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Original Research

Research on the Dynamic Evolution and Improvement Path of Inclusive Green Development Efficiency in China: a Perspective of Urban

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Abstract

Rapid urbanization in China has led to resource depletion, environmental pollution, and social inequity. The cornerstone of China's high-quality economic development is inclusive green development, which has developed as the society's primary objective. Based on the panel data of 16 prefecture-level cities in Anhui Province from 2011 to 2020, the study explores the connotation of urban inclusive green development efficiency (IGDE) and evaluates IGDE using the hierarchical entropy weight TOPSIS model combined with the global-Super-SBM model. The current situation and problems of IGDE in Anhui Province are thoroughly analyzed, then the Global-Malmquist index is used to analyze the structural dynamics of efficiency dynamics, the Theil index to explore the sources of regional differences in efficiency and the efficiency slackness index to discover the causes of low-efficiency losses. The results indicate that, technological progress is the key factor affecting IGDE. Intra-regional variation is the primary source of regional variation in IGDE. The inadequacy of infrastructure, medical level, educational equity, and green status are the four decisive aspects that cause the low efficiency of IGDE for the whole, but the weaknesses of IGDE are specifically from city to city. According to the above, the practical promotion path of IGDE in Anhui province has been obtained.

Keywords: inclusive green development efficiency, improving path, evolutionary characteristic, Global-Super-SBM model

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Table 1. IGDE evaluation index system.

	First-level indicator		Second-level indicator	Type	Grading weights（%）
Input indicators	(I_1) Labor		(X_1) Employment rate	+	100
	(I_2) Capital		(X_2) Investment in fixed assets per unit of GDP	+	100
	(I_3) Resource		(X_3) Per capita land area of administrative area	+	63.52
			(X_4) Energy consumption per unit of GDP	-	5.78
			(X_5) Electricity consumption per unit of GDP	-	17.45
			(X_6) Per capita water consumption	-	13.25
	(I_4) Technology		(X_7) Full-time equivalent of Rand D personnel per 10,000 people	+	60.58
			(X_8) Rand D expenditure as a percentage of GDP	+	39.42
Output indicators	Economic development	(O_1) Development Quality	(Y_1) Proportion of output value of tertiary industry in GDP	+	100
		(O_2) Growth quantity	(Y_2) GDP per capita	+	85.29
			(Y_3) GDP growth rate	+	14.71
	Social inclusion	(O_3) Income distribution	(Y_4) Ratio of urban and rural per capita disposable income	-	100
		(O_4) expand employment	(Y_5) Urban registered unemployment rate	-	100
		(O_5) Education opportunities	(Y_6) Illiteracy rate	-	35.88
			(Y_7) Years of schooling per capita	+	64.12
		(O_6) Medical level	(Y_8) Number of health technicians per 1,000 population	+	46.62
			(Y_9) Number of beds in medical and health institutions per 1,000 people	+	53.38
		(O_7) Social Security	(Y_{10}) Basic pension insurance participation rate	+	27.59
			(Y_{11}) Basic medical insurance participation rate	+	35.72
			(Y_{12}) Unemployment insurance participation rate	+	36.69
		(O_8) Infrastructure	(Y_{13}) Fixed, mobile and Internet per capita	+	73.55
			(Y_{14}) Urban road area per capita	+	26.45
	Ecological environment	(O_9) Pollution emissions	(Y_{15}) SO_2 emissions per capita	-	50.00
			(Y_{16}) Wastewater discharge per capita	-	50.00
		(O_{10}) Green status	(Y_{178}) Green coverage in built-up areas	+	42.89
			(Y_{18}) Green space per capita	+	57.11
		(O_{11}) Environmental governance	(Y_{19}) General industrial solid waste comprehensive utilization rate	+	6.93
			(Y_{20}) Centralized treatment rate of sewage in sewage treatment plants	+	5.11
			(Y_{21}) Harmless disposal rate of urban waste	+	5.06
			(Y_{22}) Afforestation area per capita	+	82.90

Notes: The fixed asset investment amount of the whole society uses the fixed asset price index, and the GDP uses the GDP index (previous year = 100), all of which are deflated to the constant price with 2010 as the base period. Data source: Anhui Statistical Yearbook, Hefei Statistical Yearbook, China City Statistical Yearbook.

Introduction

Extensive growth mode with high input, high consumption, high pollution, and low benefit has previously resulted in resource depletion, pollution, and ecological damage [1]. Simultaneously, the development opportunities provided by economic growth have not been equally distributed, and the fruits of growth have not been fairly shared, resulting in an ever-widening income gap and increasing social inequality [2]. The above issues have hampered socio-economic development, resource preservation, and environmental preservation. Humanity has made it a universal objective to create an inclusive, green, and sustainable society [3, 4]. The word "inclusive" has been mentioned 52 times in the UN Global Sustainable Development Report 2015 [5]. The national development concept of "innovation, coordination, green, openness, and sharing" has been advocated in China. Many significant conferences have highlighted the need to promote green development and enhance people's well-being. In 2021, the National People's Congress reiterated China's commitment to developing a green, low-carbon, and circular economy and improving environmental governance, educational equity, medical reform, and aged care services. From this, it can be seen that "inclusive" and "green" development modes are gradually becoming the modes of pursuing high-quality national economic development in the new era. Using limited resources to accomplish a socially inclusive, environmentally friendly, and long-term development model is a critical challenge in today's society.

This article assesses the urban inclusive green development efficiency (IGDE), identifies problems, and explores the underlying causes. In order to establish a scientific foundation for enhancing the region's IGDE. It also fosters people's well-being and produces green, long-term development.

Literature Review

Theories and Implications of Inclusive Green Development

Scholars' research on inclusive green development started from theory. In 2012, the Rio+20 Summit launched the topic of "Green Economy in the Context of Sustainable Development and Poverty Eradication", introducing the concept of "inclusive green development" for the first time, pointing out that it is necessary to promote inclusive economic growth, social development, and environmental protection. The connotation of inclusive green development is mainly based on development economics and welfare economics. Development economics, led by the World Bank, considers inclusive green development as a sustainable approach that combines social inclusion and ecological balance [6, 7]. From the perspective of welfare economics, scholars believe that inclusive green development is committed to the shared growth of welfare for current and future generations [8]. Inclusiveness, first and foremost, is a kind of growth beneficial to the poor, and scholars' research on the topic generally focuses primarily on "poverty" [9, 10]. In continuous research, scholars have significantly improved and modified the concept of inclusive development. Gupta and Pouw argue that inclusive development should emphasize "equity" in distributing social, economic, and ecological resources [11]. Bakker and Nooteboom emphasize the importance of people in inclusive development by arguing that social inclusion and exclusion are influenced by human behaviors, desires, and cultural preferences [12]. Sun believes inclusive growth should have the characteristics of "survival, capability, development, freedom, and opportunity" [13]. When studying "inclusiveness," scholars have strongly emphasized the content of "ecology, resources, and the environment." Similarly, the definition of green development has begun to cover the content of social subsystems [14, 15]. "Green" and "inclusive" are increasingly closely linked.

