Original Research Article

Research on the spatio-temporal evolution of green building economic competitiveness and pathways for high-quality development in the Guangdong-Hong Kong-macao greater bay area

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Abstract: The rapid advancement of industrialization has exacerbated ecological issues and led to excessive resource consumption, creating an imbalance between resource carrying capacity and economic development. Against this backdrop, as the economy transitions toward high-quality development, the green economy has become an inevitable choice for promoting coordinated regional development. As one of China's most open and economically dynamic regions, enhancing the green economic competitiveness of the Guangdong-Hong Kong-Macao Greater Bay Area holds critical significance for achieving the dual carbon goals and advancing national strategic planning.

Against the backdrop of the “dual carbon” goals and high-quality development requirements, this paper focuses on the dynamic development mechanism of the Greater Bay Area's green economic competitiveness. It first defines the core essence of the green economy, clarifies its synergistic relationship with the low-carbon economy and circular economy, and emphasizes its leading role as a comprehensive development model that integrates economic, social, and ecological dimensions. Using multi-source statistical data from 2005 to 2021 and employing the entropy method to construct a comprehensive evaluation system, the study analyzes the temporal evolution of the region's green economic competitiveness. Results show its composite index increased from 0.396 in 2005 to 0.602 in 2022, representing a 52.1% growth, though growth exhibited fluctuations due to factors like the global financial crisis and the pandemic. Analysis of coexisting growth poles reveals a gradient pattern of “core polarization-peripheral dependency” in the Greater Bay Area. The four core cities—Guangzhou, Shenzhen, Hong Kong, and Macao—Contribute over 60% of green technology output, while secondary cities exhibit significant asymmetry in industrial synergy and ecological compensation. The study proposes a three-dimensional E-S-E analytical framework integrating economic vitality, ecological carrying capacity, and social coordination assessment dimensions. This framework provides empirical evidence for optimizing regional green development strategies and advancing high-quality coordinated development.

Keywords: green economic competitiveness; guangdong-Hong Kong-Macao greater bay area

1. Introduction

Against the backdrop of global advocacy for sustainable development, the green economy has become the primary direction for economic growth across regions. As public awareness of ecological conservation continues to rise and the urgent need to address climate change intensifies, the concept of green development has gained widespread acceptance. Countries are actively formulating policies to drive the transition toward a green economy.

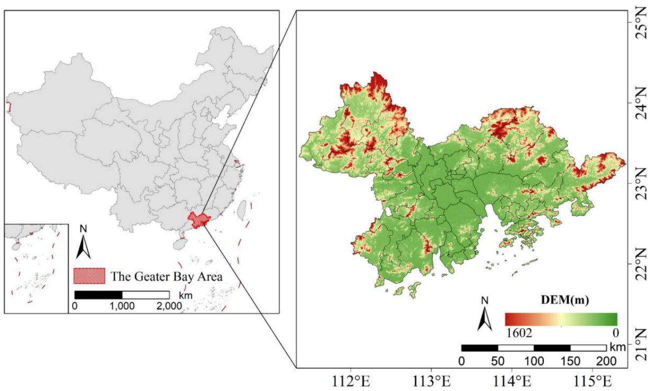

Figure 1. view of the Guangdong-Hong Kong-Macao greater bay area.

1.1. Definition of green economy-related concepts

1.1.1. Definition of the green economy

The concept of a green economy is rich and dynamic, with varying definitions proposed by different scholars and institutions. The United Nations Environment Programme defines a green economy as one that enhances human well-being and social equity while significantly reducing environmental risks and ecological scarcities. Some domestic scholars emphasize that a green economy is an economic development model constrained by ecological capacity and resource carrying capacity, where environmental protection serves as a crucial pillar for achieving sustainable development. Despite variations in expression, the core emphasis remains on the coordinated unity of economic growth and environmental protection—Pursuing economic development while prioritizing efficient resource utilization and ecological conservation.

1.1.2. The relationship between the green economy and related concepts

The green economy employs low-carbon and circular approaches, yet its essence emphasizes the coordinated development of economic, social, and ecological dimensions. The low-carbon economy focuses on reducing carbon emissions, primarily through energy technology innovation and industrial restructuring to decrease reliance on high-carbon energy sources. The circular economy emphasizes the reuse of resources, enhancing resource utilization efficiency by establishing a feedback loop process of "resources-products-waste-recycled resources." The green economy, however, encompasses a broader scope. It integrates the concepts of both the low-carbon and circular economies, addressing not only carbon emissions and resource circulation but also ecosystem conservation, social equity, and other multifaceted aspects. As a comprehensive economic development model, it occupies a central and overarching position within the relevant conceptual framework.

