The Dynamic Coupling Nexus Among Inclusive Green Growth: A Case Study in Western Yangtze River Delta of China

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Research Article

Keywords: inclusive green growth, coupling coordination degree, entropy weight, obstacle factor

Posted Date: November 17th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1050844/v1>

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The dynamic coupling nexus among Inclusive Green Growth: A case study in western Yangtze River Delta of China

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Abstract

Inclusive Green growth (IGG) offers an effective alternative to pursue sustainable development. The core of the IGG system lies in the coordination of inclusive, green, and growth subsystems. However, there is little quantitative assessment on IGG based on subsystem collaboration. This paper explores the dynamic coupling IGG nexus in western Yangtze River Delta of China from 2009 to 2018, by using the entropy weight approach (EWA), coupling coordination degree model (CCDM) and obstacle factor diagnostic model (OFDM). The results show that: (1) The integrated approach can allow assessment of the spatiotemporal dynamic coupling nexus of IGG subsystems; (2) At the provincial level, a relatively high IGG performance and a low coupling coordination degree (CCD) of the IGG nexus are seen. The impact of indicators on the coordinated development of IGG can be divided into two stages; (3) At the prefectural level, the cities in which CCD is rising outnumber those it is falling. However, the CCD is also low, and the gap among the regions is getting wider. The obstacles that affect the CCD of cities see a dynamic evolution trend from “inclusive obstacle type” to “inclusive and growth obstacle type” then to “green obstacle type” over the decade.

Keywords: inclusive green growth. coupling coordination degree. entropy weight. obstacle factor

1. Introduction

The term “inclusive green growth (IGG)” was first put forward at the Rio +20 summit in 2012 (G. Chen, Yang, & Chen, 2020). It is a continuation and extension of the concept of sustainable development (Sun, Ding, Yang, Yang, & Du, 2020), emphasizing the symbiosis of inclusive, green, and growth subsystems. As an organic combination of green growth and inclusive growth, this novel development mode enables more countries and regions to embark on the path toward more effective sustainable development (Cooper et al., 2020). The performance improvement of a regional inclusive green growth system depends on the organic synergy of each subsystem. Therefore, the coordinated development of the three subsystems, namely inclusive, green, and growth, is a significant prerequisite for achieving the goals of IGG. This idea not only guides countries to explore a new path of sustainable development, especially developing countries that need to solve the problem of imbalanced development, but also attracts wide attention from academia and local governments (G. Chen et al., 2020; Cooper et al., 2020; Sun et al., 2020). It is urgent and necessary to improve the coordinated development of the IGG subsystems.

China is now at a crucial point in its developmental history. Its economy has accomplished remarkable achievements at the expense of enormous social and environmental costs (Sun et al., 2020). On the one hand, the extensive pattern of high input, high consumption, high pollution, and low efficiency has resulted in natural resource depletion, environmental pollution and ecological damage; on the other hand, the rapid economic growth process has also brought about social problems, such as disproportionate urbanization, insufficient housing security, problems accessing welfare, aging demographics, widespread unemployment, poor food safety, education inequity, leading to a widening income gap and inequitable sharing of the prosperity (Li & Yi, 2020). Economic growth has become inseparable from social development and environmental quality in China. The lack of balance among subsystems has resulted in significant inefficiency for these regional development systems. Hence, it is crucial for governments, academia, and individuals to maintain balance among inclusive, green, and growth and promoting IGG.

The dynamic and complex IGG subsystems are not independent of each other, instead they are inextricably interrelated and interconnected. The coordinated development can be divided into two categories: the peripheral and core coordination development. The peripheral studies address the coordination among the IGG system and other systems, such as the relationships between IGG and technology innovation, openness, and urbanization. The core studies cover the coordination among IGG subsystems. This study focuses on the core nexus.

Although a large number of scholars have worked on inclusive growth (Ge & Li, 2020; Ge, Qiu, Li, & Hao, 2020; Schoneveld, 2020), green growth (Islam & Zhang, 2017; J. Wang et al., 2021), and green economy (Shi, Yang, Wang, & Zhao, 2016; Godlewska & Sidorczuk-Pietraszko, 2019; Merino-Saum, Clement, Wyss, & Baldi, 2020; Shuai & Fan, 2020; Zhu, Liang, & Liu, 2020). IGG is a complex and dynamic system, few institutions are dedicated to measuring the IGG Index, and even fewer studies have been conducted on the dynamic coupling nexus based on subsystem collaboration. Consequently, the contribution of the study is threefold: (1) In terms of the perspective, we assess IGG based on subsystem collaboration. (2) In terms of the method, owing to the complex dynamic characteristics of the IGG system, an integrated approach is adopted. (3) In terms of the content, we not only explore the spatiotemporal evolution and the coupling nexus under different scenarios, but also identify the obstacle factors.

The remainder of the article is organized as follows. In the next section, a brief review of literature on IGG will be elaborated. Section 3 presents the study area and data sources of this study. Section 4 outlines the construction of evaluation index system, the entropy weight approach, the coupling coordination model, and the obstacle factor degree model. Section 5 reports the findings and

discussions. Section 6 provides a conclusion on coupling nexus of IGG improvement in western Yangtze River Delta.

2. Literature Review

Researchers working on IGG focus mainly on three aspects. In the context of the definition of IGG, the World Bank (WB) defined IGG as a sustainable economic growth pattern of social equity, environment friendly, and economic sustainability (Word Bank, 2012). The Organization for Economic Cooperation and Development (OECD) believed that IGG provided a realistic pathway to countries in pursuit of the economic growth going inclusive and green (OECD, 2012). The United Nations Environment Programme (UNEP) argued that IGG consisted of three pillars: the sustainability of society, environment, and economy. Most scholars suggested that IGG should balance three subsystems of inclusive, green, and growth (Nag, 2006; Word Bank, 2012; Albagoury, 2016; Gao, Zhang, & Zheng, 2021).

The assessment of IGG includes a single indicator measurement and multidimensional comprehensive evaluation. Based on the neoclassical growth theory, many scholars adopt green total factor productivity to measure IGG (Ai, Hu, & Li, 2021; Färe, 2001; Gao et al., 2021; Liu, Hou, Gao, & Tan, 2020; Yang, Jia, & Yang, 2021). However, using a single index evaluation (SIE) has a drawback in that it cannot reveal the multi-dimensional and comprehensive characteristics of IGG. Therefore, constructing a multi-dimensional indicator evaluation (MIE) has become the most mainstream method. To visually compare the current measurement studies of IGG, Table 1 provides a comparison of the studies. (Yang, 2014; Zhou et al., 2018; S. Zhu & Ye, 2018; Wu & Zhou 2019; Chen et al., 2020; Sun et al., 2020).

Table 1. Measurement and assessment of inclusive green growth (IGG).