Assessment of Inclusive Green Development

Regarding the measurement of the degree of regional inclusive green development, on the one hand, inclusive green development is influenced by various factors and requires a multi-dimensional factor system to measure it scientifically. Scholars mainly select evaluation factors based on the framework of three dimensions: economic, social, and environmental [16, 17], and use the entropy method [18] and factor analysis [19] to filter and cluster the factors to measure the level of inclusive green development. On the other hand, the formation of inclusive wealth results from a combination of productive capital, human capital, natural capital, social capital, and so on [20, 21]. Solving the "redistribution" of resources and promoting environmental elements such as justice in space allocation is one of the important issues, and improving "efficiency" is an effective way to determine whether resources are allocated reasonably [22]. Therefore, some scholars measure the level of inclusive green development from input-output efficiency. Most scholars take capital and energy consumption as input indicators, economic output and social welfare as the expected output, and environmental pollution as an unexpected output. However, in these literature studies, the input and output indicators cover less content, and only a single indicator is used to measure each aspect of the content, which is not comprehensive enough [23, 24].

Empirical Evidence of Inclusive Green Development

Scholars have begun to study regional inclusive green development from multiple perspectives

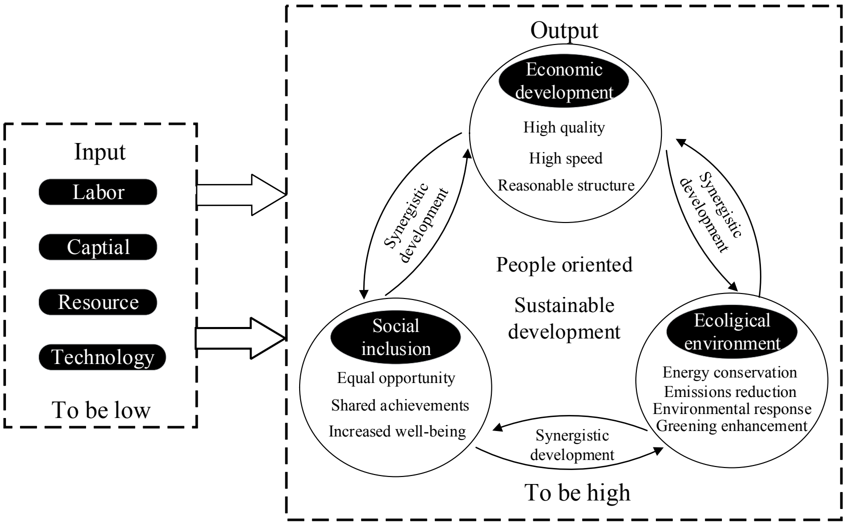

Fig. 1. Theoretical framework of IGDE.

and pertinence based on the measurement of inclusive green development. The research regions mainly involve the sub-Saharan African countries [25], the Russian Federation [26], river basins or economic belts of China [27]. First, spatial and temporal characteristics and regional variability are analyzed. Scholars have mainly employed exploratory spatial data analysis (ESDA) and other methods to explore the features of spatial aggregation, using the coefficient of variation and Gini coefficient to explore the characteristics of regional differences in inclusive green development [24, 28]. Second, analysis of influencing factors of inclusive green development. Scholars explore the impact of various factors such as economic policy uncertainty [29], environmental regulation intensity [30], and infrastructure [31, 32] on regional inclusive green development and accordingly guide the enhancement of inclusive green development. In particular, Lapinskas confirmed that sustainable development and enhanced resource use contribute to inclusive growth in the country [33]. Juniardi's research found that inclusive human development, regional independence, infrastructure, and industrialization significantly impact inclusive green growth in Indonesia [34].

Based on the above studies, this paper summarizes the deficiencies in inclusive green development: (1) There is less research on inclusive green development at the city level than at the national, federal district, and provincial levels. (2) The definition of inclusive green development is still to be improved. Scholars can build a multi-dimensional indicator system to evaluate inclusive green development comprehensively, but the index selected to measure its efficiency is relatively narrow and not comprehensive enough. (3) The majority of the literature merely evaluates the existing state of inclusive green development and does not conduct a comprehensive study on the factors that contribute to efficiency improvement or decline. Scholars analyze inclusive green development as affecting variables at the macro level, which results in the implementation of policies promoting inclusive green development being excessively permissive and unfocused. Therefore, the following improvements are made in this paper to overcome the limitations above. (1) The city is the crucial foundation of national development. This paper takes the city as the research unit and refines the research scale. It is easier for local governments to implement effective remedial measures when the basic issues with regional inclusive green development are identified at the micro-level. (2) In this paper, relevant indicators are thoroughly selected, and the hierarchical entropy weight TOPSIS model is adopted to effectively reduce the number of input and output indicators in the Super-SBM model while retaining all the essential information of the original indicators to comprehensively and scientifically evaluate the efficiency of urban inclusive green development (IGDE). (3) The paper adopts the research method of "scientific measurement - current situation analysis - problem identification - problem solving" to explore the ways to improve urban IGDE, making the research results more scientific and reasonable and the improvement path more accurate and effective.

Material and Methods

Study Area

Anhui Province is located in the eastern part of China, and the Yangtze River Delta city cluster formed with Jiangsu, Zhejiang, and Shanghai is one of the regions with the most active economic development, the highest degree of openness, and the strongest innovation capacity in China. Although the area is rich in natural resources, it formerly relied primarily on outdated industrial techniques, damaging the environment Anhui Province has a large population, and whether education, medical, and infrastructure development meet the needs of people's lives is one of the purposes of conducting an evaluation of inclusive green development.

Evaluation Index System

This paper concludes that inclusive green development is a sustainable development approach with the synergistic development of various elements such as high-quality economic growth, income increase, poverty reduction, equal social opportunities, result sharing, resource utilization, and environmental protection, based on the theoretical studies of the above scholars. In order to optimize inclusive green development reasonably, this paper studies the inclusive green development efficiency (IGDE) and defines it as the ratio relationship between input factors (labor, capital, resources, and technology) and outputs (economic, social, and ecological environment). Fig. 1 depicts the theoretical framework.

The social and economic development of a city can significantly affect the allocation of green space [35], and the environmental quality will also change with inclusive growth [25]. The three subsystems of "economy, society, and environment" promote each other and develop in concert. In terms of indicators, education, infrastructure, and employment are all intimately linked to inclusive growth [36, 37]. Green development aims to improve people's living conditions, water resources, and other essential human survival needs, as well as pollution emission control [38-40]. A system of urban IGDE indicators is constructed based on academic studies and considering the scientificity and accessibility of the selection of city-level indicators (Table 1). In addition, relativity indicators are used in this paper to avoid the results being biased by very big or minimal absolute indicators.

Research Method

Entropy Weight TOPSIS Method

The number of decision-making units in the DEA model should be more than twice the sum of input and output, and the input (output) indicators should follow the principle of weak correlation. Otherwise, the accuracy and efficiency of DEA efficiency measurement abilities will be harmed. In the article, more indicators have been chosen. As there may be some correlation among the indicators, it is necessary to calculate the composite index as a representative for the indicators under the same criterion layer, which reduces the number of input-output indicators, highlights the composite significance of the indicators, and reduces the hyperactivity among the indicators. The entropy weighting method is based on the amount of information reflected by the variability of each indicator data, overcoming the overlap of information between multidimensional variables and reducing the interference of subjective human factors when assigning indicators [41, 42]. The TOPSIS method quantifies the ranking by calculating the distance between the evaluation object and the best and worst solutions [43, 44]. Many scholars have combined the two methods to determine the index weights in recent years, calculating index weights more objective and reasonable [45, 46].