2. Theinevitable path to high-quality development in the Guangdong-Hong Kong-Macao greater bay area

2.1. The essence of green economic competitiveness and high-quality development

2.1.1. Definition of green economic competitiveness

Green economic competitiveness refers to the capacity of a region or economy to effectively integrate resources, promote green industrial development, and achieve coordinated progress between economic growth and environmental protection under the concept of green development. Its core elements encompass green technological innovation capabilities, green industrial development levels, resource utilization efficiency, and ecological and environmental protection outcomes. Measurement standards include indicators such as carbon productivity, the proportion of green industries in GDP, and energy consumption per unit of GDP. Carbon productivity reflects the relationship between economic growth and carbon emissions, the share of green industries indicates the degree of industrial structure greening, and energy consumption per unit of GDP measures resource utilization efficiency.

2.1.2. Characteristics of High-quality development

High-quality development exhibits multiple distinctive characteristics. Innovation-driven growth serves as its core engine, enhancing total factor productivity through scientific and technological innovation, management innovation, and institutional innovation to propel industrial upgrading and economic restructuring. Sustainability is a fundamental requirement, emphasizing coordinated economic, social, and environmental development while prioritizing rational resource utilization and ecological conservation to achieve intergenerational equity. Balance is another key feature, encompassing coordinated regional development, integrated urban-rural development, and balanced industrial growth to reduce imbalances and disparities in development. Furthermore, high-quality development pursues high efficiency, focusing not only on the speed of economic growth but also on the quality and effectiveness of growth, thereby enhancing the stability and resilience of economic development.

2.1.3. The intrinsic connection between the two

Green economic competitiveness and high-quality development share a close logical relationship. Enhancing green economic competitiveness is a crucial pathway to achieving high-quality development. Strengthening green economic competitiveness means better balancing economic growth with environmental protection during economic development, improving resource utilization efficiency, and reducing energy consumption and environmental pollution. This helps drive industrial upgrading and transformation, promotes the development of emerging green industries, and provides new growth points for high-quality development. Simultaneously, high-quality development creates favorable conditions for enhancing green economic competitiveness. The emphasis on innovation-driven development and sustainability inherent in high-quality development can stimulate green technological innovation, refine the policy environment and market mechanisms for green industrial development, thereby further enhancing green economic competitiveness and achieving sustainable socioeconomic development.

3. Spatio-temporal analysis of the green economic competitiveness in the Guangdong-Hong Kong-macao greater bay area

3.1. Data sources

This study examines the evolution and development characteristics of China's Guangdong-Hong Kong-Macao Greater Bay Area over the period from 2005 to 2021. Regarding data collection, it primarily relies on multi-dimensional official data sources: First, national-level statistical documents encompassing annual reports from 2006 to 2022, including the Statistical Yearbook of Chinese Cities, Statistical Yearbook of China's Urban and Rural Development, Statistical Yearbook of China's Regional Economy, and Statistical Yearbook of China's Science and Technology; Second, regional data integrated statistical yearbooks and statistical bulletins on national economic and social development at provincial administrative and city levels. Third, supplementary data were obtained from government open information platforms such as the National Bureau of Statistics website, the National Intellectual Property Administration data system, and the National Population Census database. Fourth, specialized database resources including the CNKI China Economic and Social Big Data Research Platform, the CEADs Carbon Emissions Dataset, and the China Economic Net Statistical Database collectively form the empirical foundation of this research.

3.2. Research methods

Standardize the above data by transforming sequence x into $y_i = \frac{x_i - \overline{x}}{s}$, where $\overline{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$, $s = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \overline{x})^2}$, and the new sequence y have a mean of 0 and a variance of 1, rendered dimensionless. The forward indicator is defined as:

$$X_{ij} = \frac{x_{ij} - \min\left\{x_{1j}, \dots, x_{nj}\right\}}{\max\left\{x_{1j}, \dots, x_{nj}\right\} - \min\left\{x_{1j}, \dots x_{nj}\right\}}$$

Formula（1）

Negative indicators include:

$$X_{ij} = \frac{\max\left\{x_{1j}, \dots, x_{nj}\right\} - x_{ij}}{\max\left\{x_{1j}, \dots, x_{nj}\right\} - \min\left\{x_{1j}, \dots x_{nj}\right\}}$$

Formula（2）

In the formula: X_{ij} represents the value of the jth indicator within group i in the data. Subsequently, the weight under the jth indicator for group i is calculated:

$$y_{ij} = \frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}$$

Formula（3）

Then calculate the entropy value based on the weighting in the above formula e_j :

$$e_j = -\frac{1}{\ln m}\sum_{i=1}^{n} y_{ij}\ln\left(y_{ij}\right), \frac{1}{\ln m} > 0$$ Formula (4)

