Article

Spatial–Temporal Evolution and Driving Factors of Coupling Coordination between High-Quality Urban Development and Carbon Emissions Intensity in Guangdong Province

Xiaoning Yang 1,†, Junyi Liang 2,‡ and Shaojian Wang 2,*

1 School of Public Policy and Administration, Xi’an Jiaotong University, Xi’an 710049, China; xnyang@stu.xjtu.edu.cn
2 School of Geography and Planning, Sun Yat-sen University, Guangzhou 510006, China; liangyy256@mail2.sysu.edu.cn
* Correspondence: wangshj8@mail.sysu.edu.cn
† These authors contributed equally to this work.

Abstract: Promoting urban green growth necessitates a dual focus on reducing carbon emissions and fostering high-quality development. However, the body of research on the coupling relationship between high-quality urban development and carbon emissions remains remarkably limited. Taking Guangdong province as an example, this study strived to establish a comprehensive evaluation system for high-quality urban development encompassing economic, societal, and ecological dimensions and further conducted an in-depth examination of the spatiotemporal pattern and driving forces of coupling coordination degree between high-quality urban development and carbon emission intensity during 2000–2017. The coupling coordination degree in Guangdong province has shown continuous growth, transitioning from moderate incoordination to moderate coordination. The coupling coordination degree showed the overall spatial distribution characteristics of “high in southeast and low in others”, with Zhuhai, Zhongshan, Foshan, Guangzhou, Dongguan, and Shenzhen as the core. Notably, technological advancement, environmental governance, and economic development emerge as pivotal factors that positively affect carbon emission intensity reduction, environmental quality improvement, and coupling coordination enhancement. This research provides valuable insights for achieving harmonized high-quality development in Guangdong province involving policies of regional differences, industrial competitiveness, and new-type urbanization.

Keywords: coupling coordination degree; high-quality urban development; carbon emission intensity; Guangdong province

1. Introduction

China’s economic growth has shifted from a high-speed growth phase to a high-quality development phase. China needs to realize high-quality development by achieving carbon peak and carbon neutrality and adhering to the concept of green development. Cities are the spatial units and action carriers for energy conservation, emissions reduction, and ecological transformation [1]. Their high-quality development contributes to economic transformation and upgrading, expanding consumption and investment, and achieving green development and sustainability, which holds profound significance for China’s pursuit of high-quality development. As the largest emitter worldwide [2], China has the responsibility and capability of fulfilling the energy-conservation and emission-reduction task. Cities are the primary sources of carbon emissions and the critical regional units for achieving carbon reduction [3,4]. Thus, promoting high-quality development while reducing carbon emissions is critical for China’s government to achieve carbon goals and sustainable development.
Guangdong province has been at the forefront of China’s rapid economic growth. In 2022, Guangdong’s GDP exceeded 12.9 trillion CNY, ranking first in China for 34 consecutive years. Meanwhile, the urbanization rate of permanent residents in Guangdong reached 71.3%, far higher than the national average (64.8%). In light of this, Guangdong had the largest volume of carbon emissions, with 266 million tons in 2022, but its carbon emission intensity was the third lowest nationwide. As a leading economic region in China, Guangdong performed well in economic growth and environmental performance, but it still faced various challenges to achieving sustainable and green development, such as pronounced urban–rural development disparities, lack of an effective mechanism of emissions reduction, and stubborn industrial structure. Therefore, it is imperative for Guangdong to incorporate the dual carbon strategy into high-quality urban development. The precondition is to explore the coupling relationship between urban development and carbon emission intensity over time and space. Moreover, the practice of Guangdong offers insights for other cities to achieve the balance of rapid economic growth and improved environmental efficiency.

As a concept of physical science, coupling refers to a phenomenon in which two or more than two systems influence each other via different interactions [5]. The coupling degree measures the strength of interaction and the degree of correlation between the systems [6], but in some cases, it cannot explain the synergies between the systems [7]. Hence, the concept of coupling coordination is proposed to reflect the coupling and synergies between the systems. Coordination, the process of organizing and synchronizing various elements or activities to work together effectively, can explain the sustainability of the system [8]. The coupling coordination degree model is an adequate model used to measure both the coupling and coordination relationship among systems, which has been widely used in studies of high-quality development [9,10]. Given the nature of these concepts, the analysis of the coupling coordination between high-quality urban development and carbon emissions would provide effective support for facilitating the coordinated development of the economy, society, and environment in a region.

Existing literature measured high-quality urban development based on single indicators. In particular, the scholars pay more attention to high-quality economic development [11,12]. Yang et al. (2021) proposed high-quality economic development measurements regarding the ecological environment, economic efficiency, and economic structure [13]. Guo et al. (2023) established an evaluation index system of high-quality economic development concerning the industrial structure, inclusive total factor productivity, technology innovation, ecological environment, and residents’ living standards [14]. Some studies focused on high-quality development concerning society and ecology [15,16]. Artmann et al. (2019) proposed a systemic conceptual framework for sustainable cities by combining the ecological concepts of smart growth and green infrastructure [17]. Wang et al. (2023) focused on a series of environmental indicators, such as average rainfall and PM2.5, to improve the framework of high-quality development [18]. Moreover, some studies incorporated sustainability into urban high-quality development [19–21]. For instance, Artmann et al. (2019) utilized multi-dimensional—ecological, economic, and social, as well as multi-scale—regional, city, and neighborhood—indicators to form a framework of urban sustainable development [17]. Although the current analysis investigated the level of high-quality development based on a single system, it provides a reference for establishing a comprehensive evaluation index system of high-quality development.

