sustainability

MDPI

Article

Study on the Spatial–Temporal Pattern Evolution and Carbon Emission Reduction Effect of Industry–City Integration in the Yellow River Basin

Zhengyun Jiang [1], Yun Feng [2,*], Jinping Song [1], Chengzhen Song [1], Xiaodi Zhao [3] and Chi Zhang [4]

[1] Faculty of Geographical Science, Beijing Normal University, Beijing 100875, China
[2] College of Business, The University of New South Wales, Sydney, NSW 2052, Australia
[3] Glorious Sun School of Business and Management, Donghua University, Shanghai 200050, China
[4] College of Business, Zhejiang University City College, Hangzhou 310015, China
* Correspondence: y13013066708@126.com

Abstract: The coordinated promotion of industry–city integration and carbon emission reduction is of great significance to the construction of a green economic system and deep participation in global environmental governance. Based on the overall framework of the "production–life–ecology" system, the theoretical mechanism of the impact of industry–city integration on carbon emissions is systematically clarified. Taking the Yellow River basin as a sample, the spatiotemporal heterogeneity of the effect of industry–city integration on carbon emissions is empirically tested by using the methods of the dispersion coefficient coordination function, standard deviation ellipse and STIRPAT model. The results show the following: (1) The coordinated integration of industry and city has significant carbon emission reduction effects, thus indicating that industry–city integration and carbon neutralization can achieve both, and that the conclusion is still valid after endogenous treatment and a series of robustness tests. (2) The development of an export-oriented economy and informatization can significantly promote carbon emission reduction. The process of economic development, infrastructure construction and population quality improvement may aggravate regional carbon emissions in the short term. (3) Further analysis shows that the carbon emission reduction effect of industry–city integration has significant spatial heterogeneity, especially in the upper and lower reaches of the Yellow River and regions with moderate carbon emission intensity. Scientific and technological innovation and environmental regulation play a positive role in regulating the carbon emission reduction effect of industry–city integration.

Keywords: industry–city integration; carbon emission reduction; deviation coordination coefficient; STIRPAT model; Yellow River Basin

check for updates

Citation: Jiang, Z.; Feng, Y.; Song, J.; Song, C.; Zhao, X.; Zhang, C. Study on the Spatial–Temporal Pattern Evolution and Carbon Emission Reduction Effect of Industry–City Integration in the Yellow River Basin. *Sustainability* **2023**, *15*, 4805. https://doi.org/10.3390/su15064805

Academic Editor: Silvia Fiore

Received: 6 February 2023
Revised: 26 February 2023
Accepted: 6 March 2023
Published: 8 March 2023

1. Introduction

Carbon emissions, as the main factor affecting global climate change, have always attracted much attention. The research on carbon neutrality has also continued to deepen with the intensification of the wave of green revolution around the world [1,2]. As the world's second largest economy and the world's largest carbon emitter, the Chinese government formally put forward the ambitious goal of carbon peak and carbon neutrality in September 2020, and put the promotion of "double carbon" into the overall layout of ecological civilization construction from the national strategic level, which made it possible to study China's carbon emissions more clearly [3]. "Carbon peak" is China's commitment to stop the growth of carbon dioxide emissions before 2030, and reduce them slowly after reaching the peak; by 2060, all carbon dioxide emissions will be offset by planting trees, energy conservation and emission reduction, which is called "carbon neutrality". At the same time, as China's economic development moves from rapid growth, it will enter a high-quality development stage, focusing on improving the quality production; indeed, the sustained growth of the national economy has gradually changed from the single-engine mode of industrialization to the "two-wheel" drive of industrialization and urbanization. Industry–city integration also has a profound impact on the dynamic process of regional industrial structure upgrading and development model transformation by virtue of its regulatory and matching role in urban and industrial development, and has gradually become an important starting point for regional high-quality transformation and development in the new era and a necessary way to achieve the goal of common prosperity [4]. In this context, does the integration of industry and city produce a certain form of carbon emission effect in the process of enriching the role of developing and optimizing the allocation of resources? What is the internal mechanism between the two? The exploration of such issues is of great significance, in order to clarify the implementation of major regional strategies and the path choice of carbon neutrality in the period of high-quality development.

Industry–city integration refers to the integrated development of industry and city; this is based on the city, involves the industrial space and the development of the industrial economy, drives urban renewal and improves the service-supporting facilities with the industry as the guarantee, so as to achieve the dynamic and sustainable upward development mode among industry, the city and people [5]. Based on the dynamic evolution of the development environment, the existing research on the industry–city integration and its environmental effects has continued to deepen, with different emphasis on the content. Early research on the issue of industry–city integration mainly focuses on the industry–city relationship, the healthy and sustainable development of cities, and the theory of industry–city interaction, such as Weber's industrial location theory, Perroux's spatial "polarization" theory, and Boudeville's "Lyon Sif multiplier effect" theory [6–11]. Paul R Krugman believes that urban planning and construction have a positive role in promoting industrial scale gains, and on the contrary, that industrial agglomeration benefits also promote the further development of urban economy and construction. At the same time, based on the perspective of geographical space, industrial agglomeration gradually changes the urban geographical space planning and situation, and promotes urban construction and development [12]. This period mainly focused on qualitative analysis and initially clarified the internal logic and evolution mechanism of the integration of industry and city. The content related to the integration of industry and city in China was put forward relatively late, and the academic community has not conducted much systematic research on it in general. The theme is relatively concentrated on the definition of the integration of industry and city, the arrangement of the path mechanism and the construction of the evaluation system [13–15]. Industry–city integration is essentially a "two-way balance" between urbanization and industrialization. Its key is that the industrial structure should conform to the orientation of urban development and achieve the improvement of urban functions and public service supply through the adjustment of industrial structure [16]. With the new normal of the economy and the continuous promotion of urbanization, the integration process of industry and city is further emphasized to highlight the core position of "people". It is believed that the integration of industry and city should be the organic integration of industry, city and people. The mutual promotion of "industry" and "city" should take "people" as the main link [13]. In terms of research methods, the direction of qualitative analysis has gradually changed to quantitative research. Relevant research is mostly based on the analysis and interpretation of the connotation of industry–city integration from different perspectives, refers to the basic framework of collaborative development or comprehensive evaluation, and uses the methods of the analytic hierarchy process, principal component, entropy weight TOPSIS, coupling coordination model and other methods based on the administrative, economic and other human attributes to measure the degree of integration of industry–city development in provinces, urban agglomerations, development zones and other scale areas, in order to analyze and judge its development evolution accordingly [17–19]. The existing evaluation system mainly focuses on the two-way linkage between industry and city. It starts with the system characteristics of industry and city, respectively, comprehensively evaluates the integrated development of the two systems, and seeks the optimal path for the integrated development of industry and city through the comparative analysis of the two systems. Based on this, the study of 285 cities in China found that the degree of coordination between industry and city in China is different, and that the areas with a high degree of integration between industry and city are mainly concentrated in the east. The promotion effect of industry–city integration on green development is more significant in developed cities than in underdeveloped cities [15,20]. However, research on the industrial clusters shows that the overall efficiency of industry–city integration in industrial clusters is generally low, but the trend is gradually improving. Excessive energy consumption is an important factor that hinders the development of industry–city integration [21]. In fact, this evaluation system regards industry and city as two relatively independent systems, ignoring the dependence between systems and the principal position of people in the process of regional development, which may lead to uncertainty in the evaluation results.

In recent years, with the continuous enrichment of research content, some scholars of urban economics and environmental economics have begun to pay attention to the environmental effects and sustainable development direction of industrial and urban integration, and believe that industrial and urban integration, as the key content of new urbanization, has different effects on the development of social, economic and ecological systems under different path biases [22]. Among them, the STIRPAT model, as an effective method for the study of problems in the field of environmental economy, has been widely used in the study of related problems due to its simple setting form and the fact that it allows the proper decomposition of the parameters in the model. However, research on the relationship between industrial and urban integration and carbon emissions is still rare. Some scholars, based on the perspective of new urbanization, use the STIRPAT model, SFA model, intermediary effect model, etc., to discuss it from the perspective of a welfare effect or intermediary mechanism, but there is still no consensus on the research conclusions. On the one hand, it is believed that the high concentration of population and industry in the process of new urbanization may aggravate the per capita carbon emissions of cities through the improvement in energy consumption intensity and per capita consumption level [23–25]; on the other hand, it is believed that industry–city integration can promote the efficiency of urban green innovation, but that its impact on carbon emissions is non-linear inverted U-shaped, and that economic transformation and upgrading, the upgrading of industrial structure and technological innovation have significant positive regulatory effects on it [5,26].

To sum up, most of the existing studies focus on the relationship between new urbanization and carbon emissions, or focus on the coordination and optimization of the structure of the industry–city integration system in the process of new urbanization; meanwhile, studies that focus on the carbon emissions effect of industry–city integration are rarely involved, especially lacking a mechanism analysis of the internal relationship between the two. At the same time, there is no agreement on the selection of indicators and evaluation methods for the empirical measurement of industry–city integration. Embedding a human-oriented idea into the integration and interaction process of industry and city has gradually become an important factor in the development of industry–city integration in the new era. Therefore, the research is based on the theoretical framework of the "production–life–ecology" system, and focuses on the mechanism of the impact of industry–city integration on regional carbon emissions; it takes the Yellow River basin as the spatial target, combines with the multiple comprehensive evaluation method, selects the more applicable coordination function of the deviation coefficient to fit the integration degree of industrial and urban development, and uses the STIRPAT model analysis framework, which is in-depth study of the practical characteristics of the effect of industry–city integration on carbon emissions. The possible contributions of this study are as follows: ① Focusing on the realistic background of the development of the Yellow River basin, based on the superimposed attribute of "nature and humanity", we systematically studied and judged the structural characteristics and evolution trends in the integration of industry, city and carbon emissions in the basin from a multidimensional perspective of time and space, providing an effective starting point for the coordinated promotion of ecological protection and high-quality development strategies in the Yellow River basin; ② The integration of industry and city and carbon emissions are included in the same analysis framework, and the heterogeneity and adjustment mechanism of carbon emissions in the region affected by the integration of industry and city are demonstrated from the perspective of the mechanism and an empirical test, which enriches the theoretical connotation and path selection of carbon neutralization research, and provides certain experience reference for the realization of carbon peak–carbon neutralization strategic objectives.

