

A Comparative Study on the Spatial Heterogeneity of Carbon Emission Reduction Potential and Green Investment Opportunity in Three Major Urban Agglomerations under the "Dual Carbon" Goal Based on ArcGIS Spatial Analysis

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Abstract: To address the problems of unbalanced regional green investment layout and mismatched carbon emission reduction potential under the "Dual Carbon" goal, this study takes 50 cities in three major urban agglomerations as the research objects, constructs a spatial analysis framework of "carbon emission reduction potential-green investment opportunity", and conducts research by integrating the entropy weight-TOPSIS method, ArcGIS spatial analysis technology and panel data fixed effect model. The results show that the carbon emission reduction potential of the three major urban agglomerations presents a pattern of "core agglomeration and peripheral gradient decline" with a significant high-value agglomeration effect, and the green investment opportunity forms a characteristic of "polycentric distribution and corridor extension". The spatial matching of the two can be divided into four types of regions, among which the "high potential-low opportunity" gap areas account for 23.1% and concentrate in the peripheral counties of the urban agglomerations. Empirical evidence shows that four factors including economic development level have a significant positive impact on the spatial matching degree, and the effects of some variables may differ across regions, which requires further verification. Based on this, an optimized green investment strategy of "differentiated layout + spatial coordination" is proposed, which provides a scientific basis for precise policy-making and investment decisions.

Keywords: Dual Carbon Goal; Three Major Urban Agglomerations; Carbon Emission Reduction Potential; Green Investment Opportunity; Spatial Heterogeneity; ArcGIS Spatial Analysis

1. Introduction

Global warming has made carbon neutrality a global consensus. China put forward the strategic goal of the "Dual Carbon" in 2020, incorporating green and low-carbon development into the overall economic and social development. Green investment is the key link connecting ecological protection and high-quality economic development. As the main carrier of carbon emissions, urban agglomerations determine the progress of achieving the national Dual Carbon goal. The three major urban agglomerations of the Beijing-Tianjin-Hebei, the Yangtze River Delta and the Guangdong-Hong Kong-Macao Greater Bay Area account for only 5.2% of China's land area, but contribute 41.3% of the GDP and 37.6% of carbon emissions, making them the core areas for carbon emission reduction [1]. However, the current three major urban agglomerations face the problem of spatial mismatch between carbon emission reduction potential and green investment opportunity, with insufficient investment supply in high-potential areas and excessive agglomeration of investment in low-potential areas, which seriously restricts the quality of regional green development[9]. Existing studies mostly focus on a single urban agglomeration and adopt traditional statistical methods for analysis, failing to carry out in-depth linkage analysis of carbon emission reduction potential and green investment opportunity combined with geographical spatial characteristics [2]. The spatial analysis function of ArcGIS can provide technical support for revealing the spatial relationship between the two [5]. Therefore, exploring the spatial heterogeneity and matching rules of the two in the three major urban agglomerations relying on this technology has both theoretical and practical significance. Theoretically, this study integrates

the spatial geographical perspective into the linkage analysis of the two, constructs a complete analysis framework, enriches the interdisciplinary theoretical system, and deepens the application of ArcGIS in environmental economics. Practically, it accurately identifies four types of key regions, which can provide a scientific basis for the government to formulate policies, enterprises to select locations and urban agglomerations to establish coordination mechanisms.

Scholars at home and abroad have carried out a lot of research on green investment and carbon emission reduction, but there are still many deficiencies: the spatial analysis methods are single, failing to realize the "spatial + attribute" linkage analysis of the two; the research scope mostly focuses on a single urban agglomeration, lacking systematic comparison between regions [4]; the spatial matching relationship between the two has not been deeply explored, and no linkage analysis framework has been constructed. Based on this, this study innovates in three aspects: systematically comparing the spatial heterogeneity of the three major urban agglomerations, deepening the comprehensive application of ArcGIS to realize scale conversion, and proposing operable green investment optimization strategies based on four types of matching regions.

The subsequent content of this paper will first elaborate on the research design, then carry out the empirical results and analysis, and finally condense the research conclusions, put forward policy recommendations and prospect the future research directions.

2. Research Design

2.1 Definition of Research Area

The research scope of this paper covers the core cities and surrounding linkage areas of the three major urban agglomerations, involving a total of 50 cities and 389 county-level units: the Beijing-Tianjin-Hebei Urban Agglomeration includes Beijing, Tianjin and 11 prefecture-level cities, with a total of 13 cities; the Yangtze River Delta Urban Agglomeration includes Shanghai, 9 cities in Jiangsu, 8 cities in Zhejiang and 8 cities in Anhui, with a total of 26 cities; the

Guangdong-Hong Kong-Macao China Greater Bay Area includes Hong Kong China, Macao China and 9 prefecture-level cities in Guangdong, with a total of 11 cities. This scope is selected because the three major urban agglomerations are the core carriers for China to achieve the Dual Carbon goal, and the data availability and integrity are high, which can meet the needs of refined spatial analysis[17].

