35 | 1.43 | 1.39 |
| Hubei | 0.99 | 1.02 | 0.99 | 1.04 | 0.30 | 1.06 |
| Hunan | 1.00 | 1.03 | 1.01 | 0.24 | 1.62 | 1.06 |
| Zhejiang | 0.98 | 1.02 | 1.00 | 0.25 | 1.38 | 1.29 |
| Shanghai | 0.97 | 1.01 | 1.01 | 0.23 | 1.64 | 1.68 |
| Jiangsu | 0.97 | 0.99 | 1.01 | 0.25 | 1.13 | 1.19 |
| Anhui | 0.98 | 1.00 | 1.02 | 0.27 | 1.57 | 1.09 |

(2) By comparing Table 12 and Table 13, we can see that in the provinces and cities of the Yangtze River Economic Belt, overall, the scale efficiency of green development is higher than pure technical efficiency. Overall, scale efficiency is higher than pure technical efficiency, indicating that the green

development efficiency of the 11 provinces in the Yangtze River Economic Belt is largely driven by scale efficiency, not just pure technical efficiency. Taking Jiangsu Province as an example, Sichuan Province, Guizhou Province, and Shanghai Province represent the highest scale efficiency, which is 1.01,1.01, and 1.01 respectively, indicating a relatively low level. Therefore, these provinces have not achieved the effectiveness of DEA. From a longitudinal perspective, there are differences in the trends of scale efficiency and pure technical efficiency across provinces and cities. In terms of scale efficiency changes, Guizhou Province increased by 43.42% compared to 2021, compared to 2011; Sichuan Province increased by 31.16% compared to 2011; Hunan Province increased by 44.44% compared to Yunnan Province; and Yunnan Province increased by 28.91% compared to 2021. Compared to 2011, Hubei Province's green development efficiency has declined significantly, decreasing by 14.69% in 2020 compared to 2011, while Anhui Province decreased by 3.4% compared to 2011, leading to an overall decline in green development efficiency. In terms of pure technical efficiency changes, a few provinces have shown a downward trend, such as Hubei Province, which decreased by 14.03% compared to the same period last year, reaching 0. 3: The pure technical efficiency of green development in Yunnan Province, Jiangxi Province, Hunan Province, and Guizhou Province increased by 5.57%,10.87%, and 12.47%, respectively, to 1.81,1.43, and 1.62, reaching 2.06. From the above analysis, it is clear that scale efficiency has the highest contribution to the improvement of green development efficiency. This indicates that for the Yangtze River Economic Belt to achieve green and sustainable development, current scale investment plays a positive role. Future development will require stable investment on this foundation, and further efforts are needed in technological investment to make green development more stable and sustainable.

Table 12 Scale efficiency of provinces in the Yangtze River Economic Belt from 2011 to 2021

| | 2011 | 2012 | 2013 | 2014 | 2015 |
|---|---|---|---|---|---|
| Chongqing | 0.72 | 1.17 | 1.06 | 1.01 | 0.82 |
| Sichuan | 0.77 | 1.18 | 1.01 | 0.98 | 0.86 |
| Yunnan | 0.83 | 1.10 | 0.97 | 1.03 | 0.83 |
| Guizhou | 0.76 | 1.15 | 1.01 | 0.99 | 0.86 |
| Jiangxi | 0.70 | 1.56 | 1.02 | 1.01 | 0.88 |
| Hubei | 0.74 | 1.38 | 1.07 | 0.96 | 0.81 |
| Hunan | 0.72 | 1.36 | 1.01 | 0.98 | 0.80 |
| Zhejiang | 0.69 | 1.88 | 0.93 | 0.95 | 0.89 |
| Shanghai | 0.78 | 1.47 | 0.95 | 0.98 | 0.90 |
| Jiangsu | 0.71 | 2.04 | 0.84 | 0.93 | 1.04 |
| Anhui | 0.73 | 1.55 | 1.03 | 0.99 | 0.88 |