2. Theoretical Mechanism Analysis

The new urbanization highlights the "people" as the core, since the transformation of cities and industries has always been carried out closely around the comprehensive development of people. The National New Urbanization Plan (2014–2020) puts forward the development concept of the "benign interaction between industrialization and urbanization", and emphasizes the need to "promote functional integration and industrial and urban integration". The integrated development of the two is the core issue addressed in order to ensure the balanced development of China's social production, life and ecology in the new era [26]. Accordingly, following the people-oriented concept of new urbanization, taking urban functions that meet the needs of industrial development and a better life as the core, and based on the overall framework of the "production–life–ecology" system, the mechanism of the impact of industry and urban integration on carbon emissions is constructed (Figure 1).

(1) Production effect. On the one hand, the integration and coordination of industry and city can effectively reduce the proportion of traditional resource-intensive, high-polluting and energy-consuming industries by improving the functional structure and spatial layout of the region, speeding up the rational flow and optimal allocation of production factors, upgrading and transforming the existing industrial departments and structural systems, and by increasing investment in innovation. On the other hand, the promotion of industry–city integration will trigger the balance effect of regional industrial structure. While leading the development of new industrialization, it will promote the emergence of corresponding service industries and knowledge-intensive industries, which will be accompanied by an improvement in production and living facilities and the gathering of high-quality talents, which will effectively promote the functional and three-dimensional development of urban resource elements. At the same time, the resulting rich human capital and innovation resources will accelerate the benign competition among enterprises in terms of environmental costs, cleaner production and other technological development, so as to achieve the indirect purpose of influencing regional carbon emissions [5].

(2) Life effect. The integration of industry and city will accelerate the transfer of rural population to the city and the flow and accumulation of talents. Due to this effect, the population and industrial density of the urban core area will be greatly increased, and the overall connection of the urban sector will become closer, thusbringing many benefits to urban life. The efficient use of production and living infrastructure will make it easier for residents to travel and commute, and the energy consumption of transportation will be effectively controlled. At the same time, the popularization of technical facilities, such as coal to gas and coal to electricity, in daily life will also greatly reduce the use of coal resources and pollution emissions. In addition, the adjustment and transformation of urban functional areas and the structural layout in the process of industrial and urban integration will promote the strengthening of urban governance and daily management functions at the community level. The urban pattern, characterized by functional agglomeration, will lead to more strict and orderly community division and public governance measures; this will guide the behavior of residents through scientific and sophisticated means, eliminate unnecessary

pollution and waste, and reduce the damage that urban life causes to resources and the environment, thus ensuring the sustainability of urban development.

(3) Ecological effect. Industry–city integration will accelerate the improvement in and implementation of relevant policies and facilities under the leadership of government departments. On the one hand, in the context of high-quality development, the government departments will further improve the environmental protection infrastructure and energy conservation and emission reduction-supporting programs in the city; this is in order to improve the overall environmental carrying capacity of the city for new industries and population gathering, to create a livable and business-friendly urban landscape by means of multiple measures and environmental regulation, and to enhance the attraction of high-end industries and talents. At the same time, the "double carbon" goal requires the formation of a good pattern of national participation, which will also urge the government, communities, enterprises and other multiple entities to strengthen environmental protection publicity and education for residents and employees; this will pay attention to improving the quality of the population and its environmental awareness, so as to reduce unnecessary carbon emissions. On the other hand, the continuous improvement in the requirements for environmental quality in the process of industry–city integration will force the relevant responsible subjects to increase their investment in the construction of environmental protection and greening, and actively develop and introduce new energy and new materials to gradually reduce or even replace the use of fossil energy. Some enterprises will also actively explore new ways to reduce consumption and reduce emissions under the pressure of social influence and market mechanisms in order to seek sustainable development space in the era of ecological civilization.

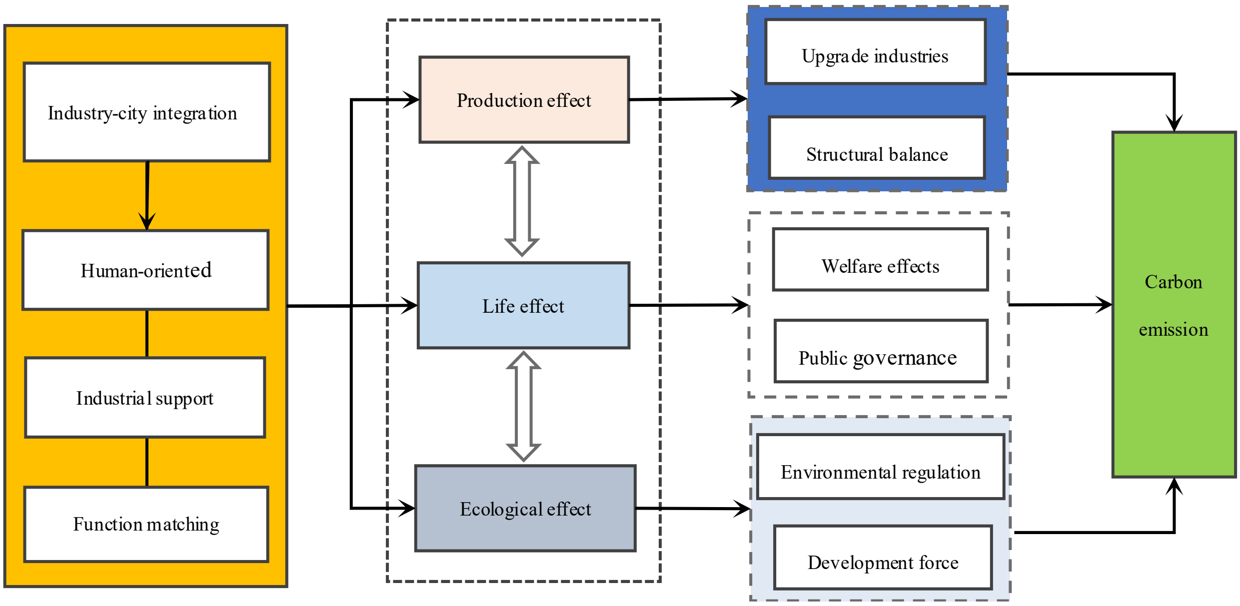


Figure 1. The path mechanism of the impact of industry–city integration on carbon emissions.

3. Materials and Methods

3.1. Measurement of Industry–City Integration

3.1.1. Construction of Evaluation Index System for Industry–City Integration

In the process of new urbanization, "industry" and "city" are not aspects of mechanically isolated development, but are dynamically evolved factors under certain environmental conditions. The organic integration of the two should not only achieve the integration of industrial structure layout and urban spatial planning, or achieve the balanced distribution of the population in industry and the urban system, but should also, more importantly, achieve an effective matching between urban functions and industrial positioning. According to this, combined with existing research and referring to Cong Haibin and other practices, the evaluation index system of industry–city integration is constructed from the dimensions of a people-oriented perspective, industrial support and functional matching [22,27] (Table 1).

Table 1. Evaluation index system of industry–city integration.

Target Layer	System Layer	Index Layer
Industry–city integration	Human-oriented	Proportion of urban population
		Urban population density
		Registered unemployment rate of urban population at the end of the year
		Per capital disposable income of urban residents
		Per capital retail sales of social consumer goods
	Industrial support	Proportion of output value of secondary industry
		Proportion of output value of tertiary industry
		Output value of land area per unit built-up area
		Gross output value of industries above designated size
	Function matching	Per capital postal business volume
		Number of college students per 10,000 people
		Number of buses per 10,000 people
		Number of beds per capital
		Per capital public library collection
		Per capital green area

3.1.2. Coordination Function of Dispersion Coefficient

Industry–city integration is a wide-ranging and complex engineered system. For the measurement of industry–city integration, it is necessary to consider not only the growth characteristics of each constituent element, but also the benign interaction and functional coordination among all systems. Based on the above purposes, existing studies have extensively used the coupling coordination and coordinated development principles to build a coordination degree evaluation model to quantitatively describe the coordination degree of industry–city integration in different types of regions [21,27,28]. Due to the differences in the applicable situations, most studies have not reached a consensus on the definition of the concept of "coupling", "coordination" and other concepts, and there have been major disputes in terms of the theoretical interpretation and model derivation, which may lead to some errors in the evaluation results [29]. Based on the consideration of the theoretical basis and the applicability of the scene, and drawing on the practices of Wang Manyin, Tang Ling, etc. [30,31], the coordination function of the deviation coefficient is used to quantitatively describe the coordination degree of the development of industry–city integration. This function is based on the analogy principle of the minimum deviation coefficient of the system's comprehensive evaluation index, and has significant advantages in the adaptability of the data structure type and the degree of freedom required by the system characteristics. The model formula is as follows [30]:

When the number of systems is m, the general formula of the dispersion coefficient model can be expressed as follows:

$$C^m = \left(\frac{2}{m(m-1)} \sum_{i \neq j} x_i \cdot x_j / (\sum_{i=1}^{m} x_i / m)^2 \right)^k \quad (1)$$

In order to effectively measure the level of coordinated development between systems, the comprehensive development information of multiple systems is usually included on the basis of the dispersion coefficient model, and the model is further expanded to that as follows:

$$D = \sqrt{C^m \times T}, T = \sum_{i=1}^{m} \lambda_i f(x_i), \sum_{i=1}^{m} \lambda_i = 1 \quad (2)$$

In the above formula, D is the coordinated development degree, C^m is the deviation coefficient, T is the comprehensive development level of multiple systems, m is the number of systems, x is the index value describing the target system, k is the adjustment coefficient, and λ is the system weight. During the use of this model, the setting of the adjustment coefficient and system weight is particularly critical. On the one hand, the value of coordination coefficient k is directly related to the density of the coordination degree, and, on the other hand, the system weight λ. The setting has a certain degree of freedom and needs to be flexibly adjusted according to the actual situation.