2.2 Theoretical Basis

Regional economic disparity theory: Differences in natural endowments, economic foundations and other aspects between regions lead to unbalanced development, and then form spatial heterogeneity of resource allocation, which is the core theoretical basis for explaining the spatial heterogeneity of carbon emission reduction potential and green investment opportunity in the three major urban agglomerations [6].

Ecosystem service theory: It emphasizes the supporting function of the ecosystem. The carbon sequestration capacity of ecological resources such as forests and wetlands is an important component of carbon emission reduction potential [20]. This study incorporates carbon sequestration support into the carbon emission reduction potential evaluation system based on this theory.

Spatial agglomeration theory: The spatial agglomeration of factors can generate scale and synergy effects. Traffic convenience, policy intensity and other factors are the key to affecting the agglomeration of green investment [19]. This study explores the agglomeration mode of green investment opportunity through spatial correlation analysis, which is an empirical application of this theory.

2.3 Construction of Indicator System

2.3.1 Evaluation indicator system for carbon emission reduction potential

Following the principles of scientificity, systematicness and operability, an evaluation system including 3 first-level indicators and 6 second-level indicators is constructed, and the weight of each indicator is determined by the entropy weight method. Table 1 shows the detailed indicator system.

Table 1. Evaluation Indicator System for Carbon Emission Reduction Potential

First-level Indicator	Second-level Indicator	Indicator Nature	Weight (Entropy Weight Method)	Indicator Explanation
Emission	Carbon intensity per	Inverse	0.22	Reflects the carbon emission efficiency

Reduction Capacity	unit of GDP (ton/10,000 yuan)			of economic development; the lower the value, the greater the emission reduction potential
	Energy consumption structure (%)	Positive	0.18	Proportion of clean energy consumption in total energy consumption; the higher the value, the stronger the emission reduction capacity
Emission Reduction Foundation	Advanced industrial structure rate (%)	Positive	0.20	Proportion of the added value of the tertiary industry in GDP; the higher the value, the higher the level of industrial low- carbonization
	Technological R&D investment intensity (%)	Positive	0.21	Proportion of R&D expenditure in GDP, reflecting the potential of technological emission reduction
Carbon Sink Support	Forest coverage rate (%)	Positive	0.11	Proportion of forest area in the total regional area, reflecting carbon sequestration capacity
	Wetland area ratio (%)	Positive	0.08	Proportion of wetland area in the total regional area, assisting in improving carbon sequestration function

Table 2. Evaluation Indicator System for Green Investment Opportunity

First-level Indicator	Second-level Indicator	Data Source	Indicator Explanation
Capital Supply	Green credit balance (100 million yuan)	Annual reports of branches of the People's Bank of China, Wind Database	Loan balance issued by financial institutions to green projects, reflecting the scale of capital supply
	Green bond issuance volume (100 million yuan)	Wind Database, financial operation reports of provinces and cities	Total annual green bond issuance in the region, supplementing the dimension of capital supply
Project Implementation	New energy project investment (100 million yuan)	Green project filing database of development and reform commissions	Total annual investment in new energy projects such as wind power and photovoltaic power
	Number of energy conservation and environmental protection projects (unit)	Green project filing database of development and reform commissions	Total number of filed energy conservation and environmental protection projects in a year
Policy Support	Green investment subsidy intensity (%)	Green and low- carbon development plans, finance department announcements	Proportion of government subsidies for green projects in total project investment
	Carbon emission reduction target completion rate (%)	Ecological and environmental department annual bulletins	Ratio of actual carbon emission reduction to target carbon emission reduction, reflecting policy implementation intensity

2.3.2 Evaluation indicator system for green investment opportunity

Three types of core indicators including capital supply, project implementation and policy support are selected to fully reflect the feasibility and potential of regional green investment. Table 2 presents the indicator composition and data sources.

2.4 Model Construction

Entropy weight-TOPSIS model: Used for the comprehensive measurement of carbon emission reduction potential. First, a standardized decision matrix is constructed, then the indicator weights are determined by the entropy weight method, finally the positive and negative ideal solutions

are constructed, and the Euclidean distance between each evaluation unit and the ideal solution is calculated to obtain the comprehensive score [3]. The higher the score, the greater the carbon emission reduction potential.