Many scholars have studied the relationship between carbon emission and urban high-quality development with regard to a unilateral relationship [22–24] or a bilateral relationship [25–27]. On the one hand, some literature analyzed the unidirectional relationship between carbon emission and specific aspects of high-quality development [28,29]. Rapid industrial transformation requires massive energy use, resulting in a large-scale of carbon emissions, especially in India, Egypt, and other developing countries [30,31]. In particular, Pan et al. (2020) took Stockholm County, Sweden, as a case study, analyzing the temporal change of greenhouse gas emissions under urban development [32]. Wang
et al. (2016) investigated the effect of urbanization on carbon emission in BRICS countries, esteeeming that there is a long-run causality from urbanization to carbon emission [33]. On the other hand, some scholars investigated the coupling coordination between carbon emission and specific aspects of high-quality development [34,35]. Zhang et al. (2023) explored the coupling coordination degree between socio-economic development and carbon emissions of 76 contracting countries in The Paris Agreement, concluding that the coupling coordination degree at the global level is not symmetrical in spatial distribution. That is, European countries were generally rated higher than their African counterparts [36]. Wang et al. (2015) applied a semi-parametric panel fixed-effects regression model to investigate the coupling between urbanization and carbon emissions in OECD countries, verifying the Environmental Kuznets Curve hypothesis [37]. Huang et al. (2020) analyzed the temporal change and driving factors of the coupling coordination degree of urbanization and ecological environment in Kazakhstan [38].

Moreover, some scholars attempted to probe into the influencing factors of coupling coordination between urban development and carbon emissions [39–41]. Yang et al. (2023) used coupled coordination models and panel regression models in 166 countries to identify the influencing factors of coupling coordination of sustainable development, concluding that carbon emissions have a significant spatial spill-over effect on the sustainable development coupling coordination degree [42]. Taking Kazakhstan as an example, Huang et al. (2020) discovered that the GDP per capita and social fixed asset investment per capita, employment in industry, and services positively affected the coupling coordination degree of urbanization and ecological environment [38]. With the IPAT/Kaya approach and variance analysis technology, Chontanawat (2018) investigated the driving factors of the relationship between increasing carbon emission and economic growth in the Association of Southeast Asian Nations during 1971–2013, concluding that population growth and per-capita income increase were the most important factors increasing carbon emission [43]. However, only a few studies focused on the driving factors of the coupling coordination between urban development and carbon emission intensity [44,45].

This research contributes to the literature in the following aspects. First, this paper attempted to establish a comprehensive evaluation index system of high-quality development concerning innovation, coordination, greenness, openness, and sharing, whereas previous studies focused more on one or two aspects of high-quality development, especially the economy and ecology. Second, in contrast to previous literature that explored the coupling relationship between urban development and carbon emission, this research paid attention to carbon emission intensity, measuring the environmental performance and efficiency. Third, multiple aspects of high-quality urban development are addressed in order to investigate the driving forces of the coordinated development of carbon emission intensity and high-quality development from different perspectives. This study endeavors to provide some insightful implications for harmonized and effective high-quality development in Guangdong province and even in other regions.

The rest of this research is organized as follows: Section 2 explains the methodology and materials of the research; Section 3 reports the estimated results; Section 4 discusses the empirical results. Section 5 provides the policy suggestions and limitations.

2. Methods and Data

First, this paper calculated carbon emission intensity and constructed a comprehensive evaluation index system of high-quality urban development levels based on existing literature. Second, Hausman test was employed to select the key influencing factors of coupling coordination degree between high-quality urban development and carbon emission intensity. Third, the entropy weight method was utilized to calculate a comprehensive score of high-quality urban development, and coupling coordination degree model was used to analyze the coupling coordination degree between high-quality urban development and carbon emission intensity. Last, Moran’s test and Spatial Lag Model were exploited to analyze the spatial correlation of driving factors of coupling coordination degree. Figure 1
illustrates the conceptual framework of this study. The bold in Figure 1 illustrates the four steps in the methodology.

Figure 1. Flowchart of methodology.

2.1. Data Sources and Processing

2.1.1. Accounting of Carbon Emission Intensity

Carbon emission intensity refers to carbon dioxide emissions per GDP value, indicating how clean a country or region’s economy is. Carbon emission intensity enjoys some advantages over carbon dioxide emissions. On the one hand, with the characteristic of normalization, it is possible to compare the carbon emission efficiency among regions, industries, and activities of different scales and production levels, offering a fair basis for assessing carbon emissions. On the other hand, as a valuable concept in understanding how efficiently carbon emissions are associated with specific activities, carbon emission intensity plays a critical role in environmental assessments, climate change mitigation strategies, and making informed decisions to reduce the carbon footprint of various processes and sectors. Official statistics lack data on the carbon emissions of prefectural-level cities, let alone the carbon emission intensity of prefectural-level cities. Given data availability, this paper applied the carbon emissions from Carbon Emission Accounts and Datasets (CEADs), covering from 2000 to 2017. Moreover, the GDP data of prefectural-level cities stemmed from the China City Statistical Yearbook. In this paper, the GDP deflator method is used to make the calculation results of different years comparable; that is, the appropriate GDP
index (CNY at 2000 constant prices) was used to adjust all of the monetary data. The calculation formula is as follows:

\[ CI_{it} = \frac{CE_{it}}{GDP_{it}} \]  

(1)

where \( i \) and \( t \) represent the city and the year, respectively. Carbon emission intensity was assumed to be a negative indicator, normalized and standardized.

2.1.2. Evaluation Index of High-Quality Urban Development Level

High-quality development is a highly intricate economic, social, and ecological system [46,47]. Research on high-quality development helps build a strong foundation for the definition and features of high-quality development and has contemporary implications [48]. From the perspective of “double carbon” goals, this paper referred to the Five Principles for Development proposed at the Fifth Plenary Session of the 18th Central Committee of the Communist Party of China: innovation, coordination, greenness, openness, and sharing. Based on the studies of Gan et al. (2022) [49] and Bei (2018) [50], we established an evaluation index system for high-quality urban development levels (Table 1). The original data were from the China City Statistical Yearbook and Guangdong Statistics Yearbook. Some missing data were supplemented and improved using the interpolation method.