In this paper, the measurement of the development of industrial and urban integration mainly involves three subsystems: people-oriented, industrial support and functional matching, that is, the number of systems $m = 3$. According to previous experience, k is generally close to 4. At the same time, the research believes that the role of each system in the development of industry–city integration may be different in the same period. In order to ensure the objectivity and authenticity of the research results, the weight of each system is directly calculated using the entropy weight method [32].

3.2. Standard Deviation Ellipse Model

Standard deviation ellipse (SDE) is a spatial statistical method to quantitatively describe the overall characteristics of the spatial distribution of geographical elements [33]. This method is based on the spatial location and spatial structure of the research object. It takes the average distribution center of the geographical elements as the center, the main trend direction of the element distribution as the azimuth θ (the major axis of the ellipse rotates clockwise from the due north direction), and takes the standard deviation of the elements in the X direction and the Y direction as the ellipse axis by constructing the spatial distribution ellipse of geographical elements; this in order to quantitatively explain the centrality, distribution, directionality, spatial form and other characteristics of the spatial distribution of geographical elements from the global and spatial perspective [34]. The spatial distribution range of the ellipse represents the main area of the spatial distribution of geographical elements, where the center represents the relative position of geographical elements in the two-dimensional space, the azimuth reflects the main trend direction of their distribution (that is, the angle of clockwise rotation from the due north to the major axis of the ellipse), and the major axis represents the degree of the dispersion of geographical elements in the main trend direction [35].

3.3. Econometric Model Construction

Based on the STIRPAT model analysis framework in the field of environmental and economic research, a quantitative analysis model of the impact of industry–city integration on regional carbon emissions is constructed. The model formula can be expressed as follows [36]:

$$I_i = a \cdot P_i^b \cdot A_i^c \cdot T_i^d \cdot e \quad (3)$$

Among them, α is the model coefficient, I, P, A and T, respectively, represent the environmental quality, population development, affluence and technological progress, and e is the model error term. The STIRPAT model can not only estimate the coefficients as parameters, but also allow the proper decomposition of the influencing factors. Therefore, a large number of documents are expanded and improved according to the research needs based on formula (3) [37,38]. This paper attempts to test the carbon emission reduction effect mechanism of the integration of industry and city in the Yellow River basin under the "double carbon" target threshold. Therefore, environmental quality I can be replaced by carbon emissions (*Ce*) as the explained variable of the study, and the integration degree of industry and city (*Ici*) can be the core explanatory variable of the study; this can be incorporated it into the model (3) in order to obtain the relationship equation between industry and city integration and carbon emissions as follows:

$$Ce = a_0 + a_1 Ici + a_2 P + a_3 A + a_4 T + \varepsilon \tag{4}$$

At the same time, considering the possible impact of missing variables on the estimated results, factors such as opening to the outside world (*Op*) and infrastructure (*Inf*) are further included as control variables in the analysis framework of carbon emissions, and the logarithms on both sides of the equation are taken to build a measurement model between industry–city integration and carbon emissions:

$$\ln Ce_{it} = \ln a_i + \beta_1 \ln Ici_{it} + \beta_2 \ln P_{it} + \beta_3 \ln A_{it} + \beta_4 \ln \mathrm{T}_{it} + \beta_5 \ln Op + \beta_6 \ln Inf_{it} + \ln \varepsilon_{it} \tag{5}$$

where β_1, β_2, β_3, β_4, β_5, β_6 is the elastic coefficient of each explanatory variable, and ε represents the random disturbance term of the model. The connotation of each variable is defined as follows: ① *Ce* is the proxy variable of carbon emission reduction effect, that is, the annual carbon emission of the region; ② *Ici* is the agent variable of industry–city integration, which is calculated according to the evaluation index system of industry–city integration built previously; ③ *P* is the population development situation, where the population quality replaces the traditional population size and the proportion of employees with college degree or above is used to represent this; ④ *A* refers to the degree of affluence, which is represented by the actual per capital GDP of each region in the current year with reference to the existing research. In order to ensure the comparability of data and eliminate the impact of price f-actors, the present value of the per capital GDP of each region is obtained by taking 2005 as the base period in the study [38]; ⑤ *T* refers to technological progress, which is replaced by the degree of informationization. This is based on the availability of data, and is characterized by the number of Internet broadband access ports per 10,000 people [39]; ⑥ *Op* refers to open to the outside world, which is characterized by the actual proportion of foreign direct investment in regional GDP [40]; and ⑦ *Inf* is the infrastructure, using the per capital urban road area to represent it [41].

3.4. Data Source and Processing

Considering that the goal of China's carbon peak and carbon neutrality is to measure the total carbon emissions as the standard, the carbon emissions of the nine provinces covered by the Yellow River basin are selected as the explained variable [41]; these data are gathered from the China Carbon Emissions Database (CEADs). At present, the available data are up-to-date up to 2019. In order to ensure the balance of the research period, and further investigate the phased law of the development and evolution of the integration of industry and city in the Yellow River basin and regional carbon emissions, the period 2005–2019 is selected as the research time sequence, taking 2012 as the node at which the construction of ecological civilization is officially established as the national strategy of China. Among them, the basic indicator data of the industry–city integration measurement and measurement model are summarized and collated in the China Statistical Yearbook, the China Population and Employment Statistical Yearbook, the China Environmental Statistical Yearbook and the national economic and social development statistical bulletin of each provincial administrative region in the relevant years; some missing data are supplemented by an interpolation method in order to ensure the integrity of the sample data (Table 2).

Table 2. Descriptive statistics of variables.

Variables	Index	Connotation	Unit	Mean	Std	Min	Max
Dependent variable	ln*Ce*	Carbon emission	*Mt*	5.711	1.013	3.050	7.440
Independent variables	ln*Ici*	Industry–city integration	–	−0.586	0.112	−0.917	−0.389
Control variables	ln*P*	Proportion of employees with college degree or above	%	2.446	0.511	1.197	3.371
	ln*A*	GDP per capital	Yuan	10.322	0.566	8.920	11.242
	ln*T*	Internet broadband access port per 10,000 people	Individual	−1.851	1.030	−3.731	−0.290
	ln*Op*	Proportion of FDI in GDP	%	−1.765	0.430	−2.678	−0.495
	ln*Inf*	Per capital urban road area	m^2	2.660	0.305	2.071	3.266

3.5. Study Area Overview

The Yellow River basin is one of the oldest birthplaces of civilization in China and even in the world. It is also a densely populated area with economic activities. It plays an important role in the realization of the goal of global ecological environment governance. In October 2021, the Chinese government upgraded the ecological protection and high-quality development of the Yellow River basin into a major national strategy, highlighting the strategic position of the Yellow River basin in the overall situation of the national development layout and deep participation in global environmental governance [42]. From the dual perspective of spatial pattern and historical law, the Yellow River basin does not use the same axis development model as the Yangtze River Economic Belt and the Great Lakes Basin in North America [43]. Because it spans the three major regions of China, the economic development gap within the basin is large, the inter-regional production and city relations are loose, communication and coordination are not smooth, and unbalanced and inadequate development contradictions are more acute. On the other hand, the Yellow River Basin, as an important heavy and chemical energy base in China, is rich in coal resources. The area of coal-bearing land accounts for 44.625% of the total area of the basin. The economic recoverable amount of coal resources and coal output is currently the first in the country, and the associated excessive carbon emissions are particularly typical [44]. With the intensification of the green revolution throughout the world, the contradiction between economic growth and ecological environment is increasingly prominent. The Yellow River basin, with its dual attributes of ecology and economy, provides a practical model for the research of and finding of solutions for global green and low-carbon development issues. Therefore, this research on the carbon emission reduction effect of the industry–city integration in the Yellow River basin has a positive exemplary role and practical significance for breaking the development bottleneck that makes it difficult to coordinate the development and protection of different types of regions; it explores a new model that can be replicated and popularized in order to coordinate the construction of ecological civilization and high-quality development (Figure 2).

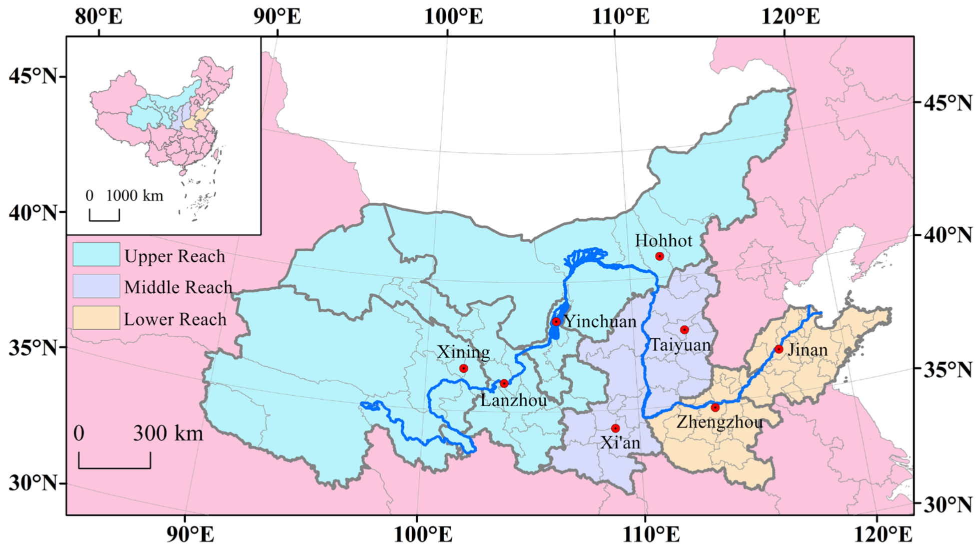


Figure 2. Scope of Study Area.