Let t be the year, i be the city, and j be the secondary index. The specific calculation processes are as follows:

Normalize the original evaluation matrix:

$$x_{itj} = \begin{cases} \dfrac{a_{itj} - \min\{a_j\}}{\max\{a_j\} - \min\{a_j\}}, Positive \\ \dfrac{\max\{a_j\} - a_{itj}}{\max\{a_j\} - \min\{a_j\}}, Negative \end{cases}$$
$$i=1,2,\dots,n, j=1,2,\dots,m, t=1,2,\dots,k \quad (1)$$

Calculate the enrtropy value of the j indicator:

$$P_{itj} = \frac{x_{itj}}{\sum_i \sum_t x_{itj}}, i=1,2,\dots,n, j=1,2,\dots,m, t=1,2,\dots,k \quad (2)$$

$$e_j = -\frac{1}{\ln(n\times k)} \sum_i \sum_t P_{ijt} \ln P_{ijt}, j=1,2,\dots,m \quad (3)$$

Calculate the weight of the indicator j:

$$w_j = \frac{1-e_j}{\sum_j 1-e_j}, j=1,2,\dots,m \quad (4)$$

The weighted Normalization matrix is shown as follows:

$$R = (r_{itj})_{m\times n}, r_{itj} = w_j x_{itj} \quad (5)$$

Determinate the positive ideal solution S_j^+ and the negative ideal solution S_j^-:

$$S_j^+ = \max(r_{1tj}, r_{2tj}, \dots, r_{itj}), S_j^+ = \min(r_{1tj}, r_{2tj}, \dots, r_{itj}) \quad (6)$$

Calculate the Euclidean distance of each evaluation unit and the positive and negative ideal points:

$$D_j^+ = \sqrt{\sum_{j=1}^m (S_j^+ - r_{itj})^2}, D_j^- = \sqrt{\sum_{j=1}^m (S_j^- - r_{itj})^2} \quad (7)$$

Calculate the composite index of each evaluation unit:

$$T_{it} = \frac{D_j^-}{D_j^+ + D_j^-} \tag{8}$$

Global-Super-SBM

Scholars prefer to utilize the Date Envelopment Analysis (DEA) to calculate efficiency, such as the BCC and the CCR models, which are based on different scale assumptions. However, the two models mentioned above are radial and cannot eliminate the influence of slack variables and maximize the degree of improvement in efficiency. Based on this, Tone proposed the SBM model [47], which accounts for the influence of slack variables, and the Super-SBM model [48], to rank and compare decision units with an efficiency evaluation of 1 in the SBM model. The Super-SBM model can only allow comparison of efficiency levels across cities for the same period, not across time. Accordingly, this paper refers to Oh (2010) [49] and constructs the Global-Super-SBM model, which overcomes the problem of comparing efficiency values across periods by using the production possibilities for all times in all cities as a common reference set. The global reference set is as follows:

$$P^G = P^1 \cup P^2 \cup, \dots, \cup P^T \tag{9}$$

$$P = \left\{ (x,y) \mid \overline{x_i} \geq \sum_{t=1}^{T} \sum_{j=1, j\neq 0}^{n} \lambda_j x_j, \overline{y_k} \leq \sum_{t=1}^{T} \sum_{j=1, j\neq 0}^{n} \lambda_j y_j, \lambda_j \geq 0 \right\} \tag{10}$$

With each city as a decision-making unit (DMU) each year, a non-radial, non-angle Super-SBM model with variable payoffs of scale is used to measure the IGDE in cities. The following is the exact formula:

$$P = E(x^t, y^t) = \min \frac{\frac{1}{m}\sum_{i=1}^{m} \frac{\overline{x_i}}{x_{i0}}}{\frac{1}{s}\sum_{k=1}^{s} \frac{\overline{y_k}}{y_{k0}}}$$

$$s.t.\begin{cases} \overline{x_i} \geq \sum_{t=1}^{T} \sum_{j=1, j\neq 0}^{n} \lambda_j x_j, \forall\ i \\ \overline{y_k} \leq \sum_{t=1}^{T} \sum_{j=1, j\neq 0}^{n} \lambda_j y_j, \forall\ k \\ \overline{x_j} \geq x_{i0}, 0 \leq \overline{y_k} \leq y_{k0} \\ \lambda_j \geq 0, \sum_{j=1, j\neq 0}^{n} \lambda_j = 1 \\ \overline{x_i} = x_{i0} + s^-(i = 1, 2, \dots, m) \\ \overline{y_k} = y_{k0} - s^+(k = 1, 2, \dots, s) \end{cases} \tag{11}$$

In this formula, (1) ρ is the inclusive green development efficiency value of DMU, the larger the value, the higher the efficiency, and $\rho \geq 1$ means that the efficiency value of the decision unit is valid, and vice versa. (2) Each DMU consists of m inputs and s outputs, and its input vector is $X = (x_1, x_2, ..., x_n) \in R_+^m$, and output vector is $Y = (y_1, y_2, ..., y_n) \in R_+^s$. (3) The weight of the corresponding input or output indicator is λ, $\lambda = (\lambda_1, \lambda_2, ..., \lambda_n)$. (4) The vectors s^- R_+^m and s^+ R_+^m , denote the input and output slack variables.

Global-Malmquist (GM) Index

The Malmquist index compares the degree of productivity change between two periods and further decomposes it to reflect the structural drivers of efficiency change, avoiding the discrepancies produced by period selection arbitrariness and improving the model's identification ability [50]. The article draws on the Global-Malmquist (GM) index constructed by PL(2005) [51]. Based on the Super-SBM model, the sum of all periods is used as the reference set, further decompositions the GM index into two parts: change in technical efficiency (EC) and change in technological progress (BPC). See Equations (12) to (15).

$$GM(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{E^g(x^{t+1}, y^{t+1})}{E^g(x^t, y^t)} \tag{12}$$

$$GM = EC \times TC \tag{13}$$

$$EC = \frac{E^{t+1}(x^{t+1}, y^{t+1})}{E^t(x^t, y^t)} \tag{14}$$

$$BPC = \frac{E^g(x^{t+1}, y^{t+1}) / E^{t+1}(x^{t+1}, y^{t+1})}{E^g(x^t, y^t) / E^t(x^t, y^t)} \tag{15}$$

In this formula, (x_t, y_t) and (x_{t+1}, y_{t+1}) denote the input-output vectors in periods t and t+1, respectively. Global-Malmquist measures the change in IGDE of cities from period t to period t+1, with no change in IGDE when GM = 1, GM>1 (<1), improvement(decrease). EC>1 (<1) represents technical efficiency increase (decrease) and BPC>1 (<1) means technical progress (regression).

Input and Output Redundancy Rate

The degree of redundancy (insufficient) in the optimized DMU compared to the previous one is the proportion of input variables that can be reduced (the proportion of output variables that can be increased), which is used to analyze the direction that can be improved in the process of realizing inclusive green development in the region and achieving optimal allocation of resources [52, 53]. The input over excess

Table 2. IGDE rating of Anhui from 2011 to 2020.