In the formula, y_{ij} is a constant to be determined. When $y_{ij} = 0$, let $y_{ij}\ln\left(y_{ij}\right) = 0$.
Subsequently, based on the above formula, calculate the information entropy redundancy d_j .

$$d_j = 1 - e_j$$ Formula (5)

Calculate the weight w_j based on all indicators:

$$w_j = \frac{d_j}{\sum_{j=1}^{n} d_j}$$ Formula (6)

Finally, calculate the composite index S_i :

$$S_i = \sum_{j=1}^{n} W_j y_{ij}$$ Formula (7)

Where: S_i is the comprehensive evaluation of the green economic competitiveness of the Guangdong-Hong Kong-Macao Greater Bay Area in year i.

3.3. Temporal evolution characteristics of the Guangdong-Hong Kong-macao greater bay area

Using the entropy method, a quantitative analysis was conducted on the indicator system for evaluating the green economic competitiveness of the Guangdong-Hong Kong-Macao Greater Bay Area. The calculated composite index of green economic competitiveness for the urban cluster served as the dependent variable to assess the overall level of green economic competitiveness in the Greater Bay Area.

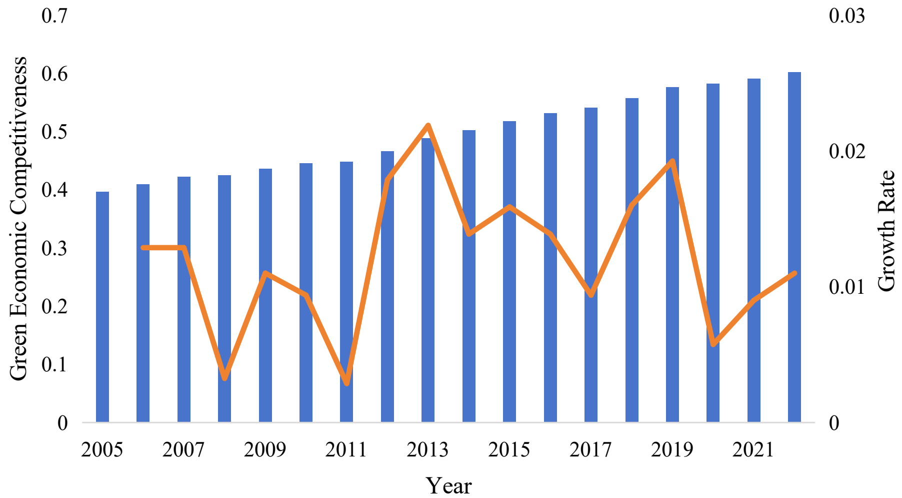

Figure 2. Evolution and growth rate of overall green economic competitiveness in the Guangdong-Hong Kong-macao greater bay area.

A comprehensive analysis of data from the study period reveals that the green economic competitiveness of the Guangdong-Hong Kong-Macao Greater Bay Area increased from 0.396 in 2005 to 0.602 in 2022, representing a growth rate of 52.1%. This indicates a consistent upward trend in green economic competitiveness over the years. Regarding the fluctuation characteristics of the growth rate, a brief decline occurred between 2005 and 2008. From 2009 to 2019, the growth rate exhibited significant fluctuations with large amplitude swings. In contrast, the period from 2020 to 2022 demonstrated a pattern of slow growth. Notably, growth rates dropped significantly in 2008, 2011, and 2020. This was primarily attributed to the impacts of the 2008 global financial crisis and the 2020 COVID-19 pandemic on both the supply and demand sides of the global economy, indirectly indicating that its stability remains insufficient[3].

3.4. Analysis method for the coexistence of multiple growth poles

This study adopts urban agglomerations as the regional-scale analysis unit, thus treating cities as the core of growth poles. When determining whether a city possesses growth pole status, it is essential to comprehensively evaluate both its economic attributes and relational attributes. Based on this, this study constructs a composite indicator P for city i, combining its regional GDP with its degree centrality within the spatial economic network, serving as a quantitative tool for measuring growth poles. Its specific calculation formula is as follows:

This study adopts urban clusters as regional analysis units, treating cities as the core carriers of regional growth poles. Within the growth pole identification framework, two dimensions must be comprehensively considered: a city's economic agglomeration effect and its network connectivity strength. Based on this, this study innovatively constructs the composite indicator P. This indicator integrates three core elements of city i: economic scale (represented by regional GDP), network hubness (calculated based on the degree centrality within the spatial economic network), and factor coordination efficiency. Its calculation formula is as follows:

$$P_{it} = w_1 G_{it} + w_2 C_{it} \quad \text{Formula (8)}$$

In the formula: P_{it} represents the growth pole index of node city i in year t, G_{it} false denotes the GDP of node city i in year t, C_{it} indicates the annual centrality of node city i. Both variables undergo normalization processing, with w and c calculated using the entropy method.