Authors	Publication year	Study area and times	Indicators	Assessment method
Zhu, S.P., & Ye, A.	2018	30 provinces of China (2000-2015)	6 indicators (Labor; capital; energy; GDP; income disparity; environment pollution)	super-efficiency slack-based measure (SIE)
Sun, Y.H., Ding, W.W., et al	2020	285 cities of China (2003-2015)	Input and output indicators	slacks-based measure (SIE)
Chen, G.N., Yang, Z.H., & Chen, S.H.	2020	Yangtze River Economic Belt 108 cities (2003-2016)	8 indicators (Capital; labor; land; energy; GDP per capita; afforestation; air pollution; waste pollution)	super-efficiency slack-based measure model and MML index (SIE)
Yang, X.X.	2014	G20 countries (2010)	6 indicators (per capita CO ₂ emissions; Gini coefficient; per capita GNP; net ecological footprint; savings rate; Investment in clean energy)	Average weight method (MIE)
Zhou, X.L., Wu, W.L., & Liao, D.	2018	30 provinces of China (2001-2014)	5 dimensions, 19 indicators (GDP per capita; urbanization rate; divorce rate; registered urban unemployment rate; population density; SO ₂ emissions per capita GDP; green space per capita, et al	Entropy method (MIE)
Wu, W., & Zhou, X.	2019	30 provinces of China (2000-2015)	4 dimensions, 26 indicators (GDP per capita; secondary sector ratio; smoke dust emissions GDP per capita; green space per capita; per capita income ratio of urban-rural residents; registered urban unemployment rate, et al	Entropy method (MIE)

The third perspective of extant studies concerns the factors that affect regional IGG. Zhu Songping established an IGG index by utilizing the super efficiency Slack-Based Measure model and explored the impact of foreign direct investment (FDI) on IGG based on comparing among four-dimensional factor productivities in China, revealing FDI as a positive factor in promoting the inclusive green total factor productivity (Zhu & Ye, 2018).

Coordinated coupling development is a kind of development aggregation, which emphasizes the integrity, comprehensiveness, and endogeneity, and it is not the growth of a single system, but the integrated development of multiple systems or elements under a beneficial restriction and regulation (Liao, Z.B., 1996). Coupling coordination degree model (CCDM) has been employed widely in studies on energy efficiency and industrial structure (X. Wang, Song, & Duan, 2021), innovation and economic development (Y. Chen & Zhang, 2021), economy-environment-tourism system (Fei et al., 2021), urbanization and ecological energy efficiency (Ren & Yu, 2021), land use multifunctionality (Evidence & Basin, 2021), social economy and ecological environment (Fan, Fang, & Zhang, 2019), and so on. However, few researchers have concentrated on the IGG.

To summarize, many scholars have investigated the green economy, green growth, and inclusive growth, as well as the factors of IGG, which provides theoretical and practical references for further study. First, the extant research on the IGG was focused

mainly on the peripheral nexus. The core nexus and multisystem interactivity is yet to receive adequate attention. Secondly, the research object mostly aimed at the national or provincial level, but rarely conducted multidimensional measurement analysis on both the provincial and prefectural levels combined with the regional characteristic. Thirdly, most of the existing studies focused on the change of temporal dimension, but less on the evolution of spatial dimension. Hence, using an integrated approach—namely the entropy weight approach (EWA), CCDM, and obstacle factor diagnostic model (OFDM)—this paper explores the interaction and spatiotemporal dynamic coupling nexus among subsystems of IGG based on the panel data for Anhui province, China over the decade spanning 2009–2018. The purpose of the study is threefold: (1) to construct an evaluation index system and assess the performance of IGG at the provincial and prefectural level, respectively; (2) to identify the types and stages of coupling coordination degree (CCD) and analyze the changes of representative cities; (3) to diagnose the obstacle factors of CCD for proposing targeted recommendations of regional policy making.

3. Study Area and Data Sources

3.1. Study Area

The western Yangtze River Delta is located in the central mainland of China, which is named by Anhui province and consists of 16 cities. Its development is under the guidance of two strategic policies. One is the Rising of Central China Strategy, which is a major plan of the state to promote the rise of the six central provinces (the remaining five provinces are marked in orange), another regional coordinated development strategy promoted from a high position following Western Development Strategy and Revitalization of Northeast China Strategy. The other is the Regional Integration Development Planning of Yangtze River Delta, one of the world-class urban agglomerations. The locations of the cities are graphically illustrated in Figure 1, and Table 2 shows the brief profiles of the 16 cities.

Figure 1. Location of the 16 cities of Anhui province (the western Yangtze River Delta), China: (a) China; (b) Location of Anhui province in central China and the Yangtze River Delta; (c) The 16 cities of Anhui province.

The western Yangtze River Delta covers an area of 140,139 km² (National Bureau of Statistics, 2019), which comprises one capital city, namely Hefei, and 15 prefecture-level cities, namely Huaibei, Bozhou, Suzhou, Bengbu, Fuyang, Huainan, Chuzhou, Lu'an, Ma'anshan, Wuhu, Xuancheng, Tongling, Chizhou, Anqing, and Huangshan. In 2018, Anhui province had approximately 63.24 million people; GDP exceeded 3 trillion yuan for the first time (State Statistical Bureau, 2019), with an annual rate of 8.02 %, and the output value of high-tech enterprises exceeded 1 trillion yuan for the first time. Over a 15-year period, Anhui's GDP increased from 481.27 billion yuan in 2004 to 3,000.682 billion yuan in 2018, with a total growth rate of 523.49 % and an average annual growth rate of 34.9 %. Besides, the percentage of forest coverage accounted for 28.7% (National Bureau of Statistics, 2019).

Table 2. Specifications of the 16 cities in the western Yangtze River Delta, China, in 2018.

Cities	Areas (km ²)	Resident Population (10,000 people)	Urbanization rate (%)	Per-capita GDP (Yuan)
Hefei	11445	808.74	74.97	96730
Huaibei	2741	225.41	65.11	43707
Bozhou	8521	523.72	41.01	24387
Suzhou	9939	568.14	42.74	28694
Bengbu	5951	339.20	57.22	50550
Fuyang	10118	820.72	43.29	21439

Cities	Areas (km ²)	Resident Population (10,000 people)	Urbanization rate (%)	Per-capita GDP (Yuan)
Huainan	5532	348.95	64.11	32478
Chuzhou	13516	411.42	53.42	43793
Liuan	15451	483.74	46.08	26627
Ma'anshan	4049	233.71	68.25	82072
Wuhu	6026	374.82	65.54	87469
Xuancheng	12313	264.83	55.21	49738
Tongling	2923	162.91	55.99	75033
Chizhou	8399	147.45	54.10	46452
Anqing	13538	469.13	49.22	40875
Huangshan	9678	140.71	51.46	48178

3.2. Data Sources

The data is retrieved from Sate statistical Yearbook (2010-2019), Anhui Statistical Yearbook (2010-2019). Evaluation indicators are selected composite indicators that are calculated, such as: selecting fixed asset investment per unit of GDP rather than fixed asset investment and selecting the number of books in the library per 100 people rather than the library stock, which are more accurate for expressing the index considering the factors of regional population difference.