ArcGIS spatial analysis model: It comprehensively uses Kriging interpolation, spatial correlation analysis, buffer analysis and overlay analysis to realize the revelation of the spatial pattern of carbon emission reduction potential, identification of agglomeration types, construction of the radiation range of green investment opportunity and division of four types of key regions [5].

Analytic Hierarchy Process (AHP) and K-means clustering model: The AHP method determines the weights of each indicator of green investment opportunity after expert scoring,

constructing a judgment matrix and passing the consistency test; the K-means clustering divides the research area into three opportunity levels (high, medium and low) according to the comprehensive index of green investment opportunity.

Panel data fixed effect model: Used to verify the influencing factors of spatial heterogeneity and mismatch, and the model form is as follows [7][8]:

$$Match_{ijt} = \alpha_i + \beta_1 GDP_{perijt} + \beta_2 Ind_{ijt} + \beta_3 Tech_{ijt} + \beta_4 Pol_{ijt} + \beta_5 Tra_{ijt} + \beta_6 Eco_{ijt} + \mu_{ijt} \quad (1)$$

In the formula, $Match_{ijt}$ is the spatial matching degree, the others are explanatory variables, α_i is the individual fixed effect, and μ_{ijt} is the random disturbance term.

Table 3 lists variable definitions and data sources.

Table 3. Variable Definition and Data Source

Variable Type	Variable Name	Variable Symbol	Variable Definition	Data Source
Explained Variable	Spatial Matching Degree	Match	Assignment of four types of matching regions (Type I=4, Type II=3, Type III=2, Type IV=1)	Calculated in this paper
Explanatory Variable	Economic Development Level	GDP_per	Per capita GDP (10,000 yuan)	China Statistical Yearbook 2019-2023
	Industrial Structure	Ind	Proportion of the secondary industry (%)	Statistical Yearbooks of Provinces and Cities 2019-2023
	Technological Level	Tech	Proportion of R&D investment of industrial enterprises above designated size in main business income (%)	China Industrial Statistical Yearbook 2019-2023
	Policy Intensity	Pol	Proportion of green investment subsidy in fiscal expenditure (%)	Finance Department Announcements 2019-2023
	Traffic Convenience	Tra	Highway density (km/km^2)	China Communications Statistical Yearbook 2019-2023
	Ecological Endowment	Eco	Proportion of ecological protection red line area (%)	Ecological and Environmental Department Announcements 2019-2023

3. Empirical Results and Analysis

3.1 Data Source and Processing

Data Source: Geographic data are from the National Geospatial Information Public Service Platform and the National Forestry and Grassland Administration with a precision of 1:100,000; attribute data are from authoritative sources such as the *China Statistical Yearbook*,

with a time span of 2019-2023 [12][16].

Data Processing: Missing data are filled by the linear interpolation method and the mean value method of adjacent counties, with the data integrity reaching more than 95%; all indicators are standardized to eliminate dimensional differences; geographic data are uniformly converted to the WGS-84 coordinate system, topological inspection and format conversion are completed, and an integrated "spatial-attribute"

database is constructed.

3.2 Measurement Results of Carbon Emission Reduction Potential

Descriptive Statistics: There are significant

Table 4. Descriptive Statistics of Carbon Emission Reduction Potential

Urban Agglomeration	Sample Size (unit)	Mean	Standard Deviation	Minimum	Maximum
Beijing- Tianjin- Hebei	102	0.58	0.18	0.27	0.89
Yangtze River Delta	196	0.62	0.15	0.29	0.91
Guangdong- Hong Kong- Macao China Greater Bay Area	91	0.55	0.16	0.28	0.87
Total	389	0.59	0.16	0.27	0.91

Spatial Distribution Characteristics: The carbon emission reduction potential of the three major urban agglomerations presents a pattern of "core agglomeration and peripheral gradient decline". The spatial pattern of carbon emission reduction potential is displayed in Figure 1.