Table 1. Evaluation index system of high-quality urban development level.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Variables</th>
<th>Description</th>
<th>Unit</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R&amp;D personnel input intensity</td>
<td>Number of R&amp;D employed persons/Number of employed persons</td>
<td>%</td>
<td>+</td>
</tr>
<tr>
<td>Innovation</td>
<td>R&amp;D funding input intensity</td>
<td>R&amp;D expenditure/GDP</td>
<td>%</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Scientific and technological expenditure intensity</td>
<td>Financial expenditure on science and technology/General public budget expenditure</td>
<td>%</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Per capita GDP</td>
<td>GDP/Permanent population</td>
<td>Ten thousand CNY</td>
<td>+</td>
</tr>
<tr>
<td>Coordination</td>
<td>Share of the secondary industry’s added value in GDP</td>
<td>Secondary industry’s added value/GDP</td>
<td>%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Share of the tertiary industry’s added value in GDP</td>
<td>Tertiary industry’s added value/GDP</td>
<td>%</td>
<td>+</td>
</tr>
<tr>
<td>Green</td>
<td>Industrial SO2 emission intensity</td>
<td>Volume of industrial sulfur dioxide emission/GDP</td>
<td>%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Industrial soot emission intensity</td>
<td>Volume of industrial soot emission/GDP</td>
<td>%</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Rate of harmless disposal of domestic waste</td>
<td>Quantity of harmless disposal of domestic waste/Total volume of domestic waste</td>
<td>%</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Rate of solid wastes comprehensively utilized</td>
<td>Volume of solid wastes comprehensively utilized/Volume of industrial solid wastes produced and comprehensively utilized in previous years</td>
<td>%</td>
<td>+</td>
</tr>
</tbody>
</table>
Table 1. Cont.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Variables</th>
<th>Description</th>
<th>Unit</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>Openness</td>
<td>Share of actual utilization of foreign capital in GDP</td>
<td>Actual utilization of foreign capital/GDP</td>
<td>%</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Number of international internet users per 100 people</td>
<td>Number of international internet users/Permanent population</td>
<td>Households per 100 people</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Financial expenditure on education/General public budget expenditure</td>
<td>%</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Number of books per person</td>
<td>Number of books in public libraries/Permanent population</td>
<td>Books per 100 people</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Number of beds per ten thousand persons</td>
<td>Number of beds/Permanent population</td>
<td>Per 10,000 people</td>
<td>+</td>
</tr>
<tr>
<td></td>
<td>Share of registered unemployed persons in urban area at the year-end of total population at the year-end</td>
<td>Registered unemployed persons in urban area at the year-end/Total population at the year-end</td>
<td>%</td>
<td>-</td>
</tr>
</tbody>
</table>

* It refers to the comprehensive utilization of generated solid waste, rather than simple disposal or landfilling. This includes activities such as waste sorting, recycling, reuse, and energy recovery, aiming to minimize the negative impact on the environment. Sources: Adapted from Ref. [49]. 2022, Gan, W.; Yao, W.; Huang, S. and Ref. [50]. 2018, Bei J.

2.1.3. Hausman Test

A large and growing body of literature has shown that economic development, environmental governance, and technological innovation have contributed significantly to improving coupling coordination between carbon emissions and high-quality development [34,36,51]. According to He and Liu (2022) [52] and Jiang et al. (2022) [40], we built a system of influencing factors of coupling coordination between carbon emissions and high-quality urban development, involving technology development, environmental governance, and economic development (Table 2). Technology development consists of human capital and technology expenditure intensity. Environmental governance incorporates a qualified amount of industrial wastewater and a percentage of municipal sewage disposal. Proportion of fixed asset investment, number of employed persons at the year-end, financial efficiency, and population density constituted economic development. The data originated from the China City Statistical Yearbook, the Guangdong Statistical Yearbook, and statistical bulletins of prefectural-level cities.

Table 2. Influencing factors of coupling coordination between carbon emissions and high-quality urban development.

<table>
<thead>
<tr>
<th>First-Level Indicators</th>
<th>Second-Level Indicators</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology development (TECH)</td>
<td>Human capital (TECH1)</td>
<td>Number of university students per 10,000 people</td>
<td>/</td>
</tr>
<tr>
<td></td>
<td>Technology expenditure intensity (TECH2)</td>
<td>Technology expenditure/GDP</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Qualified amount of industrial waste water (ENVI1)</td>
<td>/</td>
<td>Ten thousand tons</td>
</tr>
<tr>
<td>Environmental governance (ENVI)</td>
<td>Percentage of municipal sewage disposal (ENVI2)</td>
<td>Volume of municipal sewage disposal/Total wastewater discharge</td>
<td>%</td>
</tr>
</tbody>
</table>
Table 2. Cont.

<table>
<thead>
<tr>
<th>First-Level Indicators</th>
<th>Second-Level Indicators</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic development (ECO)</td>
<td>Proportion of fixed asset investment (ECO1)</td>
<td>Amount of fixed asset investment/GDP</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Number of employed persons at the year-end (ECO2)</td>
<td>/</td>
<td>Ten thousand persons</td>
</tr>
<tr>
<td>Financial efficiency (ECO3)</td>
<td>Loans in financial institutes at the year-end/Deposits in financial institutes at the year-end</td>
<td>/</td>
<td></td>
</tr>
<tr>
<td>Population density (ECO4)</td>
<td>Permanent population/Land area</td>
<td>Thousand persons/sq.km</td>
<td></td>
</tr>
</tbody>
</table>

2.2. Methods

2.2.1. Entropy Weight Method

This paper applied the entropy weight method to process the indicators. The entropy weight method is an objective weighting approach avoiding the biases induced by human subjective judgment [53]. It determines the weight of each factor based on the variation in their values. The entropy weight method is widely accepted in environmental assessment, corporate performance, investment decisions, and energy use. One of the most outstanding advantages of this method is that it is assumed to be suitable for all decision-making processes requiring weight determination [54]. The uncertainty of variables and the influences of controlling elements on outcomes can be measured, so this approach is highly acceptable in modeling and mapping natural hazards [55,56]. Therefore, the entropy weight method was utilized to measure the high-quality urban development and carbon emission intensity in Guangdong province during 2000–2017.