Area		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
South Anhui	Wuhu	V	V	V	V	III	V	V	V	V	V
	Ma'anshan	V	V	V	IV	V	V	V	V	V	V
	Tongling	V	V	V	V	VI	V	V	V	V	VI
	Huangshan	V	V	III	III	V	V	V	V	V	VI
	Chizhou	V	V	V	V	III	V	V	V	V	V
	Xuancheng	I	I	II	II	I	I	II	II	II	II
Central Anhui	Hefei	V	V	V	II	II	II	V	V	V	V
	Anqing	V	V	V	II	II	II	V	V	V	V
	Chuzhou	I	I	V	II	II	II	II	II	V	V
	Lu'an	V	V	V	V	V	V	V	V	V	V
Northern Anhui	Bengbu	I	I	II	II	II	II	II	V	III	V
	Huainan	V	V	V	V	V	V	III	III	V	VI
	Huaibei	V	V	V	III	V	V	V	V	V	V
	Fuyang	V	V	V	V	V	V	V	V	V	VI
	Bozhou	V	V	V	V	V	V	V	V	V	V
	Suzhou	V	VI	V	V	V	V	V	V	V	VI

rate and output insufficiency rate of each DMU are defined by the global-super-SBM solution, as shown in Formula (16) below.

$$\alpha_{ij} = \frac{S_{ij}^-}{x_{ij}}, \beta_{kj} = \frac{S_{kj}^+}{y_{kj}} \tag{16}$$

Kernel Density Estimation (KDE)

KDE is a nonparametric estimation method for describing a random variable's distribution pattern by estimating its continuous density profile without making assumptions [54]. As a result, KED can be conducted to analyze the IGDE's dynamic evolutionary trend and spatial equilibrium characteristics in Anhui Province. The formula is shown in (17).

$$f(x) = \frac{1}{Nh}\sum_{i=1}^{N} K(\frac{x_i - x}{n}) \tag{17}$$

Where $K(p)$ denotes a Kernel function, x_i is the sample value of the random variable, x is the mean of the sample value, N is the sample capacity, h denotes the bandwidth, the choice of bandwidth will directly affect the estimation results, such as the smaller the bandwidth is the higher the accuracy of the estimation. There are many commonly used Kemel functions, and this paper selects the Epanechnikov kernel function, which is calculated by Formula (18).

$$K(p) = \begin{cases} \frac{3}{4}(1-p^2), |p| \leq 1 \\ 0, otherwise \end{cases} \tag{18}$$

Theil index

The Thiel index assesses the unevenness of the research subject's geographic development [55]. The method measures the degree of geographical disparities using information entropy. It decomposes the overall differences into inter-group and intra-group, allowing researchers to better understand regional disparities' structural characteristics [56]. The Thiel index has been widely combined with the DEA model [57]. As a result, the paper uses the Thiel index to measure regional variances and reasons for differences in inclusive green development efficiency in Anhui Province so that improvement countermeasures may be focused. The following is the particular calculating formula:

$$T = T_w + T_b = \frac{1}{n}\sum_{i=1}^{n} \frac{y_i}{\bar{y}} \ln(\frac{y_i}{\bar{y}}) \tag{19}$$

$$T_w = \sum_{k=1}^{l} (\frac{n_k}{n} \frac{\overline{y_k}}{\bar{y}}) T_k \tag{20}$$

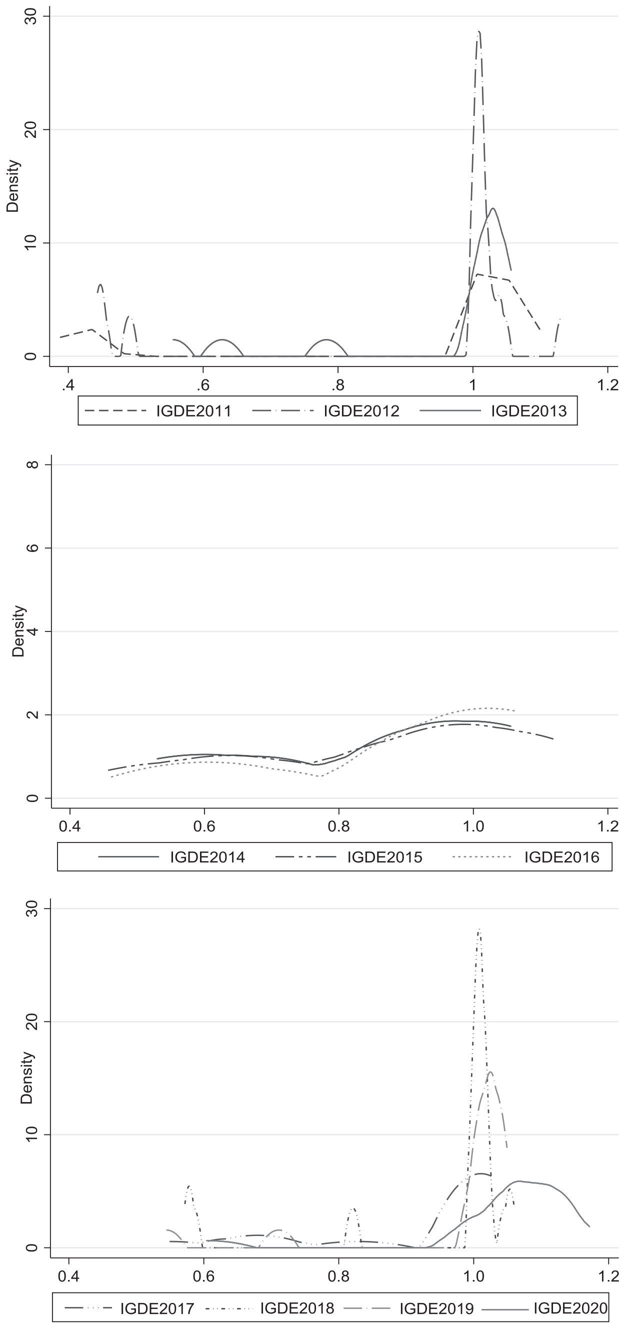

Fig. 2. Kernel density curve of IGDE in Anhui Province.

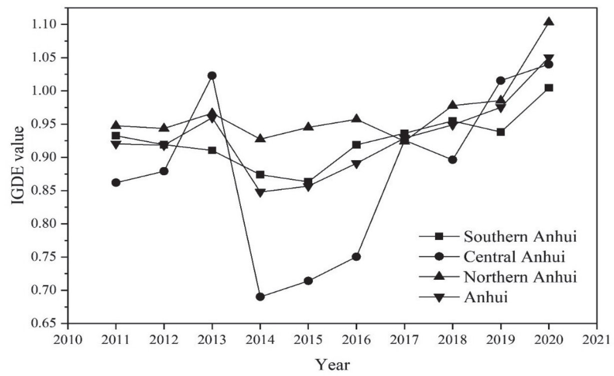

Fig. 3. Annual mean change of regional IGDE.

$$T_b = \sum_{k=1}^{l} \left(\frac{n_k}{n}\frac{\overline{y_k}}{\overline{y}}\right) \ln\left(\frac{\overline{y_k}}{\overline{y}}\right) \tag{21}$$

Where T denotes the total Thiel index, the higher the value, the greater the inequality between regions. T_W and T_B denote the inter-group and intra-group differences respectively. y_i represents the IGDE value of the ith city, $\bar{y}$ is the average IGDE of all cities in the study area. k is the number of sub-city groups, n_k is the number of cities included in the kth sub-city group, and T_K is the Theil index of the kth sub-city group.