4. Analysis of Empirical Results

4.1. The Space–Time Characteristics of Industry–City Integration and Carbon Emissions

4.1.1. The Timing Evolution of the Integration of Industry and City and Carbon Emissions in the Yellow River Basin

Using the coordination function of the deviation coefficient, the development index of the integration of industry and city in the Yellow River basin from 2005 to 2019 is calculated (Figure 3). According to the figures, (3) The level of the integration of industry and city in the Yellow River basin has significantly improved dynamically, with an overall increase of 36.428% during the study period, and an annual growth rate of about 2.429%. The spatial pattern of industrial and urban integration has evolved from "middle reach bulge" to "upper reach–middle reach–lower reach" with a gradient increase. The relative difference of industrial and urban integration between provinces within the region has first spread and then converged. The overall level of industrial and urban integration in most provinces and regions is higher than the average of the basin. (2) Carbon emissions in the Yellow River basin have continued to rise, with the carbon emissions increasing from 2124.583Mt in 2005 to 5752.307Mt in2019, with an overall increase of 170.749% and an average annual growth rate of about 7.573%. The overall pattern of carbon emissions in space has gradually evolved from "lower reach > middle reach > upper reach" to "middle reach > lower reach > upper reach". Among them, the overall carbon emissions in the middle and lower reaches have been high for a long time. Since 2013, the middle reaches have surpassed the lower reaches and become the peak source of carbon emissions in the basin. The carbon emissions in the upper reaches have been growing steadily. The relative differences in carbon emissions between regions have shown a significant diffusion trend. (3) After comparison, it is found that the growth trajectory of the two systems changed from steep to slow or even to a short-term decline around 2014, especially in the middle reaches of the river basin. The reason for this may be related to the policy orientation of ecological civilization construction and the strategic regulation of the new normal of economic development after the 18th CPC National Congress in 2012. From 2013 to 2015, the overall growth of China's economy shifted gears, and various regions faced the transformation of the driving force of economic development and structural transformation. The integration of industry and city and energy utilization also entered a new phase after undergoing some adaptive adjustment.

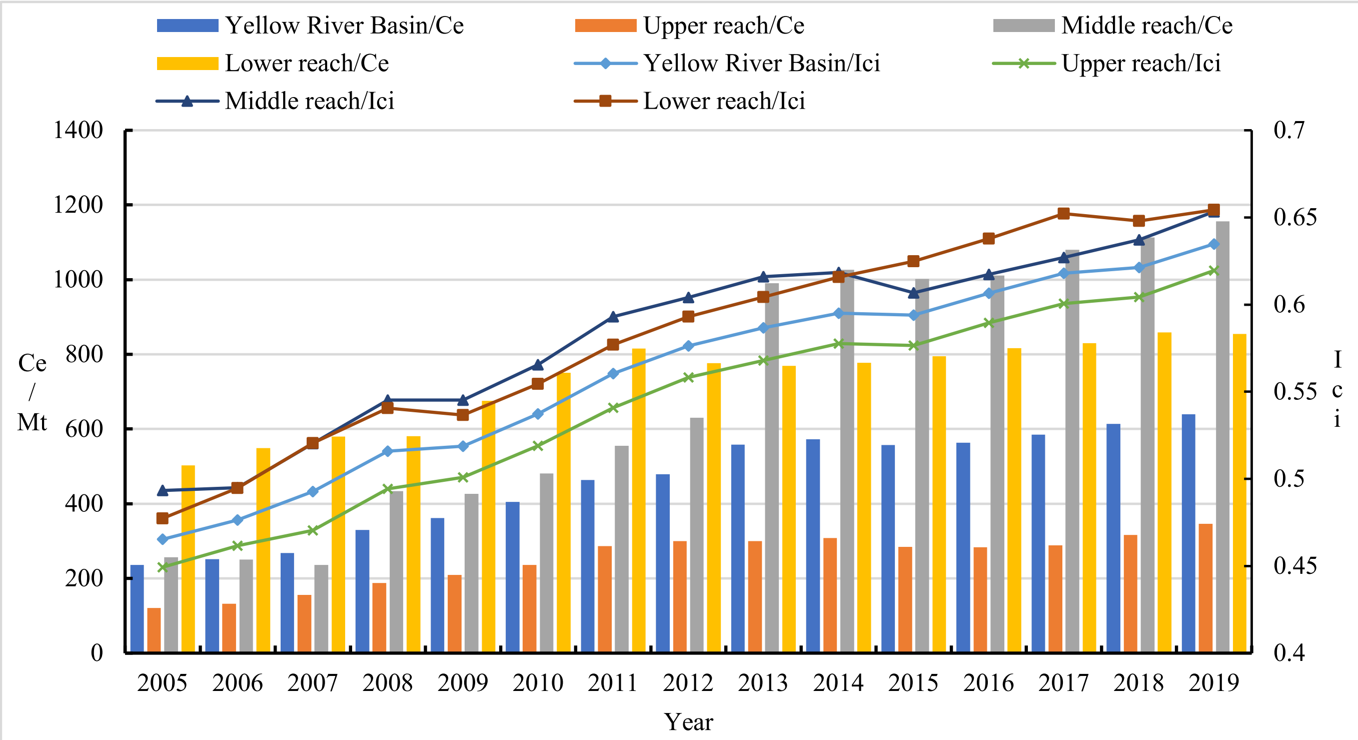


Figure 3. Time series evolution of the integration of industry and city and carbon emissions in the Yellow River basin (2005–2019).

4.1.2. The Spatial Pattern of Industry–City Integration and Carbon Emissions in the Yellow River Basin

In order to facilitate observation, based on the data calculation results, the industry–city integration and carbon emissions are divided into three levels: "high–middle–low"; then, the spatial pattern and standard deviation ellipse distribution of the industry–city integration and carbon emissions in the Yellow River Basin in 2005, 2012 and 2019 are drawn using the ArcGIS spatial visualization tool (Figure 4), specifically as follows:

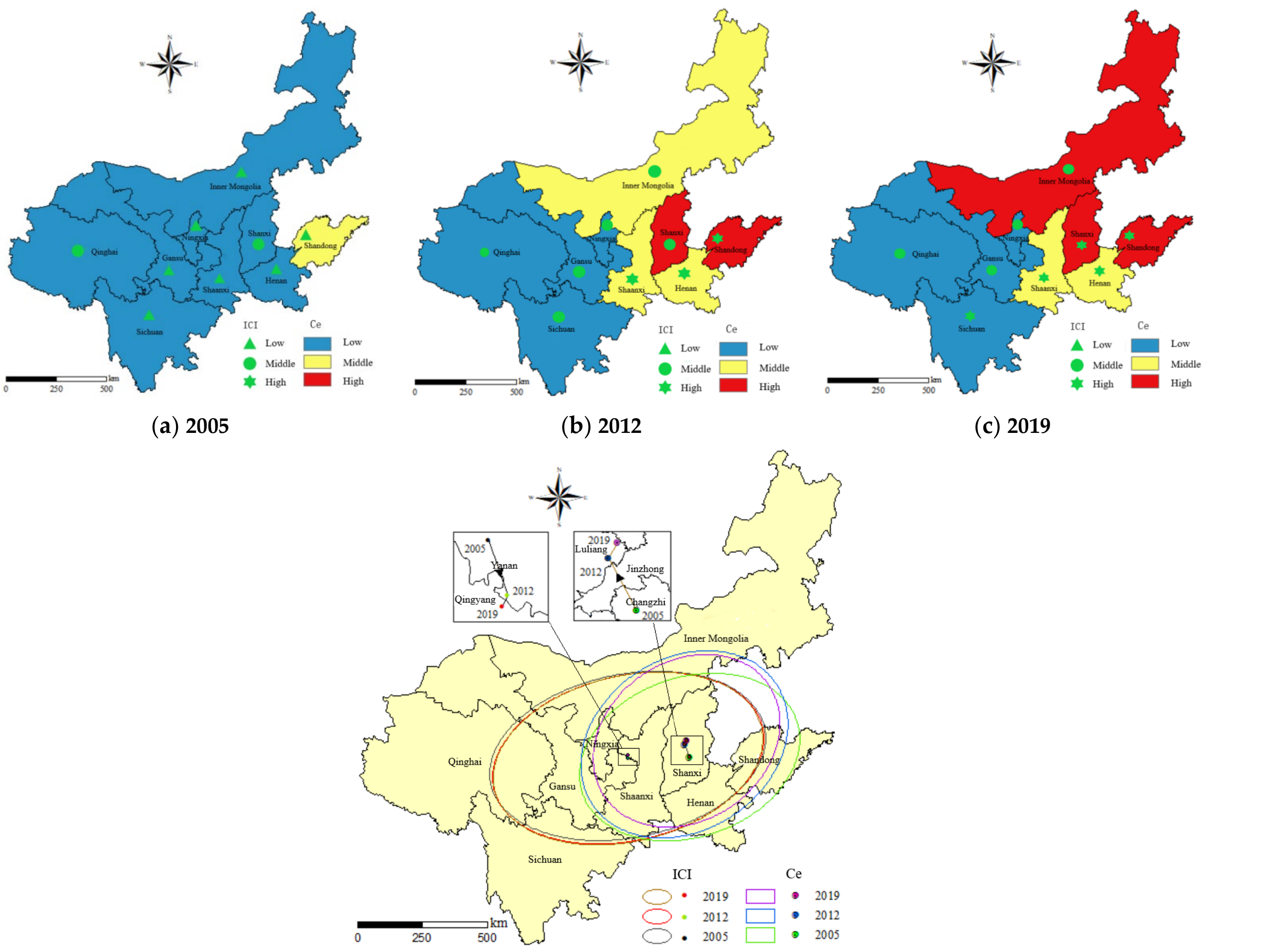
(1) At the level of industry and city integration, from 2005 to 2019, the degree of industry and city integration of all provinces and regions in the Yellow River basin has been improved to varying degrees. Provinces with relatively high levels are mainly concentrated in the middle and lower reaches and the southwest of the basin. This type of region is driven by the radiation of geographical location (Shandong), national strategy (Henan, Shaanxi, Sichuan) and resource endowment (Shanxi), and other factors. Urbanization and the development basis and function matching of secondary and tertiary industries are relatively good, provideing good support and sustained impetus for the deep integration of industry and city. The provinces and regions at the middle and lower levels are mainly concentrated in the upper reach of the river basin. Most of the relevant provinces are deep in the hinterland of China, with a weak foundation for economic development, an overall lack of factor endowment, a single industrial structure and a relatively lagging level of transformation and upgrading. Provinces and regions such as Qinghai, Gansu and Inner Mongolia have faced multiple constraints, such as an unbalanced development and a fragile natural environment for a long time. The development of industries and cities lacks effective driving force. Traditional agriculture and animal husbandry-oriented and resource-dependent industries still account for a large proportion, resulting in a difficulty in terms of forming a joint force in the process of industry–city integration and the slow progress of the overall transformation.