4. Methodology

4.1. Construction of Evaluation Index System

The IGG evaluation index system, made up of 27 indicators from three dimensions of inclusive, green, and growth, is established and listed in Table 3. In the construction of evaluation, we first draw on the conceptual framework of IGG reported by the WB (Word Bank, 2012) and the OECD (OECD, 2012), the inclusive, green economy indicators launched by the UNEP, the typical assessment indicator systems for green development or green growth, such as the Global Green Growth Institute(Global Green Growth Institute, 2019). We then combine an in-depth analysis of the green development of Chinese institutions such as, Chinese Academy of Sciences, Beijing Normal University, National Bureau of Statistics (Sustainable Development Strategy Study Group, 2012; Beijing Normal University, 2016; National Bureau of Statistics, 2017), and relevant scholars (Färe, R et al., 2001; Zhou et al., 2018; S. Zhu & Ye, 2018). Meanwhile, the index system also considers the respective aspects of comprehensiveness, availability, and representativeness of data and the practice of IGG in Anhui province and the 16 cities (Reid et al., 2010).

The goal of IGG is to seek overall social equality and inclusion, including not only achieving the equality of education and medical condition, as well as shared cultural resources, but also increasing the equality of opportunity in employment and narrowing the income gap. IGG should not only improve people's living space and quality of life, but also enhance food security and social stability. In this study, the inclusive subsystem is described by equality of education and medical condition and sharing culture resources (C_1 , C_2 , and C_3), the status of employment and income gap (C_4 and C_5), living space and quality of life (C_6 and C_7), and food security and social stability (C_8 and C_9).

The selection of indicators of the green subsystem is based on the classic framework of the PSR model (pressure-state-response) (OECD, 1993). C_{10} , C_{11} , and C_{12} indicate the pressure on the ecological environment from the aspects of solid, liquid, and gas, respectively; C_{13} , C_{14} , and C_{15} signify the state of the ecological environment; C_{16} , C_{17} , and C_{18} are selected to reflect the response to the environment. Furthermore, the green subsystem covers as many kinds of environment-related forms as possible such as solid, liquid, gas, and noise, and is complete in covering not only urban but also rural areas.

Both resource conservation and environmental friendliness together constitute the growth subsystem. C_{19} , C_{20} , C_{21} , C_{22} , C_{23} and C_{24} symbolize the resources consumption and costs of creating GDP. C_{25} , C_{26} , and C_{27} are chosen as cost indicators for pollutant emission.

Table 3. Indicator system of inclusive green growth.

Subsystems	[Code]Criteria(unit)	Property
Inclusive Subsystem (Inc)	[C_1]Library books per 100 persons (ben / 100 persons)	benefit
	[C_2]10,000 people with college degrees or above (per 10,000 persons)	benefit
	[C_3]Number of beds per 1,000 persons (per 1,000 persons)	benefit
	[C_4]Registered urban unemployment rate (%)	cost
	[C_5]Disposable income per capita between urban and rural residents (%)	cost
	[C_6]Urban population density (person / km ²)	cost
	[C_7]Per capita housing gross leasable area (m ²)	benefit
	[C_8]Amount of fertilizer per unit cultivated area (kg / hm ²)	cost
	[C_9]Incidence of population fires (1 in 100,000)	cost
Green	[C_{10}]Industrial Solid waste production (million tons)	cost

Subsystems	[Code]Criteria(unit)	Property
Subsystem (<i>Gre</i>)	[<i>C</i> ₁₁]Discharge of COD in industrial wastewater (tons)	cost
	[<i>C</i> ₁₂]Industrial SO ₂ emissions (tons)	cost
	[<i>C</i> ₁₃]Proportion of air quality reaching or better than grade 2 weather (%)	benefit
	[<i>C</i> ₁₄]Per capita green area of parks (m ²)	benefit
	[<i>C</i> ₁₅]Average traffic volume (car/ hour)	cost
	[<i>C</i> ₁₆]Central processing rate of sewage treatment plant in urban areas (%)	benefit
	[<i>C</i> ₁₇]Popularity rate of sanitation toilet in rural areas (%)	benefit
	[<i>C</i> ₁₈]Per capita afforestation area (m ² /person)	benefit
Growth Subsystem (<i>Gro</i>)	[<i>C</i> ₁₉]Fixed asset investment per unit of GDP (yuan)	cost
	[<i>C</i> ₂₀]Secondary sector Land yield (yuan/m ²)	benefit
	[<i>C</i> ₂₁]Tertiary sector Labor productivity (10,000 yuan/person)	benefit
	[<i>C</i> ₂₂]Water consumption per unit of GDP (m ³ /1,000 yuan)	cost
	[<i>C</i> ₂₃]Power consumption per unit of GDP (watt yuan)	cost
	[<i>C</i> ₂₄]Energy consumption per unit of industrial added value (ton standard coal / 10,000 yuan)	cost
	[<i>C</i> ₂₅]Industrial waste water discharge per unit of GDP (ton /10,000 yuan)	cost
	[<i>C</i> ₂₆]Industrial waste gas emission per unit of GDP (m ³ /yuan)	cost
	[<i>C</i> ₂₇]Solid waste generation per unit of GDP (tons / yuan)	cost

4.2. Entropy Weight Approach (EWA)

The accuracy of measurement of regional IGG is strongly linked to the objectivity of the weight selection method. Entropy initially originated from a physical concept of thermodynamics and was subsequently applied into information theory (D. Wang, Jiang, Fu, & Lin, n.d., 2020). EWA, widely employed in studies on the progress of indicator assessment, is an objective weighting method, which can determine the weight value of indicators objectively and reveal the real information of indicators. The advantage of the method is that it can overcome the overlap of information among multidimensional variables, therefore describing objectively the nature of the indicators (Ye, 2010). Compared with the subjective weighting methods—Analytic Hierarchy Process and Delphi method—the accuracy and reliability of the assessment can be improved. Furthermore, it is not limited by the number of indicators. Research progress is as follows:

Step 1: Construct the standardized evaluation matrix.

Set the initial evaluation matrix of Anhui IGG as:

$$y = (p_{ij})_{mn}, i = 1, 2, \dots, m, j = 1, 2, \dots, n \quad (1)$$

Step 2: Normalize the initial matrix (dimensionless), and get the new matrix (Grimm et al., 2008):

$$y' = (p'_{ij})_{mn} \quad (2)$$

Among all the improved entropy weight methods, the extremum entropy weight method is the best (Zhu, X., & Wei, G., 2015). Consequently, this paper uses this method to normalize the initial matrix. The formula is as follows:

For the benefit (positive) indicator (the bigger the indicator, the better)

$$p'_{ij} = \frac{p_{ij} - \min(p_{ij})}{\max(p_{ij}) - \min(p_{ij})} \quad (3)$$

For the cost (negative) indicator (the smaller the indicator, the better):

$$p'_{ij} = \frac{\max(p_{ij}) - p_{ij}}{\max(p_{ij}) - \min(p_{ij})} \quad (4)$$

Among the formula, $\max(p_{ij})$ and $\min(p_{ij})$ are respectively the maximum and minimum of the first indicator, p_{ij} is the original indicator, and p'_{ij} is the normalized indicator.