Results and Discussion

The Status of IGDE in Anhui Province

The Global-Super-SBM model examines the IGDEs of 16 prefecture-level cities in Anhui Province from 2011 to 2020. The IGDEs were classified into six levels based on their efficiency values: early-warning I (values between 0 and 0.5), risk II (values between 0.5 and 0.7), sensitive III (values between 0.7 and 0.9), general IV (values between 0.9 and 1), sub-health V (values between 1 and 1.1), and health VI (values greater than 1.1). Obtain the IGDE grade distribution for each city each year (see Table 2). On this basis, the current situation of IGDE in Anhui Province was analyzed in terms of the dynamic evolution of the temporal dimension and pattern changes in the spatial dimension. The overall distribution dynamic of IGDE in Anhui Province over time was analyzed using kernel density estimation (KDE). As can be seen from the kernel density estimation (Fig. 2), the kernel density curve from 2011 to 2020 revealed a "left trailing" state. The curve gradually changed to the right, with the trailing phenomenon weakening, indicating that the overall level of IGDE in Anhui Province kept improving, while the relative difference of IGDE at the municipal scale exhibited a convergence trend, with the gradient affected weakening. Analyzed by period, the main wave peak shifted to the right continuously from 2011 to 2013, and the peak of the main wave experienced the change process of "rising-declining," and the width of the wave showed the characteristic of "shrinking-expanding," indicating that the regional difference of IGDE in Anhui Province decreased first and then increased. The nuclear density curve showed a multi-peak trend. The peaks of the side peaks were more minor and kept shifting to the right, and the distance between the side peaks and the main peak decreased, indicating that there was a trend of multi-level differentiation of IGDE levels in Anhui Province while the polarization level was weakened. The nucleation density curves from 2014 to 2016 were roughly identical, without prominent peaks, while the regional differences in IGDE in Anhui province peaked during these three years, with the most apparent gradient impact. From 2017 to 2020, the center peak's peak shifted to the right, the height of

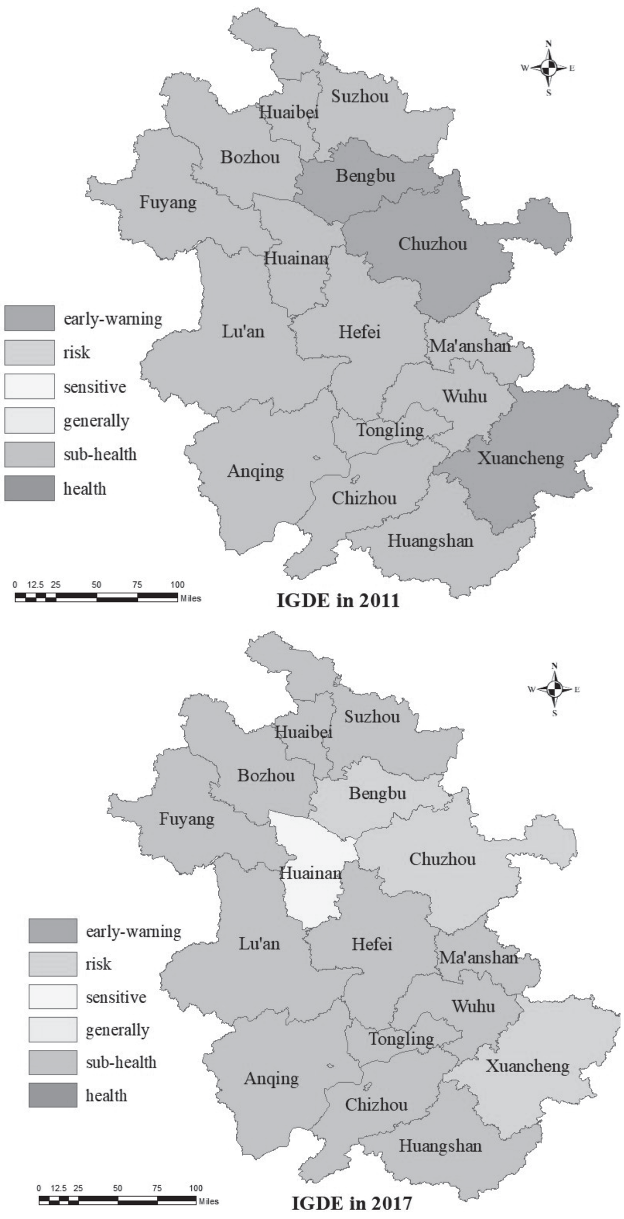

Fig. 4. Spatial distribution of IGDE of cities in Anhui in 2011, 2014, 2017 and 2020.

the main peak underwent a "rising-declining" change process, and the prominent peak widened. The changes in the kernel density curves from 2011 to 2013 and 2017 to 2020 were relatively comparable, indicating that Anhui Province was making efforts to ameliorate urban IGDE differences. However, the implementation effect was inconsistent enough, as seen by the kernel density graphs.

Table. 3. Regional GM Index average and its decomposition from 2011 to 2020.

Area	GM	EC	BPC
Southern Anhui	1.0173	0.9863	1.0364
Central Anhui	1.0375	0.9956	1.0416
Northern Anhui	1.0139	0.9931	1.0209
Anhui	1.0229	0.9917	1.0329

Changes in the annual mean values of IGDE in Anhui Province and its sub-regions were studied in detail (Fig. 3). The annual average value of IGDE in Anhui Province indicated a minor increase from 2011 to 2013, a sudden decrease from 2013 to 2014, and a steady increase from 2014 to 2020. Northern Anhui was responsible for this change, as shown in the graph. In 2014, the IGDE in Central Anhui reached a trough value of 0.69, owing to the fact that the IGDE in the three cities of Hefei, Anqing, and Chuzhou plummeted from a sub-healthy state (V) to a risk state (II) (Table 2). Northern Anhui had the highest IGDE level among the three sub-city groups, followed by Southern Anhui. The IGDE in Central Anhui was the most volatile, with the most noticeable decrease and improvement.

According to Table 2, Anhui Province had 160 DMUs in 16 prefecture-level cities from 2011 to 2020. Among them, DMUs with IGDE in a sub-healthy condition and above made up 75.63%, whereas inefficient DMUs accounted for 24.37%, indicating that most cities in Anhui Province were in a better IGDE state during the research years. However, some cities' IGDE status was undesirable. In order to illustrate the spatial pattern state and evolution trends of IGDE in 16 prefecture-level cities, three typical years, 2011, 2014, 2017, and 2020, were chosen to visualize the spatial pattern status and evolution trends using ArcGIS software (Fig. 4). Fig. 4 demonstrated significant regional disparities in IGDE in Anhui Province, with the most prominent regional variances occurring in 2014. Specifically, during the study years, the IGDE in the four cities of Wuhu, Chizhou, Lu'an, and Bozhou remained sub-healthy level (V). The most obvious improvement was in the IGDEs of Chuzhou, Bengbu, Hefei, and Anqing, which went from risk status (II) to sub-health level (V). The IGDEs of Tongling, Xuancheng, Fuyang, and Suzhou remained constant and were reach a peak in 2020. Huangshan's IGDE was moving in a "V" form, with a trough in 2014 and a peak in 2020. The IGDE of Xuancheng was the worst, hovering between the initial warning (I) and risk (II) among the study years. From the above analysis, the problem of inadequate and unbalanced development within Anhui Province's urban structure was prominent.

Based on the preceding analysis of the current situation, it was determined that the IGDE fluctuated significantly and had a regional gradient effect over time, and the IGDE in Anhui Province required improvement. Thus, this research examined the improvement path of urban IGDE in Anhui Province in three aspects: dynamic evolution structure motivation, sources of regional differences, and sources of inefficiency losses from surface to point and from the whole to individual cases.