(2) In terms of carbon emissions, from 2005 to 2019, the carbon emissions of all provinces and regions in the Yellow River basin increased significantly. The regions with high emissions mainly include Shanxi, Shandong, Inner Mongolia and other provinces. The three provinces account for nearly half of the national large coal bases in the basin, of which Shanxi and Inner Mongolia are typical resource-dependent development areas in China. The reserves of coal, metal, minerals and other energy resources are rich, and the corresponding high energy-consuming industries account for a large proportion, leading to their long-term dominance in the overall carbon emission pattern of the basin. Shaanxi and Henan also have a certain quantity of coal resources and industrialism, but thanks to the development of characteristic agriculture, high-end manufacturing and the tourism economy, the overall growth of carbon emissions is relatively controllable, and its intensity is in the middle range in the overall pattern of the basin. The other upstream provinces are jointly affected by factors such as resource endowment, the development mode and industrial structure. The overall carbon consumption of economic development and human activities is relatively small. The growth trend in these carbon emissions over a long period of time is basically stable, and they are low-pressure source areas for carbon emission reduction in the basin.

(3) At the level of spatial structure, the overall layout of the integration of industry and city and carbon emissions in the Yellow River basin is significantly different, and the extension direction of the standard deviation ellipse of the two systems and the structural center of gravity show a dynamic migration and decoupling trend. It can be found from the observation of Figure 4 that the spatial pattern of the integration of industry and city in the basin is generally distributed in the east–west direction, that the elliptical angle is generally maintained at about 36.60° with a small deflection, and that the area generally covers most of the basin. Compared with the evolution trend seen in the long and short axis, the ellipse gradually diffuses along the east–west direction and converges in the south–north direction, which is closer to the overall geometric shape of the basin, indicating that the inter provincial integration of industry and city in the region is gradually balanced. The overall pattern of the carbon emission standard deviation ellipse is generally northeast to southwest, and the ellipse area is relatively small, mainly covering the middle and lower reach and some upstream areas. From the perspective of the dynamic evolution trend, the ellipse is generally convergent in both the long and short axis directions, while the ellipse angle is deflected from 55.64° in 2005 to 71.36° in 2019, indicating that the carbon emissions in the northwest of the basin increased significantly during this period, and the spatial scope is gradually locked to the middle reaches. A further comparison of the center of gravity migration tracks of the two systems shows that the structural center of the integration of industry and city in the basin is roughly located at the junction of northwest Shaanxi and Gansu. During the study period, the center of gravity of the system moved about 17.686 km from north to south, and was transferred from Yan'an city to Qingyang city, with a relatively stable overall change. The structural center of carbon emissions is located in the central part of Shanxi Province. During the study period, the system's center of gravity moved about 101.419 km from south to north, and shifted from Changzhi city to Luliang City, with a relatively large change. In general, the spatial distance between the structural centers of gravity of the two systems is relatively far, and the dynamic trend in migration and decoupling is "opposite to each other, with the same frequency"; this indicates that the development and evolution of the two systems have potential temporal and spatial correlation, and also preliminarily confirms that the integration of industry and city may have a certain linear correlation effect on carbon emissions.

4.2. Benchmark Regression Results

In order to avoid the result deviation caused by pseudo-regression, the method of adding variables one by one was adopted. According to the results of the Hausman test, the model selected the fixed effects. The estimated results are shown in Table 3. From the benchmark regression results, after adding the influence of the control variables designed in this paper, the industry–city integration shows a significant carbon emission reduction effect. The regression coefficient is −1.9698, which is significant at the 1% confidence level, that is, the industry–city integration degree increases by 1%, and the carbon emissions decrease by 1.9698%.



(**a**) **2005** (**b**) **2012** (**c**) **2019**

(**d**) **Standard deviation ellipse**

Figure 4. Spatial pattern and standard deviation ellipse distribution of industry–city integration and carbon emissions in the Yellow River basin (2005–2019).

The regression results of the other control variables are basically in line with expectations, and the impact coefficient of population quality, affluence and infrastructure is significantly positive, indicating that the overall economic development quality of the Yellow River basin during the study period is relatively low, and that the population quality and infrastructure are constrained by the regional development environment; this still cannot achieve the ideal effect of promoting energy conservation and emission reduction. The regression coefficient of openness and informationize is negative, which is not statistically significant, indicating that a reasonable pattern of openness and digital transformation can drive the optimization and upgrading of regional development models and thus affect the carbon emission results; meanwhile, the overall level of the two in the current Yellow River basin still needs to be further improved.

Table 3. Benchmark Regression Estimation Results.

Independent Variables	**Dependent Variable/ln*Ce***				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
ln*Ici*	−1.2963 **	−1.1271 *	−1.0972 **	−1.1287 *	−1.9698 ***
	(−1.64)	(−1.55)	(−1.49)	(−1.56)	(−2.68)
ln*P*	0.2011	0.0699	0.0880	0.0911	0.1090
	(1.63)	(0.62)	(0.69)	(0.71)	(0.90)
ln*A*		0.7718 ***	0.8057 ***	0.7605 ***	0.8005 ***
		(5.67)	(4.60)	(4.00)	(4.44)
ln*T*			−0.0275	−0.0013	−0.0778 *
			(−0.31)	(−0.01)	(−0.81)
ln*Op*				−0.0412	−0.0340
				(−0.62)	(−0.54)
ln*Inf*					0.7205 ***
					(3.84)
_*cons*	−2.2552 **	−3.0879 **	−3.5158 *	−3.0993	−6.0939 **
	(−1.80)	(−1.76)	(−1.57)	(−1.32)	(−2.95)
R^2	0.5969	0.6804	0.6807	0.6817	0.7165
Num	135	135	135	135	135

Note: () is *t* value, and ***, ** and * are significant at the levels of 1%, 5% and 10%, respectively.

4.3. Robustness Test

In order to further test the robustness of the regression results, the study conducted a comparative analysis from the following aspects:

(1) Replace the interpreted variable. Referring to the calculation method used for the energy consumption intensity by Li Shuoshuo et al. [23], the carbon emissions per unit of GDP in each sample region are used as the characterization variable of regional carbon emissions. The regression results are shown in column (1) of Table 4. It can be seen that the impact coefficient of industry–city integration after replacement is significantly negative at the level of 1%, indicating that industry–city integration has a significant carbon emission reduction effect, and that the research results have certain robustness.

(2) Split core explanatory variables. Combined with the path analysis of the impact of industry–city integration on carbon emissions, the development and evolution of different dimensions in the dynamic interaction process of the industry–city system will also have a direct impact on regional carbon emissions. Therefore, based on the selection of the indicator composition, the core explanatory variable of industry–city integration is split, and its carbon emission reduction effect is verified from the basic dimensions of a people-oriented perspective, industrial support and functional matching [45]. In column (2) of Table 4, apart from the industry–city integration index, the three dimensions of people-oriented orientation, industrial support and functional matching are included as the core explanatory variables. The results show that the regression coefficients of the three combined dimensions are significantly negative at the level of 5% and 1%, respectively. This shows that the occurrence of the carbon emission reduction effect of industry–city integration to a certain extent stems from the dynamic process of improving the functions and structures of industry and urban systems.

(3) Remove some samples. In order to eliminate the impact of extreme values and outliers on the regression results of the model, the two provinces and regions with the highest and lowest carbon emissions during the study period were selected. According to the observed data characteristics, Shanxi and Qinghai provinces and regions occupy the first and last positions, respectively, in terms of time series evolution and the

multi-year mean compared with other provinces and regions. Therefore, Shanxi and Qinghai are excluded from the sample sequence, and the regression results are shown in column (3) of Table 4. It can be seen that after this treatment, the carbon emission reduction coefficient of industry–city integration is still significant.

(4) Endogenous treatment. In the model analysis, fixed effect regression has been used to control the impact of unobservable regional characteristic variables on the estimation results, but it may still be disturbed by potential endogenous and reverse causal problems, so the instrumental variable method is further used for the analysis and test. Since the development of industrial and urban integration may face the dynamic cycle of planning and construction, which has a certain time inertia in terms of its impact on carbon emissions, consider selecting the lag t-n period of the industrial and urban integration index as a tool variable, referring to the five-year cycle of China's development planning, and adopt the 2SLS method in order to analyze and deal with the possible endogenous problems (Table 5).