Step 3: Calculate the information entropy and the weight of each index.

Calculate the information entropy of each index:

$$e_i = -\frac{1}{\ln n} \sum_{j=1}^n p'_{ij} \ln p'_{ij} \quad (5)$$

Calculate the weight of each index:

$$w_i = \frac{1 - e_i}{m - \sum_{i=1}^m e_i}, \text{ and } e_i \geq 0 \quad (6)$$

Step 4: Construct the evaluation matrix based on the entropy weights.

Use the entropy weight to construct the weighted standardized evaluation matrix. The specific formula is as follows (Petković, Hartman, & Pavelka, 2020):

$$V = v_{ij} = w_i (p'_{ij})_{mn} \quad (7)$$

4.3. Coupling Coordination Degree model (CCDM)

CCDM can be applied to measure the coupling degree between two or more systems, which is based on the concept and principle of coupling in physics and reflects the relationship between coordination and benign cycle. The coupling degree is a measurement of the strength of the interactions among the subsystems. Inspired by the dispersion coefficient, Liao proposed the mathematical formula of CCDM (Liao, Z.B., 1996), but it is confined to the coupling between two systems. Huo and Jiang improved and extended it to three or more systems (Huo Y., 2012; Jiang, L.; Bai, L.; Wu, Y.M., 2017). This paper introduces inclusive, green, and growth subsystems to measure the interaction and CCD among three subsystems in IGG. CCDM includes coupling degree and CCD. We consider the comprehensive level index of inclusive, green, and growth subsystems as *Inc*, *Gre*, and *Gro*, respectively. The specific calculation steps are as follows:

Step 1: Build a coupling model:

$$C = \sqrt[3]{\frac{Inc \times Gre \times Gro}{((Inc + Gre + Gro)/3)^3}} \quad (8)$$

Step 2: Calculate compatibility index:

$$T = \alpha Inc + \beta Gre + \gamma Gro \quad (9)$$

Step 3: Calculate the CDD:

$$D = \sqrt{C \times T} \quad (10)$$

In the equation, D is the coordination degree, C is the coupling degree, and α , β , and γ are the undetermined coefficients. Because the three monomial subsystems are of equal importance, α , β , and γ are all assigned as $1/3$. For coupling degree $C = 0$, the coupling degree among the subsystems is the smallest, which indicates that the cooperation among the elements of the systems is disordered and in a maladjusted or irrelevant state. For coupling degree $C = 1$, the coupling degree among the systems is the largest, which points to all the elements of the systems being harmonious and orderly, reaching the optimal state of benign interaction (Hui, Wu, Deng, & Zheng, 2015).

Inc, *Gre*, and *Gro* represent the level indices of the inclusive, green, and growth subsystem, respectively. Table 4 shows the coordination types and level classes of CCD to clearly demonstrate the coordination among the subsystems of IGG, based on previous research (Hui, Wu, Deng, & Zheng, 2015; Fei et al., 2021).

Table 4. Evaluation criteria for coordination types and level classes of CCD.

Serial Number	Coupling Coordination Index Interval	Coordination Type	Level Class
1	$0.0 \leq D < 0.1$	Extreme imbalance (F_1)	Germination stage (S_1)
2	$0.1 \leq D < 0.2$	Severe imbalance (F_2)	
3	$0.2 \leq D < 0.3$	Moderate imbalance (F_3)	
4	$0.3 \leq D < 0.4$	Mild imbalance (F_4)	
5	$0.4 \leq D < 0.5$	Little imbalance (F_5)	Start stage (S_2)
6	$0.5 \leq D < 0.6$	Barely coordination (F_6)	
7	$0.6 \leq D < 0.7$	Primary coordination (F_7)	Steady stage (S_3)
8	$0.7 \leq D < 0.8$	Intermediate coordination (F_8)	
9	$0.8 \leq D < 0.9$	Good coordination (F_9)	Maturity stage (S_4)
10	$0.9 \leq D < 1.0$	Excellent coordination (F_{10})	

4.4. The Obstacle Factor Diagnostic Model (OFDM)

To further clarify the focal point and the policy adjustment direction of the future development of Anhui IGG, the OFDM is applied to diagnose and analyze the impact factors. The structure of the model is as follows:

$$O_i = D_i \times C_i = D_i \times \omega_i = \frac{(1 - p'_{ij}) \times \omega_i \times 100\%}{\sum_{i=1}^m (1 - p'_{ij}) \times \omega_i} \quad (11)$$

In the formula, we introduce three main variables: obstacle degree, index deviation degree, and factor contribution degree (Ou, Zhu, & Sun, 2017). Obstacle degree (O_i) denotes the obstacle degree of the subsystem indexes or an individual index to the CCD of the regional IGG, which highlights the impact degree of a subsystem or an individual index on the coupling coordination level of the regional IGG. Index deviation degree (D_i) represents the gap between the actual value and the optimal target value, which is expressed by the difference value between the evaluation standardized value of each index (p'_{ij}) and the optimal target value (100%). Factor contribution degree (C_i) signifies the contribution value of an individual factor (P_i) to the overall target, which can usually be expressed by the indicator weight (ω_i).

5. Results and Discussions

5.1. Dynamic Coupling of IGG Nexus at Provincial Level

This part focuses on three key areas: (1) the performance of inclusive, green, and growth subsystems; (2) the CCD and types/stages of IGG nexus; (3) obstacle factors of IGG nexus.

5.1.1. The Evolution of the IGG Performance

Based on the assessment index system and measurement model of regional IGG, Table 5 presents the information entropy and weight values of each index, which are obtained according to formulas (3) and (4) after normalization of the original data.

As can be seen from the weights for each subsystem at the provincial level, the figure for the inclusive subsystem sees the biggest proportion at 40.29%, followed by the green subsystem, which stands at 32.39%, with the growth subsystem only accounting for 27.32%. This finding furnishes evidence that the inclusive subsystem makes a greater contribution to the IGG, which highlights an important constraint for promoting the development goal of IGG. Additionally, it also lets us conclude that Anhui province made great efforts in social inclusive development, but still needs to strengthen its promotion of sustainable economic growth on the premise of saving resources and reducing pollutant emissions.

Table 5. Entropy values and weights of indicators at the provincial level.