IGDE Promotion Path in Anhui Province

To illustrate the dynamics of IGDE and the structural reasons for the changes, the Global-Malmquist index (GM) was used to measure the change in IGDE and its decomposition terms technical efficiency (TC) and technical progress (BPC) for cities in Anhui Province

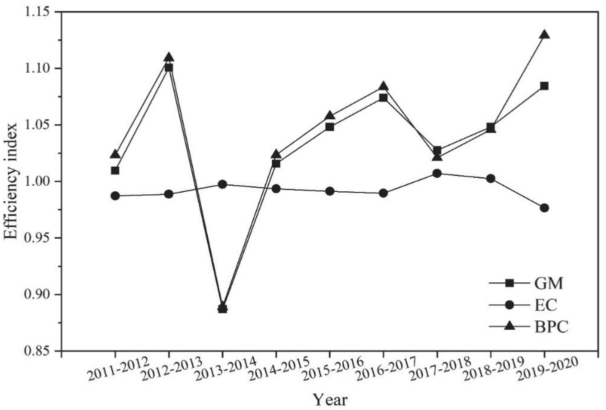

Fig. 5. GM index and its decomposition in Anhui Province.

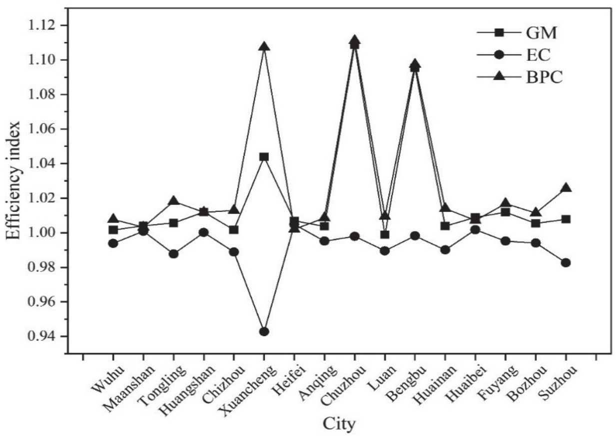

Fig. 6. Urban GM index and its decomposition.

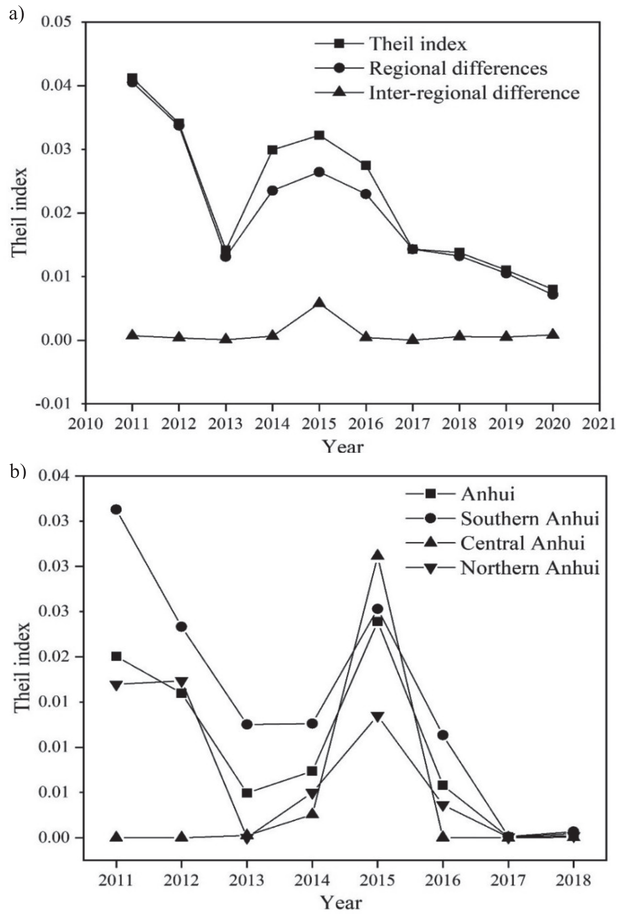

Fig. 7. Changes in the Theil index from 2011 to 2020. a) Theil index and its decomposition of overall Anhui Province, b) Theil index of each sub-region in Anhui Province.

from 2011 to 2020. Table 3 shows the yearly average GM index and its decomposition terms for Anhui Province and its sub-city groups from 2011 to 2020. The results indicate that the IGDE of Anhui Province and its sub-city groups increased. IGDE grew at a 2.29% average rate, of which TC decreased by 0.83%, and BPC increased by 3.29%. The increase in BPC was greater than the decline in TC, resulting in an increased growth in IGDE. In each sub-region, the average annual growth rate of IGDE was Central Anhui (3.75%)> Southern Anhui (1.73%)>Northern Anhui (1.39%). All regions had advanced technology (BPC>1) and declining technical efficiency (EC<1).

Looking at the GM index of Anhui Province over the period (Fig. 5), only IGDE decreased from 2013 to 2014(GM<1), which was due to technological progress (BPC<1). In the years of IGDE growth (GM>1), technological progress was the key driver for IGDE growth in Anhui Province (PBC>1). From the trends of GM index, EC index, and BPC index, technical efficiency maintained a stable trend, technical progress had a significant change, and the change of IGDE showed the same change trend as technical progress. It can be inferred that technological progress was crucial for IGDE growth in Anhui Province. Technical efficiency refers to the management methods