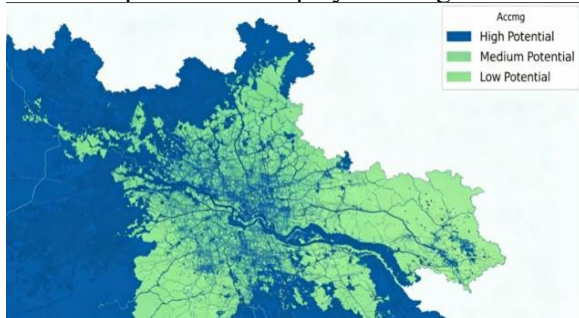


Figure 1. Spatial Distribution of Carbon Emission Reduction Potential in Three Major Urban Agglomerations

Spatial Correlation Analysis: The global Moran's

Table 5. Spatial Correlation Test of Carbon Emission Reduction Potential

Urban Agglomeration	Moran's I Value	Z Value	P Value
Beijing- Tianjin- Hebei	0.38	5.21	0.000
Yangtze River Delta	0.42	6.35	0.000
Guangdong- Hong Kong- Macao China Greater Bay Area	0.35	4.89	0.000

Table 6. Grade Division of Green Investment Opportunity

Urban Agglomeration	Sample Size (unit)	High- opportunity Areas (unit)	Proportion (%)	Medium- opportunity Areas (unit)	Proportion (%)	Low- opportunity Areas (unit)	Proportion (%)
Beijing- Tianjin- Hebei	102	29	28.4	53	52.0	20	19.6
Yangtze River Delta	196	70	35.7	98	50.0	28	14.3
Guangdong- Hong Kong- Macao China Greater Bay Area	91	29	31.9	47	51.6	15	16.5
Total	389	128	32.9	198	50.9	63	16.2

3.3 Identification Results of Green Investment Opportunity

Comprehensive Index and Grade Division: The Yangtze River Delta has the highest mean value of green investment opportunity (0.61), with high-opportunity areas accounting for 35.7%. Table 6 shows the grade division results.

Spatial Distribution Characteristics: Green

differences in the carbon emission reduction potential of the three major urban agglomerations at the county level. Table 4 shows the statistical results.

I index shows that the carbon emission reduction potential of the three major urban agglomerations is all greater than 0.3 and passes the 1% significance test, indicating a significant positive spatial correlation [5]. Table 5 reports the spatial correlation test results.

The local spatial agglomeration characteristics are further illustrated in Figure 2.

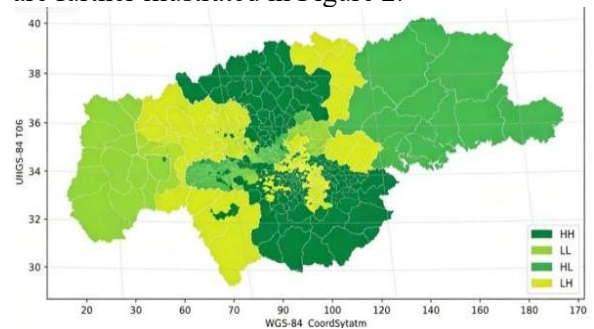


Figure 2. LISA Agglomeration of Carbon Emission Reduction Potential

investment opportunity forms a characteristic of "polycentric distribution and corridor extension". The high-opportunity areas have a high spatial coincidence with traffic networks and administrative centers, which verifies the guiding role of transportation and policies in green investment agglomeration [11]. The spatial distribution of green investment opportunity is visualized in Figure 3.

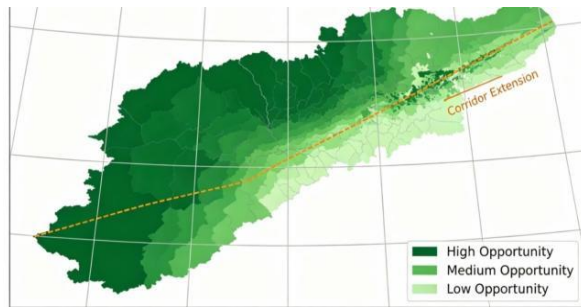


Figure 3. Spatial Distribution of Green Investment Opportunity in Three Major Urban Agglomerations

3.4 Spatial Matching Analysis Results

ArcGIS overlay analysis divides the spatial matching of the two into four types of regions.

Table 7. Distribution of Four Matching Types of Carbon Emission Reduction Potential and Green Investment Opportunity

Urban Agglomeration	Sample Size (unit)	Type I Area (unit)	Type I Proportion (%)	Type II Area (unit)	Type II Proportion (%)	Type III Area (unit)	Type III Proportion (%)	Type IV Area (unit)	Type IV Proportion (%)
Beijing- Tianjin- Hebei	102	22	21.6	28	27.5	23	22.5	29	28.4
Yangtze River Delta	196	51	26.0	42	21.4	35	17.8	68	34.7
Guangdong- Hong Kong- Macao China Greater Bay Area	91	19	20.9	19	20.9	18	19.8	35	38.5
Total	389	92	23.6	89	23.1	76	19.5	132	33.8