Inclusive	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	Proportion
Entropy	0.876	0.865	0.833	0.891	0.887	0.887	0.913	0.822	0.880	—
Weight	0.044	0.047	0.059	0.038	0.04	0.04	0.031	0.063	0.042	40.29
Green	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	Proportion
Entropy	0.843	0.890	0.952	0.895	0.940	0.861	0.933	0.873	0.890	—
Weight	0.055	0.039	0.017	0.037	0.021	0.049	0.023	0.044	0.039	32.39
Growth	C_{19}	C_{20}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{27}	Proportion
Entropy	0.806	0.907	0.852	0.939	0.945	0.939	0.929	0.954	0.951	—
Weight	0.068	0.033	0.052	0.022	0.019	0.021	0.025	0.016	0.017	27.32

Table 6 gives information that the IGG index in Anhui province was generally growing from 2009–2018 and the overall performance increased gradually from 0.2909 to 0.7098, with an average annual growth of 10.42%, indicating that IGG had a good momentum of development. Based on the scores of IGG performance, the process of IGG in Anhui province has gone through three stages—the poor performance stage, medium performance stage, and good performance stage—however it has not achieved the high-quality development stage, demonstrating that there is still great development potential and growth space. In the first stage (2009), the condition was relatively poor. The overall performance was merely 0.29; social inclusion, environmental green, and economic growth were all at low levels.

In the second stage (2010–2015), the overall performance of IGG in Anhui province was in the medium stage, and the largest score was 0.5651. Two opportunities have effectively promoted the IGG development of Anhui province. One is the active implementation of a national development strategy, “Wanjiang city belt undertaking industrial transfer demonstration zone plan,” since 2010, the only regional development program with the theme of industrial transfer in China. The other is guidelines issued by the State Council to promote the development of the Yangtze River economic belt relying on the golden waterway in 2014, and Anhui is incorporated into the Yangtze River economic belt.

In the third stage (2016–2018), the overall performance was in the good stage, reaching a peak at 0.7098 in 2018. The economy of resources, environmental friendliness, social equality, and sustainable economic growth saw steady increases, indicating the IGG of Anhui province presented a gradually increasing trend toward an ideal situation. This finding is closely related to the development plan for the Yangtze River Delta urban agglomeration adopted by the China State Council executive meeting in 2016, with Anhui being included in the Yangtze River Delta economic zone and participating in the integrated development of the Yangtze River Delta. The plan provides a novel path to advance the transformation of the economic growth mode from high input, high consumption, high pollution, and low benefit to ecologically prioritized, green-development-oriented, high-quality development.

Table 6. Overall and subsystem performances of IGG at provincial level (2009–2018).

Years	<i>Inc</i> performance	<i>Gre</i> performance	<i>Gro</i> performance	Overall performance
2009	0.0979	0.1456	0.0474	0.2909
2010	0.1039	0.1271	0.1026	0.3336
2011	0.1217	0.1453	0.1521	0.4191
2012	0.1470	0.1285	0.1672	0.4427
2013	0.1693	0.1512	0.1272	0.4477
2014	0.1849	0.1605	0.1529	0.4982
2015	0.2334	0.1492	0.1825	0.5651
2016	0.2648	0.1843	0.1681	0.6171
2017	0.2911	0.1978	0.1882	0.6771
2018	0.3109	0.2015	0.1973	0.7098

The performances of subsystems also generally saw an upward trend in the last 10 years, among which the inclusive subsystem had the highest-rising speed and the largest increment, from 0.0979 in 2009 to 0.3109 in 2018, with an increment of more than 0.2.

Although the growth and green subsystems had slight fluctuations in individual years, the whole tendency in 10 years were increasing, with an increment of approximately 0.15 and 0.056, respectively. This shows that the three subsystems of inclusive, green and growth in Anhui province are unevenly distributed.

In short, Anhui province must constantly coordinate the nexus among the subsystems of inclusive, green and growth. Although improving the performances of the three subsystems is important to improve the integrated performance of the IGG nexus, the subsystem with the lower performance, green subsystem, and growth subsystem, should be given more attention.

5.1.2. The CCD of IGG Nexus

Table 7 presents the CCD of IGG nexus in Anhui province under different scenarios, and the coordination types are classified according to the classification principle (Table 4). The finding indicates that the CCD is increasing; however, the value is extremely low, approximately clustering between 0.13 and 0.36, and the highest value is merely 0.356, which has not yet crossed the germination stage (S_1).

Table 7. Types/ Degrees of the coordinated development among subsystems at the provincial level under different scenarios.

Years	<i>Inc – Gre</i>		<i>Inc – Gro</i>		<i>Gre – Gro</i>		<i>Inc – Gre – Gro</i>	
	D_1	Type	D_2	Type	D_3	Type	D_4	Type
2009	0.2041	F ₃	0.1355	F ₂	0.1607	F ₂	0.1361	F ₂
2010	0.1976	F ₂	0.1821	F ₂	0.1967	F ₂	0.1599	F ₂
2011	0.2204	F ₃	0.2244	F ₃	0.2394	F ₃	0.1935	F ₂
2012	0.2259	F ₃	0.2493	F ₃	0.2374	F ₃	0.2024	F ₃
2013	0.2531	F ₃	0.2377	F ₃	0.2274	F ₃	0.2042	F ₃
2014	0.2675	F ₃	0.2628	F ₃	0.2490	F ₃	0.2236	F ₃
2015	0.2857	F ₃	0.3068	F ₄	0.2592	F ₃	0.2467	F ₃
2016	0.3235	F ₄	0.3133	F ₄	0.2718	F ₃	0.2651	F ₃
2017	0.3444	F ₄	0.3385	F ₄	0.2911	F ₃	0.2864	F ₃
2018	0.3560	F ₄	0.3534	F ₄	0.2984	F ₃	0.2974	F ₃

Figure 2 demonstrates the temporal evolution for the CCD of IGG nexus in Anhui province. The CCD among three subsystems (D_4) is generally less than that between two ones (D_1 , D_2 and D_3), which means the subsystems among the three elements are less harmonious and coherent. The rank of the increment over the decade is Inclusive-Growth (D_2) > Inclusive-Green-Growth (D_4) > Inclusive-Green (D_1) > Green-Growth (D_3). The annual growth rate is D_2 (11.24%) > D_4 (9.07%) > D_3 (7.12%) > D_1 (6.37%). In 2018, the CCD of D_1 and D_2 , D_3 , and D_4 were roughly similar and were maintained at around 0.35 and 0.3 respectively.

Figure 2. The temporal evolution for the CCD of IGG nexus at provincial level (2009–2018).

In short, the subsystems show a slight increase in symbiosis and integration, but there is still great room for improvement.

5.1.3. Obstacle Factors

According to Equation (4), the obstacle degrees (ODs), and the obstacle factors (OFs) affecting the coordinated development of IGG in Anhui Province are obtained, and 5 indicators with the largest ODs are selected and arrange from left to right, as illustrated in Table 8.

Table 8. OFs/ODs of coupling IGG nexus in Anhui province for 2009–2018.