Table 13 Scale efficiency of provinces in the Yangtze River Economic Belt from 2011 to 2021

| | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
|---|---|---|---|---|---|---|
| Chongqing | 0.94 | 0.78 | 1.21 | 1.45 | 1.00 | 1.13 |
| Sichuan | 0.90 | 1.12 | 1.08 | 1.15 | 1.01 | 1.10 |
| Yunnan | 0.94 | 1.40 | 0.97 | 0.96 | 1.07 | 1.09 |
| Guizhou | 0.97 | 1.19 | 1.02 | 1.01 | 1.09 | 1.25 |
| Jiangxi | 0.83 | 1.26 | 0.95 | 1.09 | 1.01 | 1.08 |
| Hubei | 0.94 | 1.32 | 0.92 | 1.30 | 0.83 | 1.03 |
| Hunan | 0.99 | 1.34 | 1.04 | 0.95 | 1.04 | 1.11 |
| Zhejiang | 0.84 | 1.52 | 0.98 | 1.09 | 1.01 | 1.09 |
| Shanghai | 0.86 | 1.17 | 1.06 | 0.99 | 1.09 | 1.21 |
| Jiangsu | 0.78 | 1.37 | 1.14 | 1.25 | 0.99 | 1.33 |
| Anhui | 0.87 | 1.11 | 1.11 | 1.06 | 1.01 | 1.13 |

## 4. Policy implications of green development in the Yangtze River Economic Belt

(1) Environmental governance and green development in the Yangtze River Economic Belt are promoted in a coordinated manner

First, establish a collaborative mechanism at the organizational decision-making level. The Yangtze River Economic Belt should transform government functions, striving to increase the weight of environmental protection and ecological governance in performance evaluations, and establish a reasonable regional green development reward and penalty system. It should also strengthen environmental supervision over enterprises. Meanwhile, the middle and upper reaches need to further improve tax incentives and fiscal subsidies for small and medium-sized enterprises, enhancing their technological research and development capabilities to achieve sustainable development.

Second, the dynamic mechanism of corporate value collaboration. This includes corporate environmental regulations, environmental management systems, and environmental organizations. The governance philosophy and environmental protection concepts of the 11 provinces along the Yangtze River are consistent with their economic development perspectives. This ensures that the environmental carrying capacity of local areas is balanced with the development of other industries, promoting harmony between humans and nature, as well as between environmental regulations and economic development levels. Establishing performance evaluation systems, environmental assessment systems, and regulatory frameworks that align with the development model within the basin will ensure consistency between government and public environmental philosophies.

Third, ensure the effective provision of resources needed for ecological protection. Establish corresponding mechanisms to promote environmental protection projects and mobilize the enthusiasm of social capital for investment in these projects. This will enable the entire society to contribute to the development of the Yangtze River Economic Belt and enhance the capabilities and service levels of market entities in participating in the investment management of environmental protection projects. By adopting bidding processes, social capital can be directed towards ecological protection projects, allowing the government to provide more comprehensive services in this area.

Fourth, coordinate the relationship between the government, capital and the public. Environmental governance is a systemic action where one move can affect the whole. The government must earnestly implement the interests of social capital and the public in environmental governance, improve governance mechanisms across regions, and develop systems that fit local development needs for areas lacking such systems, adapting measures to local conditions.

(2) Increase investment in science and technology education

Constructing a rational mechanism for "industry-academia-research," "collaboration," and "coordination" focuses on the transformation of scientific and technological achievements, optimizing resource allocation for urban green development, gradually shifting it to mid-to-upstream regions. In downstream areas, it is necessary to change the green development model that expands city size and economic investment, enhancing its guiding capabilities. The most direct effect of education is to improve corporate technical levels, strengthen environmental awareness, reinforce the concept of scientific development, and also impact environmental performance to some extent. The proportion of fiscal expenditure on education in total fiscal expenditure can comprehensively reflect a region's emphasis on education, with a positive influence. In the development of the Yangtze River Economic Belt, it is essential to optimize the investment-output structure. Economic development, government support, and technological investment will all have a positive impact on the green development efficiency of the Yangtze River Economic Belt. However, we also need to actively transform the extensive economic development model into a more intensive one. Currently, the green development efficiency of the Yangtze River Economic Belt is largely driven by economies of scale, while pure technological benefits play a minor role. Therefore, in the future, there needs to be

increased cultivation and support for enterprises, using technology as a starting point to increase technological content, reduce energy consumption and pollution, improve governance capabilities, and achieve overall improvements in green development efficiency at both the technical and scale levels.