(1) Data standardization. Suppose there are $m$ evaluated objects, and each object has $n$ indicators. Then, $m \times n$ judgment matrix can be constructed. We further standardized the indicators and obtained a new matrix $R = (r_{ij})_{m \times n}$, $r_{ij} \in [0, 1]$. The formula is as follows:

$$X = (x_{ij})_{m \times n} \quad (i = 1, 2, \cdots, m; j = 1, 2, \cdots, n)$$ (2)

If the indicator has a positive trend:

$$r_{ij} = \frac{x_{ij} - \min x_{ij}}{\max x_{ij} - \min x_{ij}}$$ (3)

If the indicator has a negative trend:

$$r_{ij} = \frac{\max x_{ij} - x_{ij}}{\max x_{ij} - \min x_{ij}}$$ (4)

(2) Calculation of entropy. We can calculate the contribution of the $i$ year under the $j$ index with the following equation:

$$P_{ij} = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}}$$ (5)

Next, the entropy value can be calculated by

$$e_j = -k\sum_{i=1}^{n} P_{ij}\ln(P_{ij})$$ (6)

where

$$k = \frac{1}{\ln n}$$ (7)
(3) Definition of the weight of entropy. The weight of the $j$ indicator is determined with the following formula:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^{m} (1 - e_j)}$$

(8)

(4) Calculation of indices. The comprehensive score in the year $i$ can be calculated as

$$S_i = \sum_{j=1}^{n} w_j p_{ij}$$

(9)

2.2.2. Coupling Coordination Degree Model

According to the definition of coupling coordination mentioned above, this paper constructed a coupling coordination degree model between carbon emission intensity and high-quality urban development. The formulas are as follows:

$$C = 2 \left\{ \frac{(u_1 \cdot u_2)/[(u_1 + u_2)(u_1 + u_2)]}{1/2} \right\}$$

(10)

$$D = \sqrt{C \cdot T}$$

(11)

$$T = \alpha u_1 + \beta u_2$$

(12)

where $C$ represents the degree of coupling between carbon emission intensity and urban high-quality development; $D$ represents the degree of coupling coordination, ranging from 0 to 1; and $T$ reflects the overall scores of these two systems. In Guangdong province, carbon emission intensity is as equally important as high-quality development, so the values of $\alpha$ and $\beta$ are equivalent, i.e., $\alpha = \beta = 0.5$.

Based on the degree of coupling coordination ($D$), the coupling of carbon emission intensity and high-quality urban development was divided into eight stages, ranging from extreme incoordination to high-quality coordination (Table 3). The higher degree of coupling coordination indicates a strong relationship between high-quality urban development and carbon emission intensity, and high-quality development and carbon emission tend to make sound progress in coordination. When the $D$ value is less than 0.5, it is coordinated at a lower level and called incoordination, indicating lower-quality urban development and worse carbon emission [46].

Table 3. Coupling coordination degree classification.

<table>
<thead>
<tr>
<th>Range of $D$ Value</th>
<th>Stages</th>
<th>Range of $D$ Value</th>
<th>Stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0–0.2</td>
<td>Extreme Incoordination</td>
<td>0.5–0.6</td>
<td>Primary Coordination</td>
</tr>
<tr>
<td>0.2–0.3</td>
<td>Serious Incoordination</td>
<td>0.6–0.7</td>
<td>Moderate Coordination</td>
</tr>
<tr>
<td>0.3–0.4</td>
<td>Moderate Incoordination</td>
<td>0.7–0.8</td>
<td>Benign Coordination</td>
</tr>
<tr>
<td>0.4–0.5</td>
<td>Mild Incoordination</td>
<td>0.8–1.0</td>
<td>High-quality Coordination</td>
</tr>
</tbody>
</table>

Sources: Yang et al. (2020) [57].

2.2.3. Moran’s I Test

Since another main objective of this research is to analyze the driving factors of coupling coordination between carbon emission intensity and high-quality urban development, we decided to apply the panel models with more sample information. Before we conducted the panel analysis, we applied the spatial autocorrelation model to detect the correlation of observed values between neighboring locations within a geographic space. Moran’s I is a correlation coefficient that measures the overall spatial autocorrelation of carbon emission...
intensity and high-quality urban development in this study, which ranges from $-1$ to $1$. The formula is as follows:

$$I = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{ij} (x_i - \bar{x}) (x_j - \bar{x})}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

(13)

In the above formula, $x_i$ and $x_j$ represent the data of city $i$ and $j$, respectively. $w_{ij}$ presents spatial adjacency matrix. The results can be classified into three categories. First, when Moran’s $I$ coefficient exceeds 0, it suggests a positive spatial correlation among the subjects. A coefficient closer to 1 signifies a more pronounced positive correlation, showing increased spatial clustering of these subjects. Second, conversely, a Moran’s $I$ coefficient below 0 implies a negative spatial correlation. A coefficient nearing -1 reveals a heightened negative correlation, denoting a more prominent spatial disparity among the subjects. Third, a Moran’s $I$ coefficient close to 0 indicates that the subjects are distributed randomly, suggesting no spatial autocorrelation [58].

2.2.4. Spatial Lag Model

The spatial correlation should be considered in delving into the driving factors of the coupling coordination relationship between carbon emission intensity and high-quality development. This research employed the spatial econometric model for examining the spatial effects of these driving factors in Guangdong province. The Spatial Lag Model (SLM) is a regression model incorporating spatial dependence into standard regression models like linear regression. It is commonly used in spatial econometrics to analyze geospatial data where observations are influenced by spatial proximity to other observations. The SLM enjoys several advantages. On the one hand, the SLM helps reduce model bias. Ignoring spatial dependence can lead to biased and inefficient estimates. SLM helps in reducing or eliminating this bias. Ignoring spatial dependence can lead to biased and inefficient estimates. On the other hand, the SLM is adaptable and can be combined with other modeling methods, such as incorporating spatially lagged independent variables or integrating time dynamics for spatiotemporal analyses. According to the results of the LM test, Wald test, and LR test, the Spatial Lag Model is more suitable for exploring the spatial effects of high-quality urban development than the Spatial Errors Model. The formula is as follows:

$$D_{it} = \rho w_{ij} D_{it} + \alpha_1 TECH + \alpha_2 ENV I + \alpha_3 ECO + \epsilon_{it}$$

(14)

where $\rho$ denotes coefficient of endogenous interaction effects, reflecting the degree of spatial spillover or diffusion effects between adjacent cities; $\alpha$ stands for linear correlation coefficients; $\epsilon$ indicates random errors.