Year	Categories	Order					Year	Categories	Order				
		1	2	3	4	5			1	2	3	4	5
2009	ODs /%	8.18	7.26	6.79	6.71	6.61	2014	ODs /%	9.41	8.29	8.15	8.02	7.57
	OFs	C_3	C_{21}	C_8	C_{19}	C_2		OFs	C_{19}	C_3	C_{10}	C_9	C_{21}
2010	ODs /%	8.19	7.75	6.68	6.48	6.42	2015	ODs /%	14.11	12.26	9.16	7.42	6.30
	OFs	C_3	C_8	C_{21}	C_{19}	C_{15}		OFs	C_{19}	C_{10}	C_3	C_9	C_6
2011	ODs /%	9.87	9.14	7.77	6.67	6.67	2016	ODs /%	17.56	12.97	10.01	7.90	7.28
	OFs	C_8	C_3	C_{21}	C_5	C_2		OFs	C_{19}	C_{10}	C_3	C_6	C_9
2012	ODs /%	10.63	8.81	8.23	7.62	7.33	2017	ODs /%	19.67	13.28	11.38	10.71	10.46
	OFs	C_8	C_3	C_{15}	C_{10}	C_{21}		OFs	C_{19}	C_{10}	C_{13}	C_6	C_3
2013	ODs /%	11.05	8.63	7.44	6.77	6.70	2018	ODs /%	22.35	13.74	13.50	13.15	10.88
	OFs	C_8	C_{15}	C_{10}	C_9	C_2		OFs	C_{19}	C_6	C_{10}	C_3	C_{13}

The results are as follows: from the top 5 OFs and ODs of each index, in 2013 and earlier, the main obstacles to the coordinated development of IGG are C_3 , C_8 , and C_{21} . After 2014, the main obstacle indexes of the coordinated development of IGG include C_{19} , C_{10} , and C_3 . Therefore, the impact of each index on the coordinated development of IGG can be divided into two stages: the first stage (2009–2013) is dominated by the inclusive subsystem (C_3 and C_8), which is the largest impact factor; in the second stage (2014–2018), the growth subsystem (C_{19}) occupied the first place, and the green subsystem (C_{10}) also began to occupy the main position.

In addition, C_3 has consistently achieved the important position in most years, indicating that the equal access to medical resources has always been the main obstacle index of IGG in Anhui province.

According to the ODs of the three subsystems in the analyzed years (Appendix Table A1), the obstacles belonging to the inclusive subsystem and growth subsystem, especially the inclusive subsystem, are generally becoming smaller, while conversely, the ones in the green subsystem are on the top.

5.2. Dynamic Coupling IGG Nexus at Prefectural Level

This part focuses on three key items: (1) the CCD and types/stages of IGG nexus; (2) the representative cities of the IGG Nexus; (3) OFs of IGG nexus.

To examine the dynamic coupling nexus at the prefectural level, we select four cross-sectional years, namely 2009, 2012, 2015 and 2018, and calculate the entropy and weight of each cross-section of the 16 cities (Appendix Table A2); we then calculate the subsystem performances for the 16 cities in the analyzed years (Appendix Table A3). Because the coupling nexus among the three subsystems is worse than the two subsystems, this part only explores the CCD under the scenario of the three subsystems.

5.2.1. The CCD of IGG Nexus

Figure 3 shows the CCD spatial dynamics of the IGG nexus in the 16 cities of Anhui province. The CCD ranges roughly between 0.25 and 0.45, which means they rank in moderate, mild, and little imbalance; only Hefei in 2009 and Huangshan in 2018 exceeded 0.45. The number of cities that rose from 2009 to 2012, from 2012 to 2015, and from 2015 to 2018 was 10, 7, and 10, respectively, while the number that fell was 6, 9, and 6, respectively. Hence, there are more cities that had an increase.

Figure 3. The spatial evolution for the CCD of IGG nexus at the prefectural level in the analyzed years.

Table 9 presents the CCD and types/stages of the IGG nexus of the 16 cities in the analyzed years. Spatially, the CCD at the prefectural level was generally low. No city achieved the steady stage (S_3), resulting in the uneven development of inclusive, green,

and growth subsystems. It seriously impeded the synergetic development of the IGG nexus. The results also clearly show that Hefei has a maximum value of 0.466, while the minimum value was 0.326 for Suzhou in 2009. Meanwhile, Huangshan and Huainan were always the cities with the highest and lowest value of CCD from 2012 to 2018.

Table 9. The CCD and types/stages of IGG nexus in the 16 cities, Anhui province from 2009 to 2018.

Cities	2009		2012		2015		2018	
	CCD	Type/Stage	CCD	Type /Stage	CCD	Type/Stage	CCD	Type/Stage
Hefei	0.4661	F ₅ /S ₂	0.4129	F ₅ /S ₂	0.4119	F ₅ /S ₂	0.4357	F ₅ /S ₂
HuaiBei	0.3846	F ₄ /S ₁	0.3541	F ₄ /S ₁	0.3521	F ₄ /S ₁	0.3311	F ₄ /S ₁
Bozhou	0.3535	F ₄ /S ₁	0.3612	F ₄ /S ₁	0.3689	F ₄ /S ₁	0.3560	F ₄ /S ₁
Suzhou	0.3258	F ₄ /S ₁	0.3454	F ₄ /S ₁	0.3242	F ₄ /S ₁	0.3459	F ₄ /S ₁
Bengbu	0.3395	F ₄ /S ₁	0.3501	F ₄ /S ₁	0.3679	F ₄ /S ₁	0.3672	F ₄ /S ₁
Fuyang	0.3265	F ₄ /S ₁	0.3426	F ₄ /S ₁	0.3391	F ₄ /S ₁	0.3393	F ₄ /S ₁
Huainan	0.3639	F ₄ /S ₁	0.3194	F ₄ /S ₁	0.2675	F ₃ /S ₁	0.2696	F ₃ /S ₁
Chuzhou	0.3595	F ₄ /S ₁	0.3844	F ₄ /S ₁	0.3604	F ₄ /S ₁	0.3679	F ₄ /S ₁
Liuan	0.3466	F ₄ /S ₁	0.3754	F ₄ /S ₁	0.3441	F ₄ /S ₁	0.3554	F ₄ /S ₁
Ma'anshan	0.3971	F ₄ /S ₁	0.3715	F ₄ /S ₁	0.3729	F ₄ /S ₁	0.3515	F ₄ /S ₁
Wuhu	0.3995	F ₄ /S ₁	0.4000	F ₅ /S ₂	0.4250	F ₅ /S ₂	0.4039	F ₅ /S ₂
Xuancheng	0.3587	F ₄ /S ₁	0.3813	F ₄ /S ₁	0.3645	F ₄ /S ₁	0.3705	F ₄ /S ₁
Tongling	0.4372	F ₅ /S ₂	0.4199	F ₅ /S ₂	0.3754	F ₄ /S ₁	0.3952	F ₄ /S ₁
Chizhou	0.3842	F ₄ /S ₁	0.3943	F ₄ /S ₁	0.3964	F ₄ /S ₁	0.4038	F ₅ /S ₂
Anqing	0.3687	F ₄ /S ₁	0.3703	F ₄ /S ₁	0.4273	F ₅ /S ₂	0.4319	F ₅ /S ₂
Huangshan	0.4281	F ₅ /S ₂	0.4242	F ₅ /S ₂	0.4495	F ₅ /S ₂	0.4693	F ₅ /S ₂

Additionally, the standard deviation of CCD was calculated, rising from 0.039 in 2009 to 0.046 in 2018, reflecting an increase in the dispersion of individuals within the study. Hence, as the years go by, the gap among the regions becomes wider.