(3) Actively opening wider to the outside world

In terms of economic openness, we need to further increase the intensity of opening up and optimize the industrial structure.

(4) Give equal importance to "protection" and "development"

The development of the Yangtze River Economic Belt must proceed on the basis of both "development" and "protection." Currently, several provinces have achieved the effectiveness of DEA, but the development of the Yangtze River Economic Belt is not stable, with some regions even experiencing decline. The green development of the Yangtze River Economic Belt remains a long and arduous task. For a region to achieve sustainable development, it must start from aspects such as resource endowments and development goals, building a long-term mechanism that can promote economic growth while also protecting the environment. In the future, the development of the Yangtze River Economic Belt must organically combine economic development with environmental protection, further strengthening requirements for green development. The development of the Yangtze River Economic Belt must continuously advance "green" construction. At present, industrial development and opening up to the outside world in the Yangtze River Economic Belt still have negative impacts on its green development, mainly due to the generation of waste and the transfer of highly polluting outdated industries. Therefore, in the green development of the Yangtze River Economic Belt, high-polluting industries should be gradually phased out, and more green industries should be cultivated, vigorously developing low-carbon and circular economies; strengthening monitoring and treatment of "three wastes," delineating "ecological red lines," strictly controlling "exceeding limits," "non-compliance," and "non-conformity"; accepting industrial transfers, paying attention to both quantity and quality, considering both the long term and the short term; reinforcing the construction of urban sewage pipelines, increasing green space areas, innovating waste management technologies, enhancing the popularization and education of residents' green living concepts, and comprehensively improving the level of green city construction. We will always implement the new development philosophy and new development ideas, and under the guidance of the 20th National Congress, create a better prospect for the green mountains and clear waters of our motherland.

## 5. Conclusion

(1) Currently, two types of provinces have shown significant improvements in green development efficiency: one is economically more developed provinces, such as Shanghai and Jiangsu; the other is economically less developed provinces, such as Hunan and Guizhou. The overall trend of green development efficiency in the Yangtze River Economic Belt is upward, with most provinces achieving DEA results. The green development benefits of the Yangtze River Economic Belt have higher economic returns compared to pure technical benefits.

(2) From a regional perspective: There are still certain differences in the efficiency of green development between the upper, middle, and lower reaches of the Yangtze River Economic Belt. The conclusion that the development efficiency of the lower reaches is higher than the other two regions can be drawn, although the gap between the upper and middle reaches has been narrowing over the past decade. In terms of scale efficiency, provinces in the lower reaches have higher efficiency compared to those in the middle and upper reaches. However, for pure technical efficiency, the upper reaches are actually higher than the middle and lower reaches. The western region, due to its lack of

heavy industry, has effectively protected resources and the environment. Moreover, with strong support from national policies in recent years, the level of green development in the western region has significantly improved. However, with rapid economic growth, the central region has experienced severe resource waste and imbalance in economic development. Therefore, relying solely on extensive resource input cannot simultaneously achieve both economic growth and green development.

(3) From the analysis by province, although there are certain differences in green development efficiency among 11 provinces, it has been on the rise over the past decade, with most provinces exceeding one, achieving DEA effectiveness. However, some provinces (Anhui, Chongqing, Hubei) have more developed industrial sectors, which pose certain obstacles to their green development efficiency. From 2011 to 2021, while some provinces saw an increase in development efficiency, a few regions such as Hubei and Yunnan experienced a downward trend. The scale efficiency of provinces along the Yangtze River Economic Belt is generally higher than pure technical efficiency, and the trends vary.

(4) The path to green development in the Yangtze River Economic Belt is still long. Along this economic belt, provinces and cities must pay attention to the coordination between economic development and environmental protection while developing. In terms of investment, they should more strictly adhere to the principle of "green development." Currently, the efficiency of green development in the Yangtze River Economic Belt is primarily scale efficiency, with pure technical efficiency contributing less. This means that we are currently in a period where the returns on green development inputs and outputs are gradually increasing in scale. However, to improve green development efficiency over the next period, it is essential to continuously increase investment in technology and research and development, enhancing both technical and scale aspects of green development efficiency.