Table 4. Results of robustness test.

Independent Variables	**(1) Replace Dependent Variable**	**(2) Split Independent Variable**			**(3) Remove Some Samples**
Industry–city integration	−0.2872 *** (−4.64)				−0.3572 *** (−5.00)
Human-oriented		−1.2721 ** (−1.87)			
Industrial support			−2.5420 *** (−3.51)		
Function matching				−1.8665 *** (−2.42)	
Control variables	Yes	Yes	Yes	Yes	Yes
_cons	0.2602 *** (4.47)	0.4858 * (0.54)	−1.6600 (−1.64)	−1.6104 * (−1.39)	0.3145 *** (7.81)
R^2	0.1469	0.7369	0.7544	0.7418	0.2051
Num	135	135	135	135	117

Note: () is t value, and ***, ** and * are significant at the levels of 1%, 5% and 10%, respectively.

Table 5. Estimation results of instrumental variables.

Statistical Items	**Lag $t-1$ (1)**	**(2)**	**Lag $t-2$ (3)**	**Lag $t-3$ (4)**	**Lag $t-4$ (5)**
Regression stages	Stage 1	Stage 2		Stage 2	
Dependent variable	Industry–city integration	Carbon emission		Carbon emission	
ln*Ici* (agent)		−2.4543 ** (−2.05)	−2.7463 ** (−2.08)	−3.7253 *** (−2.46)	−3.9628 ** (−2.33)
Control variables	0.7857 *** (13.67)				
First stage F value	295.84 ***				
Wald chi2		170.75 ***	199.55 ***	196.22 ***	186.71 ***
K-P rk LM	32.465 ***		33.239 ***	30.454 ***	27.713 ***
K-P rk Wald F	186.741 (16.38)		237.68 (16.38)	149.792 (16.38)	93.027 (16.83)
C-D Wald F	283.018 (16.38)		266.140 (16.38)	186.972 (16.38)	122.394 (16.38)
Control variables	Yes	Yes	Yes	Yes	Yes
_cons	0.4113 ** (2.43)	−6.6313 ** (−2.28)	−6.9895 ** (−2.16)	−5.6967 ** (−1.61)	−5.0504 (−1.22)
R^2	0.9304	0.3723	0.3665	0.3472	0.3349
Num	126	126	117	108	99

Note: Due to space limitation, only the regression results of the first stage of lag $t-1$ are displayed. () is t value, and *** and ** are significant at the levels of 1% and 5%, respectively.

According to the estimated results of the instrumental variable method (taking the lag $t-1$ period as an example), the F statistic in the first stage of regression is 295.84, which exceeds the threshold of 10 and is significant at the level of 1%, indicating that there is a high correlation between the instrumental variable and the endogenous variable selected in this paper; therefore, the problem of a "weak instrumental variable" can be basically ruled out. The K-P rk LM statistic passed the 1% significance test and rejected the hypothesis of "insufficient identification of instrumental variables", indicating that the selected instrumental variables did not have the problem of insufficient identification. All the test results confirm that the tool variables constructed in this paper are effective. The estimated results of the second stage of each lag period (2)–(5) show that the influence coefficients of the agent variables of industry–city integration on carbon emissions are significantly negative; this shows that the carbon emission reduction effect of industry–city integration still exists when considering endogenous issues. The equivalent of carbon emissions in the same period is not only affected by the current development of industry–city integration, but is also closely related to its previous basis. Here, it is also confirmed again that the previous estimated results are robust. It is worth noting that the carbon emission reduction coefficient of industry–city integration that is obtained by the instrumental variable method is stronger than the estimated result of the benchmark regression, which means that if the impact of endogenous problems is ignored, the practical role of industry–city integration in promoting carbon emission reduction may be underestimated. Further comparison shows that the significance level of the emission reduction coefficient of each group of instrumental variables decreases first and then increases, reaching the lowest level in the study period when it lags behind the $t - 3$ period; this indicates that there is a strong time inertia in the carbon emission reduction effect of industry city integration, and that the current construction will reach the maximum effect in the third year after completion.

4.4. Expansion Analysis

4.4.1. Heterogeneity Analysis

From the previous analysis, it can be seen that the resource endowments of different geographical locations in the Yellow River basin are quite different, and that the overall intensity of regional carbon emissions is also closely related to the stage characteristics of urban and industrial development. Therefore, this study examines the heterogeneous impact of industrial and urban integration on the reduction of regional carbon emissions from two aspects of geographical location and carbon emission intensity.

(1) In terms of geographical location, it is classified according to the upper, middle and lower reaches of the region, and the estimated results of geographical location heterogeneity are shown in Table 6. It is observed that the impact coefficient of the integration of industry and city on carbon emissions in the upstream, middle and downstream regions is negative. The carbon emission reduction coefficient in the upstream and downstream regions is large (absolute value) and significant at the level of 10% and 1%, respectively. The carbon emission reduction coefficient in the midstream region is small and not statistically significant. This shows that the coordinated integration of industry and city can effectively promote the realization of carbon emission reduction targets in the upper and lower reaches of the Yellow River basin, but its effect is not obvious in the middle reaches. The possible reason for this is that, compared with the upstream and downstream regions, the middle reaches of the Yellow River, as an important heavy and chemical energy base in China, have a wide range of industrial chains and industrial sectors; indeed, the development and utilization of resources are at their core, derived from the process of ensuring the maintenance of the national energy supply. In particular, resource-dependent industries, such as coal mining and thermal power generation, once served as the main support for the regional economy. This extensive development has led to a weak foundation for urbanization and the modern service industry, and has caused a lag in terms of transformation and upgrading. The integration of industry and city lacks power traction at the level of function matching and industrial support. It is unable to achieve the effective dilution of high-intensity carbon emissions in the short term, which means that the integration of industry and city in reducing carbon emissions is poor.

(2) In terms of carbon emission intensity, Jenks natural breakpoint method is used to divide the carbon emission intensity into three levels: high, middle and low. See Table 6 for regression estimation results. It is observed that there is a certain difference in the impact of industry–city integration on the carbon emissions of the three carbon emission intensity ranges. Among them, the impact coefficient of carbon emissions in medium-intensity areas is significantly negative, while the impact on the high-intensity and low-intensity carbon emission areas is not statistically significant. It can be said that the impact of industry–city integration on carbon emissions has certain stage characteristics and a certain matching range, and it can play a more significant role in reducing emissions in regions with a relatively moderate carbon emission intensity. The possible reason for this is that, on the one hand, regions with a moderate carbon emission intensity have a relatively low dependence on high energy consumption, and high carbon emission industries and behaviors, for their own development. According to the background characteristics and multiple endowment advantages, they can provide space for energy conversion and structural adjustments in the process of urban and industrial function optimization, which is conducive to the orderly promotion of industrial and urban integration, and to the effective control of carbon emissions. On the other hand, based on the practical experience provided by regions with a high and low carbon emission intensity, it provides a necessary reference for them to explore the virtuous cycle of regional development and ecological civilization construction, and urges them to coordinate the layout of production and urban development in various fields of production, life and ecology; this it in order to provide stable and sustainable energy output for regional carbon emission reduction. However, regions with a low carbon emission intensity are often affected by their own environmental endowments and development models. Either the demand and consumption of coal and other resources and energy in the process of production and life are not large, or the proportion of traditional industries and resource-dependent industrial sectors in the industrial structure is small. The pressure on energy conservation and emission reduction is relatively light, and there is no need to rely too much on the adjustment and dilution of carbon emissions via industrial and urban integration, so the carbon emission reduction effect of industrial and urban integration is not significant.

Table 6. Estimation results of heterogeneity analysis.

Independent Variables	Dependent Variable/ln*Ce*					
	Geographic Location			Carbon Emission Intensity		
	Upper Reach	Middle Reach	Lower Reach	High	Medium	Low
ln*Ici*	−1.3784 * (−1.33)	−0.8765 (−0.14)	−9.2869 *** (−2.88)	1.4900 (0.61)	−4.5099 ***(−6.18)	−0.4929 (−0.73)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes
_cons	−1.4945 *** (−2.13)	−0.1977 (−0.06)	−5.0789 *** (−2.30)	−0.0513 (−0.01)	−15.0088 *** (−5.87)	−2.9134 ** (−1.81)
R^2	0.8870	0.8725	0.8512	0.7808	0.8717	0.8938
Num	75	30	30	45	45	45

Note: () is *t* value, and ***, ** and * are significant at the levels of 1%, 5% and 10%, respectively.

4.4.2. Analysis of Regulatory Effect

Based on the mechanism analysis of the impact of industrial and urban integration on carbon emissions, it is not difficult to find that scientific and technological innovation and government regulation have always played an important role in the process of regional development and transformation, and that their role runs through all fields of urban production, life and ecology. Therefore, this study further tests the regulatory effect of technological innovation and government regulation on the impact of industrial and urban integration on carbon emissions from the perspective of intermediary transmission.

(1) Analysis of the regulatory effect of scientific and technological innovation

Scientific and technological innovation is not only an important factor in the high-quality development of cities and industries, but also the key to the construction of regional ecological civilization. It can influence the behavior choices of carbon emission entities through technological change and concept optimization in the process of driving the transformation and upgrading of regional development. Using Liu Yaobin and other studies for reference, the per capita patent authorization at the end of the year is used to characterize the level of technological innovation (Tec) in various regions [41]. The interactive items of scientific and technological innovation, and industrial and urban integration, are introduced into the benchmark model, and the regression results are shown in Table 7. In general, the regression coefficient of industry–city integration is significantly negative under both independent and multiple interactions, which does not change the original conclusions of the study. The independent impact coefficient of scientific and technological innovation is negative and significant, indicating that strengthening scientific and technological innovation can effectively promote regional carbon emission reduction. The regression coefficient of the interaction item is significantly negative, and the independent carbon emission reduction effect of industry–city integration and scientific and technological innovation has been strengthened to some extent after the interaction; this indicates that an improvement in the level of scientific and technological innovation can help empower its emission reduction effect in the development process of industry–city integration, and that it can promote the green and low-carbon transformation of the region.