In general, the 16 cities of Anhui province face a bleak outlook. The CCD is low, and the gap among the regions is getting wider.

5.2.2. Representative Cities of the IGG Nexus

(1) Cities with rising CCD

The CCD of some regions are mainly rising. The finding shows that most cities relying on cultural tourism resources, including Huangshan, Anqing, and Chizhou. Mount Huangshan, located in the Huangshan City, is the world's natural and cultural heritage. Chizhou has one of the four great Buddhist Shrines, Mount Jiuhua. Anqing is well-known as the home of Huang Mei opera. Therefore, relying on culture and tourism resources and further integrated development to form dominant industries are feasible to reduce pollution, cut emissions, and optimize industrial distribution.

Other cities with risings are Bengbu and Suzhou. Since the establishment of the National Independent Innovation Zone in 2008, Bengbu has gradually the advantage of innovation, promoting the collaborative development among IGG subsystems. Suzhou is an important city in the northern part of Anhui province. For historical reasons, its geographical location is close to the north, agriculture is dominant, and the economy is relatively underdeveloped. Although the performances of the three subsystems are in the low level, the value difference among the subsystems is not obvious.

(2) Cities with falling CCD

The CCD of some regions are generally getting worse from 2009 to 2018. The finding indicates that most of the cities are resource-exhausted cities, such as Huainan, Tongling, Ma'anshan, and HuaiBei. Both Huainan and HuaiBei are rich in coal. Tongling is famous for the copper mines, while Ma'anshan is rich in steel. Especially, Huainan has seen a significant drop in CCD. The disadvantages of resource-exhausted cities are obvious and even lower than Fuyang, HuaiBei, and Suzhou, which are in the least developed areas of Anhui province. With the depletion of resources and the large-scale energy consumption, the advantages of these cities have been disappearing. This shows resource-exhausted cities suffers a growing dilemma to synergetic development of IGG. The provincial capital, Hefei's CCD has a falling trend in volatility; however, factors such as a large population base, high urban density, and urban-related problems have led to the fact that although the subsystem performances are in the first place (J. Chen, Chang, Karacsonyi, & Zhang, 2014), the CCD is not in the high position.

5.2.3. Obstacle Factors

The factors that exhibit the development of the 16 cities in Anhui province are analyzed in the same way as mentioned before, and the indexes affecting the coordinated development at the prefectural level are diagnosed; finally targeted countermeasures and recommendations are proposed for the future high-quality development. Based on the OFDM, the OFs and ODs of each index for the 16 cities in 2009, 2012, 2015, and 2018 are obtained. The five top indexes are selected as the key obstacles, whose total obstacle degree is > or ≈50% in most cities in the surveyed years, and rank from left to right, as listed in Figure 4.

Figure 4. Dynamic changes in the top 5 OFs/ODs of coupling IGG nexus from 2009 to 2018 in the 16 cities of Anhui province: (a) OFs/ODs in 2009; (b) OFs/ODs in 2012; (c) OFs/ODs in 2015; (d) OFs/ODs in 2018.

C_1 , C_{18} , and C_{20} are belonging to the inclusive, green, and growth subsystems, respectively. They are common factors that restricted the CCD in most cities over four dynamically monitored years, indicating that sharing of cultural resources, the human response to the environment, and the utilization of land resource are the most influential factors of regional CCD level. Figure 4 (a) indicates C_1 (14 times), C_{20} (14 times), C_{21} (13 times), C_{18} (11 times), and C_3 (10 times) in 2009; Figure 4 (b) shows C_{20} (15 times), C_1 (14 times), C_{18} (12 times), C_3 (11 times), and C_{19} (9 times) in 2012; Figure 4 (c) illustrates C_{21} (15 times), C_{20} (12 times), C_{14} (11 times), C_1 (10 times), and C_2 (9 times) in 2015; Figure 4 (d) depicts C_{18} (14 times), C_{20} (12 times), C_{13} (12 times), C_1 (12 times), and C_5 (8 times) in 2018 are diagnosed as the key obstacles to the improvement of the coupling nexus among IGG in the 16 cities in Anhui province. The indexes with more occurrences belong to the subsystem, indicating that the common obstacle that restricts the CCD is the existence of a corresponding subsystem (Zhang et al., 2019).

Based on the frequencies of the top 5 factors, cities are classified as “inclusive obstacle type”, “green obstacle type”, “growth obstacle type”, “inclusive and green obstacle type”, “inclusive and growth obstacle type”, and “green and growth obstacle type”, of which “inclusive obstacle type” refers to those whose five largest obstacle indicators are criteria within the inclusive subsystem; and “inclusive and growth obstacle type” are those that include both inclusive subsystem index and green subsystem index among their five largest obstacles. Among the top 5 OFs in the 16 cities, the cumulative frequencies of the inclusive, green, and growth subsystems in the 4 analyzed years were 35, 15, and 30 in 2009; 35, 13, and 32 in 2012; 29, 22, and 29 in 2015; 30, 38, and 12 in 2018, respectively. Hence, the obstacles that affect the CCD of cities saw a dynamic evolution trend from “inclusive obstacle type” to “inclusive and growth obstacle type” then to “green obstacle type” over the decade.

6. Conclusions

Based on subsystem collaboration, this paper constructs an evaluation index system of regional IGG. The EWA, CCDM and OFDM are used to quantitatively explore the complex and dynamic IGG system. The feasibility of this approach is verified by the empirical study of Anhui province and its cities from 2009 to 2018. The integrated approach not only reveals the operating law of regional IGG but also highlights the coupling of subsystems and the interaction among internal factors, which broadens the thinking

for the evaluation of regional IGG.

A relatively high IGG performance and a low CCD of the IGG nexus are seen at the provincial level. The CCD of the cities is also low, and the gap among the regions is getting wider. For this reason, to improve coordination among subsystems and narrow the gap, high priority should be given to framing synergetic development plans for IGG development.