The symbiosis degree between multiple growth poles and spatial economic networks is defined as follows:

Spatial economic networks and the multi-pole growth system form a dynamic coupling relationship. This interaction mechanism manifests in two ways: on one hand, multiple growth poles reinforce the network topology through factor flows; on the other hand, the evolution of network topology reciprocally influences the energy level transitions of growth poles. To deconstruct this symbiotic relationship, this study introduces a symbiosis degree model to quantitatively reveal the types of symbiotic patterns between the two from the perspective of symbiotic energy exchange. Specifically, the symbiosis degree between multiple growth poles and spatial economic networks can be characterized by the following functional relationship:

$$\theta_{PN} = \left(\frac{dZ_P}{Z_P}\right) / \left(\frac{dZ_N}{Z_N}\right) \quad \text{Formula (9)}$$

According to the above formula, the symbiosis degree is:

$$\theta_{NP} = \left(\frac{dZ_N}{Z_N}\right) / \left(\frac{dZ_P}{Z_P}\right) \quad \text{Formula (10)}$$

This study selected 3,000 random permutations to perform QAP correlation analysis on the multi-value network of the Guangdong-Hong Kong-Macao Greater Bay Area, presenting the analytical results. Throughout this process, correlation coefficients were calculated by sequentially matching the frequency network with each factor matrix, while significance tests revealed the actual significance levels of the correlation coefficients.

Table 1. P-Values for Cities in the Guangdong-Hong Kong-Macao greater bay area.

Year	Guangzhou	Shenzhen	Hong Kong	Dongguan	Foshan	Zhuhai	Zhongshan	Huizhou	Macao	Jiangmen	Zhaoqing
2009	0.77	0.76	0.45	0.63	0.11	0.01	0.02	0.02	0.03	0.01	0
2014	0.91	0.79	0.44	0.51	0.14	0.14	0.15	0.08	0.04	0.04	0
2019	0.92	0.87	0.64	0.31	0.3	0.11	0.12	0.11	0.04	0.04	0.07

Based on the aforementioned analysis, the Guangdong-Hong Kong-Macao Greater Bay Area demonstrates a sustained positive development trajectory. However, significant regional disparities exist both between urban clusters and within individual cities. Moving forward, this study will employ a multidimensional assessment to delve into the diverse characteristics of green economic competitiveness across urban clusters. This aims to provide empirical evidence for subsequent analysis of influencing factors and the formulation of enhancement strategies[4].

4. Conclusions and outlook

This study, guided by the dual carbon goals and high-quality development requirements, conducts an in-depth academic exploration of the green economic competitiveness of the Guangdong-Hong Kong-Macao Greater Bay Area. The research follows a systematic approach: beginning with theoretical foundations and qualitative analysis, progressing to a multidimensional assessment of the urban cluster's green economic competitiveness, then analyzing the dynamic changes and network structure of the urban cluster, and finally identifying influencing factors and formulating optimization strategies.

4.1. Key findings

Analysis of Spatial Dynamic Evolution Characteristics: Empirical research indicates that the Greater Bay Area exhibits a gradient development pattern characterized by "Core polarization and peripheral dependence." The four core cities—Guangzhou, Shenzhen, Hong Kong, and Macao—Serve as innovation hubs and resource allocation centers, contributing over 60% of green technology output. Despite significant regional development shifts between 2015 and 2025, secondary cities still exhibit pronounced asymmetries in industrial coordination (e.g., Zhaoqing's new energy supporting rate remains at only 35%) and ecological compensation mechanism development, constrained by historical path dependencies and factor mobility barriers (such as cross-border data circulation restrictions). This spatial heterogeneity necessitates policy designs that balance efficiency-oriented approaches with equity principles.

4.2. Research outlook

This study proposes a three-dimensional E-S-E analytical framework for evaluating the green economic competitiveness of urban agglomerations, grounded in the dual-carbon strategy and high-quality development requirements. This framework breaks through the traditional single-dimensional research paradigm by systematically integrating an assessment system that synergistically evaluates economic vitality, ecological carrying capacity, and social factors. It constructs a multi-level evaluation indicator database tailored for the Guangdong-Hong Kong-Macao Greater Bay Area. By integrating spatial heterogeneity (such as resource endowment differences between the Pearl River Delta and Western Guangdong) with time-series data, it enables a comprehensive analysis of urban agglomeration competitiveness—Transitioning from cross-sectional static comparisons to longitudinal dynamic evolution.

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