(2) Analysis of the regulatory effect of government regulation

The intervention and control of government departments is of great significance to the stable and healthy development of the national economy. In many situations, especially in the field of ecological and environmental protection, institutional constraints and environmental governance are usually adopted to regulate the energy consumption and pollution emissions in the process of regional economic and social development; this is in order to effectively improve the environmental carrying capacity and sustainability of regional development. Using Xie Rui and other studies for reference, the ratio of environmental governance investment to GDP is used to characterize the environmental regulation (Er) intensity of regional governments [43]. In the benchmark model, environmental regulation, and the interaction between environmental regulation and industrial and urban integration, are introduced. The regression results are shown in columns (5)–(8). Under the single factor and interaction situation, the regression coefficient of industrial and urban integration is significantly negative, without changing the original conclusion. After comparison, it is found that the influence coefficients of the single factor and the interaction of environmental regulation are negative, but not statistically significant, indicating that active government regulation and environmental governance can have a certain reduction effect on regional carbon emissions. At present, the intensity and form of regulation guidance still need to be further optimized and improved. However, in the context of the model that incorporates the integration of industry and city, environmental regulation and the interaction of the two, the impact coefficient of the interaction effect significantly increases and is significant at the level of 1%; this indicates that the integration of industry and city and environmental regulation can produce the synergistic effect of carbon emission reduction, and that with the continuous improvement in the level of the two, regional energy conservation and emission reduction will increasingly rely on the interaction of the two systems.

Table 7. Estimated results of regulatory effect analysis.

Independent Variables	Dependent Variable/ln*Ce*							
	Regulation Effect of Technological Innovation				Regulation Effect of Government Regulation			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
ln*Ici*		−3.4248 *** (−2.96)	−1.7246 *** (−2.68)	−9.1590 *** (−4.71)		−1.7313 *** (−2.72)	−1.7323 *** (−2.70)	−1.6155 *** (−2.70)
ln*Tec*	−0.0252 * (−0.33)		−0.0057 (−0.08)	−0.5423 *** (−3.59)				
ln*Er*					−0.0240 (−0.30)		−0.0269 (−0.34)	1.2585 *** (4.15)
Interaction effect *		−0.1721 ** (−1.75)		−0.7991 *** (−4.03)		−0.1689 (−1.33)		−2.1492 *** (−4.37)
Control variables	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
_cons	−0.3382 (−0.17)	−2.3652 (−1.27)	−3.8532 ** (−1.66)	−8.5995 *** (−3.46)	0.2190 (0.24)	−3.7952 *** (−2.24)	−3.7536 *** (−2.20)	−3.6048 *** (−2.26)
R^2	0.7294	0.7512	0.7448	0.7756	0.7294	0.7485	0.7450	0.7805
Num	135	135	135	135	135	135	135	135

Note: () is *t* value, and ***, ** and * are significant at the levels of 1%, 5% and 10%, respectively.

5. Conclusions and Suggestions

5.1. The Main Conclusions

As an important ecological and economic zone, the Yellow River basin has important practical significance; it demonstrates its role in the construction of the world's green economic system and its deep participation in global environmental governance through the coordinated promotion of the integration of industry and city and carbon emission reduction. Based on this background, the research theoretically analyzes the path mechanism of the impact of industry–city integration on carbon emissions, and empirically tests the practical characteristics of the carbon emission reduction effect of industry–city integration using the Yellow River basin as a sample; this uses the methods of the dispersion coefficient coordination function, the standard deviation ellipse and the STIRPAT model. On the one hand, it provides an effective reference for the transformation and optimization of the development model of the Yellow River basin, and, on the other hand, it also provides a positive demonstration for the green and low-carbon development of the world economy. The main conclusions are as follows:

(1) During the study period, the overall level of the integration of industry and city in the Yellow River basin was significantly improved, and the spatial differences within the region first spread and then converged. The dynamic trend in carbon emissions is generally fluctuating and rising. The unbalanced characteristics within the region are gradually strengthened. The midstream region has gradually evolved into the peak source of carbon emissions. In terms of spatial structure, the migration track and overlapping range of the two system structure barycentres show a trend that sees both migration and decoupling with generally the same frequency, which initially shows a certain linear spatiotemporal correlation.

(2) The analysis results of the STIRPAT model show that industry–city integration has a significant carbon emission reduction effect, and that the conclusion is still valid after endogenous treatment and a series of robustness tests. The development of an export-oriented economy and an improvement in the informatization level have a positive role in promoting carbon emission reduction. Economic development, infrastructure, population quality and other factors have temporarily failed to effectively promote energy conservation and emission reduction.

(3) After further study, it is found that the carbon emission reduction effect of industry–city integration has a certain spatiotemporal heterogeneity. Affected by geographical location and the development model, this effect of carbon emission reduction is particularly significant in the upper and lower reaches of the Yellow River, and regions with moderate carbon emission intensity; the effect of other types of regions is slightly less significant. The regulatory effect analysis results show that technological innovation

and environmental regulation have a direct inhibitory effect on carbon emissions, and both have a positive regulatory function in the carbon emission reduction effect of industry–city integration.

5.2. Policy Suggestions

The policy implications based on the empirical study findings are as follows:

First, accelerate the coordination and integration of industry and city, and help the overall development and transformation of the basin. Different types of regions should fully combine their own realities, should accelerate the construction process of new urbanization and in the transformation and upgrading of industrial structure, should plant local characteristics, enrich the connotation of urban and industrial development, and promote the high-quality integrated development of industry and city. In the process of regional development and transformation, we should focus on cultivating emerging and high-value-added industries, strive to accelerate the conversion of new and old kinetic energy, accelerate the clean and efficient use of coal, deepen the energy revolution, reduce the resource dependence and environmental loss of economic and social development, and take a new green, circular and low-carbon development path. Second, deeply tap the regional emission reduction kinetic energy, and scientifically formulate the dual-carbon action plan. We should closely combine the local reality, follow the historical path of regional development, organically combine the natural background with the economic foundation, and work together in the fields of production, life and ecology in order to deeply explore the potential space for energy conservation and emission reduction. In the process of development and construction, we should pay attention to the key points, adhere to the intensive and compact development of efficiency, take scientific and technological innovation as the guide, strengthen industrial division and cooperation, strive to reduce overcapacity, build an ecological priority system, build a green and low-carbon virtuous cycle system, and work together to ensure the orderly progress of the carbon peak and carbon neutral goals. Third, promote coordinated governance and build a long-term mechanism for energy conservation and emission reduction. Industry–city integration and carbon emission reduction should adhere to the overall strategy of adjusting measures to local conditions and coordinated promotion, improve communication and cooperation channels with natural attributes, ecological functions, etc., advocate for refined zoning management and control, reasonably delimit the responsibility of regional development and governance, and form a new pattern of development and protection with effective supervision and orderly structure. At the same time, government departments should plan for development that epitomizes the harmonious coexistence between humans and nature, should play an active role in regulatory guidance and macro-control, and should build a long-term mechanism of industry–city integration in order to enable high-quality development that helps energy conservation and emission reduction.

In this study, a new evaluation system of industry–city integration has been constructed. Compared with previous studies that only focus on the interaction between cities and industries, it further emphasizes the core position of people, and believes that industry–city integration should be the organic integration of industry, city and people. In terms of research design, referring to the existing research and based on the STIRPAT model, the specific form of the carbon emission effect of industry–city integration was preliminarily tested. In addition, based on the theoretical mechanism analysis, the regulatory effect of scientific and technological innovation and government regulation was further explored; this provides an effective reference for the formulation of energy conservation and emission reduction policies. This is an improvement on the existing research, and it also enriches the theoretical connotation of industry–city integration and carbon neutralization research. It is worth mentioning that before the analysis of the results of the econometric model, the SDE model was innovatively used to systematically observe the evolution characteristics of the space–time pattern of industry–city integration and carbon emissions, which more intuitively confirmed the effectiveness of the research results. The coordinated promotion of industry–city integration and the "dual-carbon" strategy is a long-term and historical dynamic process. In future research, there are still many areas that have not been considered and that are worth exploring. Compared with existing studies, the impact of economic development, infrastructure and population quality on carbon emissions needs further dialectical discussion. With the gradual improvement in the top-level design, the implementation of relevant policies and measures needs to focus more on microcarriers, such as cities and counties, and promote the coordinated development of the whole region on the basis of fully taking into account diversity and heterogeneity. Therefore, the follow-up research needs to focus on the accurate definition of the spatial scale and the profound impact of spatial elements, and optimize and improve the model method based on the assumption of spatial homogeneity in this study. Although a relatively complete analysis framework of economic and social system has been established in the existing research, on this basis, we still need to fully consider the impact of natural factors such as climate, topography, hydrology, and so on, in view of the dual objectives of ecological protection and high-quality development; this is in order to draw more scientific and detailed research conclusions. This will be the focus of future research.