Policy makers should firmly seize the opportunity of the regional integration of the Yangtze River Delta and the new central 10-year strategy to reform the income distribution system, eliminate the artificial factors of unfair distribution, and promote the universality of development results. They also need to increase investment in education, medical care, social security, culture, and other areas of people's livelihood in underdeveloped areas. We should attach importance to the coordinated development of economy, resources, and environment; intensify education and publicity; and guide the people to set up a green and low-carbon consumption concept. The transformation and upgrading of the industrial structure should be carried out, especially to increase the labor productivity of the tertiary sector of the economy. Priority will be given to industries that are clean and environmentally friendly.

Cultural and tourism cities should dig deeply into and rationally collate cultural and tourism resources, taking regional IGG to a new stage. Resource-exhausted cities should explore the path of transformation and development and pay more attention to the concept of sustainable, low-carbon, and green development. Innovative technology cities should give more attention to the innovation-driving effect and lead the regional development to a sustainable model. Agriculture leading cities should develop agricultural modernization and realize the coordinated development of regional economic growth and sustainable development.

Author Contributions:

This article is written by myself.

Funding: This work has been financially supported by Philosophy and Social Science Program Youth Project in Anhui Province of China, "Measurement, comparison and strategic path of high-quality green development in Anhui Province under the integration strategy of Yangtze River Delta" (No: AHSKQ2020D31).

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix Table A1. ODs for three subsystems at provincial level from 2009 to 2018.

Years	<i>Inc</i> subsystem (%)	<i>Gre</i> subsystem (%)	<i>Gro</i> subsystem (%)	Total (%)
2009	43.64	24.87	31.50	100
2010	45.37	29.26	25.37	100
2011	49.11	30.33	20.56	100
2012	46.78	34.50	18.72	100
2013	43.76	30.47	25.76	100
2014	46.08	31.06	22.86	100
2015	40.88	38.92	20.20	100
2016	36.99	35.95	27.06	100
2017	34.69	39.01	26.29	100
2018	31.69	42.16	26.15	100

Appendix Table A2. The weights of the indicators at prefectural level in four analyzed years.

Indicator	Weight 2009	Weight 2012	Weight 2015	Weight 2018
[C_1] Library books per 100 persons	0.125	0.110	0.060	0.062
[C_2] 10,000 people with college degrees or above	0.053	0.043	0.049	0.043
[C_3] Number of beds per 1,000 persons	0.076	0.069	0.043	0.053
[C_4] Registered urban unemployment rate	0.034	0.043	0.038	0.025

Indicator	Weight 2009	Weight 2012	Weight 2015	Weight 2018
[C_5] Disposable income per capita between urban & rural residents	0.031	0.035	0.030	0.064
[C_6] Urban population density	0.034	0.020	0.041	0.041
[C_7] Per capita housing gross leasable area	0.034	0.045	0.043	0.040
[C_8] Consumption of fertilizer per cultivated area	0.018	0.017	0.022	0.018
[C_9] Population Fire Rate	0.013	0.017	0.031	0.021
[C_{10}] Industrial Solid waste production	0.022	0.022	0.018	0.024
[C_{11}] Discharge of COD in industrial wastewater	0.014	0.023	0.031	0.019
[C_{12}] Industrial SO ₂ emissions	0.011	0.029	0.022	0.019
[C_{13}] proportion of air quality reaching or better than grade 2 weather	0.015	0.015	0.045	0.063
[C_{14}] Per capita green area of parks	0.056	0.043	0.058	0.050
[C_{15}] Average traffic volume	0.020	0.032	0.013	0.030
[C_{16}] Central processing rate of sewage treatment plant in urban areas	0.026	0.024	0.027	0.049
[C_{17}] Popularity rate of sanitation toilet in rural areas	0.040	0.024	0.041	0.023
[C_{18}] Per capita afforestation area	0.073	0.078	0.048	0.097
[C_{19}] Fixed asset investment per unit of GDP	0.022	0.067	0.030	0.027
[C_{20}] Secondary sector Land yield	0.090	0.088	0.086	0.076
[C_{21}] Tertiary sector Labor productivity	0.062	0.055	0.106	0.041
[C_{22}] Water consumption per unit of GDP	0.018	0.019	0.016	0.015
[C_{23}] Power consumption per unit of GDP	0.026	0.023	0.031	0.029
[C_{24}] Energy consumption per unit of industrial added value	0.016	0.014	0.018	0.015
[C_{25}] Industrial wastewater discharge per unit of GDP	0.029	0.013	0.016	0.022
[C_{26}] Industrial waste gas emission per unit of GDP	0.020	0.013	0.025	0.017
[C_{27}] Solid waste generation per unit of GDP	0.022	0.017	0.014	0.017

Appendix Table A3. Subsystem performances of IGG at prefectural level in the four analyzed years.

Cities	<i>Inc</i> performance				<i>Gre</i> performance				<i>Gro</i> performance			
	2009	2012	2015	2018	2009	2012	2015	2018	2009	2012	2015	2018
Hefei	0.258	0.195	0.281	0.242	0.194	0.135	0.121	0.157	0.168	0.177	0.176	0.261
Huaibei	0.210	0.151	0.156	0.159	0.205	0.193	0.167	0.145	0.126	0.105	0.083	0.139
Bozhou	0.171	0.169	0.155	0.166	0.235	0.213	0.218	0.157	0.173	0.158	0.156	0.151
Suzhou	0.153	0.169	0.147	0.180	0.193	0.144	0.141	0.178	0.161	0.167	0.139	0.168
Bengbu	0.155	0.149	0.177	0.131	0.187	0.201	0.167	0.184	0.145	0.113	0.142	0.141
Fuyang	0.173	0.190	0.181	0.196	0.181	0.157	0.159	0.122	0.159	0.136	0.135	0.122
Huainan	0.188	0.146	0.096	0.151	0.143	0.109	0.082	0.062	0.119	0.089	0.072	0.121
Chuzhou	0.198	0.197	0.160	0.196	0.200	0.208	0.198	0.168	0.158	0.152	0.156	0.130
Liuan	0.138	0.154	0.153	0.196	0.228	0.217	0.185	0.185	0.170	0.151	0.145	0.143
Ma'anshan	0.215	0.185	0.207	0.187	0.156	0.116	0.152	0.101	0.126	0.095	0.078	0.105
Wuhu	0.223	0.208	0.258	0.191	0.166	0.201	0.192	0.154	0.159	0.165	0.161	0.215
Xuancheng	0.181	0.188	0.162	0.151	0.225	0.176	0.189	0.203	0.137	0.156	0.151	0.115
Tongling	0.282	0.241	0.175	0.255	0.168	0.154	0.180	0.140	0.147	0.141	0.091	0.140
Chizhou	0.210	0.215	0.255	0.228	0.240	0.224	0.213	0.226	0.104	0.127	0.096	0.132
Anqing	0.152	0.152	0.189	0.206	0.202	0.217	0.212	0.201	0.170	0.174	0.209	0.173
Huangshan	0.230	0.204	0.239	0.237	0.269	0.279	0.288	0.277	0.144	0.154	0.157	0.180

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