Table 8. Regression Results of Panel Data Fixed Effect Model

Variable	Coefficient	Standard Error	t Value	P Value
Constant Term	1.235	0.156	7.917	0.000
GDP_per	0.325	0.042	7.738	0.000
Ind	-0.187	0.076	-2.461	0.014
Tech	0.298	0.053	5.263	0.000
Pol	0.256	0.061	4.197	0.000
Tra	0.179	0.098	1.827	0.068
Eco	0.083	0.057	1.456	0.146
N	1945	R ²	0.683	F-value 132.56
Hausman Test	P=0.002 (Reject random effect, select fixed effect)			

3.4.1 Regression results

The regression of the panel data fixed effect model shows that economic development level, technological level, policy intensity and traffic convenience have a significant positive impact on the spatial matching degree, industrial structure has a significant negative impact, and the impact of ecological endowment is not significant. The Hausman test rejects the random effect, and the fixed effect model is selected [7][8]. Table 8 reports the regression results.

3.4.2 Robustness test

The technological level indicator is replaced with the proportion of the number of high-tech enterprises for re-regression, and the coefficient signs and significance of each core explanatory

variable have not changed substantially, indicating that the empirical results are robust.

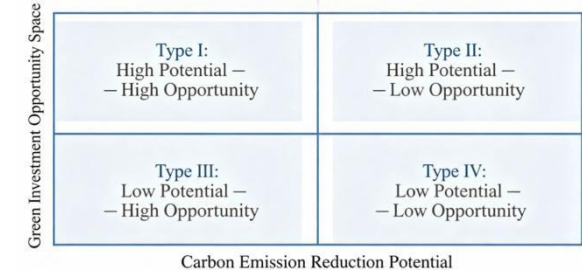


Figure 4. Spatial Matching Types between Carbon Emission Reduction Potential and Green Investment Opportunity

Table 7 shows the distribution of four matching types across urban agglomerations. ArcGIS overlay analysis divides the spatial matching of the two into four types of regions, as shown in Figure 4.

4. Conclusions and Prospects

Taking 50 cities in the three major urban agglomerations as the research objects, this study explores the spatial heterogeneity and matching relationship between carbon emission reduction potential and green investment opportunity, and draws the core conclusions as follows: The carbon emission reduction potential of the three major urban agglomerations presents a pattern of "core agglomeration and peripheral gradient decline", with the Yangtze River Delta having the highest mean value and the Beijing-Tianjin-Hebei having the largest

internal difference, and all of them have significant positive spatial correlation; green investment opportunity is driven by capital, policy and project implementation, forming a characteristic of "polycentric distribution and corridor extension", the Yangtze River Delta has the highest proportion of high-opportunity areas, and transportation and administrative centers have a significant guiding role in investment agglomeration [11]; the spatial matching of the two is divided into four types of regions, and the "high potential-low opportunity" gap areas are concentrated in the peripheral counties of urban agglomerations, accounting for 23.1%; economic development, technology, policy and transportation have a significant positive impact on the spatial matching degree, industrial structure has a significant negative impact, and the effects of some variables may differ across regions, which requires further verification.

Based on the research conclusions, to solve the problem of spatial mismatch and optimize the green investment layout, the following policy recommendations are put forward: Implement a differentiated green investment subsidy policy, formulate different subsidy and guidance strategies for the four types of regions to fill the investment gap and avoid investment redundancy; establish a spatial coordinated development mechanism for the three major urban agglomerations, build an information sharing platform, establish a cross-regional ecological compensation and investment linkage mechanism, and promote the cross-regional flow of factors; compile a precise site selection guide for green investment projects to provide scientific guidance for enterprise investment decisions; strengthen the support for low-carbon technological innovation and transfer, increase R&D investment and establish a cross-regional technology transfer mechanism to improve the emission reduction potential of peripheral areas; optimize the regional industrial structure and transportation network layout, promote the transformation of high-energy-consuming industries, improve the transportation connection between peripheral counties and core cities, and promote the agglomeration of green investment factors [1][10].

Although this study reveals the spatial heterogeneity and matching rules of the two, there are still limitations. Future research can be expanded in three aspects: Expand the research scope to the surrounding areas of the three major

urban agglomerations and other urban agglomerations, and carry out a national-scale research incorporating the perspective of urban-rural integration [18]; innovate research methods, analyze dynamic evolution characteristics by combining machine learning and spatial econometric models, and improve the indicator system by incorporating more potential influencing factors; deepen international comparison, learn from the green investment experience of urban agglomerations in developed countries, carry out policy simulation analysis, simulate the impact of different policies on the spatial allocation of green investment, and enhance the practical guiding value of the research results [13][14][15].

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