Author Contributions: Conceptualization, Z.J.; methodology, Z.J.; software, C.Z.; validation, X.Z., and C.S.; formal analysis, Z.J.; investigation, Y.F.; resources, Y.F.; data curation, Y.F.; writing—original draft preparation, Z.J.; writing—review and editing, Y.F.; visualization, C.S.; supervision, J.S.; project administration, J.S.; funding acquisition, J.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Natural Science Foundation of China, (Grant Number: 42171170).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

References

1. Available online: http://www.gov.cn/xinwen/2021-03/15/content_5593154.htm (accessed on 15 March 2021).
2. Yue, T.; Li, M.T.; Chen, H.; Long, R.; Wang, Y. Carbon neutrality research hotspots and evolution trend: Based on the scientific knowledge map. *Resour. Sci.* **2022**, *44*, 701–715. [CrossRef]
3. Cai, B.F.; Cao, L.B.; Lei, Y.; Wang, C.; Zhang, L.; Zhu, J.H.; Li, M.Y.; Du, M.B.; Lv, C.; Jiang, H.Y.; et al. Carbon Dioxide Emission Pathways under China's Carbon Neutralization Target. *Popul. Resour. Environ. China* **2021**, *31*, 7–14.
4. Liu, S.Y.; Xiang, H.L.; Wu, F. Can industry-city integration promote regional innovation?—Empirical evidence from 285 prefecture-level cities in China. *Res. Manag.* **2022**, *43*, 37–44.
5. Huang, X.Y.; Li, Y. Research on the impact of industry-city integration on green innovation efficiency in large and medium sized cities. *Jiangxi Soc. Sci.* **2020**, *40*, 61–72.
6. Button, K.J. *Urban Economics: Theory and Policy*; The Mac Millan Press: London, UK, 1976.
7. Baldwin, J.R.; Brown, W.M. Regional manufacturing employment volatility in Canada: The effects of specialization and trade. *Pap. Reg. Sci.* **2004**, *3*, 519–541. [CrossRef]
8. Perroux, F. A note on the notion of growth pole. *Appl. Econ.* **1955**, *2*, 307–320.
9. Henderson, J.V. Marshall's scale economies. *J. Urban Econ.* **2003**, *53*, 1–28. [CrossRef]
10. Weber, A. *The Location of Industries*; University of Chicago Press: Chicago, IL, USA, 1909.
11. Shi, L.; Cai, Z.; Ding, X.; Di, R.; Xiao, Q. What Factors Affect the Level of Green Urbanization in the Yellow River Basin in the Context of New-Type Urbanization? *Sustainability* **2020**, *12*, 2488. [CrossRef]
12. Boudeville, J. *Problems of Regional Economic Planning*; Edinburgh University Press: Edinburgh, UK, 1966.
13. Xie, C.Y.; Hu, H.H.; Zhou, H.B. The internal mechanism and action path of "industry-city integration" in the context of new urbanization. *Financ. Res.* **2016**, *42*, 72–82.
14. Yang, X.F.; Sun, Z. Research on the mechanism of industry-city integration under the concept of shared development. *Learn. Pract.* **2016**, *3*, 28–35.

15. Cong, H.B.; Zou, D.L.; Liu, C.J. An analysis of the spatial-temporal pattern of industry-city integration in the context of new urbanization—A practical survey from 285 prefecture-level cities in China. *Econ. Geogr.* **2017**, *37*, 46–55.
16. Hong, Y.X. Urbanization in the sense of urban function and its industrial support. *Economist* **2003**, *2*, 29–36.
17. Zhang, J.Q.; Shen, S.W. Evaluation on the integration of industry and city in urban agglomeration in the middle reaches of the Yangtze River. *Shanghai Econ. Res.* **2017**, *3*, 109–114.
18. Li, Y.X.; Zhang, W.Z. Research on the development level of industry-city integration from the perspective of new urbanization—Taking five provinces and regions in the northwest as an example. *Bus. Econ. Res.* **2018**, *1*, 147–149.
19. Huang, H.; Zhang, W.X.; Cui, Y.N. Evaluation and countermeasures of industrial and urban integration in development zones under the background of transformation and upgrading—Taking Shanxi as an example. *Econ. Issues* **2018**, *11*, 110–114.
20. Fu, G.; Lu, X.L.; Wu, C.Y. Research on Spatial Pattern Evolution of Provincial Green Innovation in China. *China Soft Sci.* **2016**, *7*, 89–99.
21. Wei, Q.N.; He, Z.C.; Chen, Y.M.; Liu, Y.R. Coordination and Comprehensive Efficiency of Industry-City Integration in Industrial Agglomeration Areas: An Analysis of Five Cities in Henan Province. *Econ. Geogr.* **2022**, *10*, 1–11.
22. Cong, H.B.; Duan, W.; Wu, F.X. Industry-city integration and its welfare effect in new urbanization. *China Ind. Econ.* **2017**, *11*, 62–80.
23. Li, S.S.; Liu, Y.B.; Luo, K. The spatial spillover effect of new urbanization on carbon emission intensity in counties around Poyang Lake. *Resour. Sci.* **2022**, *44*, 1449–1462. [CrossRef]
24. Zhang, Z.J.; Li, Z.Z.; Li, X.H. Effects of financial development and urbanization on carbon emissions from per capita energy consumption. *Stat. Decis. Mak.* **2020**, *8*, 106–110.
25. Cao, X.; Gao, Y.; Liu, Z.Q. Analysis of the impact of rural population urbanization on carbon emissions from house hold energy consumption. *China Rural. Econ.* **2021**, *10*, 64–83.
26. Wan, L.L.; Zuo, Y. Effect of industry-city integration on regional carbon emissions-based on the mediating role of economic transformation and upgrading. *J. Anhui Univ. (Philos. Soc. Sci.)* **2020**, *44*, 114–123.
27. Li, Y.X.; Zhang, Z.Y. Research on the evaluation and threshold effect of industry-city integration in the western region. *Stat. Decis. Mak.* **2021**, *37*, 86–90.
28. Zou, D.L.; Cong, H.B. Spatial-temporal pattern and influencing factors of industry-city integration in China. *Econ. Geogr.* **2019**, *39*, 66–74.
29. Jiang, L.; Bai, L.; Wu, Y.M. Analysis on the Coordination of Economy, Resources and Environment in Chinese Provinces—Also on the Coupling Formula of Three Systems and Its Extended Form. *Nat. Resour. J.* **2017**, *32*, 788–799.
30. Wang, M.Y. Comparison and selection of coordination degree models. *Stat. Decis. Mak.* **2022**, *38*, 23–28.
31. Tang, L.; Li, J.P.; Yu, L.; Qin, D.-H. Quantitative evaluation method of system coordinated development based on distance coordination degree model. *Syst. Eng. Theory Pract.* **2010**, *30*, 594–602.
32. Jiang, Z.Y.; Zhou, J.W.; Zhao, Y. Study on the spatial-temporal coupling and coordination relationship of agricultural economic-social-ecological modernization in the central region un-der the background of rural revitalization. *China Agric. Resour. Zoning* **2021**, *42*, 99–108.
33. Lauren, M.S.; Mark, V.J. Spatial Statistics in Arc GIS. In *Handbook of Applied Spatial Analysis: Software Tools, Methods and Applications*; Fischer, M.M., Gets, A., Eds.; Spring: Berlin/Heidelberg, Germany, 2010.
34. Jiang, Z.Y.; Hu, Y. Spatial-temporal pattern and heterogeneity evolution analysis of high-quality development of new urbanization in China. *Urban Probl.* **2021**, *3*, 4–16.
35. Yao, C.; Yin, W.; Huang, L.; Cui, H. Spatial-temporal pattern and coupling coordination evolution of vulnerability of grain production and consumption capacity in China. *Econ. Geogr.* **2019**, *39*, 147–156.
36. York, R.; Rosa, E.A.; Dietz, T. Bridging Environmental Science with Environmental Policy: Plasticity of Population, Affluence, and Technology. *Soc. Sci. Q.* **2002**, *83*, 18–34. [CrossRef]
37. Wang, P.; Wu, W.; Zhu, B.; Wei, Y. Examining the Impact Factors of Energy-related CO2 Emissions Using the STIRPAT Model in Guangdong Province, China. *Appl. Energy* **2013**, *106*, 65–71. [CrossRef]
38. Liu, Y.B.; Yuan, H.X.; Feng, Y.D. Spatial Spillover and Threshold Characteristics of Emission Reduction Effect of Industrial Agglomeration. *Math. Stat. Manag.* **2018**, *37*, 224–234.
39. Niu, Z.H.; Cui, B.Y. Network infrastructure construction and labor allocation distortions—A-quasi-natural experiment from the' Broadband China' strategy. *Stat. Res.* **2022**, *10*, 1–15.
40. Xie, R.; Chen, Y.; Han, F.; Fang, J.Y. Research on Influence and Time-space Effect of New-type Urbanization on Urban Eco-environmental Quality. *Manag. Rev.* **2018**, *30*, 230–241.
41. Guo, Y.; Cao, X.Z.; Wei, W.D.; Zeng, G. Study on the impact of regional integration on urban carbon emissions in the Yangtze River Delta. *Geogr. Res.* **2022**, *41*, 181–192.
42. Sun, J.W.; Cui, Y.Q.; Zhang, H. Spatial-temporal pattern and mechanism analysis of the coupling between ecological protection and economic development in urban agglomerations in the Yellow River Basin. *J. Nat. Resour.* **2022**, *37*, 1673–1690.
43. Fan, J.; Wang, Y.F.; Wang, Y.X. Research on regional high-quality development based on geographical units-And on the differences and priorities of development conditions between t-he Yellow River Basin and the Yangtze River Basin. *Econ. Geogr.* **2020**, *40*, 1–11.

44. Outline of Ecological Protection and High Quality Development Plan of the Yellow River Basin. Available online: https://www.gov.cn/zhengce/2021-10/08/content_5641438.htm (accessed on 8 October 2021).
45. Sun, J.W.; Gao, Y.J. Cultural diversity and urban entrepreneurial vitality. *China Soft Sci.* **2022**, *6*, 85–95.