2.3. Study Area

Situated on the southern coast of mainland China, Guangdong province is a pioneer of reform and opening up (Figure 2). From 1978–2021, Guangdong’s economy has grown more than 400 times and replaced Jiangsu province as China’s most prominent economic province. In 2022, the gross domestic production (GDP) of Guangdong province amounted to 12.91 trillion CNY, with a year-on-year growth of 1.9%. As a significant economic province nationwide, Guangdong province accounted for about 6.7% of the national energy consumption and 5% of national carbon emissions, supporting about 9% of the country’s permanent resident population and 10.7% of the national economy. There are 21 prefecture-level cities in Guangdong province, which is divided into Pearl River Delta (PRD), East Guangdong, West Guangdong, and North Guangdong. In general, the economic development of Guangdong follows the principle of core–periphery, with the PRD as the most developed region. In 2022, with a population of 78.29 million (61.6% of the province), the PRD region produced 10.47 trillion CNY (81% of the province). There is a significant regional disparity in the province. In 2020, Guangdong province’s urbanization rate reached 74.2%, entering a mature period of urbanization development, and
this rate is projected to reach 82% by 2035. More importantly, 2023 was the first year of the High-Quality Development Project for Counties, Towns and Villages in Guangdong province. Prefecture-level cities have unveiled relevant policies and accelerated the process of high-quality development.

Figure 2. Location of Guangdong province.

3. Results
3.1. Trends in Land Urbanization

As shown in Figure 3, the carbon emission intensity in Guangdong province decreased from 1.93 CNY/ton to 0.71 CNY/ton by 63.2% during 2000–2017. The carbon emission intensity score increased from 10.4 to 17.4 during the study period, with a growth of 67.7%. According to Equation (1), carbon emission intensity is decided by the volume of carbon emission and GDP. From 2000 to 2017, carbon emissions experienced a double increase in Guangdong province, while GDP grew sixfold. In other words, Guangdong province has been likely to witness an improvement in energy efficiency and economic structure during the study period. Meanwhile, similar to previous studies that investigated the trend of high-quality urban development in Guangdong [59,60], there was a marked increase in high-quality urban development from 6.3 to 10.7, indicating that Guangdong tended to possess a more vital ability to achieve higher-quality development.

More importantly, there was a significant difference in environmental quality and high-quality development at different stages of economic development (Figure 3). There was also a striking variation in the coupling coordination degree between carbon emission intensity and high-quality development. The results in Figure 3 revealed that the coupling coordination degree experienced stable and slow growth, ranging from 3.5 to 5.2 during the study period. During the initial period (2000–2006), the coupling coordination degree of Guangdong province stayed at 3.6 from 2007 to 2017; however, there has been a significant rise of approximately 30% in the coupling coordination degree. This result demonstrates that there has been a strong integration between carbon emission intensity and high-quality urban development in Guangdong province driven by rapid economic growth and improving environmental quality, which is also supported by Chontanawat (2018) [43].
Figure 3. Evaluation score in Guangdong province from 2000 to 2019. Overall score refers to the score of high-quality development level, calculated based on Equation (9).

Compared to a coupling degree, a coupling coordination degree is more conducive to accurately and reasonably assessing the coordination between environmental quality and high-quality urban development [61]. Figure 4 illustrates the coupling coordination degree of 21 prefectural-level cities in Guangdong province. During the study period, the mean coupling coordination degree fluctuated between 0.4, experiencing a stable growth from 0.3 to 0.5. Moreover, before 2007, Guangdong province was in the stage of mild disorder, while it has entered the stage of mild incoordination since 2008. In 2015, Guangdong province was in the stage of mild coordination, which might be due to energy conservation and environmental protection measures that were reinforced with the enhancement of high-quality urban development. This research investigated a similar trend of the coupling coordination degree between urban development and carbon emission in other studies [43,62].

Figure 4. Boxplot of coupling coordination degree in Guangdong province in 2000–2017.
Likewise, the coupling coordination degree witnessed slow growth at the city level during the study period (Figure 5). More importantly, there has been a decrease in the gap in the coupling coordination degree between prefectural-level cities over time. For instance, the difference between the highest and lowest level of coupling coordination degree was 0.40 in 2000, whereas this difference was only 0.36 in 2017. During 2000–2017, Qingyuan, Zhongshan, Huizhou, and Shaoguan experienced the fastest growth of the coupling coordination degree, with rates of 208%, 133%, 76%, and 65%, demonstrating that these cities performed well in coordination development between ecological systems and high-quality development. This result might be related to the terrain of these cities. For instance, the terrain of Shaoguan is mainly mountainous and hilly, and the plain and platform area accounts for about 20%. More importantly, Shaoguan has made great progress in environmental protection, such as pollution control and environmental governance.


3.2. Spatial Patterns of Coupling Coordination Degree

Figure 6 illustrates the spatial characteristics of coupling coordination degree in 2000, 2004, 2008, 2012, and 2017. In 2000, West Guangdong was in the stage of moderate incoordination, while East Guangdong was primarily in the stage of serious incoordination. Only Guangzhou, Zhuhai, and Foshan were in the stage of barely coordination, and Shenzhen was in the stage of mild coordination. Most cities were in a low degree of coupling coordination development at the initial stages. In 2004, the number of cities in the period of serious incoordination declined, and Shenzhen and Guangzhou began to enter the stage of moderate coordination and mild coordination. When it came to 2008, most cities were in the period of moderate incoordination, whereas Meizhou was still in the stage of serious incoordination. What stands out in Figure 6 is that Qingyuan improved its level of coupling coordination degree, switching from extreme incoordination to moderate incoordination during 2000–2008. This can be mainly attributed to the strong awareness of environmental protection.