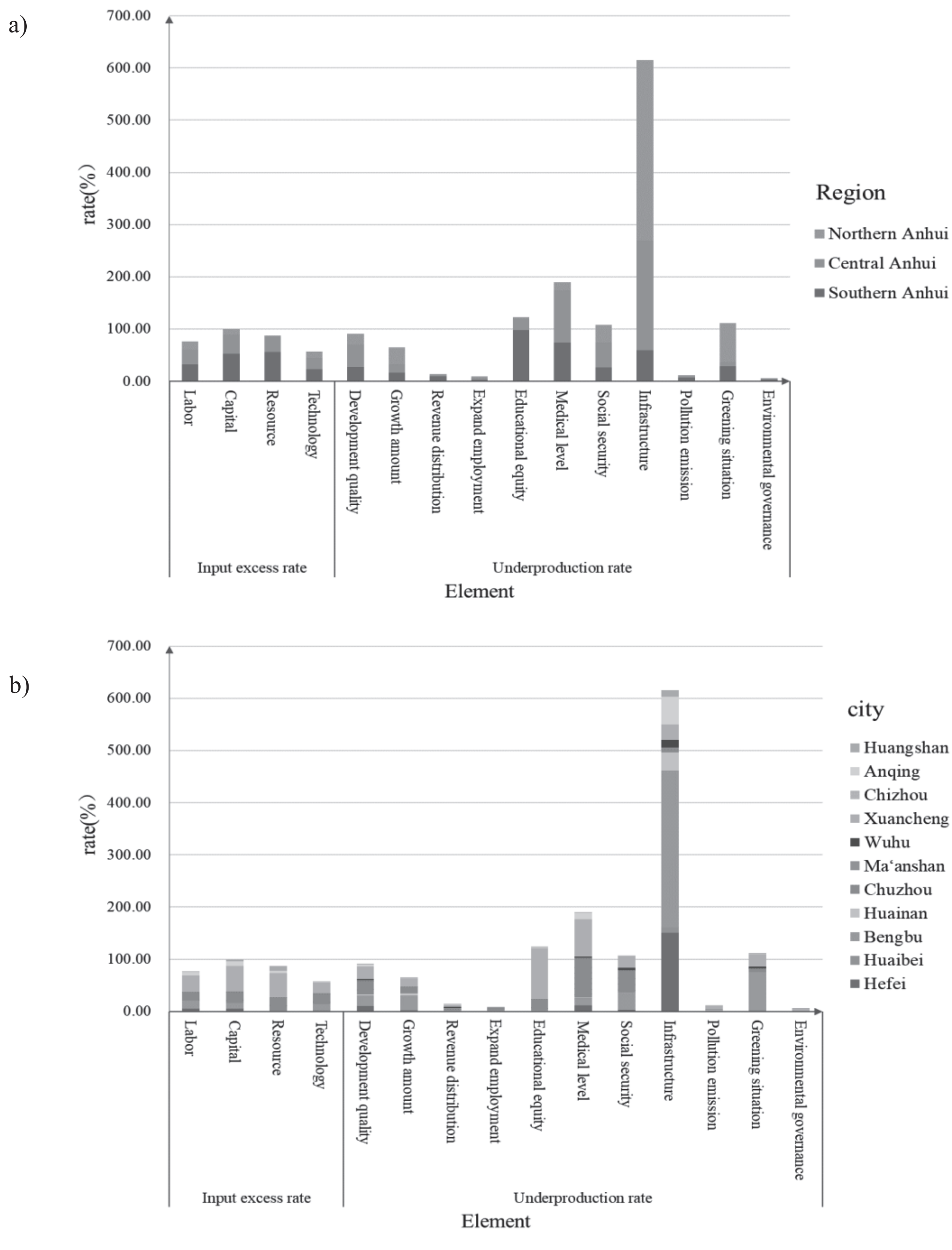

Fig. 8. Sources of IGDE efficiency losses in the province of Anhui between 2011 and 2020. a) From three sub-regions' perspective, a) From 7 cities' perspective.

and structural strengths and weaknesses of achieving inclusive green, and technological progress refers to the innovation of inclusive green development technology, which is closely related to the country's adherence to scientific and technological innovation and the implementation of the innovation-driven development strategy [58, 59]. Anhui Province can enhance IGDE by improving its research and development capacity for new technologies and products.

From the perspective of cities (Fig. 6), the IGDE of all cities in Anhui province improved (GM>1), and technology made continuous progress (BPC>1), but only four cities in Hefei, Huaibei, Ma'anshan and Huangshan showed an increase in technical efficiency (EC>1) from 2011 to 2020. The IGDE of Chuzhou and Bengbu showed the most significant improvement, with a prominent "catch-up effect." Their average annual growth rates of IGDE were 10.9% and 9.5%, respectively, owing primarily to technological progress, which increased by 11.1% and 9.7%, respectively, but the technical efficiency still has to be improved (EC<1). In Xuancheng, the average annual growth rate was 4.4%, placing it third in the city. It increased by 10.7% due to technological progress, but its technical efficiency regressed the most, dropping by 5.7%. In the remaining 13 cities, the IGDE grew more slowly, with an average yearly growth rate of roughly 1%. From the above analysis, it can be concluded that technological progress is the primary cause of urban IGDE in Anhui Province.

The regional difference, change process, and source of change of IGDE in Anhui Province are reflected by the Theil index and its decomposition. The Thiel index in Anhui Province fell from 2011 to 2013, recovered somewhat from 2013 to 2015, and decreased continuously from 2015 to 2020. The Thiel index decreased from 0.412 in 2011 to 0.008 in 2020. The regional difference of IGDE in Anhui Province gradually decreased, indicating that the regional communication in Anhui Province has strengthened and the "Matthew effect" has weakened. From the decomposition of the overall Theil index in Anhui Province (Fig. 7a), the intra-regional Theil index curve and the total Theil index curve showed the same trend. The inter-regional Thiel index maintained a stable trend, and the changes in rising and falling were not noticeable. The inter-regional Thiel index value was more petite and significantly lower than the intra-regional Thiel index. It can be observed that intra-regional differences were the primary reason for the differences in IGDE in Anhui Province, that was, the intra-regional differences of the three sub-city groups determine the overall differences in Anhui Province. Looking at the Theil indices of each sub-region from 2011 to 2020 (Fig. 7b), the Theil indices of the three sub-city groups of Southern, Centra, and Northern Anhui showed the same dynamics as Anhui Province. According to the Theil index's mean value, Southern Anhui was the largest (0.02539), followed by Central Anhui (0.02077), and Northern Anhui was the smallest (0.01616). It can be noted that the primary reason for the IGDE discrepancy in Anhui Province is the internal difference in Southern Anhui. In Southern and Northern Anhui, the Theil index was relatively stable. Theil index in Central Anhui province fluctuates greatly, decreasing from 0.05441 in 2011 to 0.00013 in 2013, then increasing to 0.03334 in 2014. From 2014 to 2020, the Theil index in Central Anhui province decreased to 0.00035 in 2020. The IGDE of cities in Central Anhui showed the most apparent decrease among the study years.

Analyzing the input excess and output deficiency of inefficient DMUs in Anhui Province, the causes of its insufficient IGDE and targeted efficiency improvement suggestions. From 2011 to 2020, the IGDEs were in the "effective" state (IGDE≥1) in five cities: Bozhou, Suzhou, Fuyang, Lu'an, and Tongling, while they were in the "invalid" state (IGDE<1) in eleven cities: Hefei, Huaibei, Hengbu, Huainan, Chuzhou, Ma'anshan, Wuhu, Xuancheng, Chizhou, Anqing, and Huangshan. This paper explores the reasons for the inefficiency of these eleven cities from two perspectives: excess inputs and insufficient outputs. The over-input and under-output indicators of 3 urban agglomerations and 7 prefecture-level cities are shown in Fig. 9, respectively. The data below in bracket represents the rates of over-input and under-output.

(1) The lack of infrastructure (615.13%) is the main factor preventing IGDE in Anhui Province, followed by the level of medical care (189.15%), educational equity (123.08%), green status (111.33%), social security (107.7%), and capital investment (100.03%). Anhui Province maintains a higher level in the four areas of income distribution (13.97%), employment expansion (8.90%), pollutant emission (11.41%), and environmental management (5.99 %).

(2) The deficiency of IGDE in Southern Anhui is mainly due to educational equity (97.89%), medical level (74.28%), and infrastructure (59.31%). Wuhu, Ma'anshan, Huangshan, Tongling, Chizhou, and Xuancheng are among the ineffective cities in southern Anhui. The main reason for the low efficiency of IGDE in Wuhu and Maanshan is the lack of infrastructure, which accounts for 15.25% and 3.03%, respectively. Inadequate infrastructure (12.06%) and excessive capital investment (3.44%) are the main reasons for the inefficiency of Huagnshan's IGDE. The IGDE of Chizhou maintains a high level, but environmental management (2.56%) and resource input (2.12%) require improvement. Although the environmental governance in Xuancheng'IGDE is better than average, there are serious deficiencies in education equity (97.43%) and health care levels (70.11%), and the inputs of labor (30.4%), capital (47.15%), and resources (44.5%) are not adequately converted.