(5) Due to the varying resource endowments and actual levels of economic development across different regions, the development levels of the upper, middle, and lower reaches of the Yangtze River are also different. The level of economic development, population size, and education levels all influence economic growth and, in turn, green development. The efficiency of green development in the Yangtze River Economic Belt is largely influenced by scale efficiency. In the future, it is necessary to strengthen support and training for enterprises, increase technological investment through technical segments, make economic development more effective, innovative, and environmentally friendly, reduce resource consumption, enhance governance capabilities along the river, and promote green development. To improve the efficiency of green development and achieve sustainable development in the Yangtze River Economic Belt, it is essential to combine development with protection, develop a low-carbon economy and circular economy, and implement more detailed construction in social development. Adhering to the "new development philosophy," we must always strive to create better prospects for the country's green mountains and clear waters.

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## References

*[1] Zhen Lin, Du Bingzhen, Liu Ji-yuan, Sun Chuanzun, Zhang Qiang. Implications of International Experience for Green Development in Western China: Policies and Practices [J]. China Population, Resources and Environment, 2013,23(10):8-16.*

*[2] Zhu Jianjian. New Concept of Green Economy and Thoughts on the Development of Green Economy in China [J]. China Population, Resources and Environment, 2012,22(05):40-47.*

*[3] Fu Baozong. Situation and Countermeasures of Green Development of Industries in the Yangtze River Economic Belt [J]. Macroeconomic Management, 2017(01):55-59.DOI:10.19709/j.cnki.11-3199/f.2017.01.013.*
*[4] Tang Xiao. Review of the latest development of green economy theory [J]. Foreign Theoretical Dynamics, 2014(01):125-132.*
*[5] Hu Angang and Zhou Shaojie. Green Development: Functional Definition, Mechanism Analysis and Development Strategy [J]. China Population, Resources and Environment, 2014,24(01):14-20.*
*[6] Xiang Shujian, and Zheng Ruikun. "Research on China's Green Economic Development Index." Statistical Research 30.03 (2013):72-77. doi:10.19343/j.cnki.11-1302/c.2013.03.011.*
*[7] CAI Shaohong, GU Cheng, Zhang Zaijie. Measurement of green development level and temporal evolution characteristics of the Yangtze River Economic Belt [J]. East China Economic Management, 2021,35(11):25-34.DOI:10.19629/j.cnki.34-1014/f.210519005.*
*[8] Cui Dangchen, Zhang Yang. Research on the Impact of Urban Economic Agglomeration in the Yellow River Basin on the Efficiency of Green Development [J]. Gansu Social Sciences, 2022(05):217-227.DOI:10.15891/j.cnki.cn62-1093/c.2022.05.024.*
*[9] Huang Jie. Regional Differences and Dynamic Evolution of Green Development Efficiency in China [J]. Regional Research and Development, 2018,37(04):13-18+31.*
*[10] Liu Xiping, Guan Ke. Measurement and Evaluation of Green Development Efficiency in Hubei Yangtze River Economic Belt [J]. Statistics and Decision, 2018,34(18):103-106.DOI:10.13546/j.cnki.tjyjc.2018.18.023.*
*[11] Zhang Zeyi and Luo Xuehua. Measurement of Green Development Efficiency in Chinese Cities [J]. Urban Issues, 2019(02):12-20.DOI:10.13239/j.bjsshkxy.cswt.190202.*
*[12] Fu Chun, Ouyang Huanrui, Zhao Xueru. Measurement and Evaluation of Green Development Efficiency in Jiangxi Province Based on DEA and Malmquist Index Model [J]. Ecological Economy, 2020,36(06):51-57+172.*
*[13] Han Jing, and Chen Xi. "The Temporal and Spatial Evolution Characteristics of Green Development Level in Cities along the Yangtze River Economic Belt." East China Economic Management 35.01 (2021):24-34. doi:10.19629/j.cnki.34-1014/f.200701001.*