Since entering 2010, Guangdong province made significant progress in improving the coupling coordination degree. Except for the cities in North Guangdong, other cities entered the stage of mild incoordination in 2012. More importantly, Zhongshan and Foshan were in a period of primary coordination. Shenzhen and Guangzhou improved the coupling coordination degree level, entering the moderate and benign coordination stages, respectively. Apparently, Shenzhen and Guangzhou were the pillar cities of the coupling coordination degree of high-quality regional development. In 2017, spatially, the coupling coordination degree showed Zhuhai, Zhongshan, Foshan, Guangzhou, Dongguan, and Shenzhen as the core; Jiangmen, Zhaoqing, and Huizhou as the sub-core; and other cities as the edge. Obviously, the PRD region leads in the high-quality urban development in the province.

The spatial agglomeration characteristics of coupling coordination degree between carbon emission intensity and high-quality development were measured using the global Moran’s I index of spatial autocorrelation in Guangdong province. As shown in Table 4, Moran’s I index of coupling coordination degree almost passed the significance level test, except for 2001–2004. In other words, no solid spatial autocorrelation existed between carbon emission intensity and high-quality development during 2001–2004. A possible explanation for this might be the small spatial scale, constraining the significance of Moran’s I index. Moreover, during 2004–2017, the value of Moran’s I index was positive, demonstrating that the coupling coordination degree of carbon emission intensity and high-quality economic development exhibits strong positive spatial autocorrelation, implying a polarization that higher-quality development usually accompanies lower emission intensity. There were high-value coupling coordination agglomeration and low-value agglomeration.

From 2004 to 2017, the values of Global Moran’s I varied from 0.137 to 0.476 and were significant at the 90% confidence level. This indicated that the coupling coordination degree in the study area showed a stronger spatial correlation during the study period. Moreover, Global Moran’s I experienced a slight decline during 2007–2008 and 2014–2015, demonstrating a steady decrease in the coupling coordination degree cluster. The former decrease was partly because of the financial crisis of 2008, reducing carbon emissions to some extent, while differentiated regional environmental protection entry policies influenced the latter decrease in Guangdong province since 2013 [63].
Table 4. Spatial autocorrelation coefficient of coupling coordination degree between carbon emission intensity and high-quality development.

<table>
<thead>
<tr>
<th>Year</th>
<th>Moran’s I</th>
<th>E(I)</th>
<th>Z</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>−0.363</td>
<td>−0.05</td>
<td>−2.115</td>
<td>0.034</td>
</tr>
<tr>
<td>2001</td>
<td>−0.192</td>
<td>−0.05</td>
<td>−0.938</td>
<td>0.348</td>
</tr>
<tr>
<td>2002</td>
<td>−0.086</td>
<td>−0.05</td>
<td>−0.238</td>
<td>0.812</td>
</tr>
<tr>
<td>2003</td>
<td>−0.02</td>
<td>−0.05</td>
<td>0.197</td>
<td>0.844</td>
</tr>
<tr>
<td>2004</td>
<td>0.137</td>
<td>−0.05</td>
<td>1.226</td>
<td>0.22</td>
</tr>
<tr>
<td>2005</td>
<td>0.203</td>
<td>−0.05</td>
<td>1.661</td>
<td>0.097</td>
</tr>
<tr>
<td>2006</td>
<td>0.259</td>
<td>−0.05</td>
<td>2.05</td>
<td>0.04</td>
</tr>
<tr>
<td>2007</td>
<td>0.312</td>
<td>−0.05</td>
<td>2.383</td>
<td>0.017</td>
</tr>
<tr>
<td>2008</td>
<td>0.254</td>
<td>−0.05</td>
<td>1.977</td>
<td>0.048</td>
</tr>
<tr>
<td>2009</td>
<td>0.321</td>
<td>−0.05</td>
<td>2.462</td>
<td>0.014</td>
</tr>
<tr>
<td>2010</td>
<td>0.342</td>
<td>−0.05</td>
<td>2.63</td>
<td>0.009</td>
</tr>
<tr>
<td>2011</td>
<td>0.367</td>
<td>−0.05</td>
<td>2.711</td>
<td>0.007</td>
</tr>
<tr>
<td>2012</td>
<td>0.404</td>
<td>−0.05</td>
<td>2.932</td>
<td>0.003</td>
</tr>
<tr>
<td>2013</td>
<td>0.427</td>
<td>−0.05</td>
<td>3.15</td>
<td>0.002</td>
</tr>
<tr>
<td>2014</td>
<td>0.443</td>
<td>−0.05</td>
<td>3.184</td>
<td>0.001</td>
</tr>
<tr>
<td>2015</td>
<td>0.439</td>
<td>−0.05</td>
<td>3.211</td>
<td>0.001</td>
</tr>
<tr>
<td>2016</td>
<td>0.464</td>
<td>−0.05</td>
<td>3.379</td>
<td>0.001</td>
</tr>
<tr>
<td>2017</td>
<td>0.476</td>
<td>−0.05</td>
<td>3.339</td>
<td>0.001</td>
</tr>
</tbody>
</table>

3.3. Analysis of Influencing Factors

As shown in Table 5, the fixed effect is more suitable for estimating the model because of the statistical significance of the P-value of the Hausman test. The value of the Hausman test was negative (−66.2) because the progressive assumption of the random-effects model cannot be satisfied. According to the results of the LM test and LR test, the Spatial Lag Model is more suitable for analyzing the driving factors of coupling coordination degree between carbon emission intensity and urban high-quality development. In other ways, a city’s coupling coordination degree is relevant to other cities.

Table 5. Drive mechanism measurement estimation results.