(3) The reasons for the lack of IGDE in Central Anhui are: infrastructure (210.23%)>medical level (99.00%)>social security (47.04%)>quality of economic development (42.13%). Looking specifically at the cities in its region, the infrastructure of Hefei City is

seriously insufficient (150.36%). The main elements of IGDE deficiency in Anqing are infrastructure (53.46%) and medical level (12.82%). Insufficient medical level (74.75%) and social security (42.39%) are the main reasons for the inefficiency of IGDE in Chuzhou.

(4) Infrastructure (345.59%), green status (74.7%), social security (33.93%), and number of economic growth (33.26%) are the causes of the lack of IGDE in Northern Anhui. Specifically, Bengbu's infrastructure (300.00%) and greening status (73.91%) are extremely lacking. Huainan and Huaibei have a better level of IGDE, with an infrastructure deficiency rate of 35.01% and 10.58%, respectively, which still require improvement.

Additionally, as mentioned in the previous article, the IGDEs of Hefei Anqing and Chuzhou in central Anhui dropped sharply in 2014. The reason can be found through the analysis of low-efficiency loss: In 2014, the insufficiency rates of infrastructure in Hefei and Anqing reached 531.76% and 215.43%, respectively, and the social security (114.11%) and medical level (113.62%) in Chuzhou were seriously lacking.

Discussion

The paper measures IGDE through the entropy weight TOPSIS method combined with the Super-SBM model, which, firstly, improves objectivity compared to using the entropy weight method [42, 60]; secondly, maintains the meaning of each indicator in its own right compared to using factor analysis and cluster analysis [19] ; and thirdly, compared to using simply the Super-SBM model [61], allows the article to select a more significant number of indicators and reduce the tolerance for error in the assessment. The measurement results show that "the IGDE of Anhui Province increased slightly from 2011 to 2013, decreased from 2013 to 2014, and increased steadily from 2014 to 2020," which is consistent with the conclusion of Cao (2022) [42] that "the inclusive green growth (IGG) of Anhui Province was at a medium stage from 2010 to 2015 and at a good stage from 2016 to 2018," which shows that the IGDE measure chosen in this paper is scientific and reasonable.

The research analyses and explores in more detail the causes of IGDE changes for time stage, sub-region, and even individual cities in Anhui Province. Compared to Gu (2021) [29] and Ge (2020) [30], which only explore the impact of economic policies and environmental regulation on IGDE, the paper's study of influencing factors includes macro (technological progress and technical efficiency) and micro (indicators such as social insurance), which is more comprehensive and specific. In particular, the article analyzes the causes of inefficiency losses in IGDE for each evaluation unit at the city and indicator levels. It is better able to pinpoint the areas of IGDE inefficiency in the province of Anhui than Cao (2022) [42], which evaluates the combined index values and changes of each subsystem and emphasizes the focus of the Anhui government in implementing measures to improve IGDE. However, the article's restriction prevents it from doing a vulnerability analysis of non-inefficient DMUs.

Conclusion and Suggestion

Conclusion

Based on clarifying the meaning of Inclusive Green Development Efficiency (IGDE) in cities, an index system that can completely express IGDE is constructed and then assessed using the Global-Super-SBM model. For the IGDE indices of 16 prefecture-level cities in Anhui Province from 2011 to 2020, we analyze the current situation in terms of dynamic evolution in the temporal dimension and pattern changes in the spatial dimension to deeply explore the problems existing in urban IGDE. We further explore three aspects of IGDE: dynamic evolution of structural drivers, sources of regional differences, and sources of inefficiency losses using the Global-Malmquist index, the Theil index, and the hyper redundancy index. Finally, we can get an effective way to improve IGDE in Anhui province. The major conclusions are as follows:

(1) From 2011 to 2020, 75.63% of DMUs in Anhui Province were in a sub-health state and above, which was generally a pretty safe state but still had numerous issues. The annual average value of IGDE in Anhui Province showed a small increase from 2011 to 2013, a sharp drop from 2013 to 2014, and a steady increase from 2014 to 2020. The average annual growth rate of IGDE in each sub-region: Central Anhui (3.75%) >Southern Anhui (1.73%)>Northern Anhui (1.39%). The Global-Malmquist index revealed that the increase in IGDE in Anhui Province was mostly due to technological progress, whereas its decline was primarily due to a decline in technological efficiency in central Anhui.

(2) From the perspective of spatial pattern, there was a gradient effect of IGDE in Anhui Province, and the relative gap of IGDE at the city scale demonstrated a convergence tendency. Theil index analysis revealed that intra-regional difference was the main reason for the difference in IGDE in Anhui Province, and the intra-regional difference was the largest in Southern Anhui, followed by Central Anhui, and the smallest in Northern Anhui. The regional differences of IGDE in Southern and Northern Anhui were relatively stable but fluctuated greatly in Central Anhui, which showed the most obvious decrease from 2011 to 2020. Thus, strengthening the IGDE of each sub-region, especially the intra-area variation in southern Anhui, was essential to enhancing the IGDE of Anhui Province.

(3) Looking at the influencing factors of IGDE in Anhui Province, educational opportunities, infrastructure, and medical level were the key factors

that cause low IGDE in Southern Anhui Province. The main reasons for the lack of IGDE in Central Anhui were the infrastructure and the medical level. The infrastructure and greening status in Northern Anhui still need to be improved. Bengbu and Xuancheng had the worst IGDEs. Specifically, there were obvious deficiencies in the level of education and medical treatment in Xuancheng. Bengbu's infrastructure and greening status were the main reasons for the low efficiency of IGDE.

Suggestion

Based on the conclusions above, in view of the reality of IGDE in Anhui Province and the path for effective improvement, the following policy suggestions are put forward:

Anhui provincial government needs to develop universal policies suitable for development across the region, to solve common regional problems. (1) Technological development is crucial for IGDE growth in Anhui Province, so the provincial government must increase the transfer of research talent, invest more in research funding, and explore new technologies to significantly increase green outcomes' transformation. Anhui Province is now technologically inefficient. It is critical to enhancing the coordination of many resource factors to accomplish a positive transformation of water, power, and energy resource inputs to optimize production efficiency given the available technology. (2) Anhui Province focuses on three dimensions: firstly, strengthening infrastructures such as transportation and communication; secondly, increasing the number of medical personnel and equipment and improving the quality of medical services; and thirdly, boosting investment in education, responsibly allocating educational resources rationally, and expanding access to education.

Regional governments should develop IGDE enhancement policies that meet local needs. (1) Southern Anhui has the most prominent regional disparity in IGDE. Cities with better IGDE (Tongling, Ma'anshan, and Chizhou) should highlight their local characteristics and play the role of area radiation to drive the expected improvement of their neighboring cities with poor IGDE (Xuancheng, Huangshan, and Wuhu). (2) Central Anhui region is a crucial area of concern for Anhui province, with an overall IGDE at a relatively poor level and fluctuating, so it should focus on infrastructure development and the level of medical services and regularly assess the IGDE in the region to determine whether the corresponding measures are effective. (3) Northern Anhui region should give full play to its geographical advantages, actively carry out a green transfer of industries, strengthen ecological and environmental protection based on its resource-carrying and environmental capacity, and focus on improving infrastructure construction and greening status of Bengbu city. (4) Anhui Province should increase cooperation and exchange with cities in neighboring provinces to share resources and complementary advantages.

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Conflict of Interest

The authors declare no conflict of interest.

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