*[14] Wu Chuanqing, Song Xiaoxiao. Factors influencing green development and efficiency evaluation of cities in the Yangtze River Economic Belt [J]. Learning and Practice, 2018(04):5-13.DOI:10.19624/j.cnki.cn42-1005/c.2018.04.001.*
*[15] Zhou Jing. Evaluation of Green Agricultural Development, Regional Difference Analysis and Optimization Path of the Yangtze River Economic Belt [J]. Rural Economy, 2021(12):99-108.*
*[16] Li Linzi, Tian Jian, Zhao Yuting, Wang Kai, Li Xiaomin. A Study on the Differentiated Green Development Index System Based on the Main Functional Zone —— Taking the Yangtze River Economic Belt as an Example [J]. Ecological Economy, 2022,38(05):222-229.*
*[17] Qiu Zhaolin. Analysis of Ecological Efficiency Differences and Influencing Factors between Yangtze River Economic Belt and Yellow River Basin [J]. Contemporary Economic Management, 2022,44(06):39-49. DOI:10.13253/j.cnki.ddjjgl.2022.06.005.*
*[18] He Shoukui. Research on the Synergistic Mechanism and Policy System of Environmental Governance and Green Development in the Yangtze River Economic Belt [J]. Contemporary Economic Management, 2019,41(08):57-63.DOI:10.13253/j.cnki.ddjjgl.2019.08.009.*
*[19] Yu Liying, Liu Hongda, Chen Zixuan. Measurement and Analysis of Green Governance Efficiency in the Yangtze River Economic Belt—Based on the Generalized Panel Three-stage DEA Model [J]. East China Economic Management, 2021,35(06):88-99.DOI:10.19629/j.cnki.34-1014/f.200814015.*
*[20] Wang Jianmin, Qiu Dingsan, Jiang Qianying, Zhang Min. Measurement and Improvement Path of Industrial Green Development Efficiency in the Yangtze River Economic Belt [J]. Science and Technology Management Research, 2019,39(12):46-52.*
*[21] Zhou Jiewen, Jiang Zhengyun, Li Feng. Research on Green Economic Development and Influencing Factors of the Yangtze River Economic Belt [J]. Ecological Economy, 2018,34(12):47-53+69.*
*[22] Huang Lei and Wu Chuanqing. Efficiency of Green Innovation and Development of Industry in the Yangtze River Economic Belt and Its Synergistic Effects [J]. Journal of Chongqing University (Social Sciences Edition), 2019,25(03):1-13.*
*[23] Zhang Jijian, Liu Qing, Ding Xuhui. Study on Carbon Unlocking Efficiency of Yangtze River Economic Belt —— Based on SE-DEA-Malmquist Index [J]. East China Economic Management, 2021,35(06):1-10.DOI:10.19629/j.cnki.34-1014/f.201122004.*
*[24] Chen Xiaoxue, Xu Nan. Measurement and Temporal-Spatial Evolution of Green Development Level in the Yangtze River Economic Belt —— Based on Data from 11 Provinces and Cities from 2007 to 2017 [J]. Journal of Hohai University (Philosophy and Social Sciences Edition), 2019,21(06):100-108+112.*
*[25] Li Tianzi, Han Yonggang. The Impact of FDI Quality on Green Development Efficiency from the Perspective of Environmental Regulation —— A Case Study of Three Major Urban Agglomerations in the Yangtze River Economic Belt [J]. International Economic and Trade Exploration, 2023,39(02):53-68.DOI:10.13687/j.cnki.gjjmts.2023.02.003.*

*[26] Deng Hongbing. Promoting the High-quality Development of the Yangtze River Economic Belt with the Concept of Green Development [J]. Regional Economic Review, 2018(06):4-7.DOI:10.14017/j.cnki.2095-5766.2018.0132.*
*[27] Du Yu, Wu Chuanqing, Deng Mingliang. Research on the Efficiency of Green Development in Yangtze River Economic Belt: Government Competition, Market Segmentation and Other Factors [J]. China Soft Science, 2020(12):84-93.*
*[28] Boyle G. Boyle G. E. The Economic Theory of Index Numbers: Empirical Tests for Volume Indices of Agricultural Output[J]. Irish Journal of Agricultural Economics and Rural Sociology,1988,13.*
*[29] Pittman, R. W. Multilateral Productivity Comparisons with Undesirable Outputs[J]. The Economic Journal, 1983, 93(372).*
*[30] Anonymous. Ontario reverses course on bill that could open Greenbelt development[J]. Daily Commercial News, 2019, 92(19).*