<table>
<thead>
<tr>
<th>Variables</th>
<th>OLS</th>
<th>SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>TECH</td>
<td>0.595 *** (0.078)</td>
<td>0.631 *** (8.240)</td>
</tr>
<tr>
<td>ENVI</td>
<td>2.827 *** (0.197)</td>
<td>2.025 *** (5.430)</td>
</tr>
<tr>
<td>ECO</td>
<td>2.979 *** (0.179)</td>
<td>2.818 *** (14.190)</td>
</tr>
<tr>
<td>_cons</td>
<td>0.184 *** (0.009)</td>
<td></td>
</tr>
<tr>
<td>ρ</td>
<td>0.737</td>
<td>−0.125 (−1.770)</td>
</tr>
<tr>
<td>R2</td>
<td></td>
<td>0.723</td>
</tr>
<tr>
<td>LM-spatiallag</td>
<td></td>
<td>4.338 **</td>
</tr>
<tr>
<td>Robust LM-spatiallag</td>
<td></td>
<td>4.547 **</td>
</tr>
<tr>
<td>LM-spatialerror</td>
<td></td>
<td>0.005</td>
</tr>
<tr>
<td>Robust LM-spatialerror</td>
<td></td>
<td>0.214</td>
</tr>
<tr>
<td>LR-spatiallag</td>
<td></td>
<td>32.980 ***</td>
</tr>
<tr>
<td>LR-spatialerror</td>
<td></td>
<td>26.780 ***</td>
</tr>
<tr>
<td>Hausman test</td>
<td></td>
<td>−66.2</td>
</tr>
</tbody>
</table>

Notes: Values in parentheses are standard errors. *** and ** denote significance at the 1% and 5% levels, respectively.

Overall, technology development, environmental governance, and economic development significantly and positively affected the coupling coordination degree in Guangdong province. First, the enhancement of education levels was conducive to accelerating the cultivation of high-quality talents and improving the foundation of scientific research, which is in accordance with Wang et al. (2017) [64] and Zhang et al. (2021) [65]. The increased number of individuals receiving higher education further facilitated technological innovation and innovative capabilities. This finding is likely to be related to the importance
given to education in Guangdong. To some extent, the increase in technology expenditure indicated a promotion of technological input and enterprise reform, thereby accelerating high-quality regional development.

Second, environmental governance had a significant and positive effect on the coupling coordination degree. Strict environmental control and continuous improvement in pollutant treatment can reduce carbon emission intensity, improve environmental quality, and enhance the coupling coordination degree. Existing studies have confirmed that provinces in eastern China have conformed to the “Porter Hypothesis” [66,67], suggesting that appropriate environmental regulations also promote technological innovation and high-quality urban development.

Third, economic development had a positive correlation with the coupling coordination degree. Improvements in the employment environment, enhancement of financial efficiency, and effective control of population density made an outstanding contribution to laying a solid foundation for high-quality urban development, realizing urban transformation from “quantitative change” to “qualitative change”. These results are consistent with Shi et al. (2020) [68], who found that economic development tended to have positive relationships with coupling coordination degrees in Eastern China. Based on the value of coefficients, economic development played the most significant role in the promotion of the coupling coordination degree, followed by environmental governance during the study period.

4. Discussion

An accurate grasp of the coupling and coordination relationship between carbon emission intensity and high-quality urban development will help accelerate the process of Guangdong province achieving its double carbon goals (carbon peaking and carbon neutrality). It involves the coordination and development of economic, social, and ecological systems. However, existing research findings primarily focus on the unidirectional and coupling relationship between carbon emissions and specific indicators or dimensions of high-quality urban development. It is worth mentioning that a city is a complex system formed by the interaction, influence, and mutual constraints of various elements such as society, economy, and ecology. Therefore, combined with a new development philosophy, this research attempted to establish an evaluation index system of high-quality urban development based on innovation, coordination, greenness, openness, and sharing. Moreover, we analyzed the coupling coordination degree between carbon emission intensity and high-quality development in 21 prefectural-level cities in Guangdong province during 2000–2017 with the entropy weight method, coupling coordination degree model, spatial autocorrelation method, and Spatial Lag Model. This study further analyzed the spatiotemporal characteristics and the driving factors of the coupling coordination degree.

Consistent with previous studies concerning carbon emission intensity [69], this study concluded that the carbon emission intensity witnessed a substantial decrease of 63.2% in Guangdong province during 2000–2017. In general, Guangdong takes the lead in high-quality urban development and carbon emission reduction attributed to technological innovation, industrial transformation, and government incentives [69]. Therefore, Guangdong made progress in harmony between high-quality development and carbon emission intensity, with a slow and stable increase in coupling coordination degree from 2000 to 2017. However, there was a significant regional disparity in the province. Spatially, the coupling coordination degrees in the PRD region were far higher than that in other regions, and the lowest coupling coordination degree was in North Guangdong, which is supported by previous studies concerning the divergence of the coupling coordination degree in Guangdong [70,71]. This was mainly attributed to an imbalance of regional development concerning the economy, society, and ecology in the province [72]. In other words, future policy makers should consider regional differences instead of adopting a “one size fits all” approach.
Moreover, during the study period, the coupling coordination degree of carbon emission intensity and high-quality urban development exhibited strong positive spatial autocorrelation in Guangdong province, demonstrating that cities are placing more emphasis on environmental protection and sustainable development through enacting more effective policy instruments. This result coincides with current studies that show that balancing rapid economic growth and environmental sustainability is a priority for many regions to achieve inclusive development [72]. Such a trend aligns with the global requirements for low-carbon, green, and sustainable development. It also indicates that cities have recognized the critical balance between economic development and environmental protection and are progressively achieving it.

According to the results of influencing factors, technology development, environmental governance, and economic development had a significant positive impact on the coupling coordination degree in Guangdong. This finding was also supported by Fengyin et al. [73], who stated that these factors were the key drivers of promoting high-quality development. These factors offer innovation elements and material bases to support a higher coupling coordination degree between high-quality urban development and carbon emission intensity. More importantly, compared with other factors, economic development had the highest coefficient, positively affecting the promotion of the coupling coordination degree. Over the study period, the economic growth reached over 10% annually, and the urbanization growth has been above the national level in Guangdong province. This result implies that economic development is a priority for achieving higher-quality development.

Furthermore, previous studies prove that strict environmental control is conducive to improving environmental performance, but the impact on the growth of productivity will become weaker with stricter environmental control [74]. In other words, stricter environmental governance will help improve the coupling coordination degree between high-quality urban development and carbon emission intensity. This is in accordance with China’s goal of upgrade and reconstruction as well as industrial structure adjustment. Recently, Guangdong has pioneered clean production, recycling transformation, and a new energy industry, promoting comprehensive green transformation of economic and social development.

5. Conclusions

This study aimed to develop an evaluation index system for high-quality urban development focusing on innovation, coordination, green practices, openness, and sharing. Taking Guangdong as an example, we examined the relationship between carbon emission intensity and high-quality development across 21 prefectural-level cities from 2000 to 2017 using the entropy weight method, the coupling coordination degree model, the spatial autocorrelation method, and the Spatial Lag Model. The main results are as follows.

First, Guangdong province witnessed a gradual and consistent rise in its coupling coordination degree, transitioning from a phase of moderate incoordination to moderate coordination during the study period. Second, regarding spatial distribution, Zhuhai, Zhongshan, Foshan, Guangzhou, Dongguan, and Shenzhen formed the primary core, with Jiangmen, Zhaoqing, and Huizhou serving as secondary hubs and the remaining cities acting as peripheral areas. Third, in Guangdong province, the degree of coupling coordination between carbon emission intensity and high-quality urban development shows a pronounced positive spatial correlation. Moreover, technology development, environmental governance, and economic growth positively influenced the coupling coordination degree.

Based on the above findings, the following policy recommendations are provided. First, it is imperative to regulate differentiated economic development strategies at the city level. This study confirmed that there was significant regional disparity of coupling coordination degree in the province. Therefore, differentiated economic transformation strategies are suitable for optimal industrial transformation. Second, it is necessary to reinforce inter-city collaborations concerning technological innovation, skill training, and investment projects to uplift the sub-core cities like Jiangmen, Zhaoqing, and Huizhou. This
research discovered that peripheral cities have the potential to achieve harmonized growth of high-quality urban development by fostering connections between them and the core cities. Third, a more mature policy system involving economic development, environmental governance, and technology development should be comprehensively enhanced to give full play to these factors. The results proved that these three factors played a significant positive role in improving the coupling coordination degree between high-quality urban development and carbon emission intensity. In other words, the integration of technology development, environmental governance, and economic development helps Guangdong achieve the goal of higher-quality development.

In summary, Guangdong’s high-quality urban development process has significant impacts not only on China’s economic, social, and environmental development but also serves as a model for global sustainable growth. China, especially Guangdong, provides valuable lessons and best practices in various aspects, including urban planning, infrastructure development, land utilization, and resource management. Nevertheless, there are still some limitations to this study. On the one hand, this study is limited by the absence of the latest data, failing to have a broader view of the relationship between carbon emission intensity and high-quality development in Guangdong province. Therefore, future research could investigate this relationship by collecting the latest data. On the other hand, this research only considered several second-level indicators for each influencing factor due to data accessibility. In contrast, many factors concerning society, economy, and ecology could influence the coupling coordination degree. These questions are left for future studies.

Author Contributions: Methodology, X.Y.; Investigation, S.W.; Writing—original draft, X.Y., J.L. and S.W.; Supervision, S.W. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the Ministry of Education Humanities Social Sciences Research Project (21YJAZH087).

Data Availability Statement: The data in this study are available from the corresponding authors upon request. Due to the sensitivity of the study area, some data cannot be made public.

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

Notes
2. The Fifth Plenary Session of the 18th Central Committee of the Communist Party of China (CPC) is a significant political meeting within the CPC’s organizational structure. This session took place in October 2015 and was a crucial event in China’s political calendar. During this meeting, China will set forth the country’s development goals and strategies for the following five years. The outcomes of the Fifth Plenary Session are encapsulated in the “13th Five-Year Plan,” which provided a comprehensive roadmap for China’s social, economic, and political development from 2016 to 2020. This plan included various policy initiatives and targets that covered areas such as economic growth, environmental protection, technological innovation, and social welfare.

References
5. Xia, F. On the concept of coupling, its modeling and measurement. J. Syst. Softw. 2000, 50, 75–84. [CrossRef]


38. Huang, J.; Na, Y.; Guo, Y. Spatiotemporal characteristics and driving mechanism of the coupling coordination degree of urbanization and ecological environment in Kazakhstan. *J. Geogr. Sci.* 2020, 30, 1802–1824. [CrossRef]
45. Ren, H.; Ou, X.; Zhu, H. Spatial characteristics and coupling coordination between carbon emission efficiency and industrial structure in three metropolitan areas of Jiangsu Province, China. *Sci Progress 2023*, 106, 0368504231176146. [CrossRef]
49. Gan, W.; Yao, W.; Huang, S. Evaluation of green logistics efficiency in Jiangxi Province based on Three-Stage DEA from the perspective of high-quality development. *Sustainability* 2022, 14, 797. [CrossRef]
50. Bei, J. Study on the “high-quality development” economics. *China Political Econ.* 2023, 50. [CrossRef]
67. Zhao, S.; Cao, Y.; Feng, C.; Guo, K.; Zhang, J. How do heterogeneous RD investments affect China’s green productivity: Revisiting the Porter hypothesis. Sci. Total Environ. 2022, 825, 154090. [CrossRef]

68. Shi, T.; Yang, S.; Zhang, W.; Zhou, Q. Coupling coordination degree measurement and spatiotemporal heterogeneity between economic development and ecological environment—Empirical evidence from tropical and subtropical regions of China. J. Clean. Prod. 2020, 244, 118739. [CrossRef]


Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.