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# Spatial-temporal patterns and evolution characteristics of the coordinated development of industrial economy, natural resources and environment in China☆

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ABSTRACT

Development of the industrial economy inevitably causes consumption of natural resources and destruction of the ecological environment. How to coordinate these three subsystems is an important issue for the sustainable economic growth of all countries. Against this background, this paper discusses the spatial-temporal patterns and evolutionary characteristics of the coordinated development of China's industrial economy, resources and environment. Based on Chinese provincial panel data from 2004 to 2017, an indicator system is constructed, and the degree of coordinated development of the industrial economy, resources and the environment is analyzed by the entropy method, coupling coordination degree model and spatial autocorrelation method. The findings show that in China and its three main regions, the overall trends of the industrial economy, natural resources and environmental quality subsystems are increasing year by year, with linear, segmented, and fluctuating growth types respectively. The degree of coupling coordination among the three systems is generally on the rise but still at a low level; its spatial pattern shows a decreasing trend from the eastern region to the central and western region, a high trend in the south region and a low trend in the north region. And the coupling coordination displays positive spatial autocorrelation, the high-high agglomeration is mainly distributed in the eastern coastal areas, and the low-low agglomeration is mainly distributed in the western regions. Finally, based on the research findings, this paper proposes relevant policy recommendations to promote the sustainable development of China's industrial economy, resources and environment.

## 1. Introduction

Industry is an important part of the secondary industry, the leading industry and the raw material production sectors of the national economy and also embodies national comprehensive strength and competitiveness overall. However, industrial development relies on the stock of resources, excessive consumption of resources and degradation of the environment can lead to a series of problems. For example, industrial wastewater, exhaust gas, and waste residues have deteriorated the environment in some areas, and the consumption of nonrenewable resources by heavy industry has accelerated resource depletion. The public and policy-makers worldwide have focused on the increasingly serious problem of resource consumption and environmental degradation. Reducing the negative impact of industry has become a major challenge for sustainable resource use and environmental protection in each economy. Since its reform and opening, China has made remarkable achievements in economic growth, and its growth largely comes from industrial development. In 2018, China's industrial output accounted for 33.9% of GDP, and in the same year, investment in industrial pollution control reached 68.153 billion yuan.[2] Economic growth in developing countries is achieved by rapid growth in the manufacturing and service industries, driven by the massive use of fossil fuels, such as coal, crude oil, and natural gas (Rahman and Kashem, 2017). The same is true in China. An emphasis on industrial

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[2] Data source: China Statistical Yearbook of 2019.

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development and a lack of awareness of sustainability in the country's early development stages defined the extensive growth mode, which promoted rapid economic development and put great pressure on natural resources and the ecological environment. In the face of the rapid growth of industrial sectors and urban expansion, energy demand in different sectors and $CO_2$ emissions are increasing. From 2000 to 2008, China's GDP grew at an annual rate of 10.1%, while more than half of the country's coal consumption was used to meet electricity demand (Lin et al., 2008). As shown in Fig. 1, in five countries, the usage of primary energy per capita of China is only higher than India, but its per capita consumption has been increasing since 1965, and the rate of growth has accelerated since 2003. Part of the reason for this situation could be the high proportion of unclean coal in China's primary energy structure and the re-emergence of China's heavy chemical industry after 2003 (Chen, 2009). In addition, because of the imperfect infrastructure in most areas of China, China has invested a large amount of transfer payment funds in infrastructure projects related to transportation, water conservancy, and power grids; these initiatives have increased the demand for resources. As of the end of July 2020, China has achieved a railway operating mileage of 1,441,400 km, ranking second in the world, and a high-speed rail mileage of 36,000 km, ranking first in the world.[2] The characteristics of high energy consumption and high emission of China's rapid industrial economic growth and the appearance of environmental problems such as global warming have forced the public to consider the sustainability of resources and the environment.

Obviously, industrial development, resources and the environment interact and influence each other. The relationship among industry, resources and environment is shown in Fig. 2. Industrial production requires the inputs of labor, capital, resources and other factors, and energy resources are the driving force for processing and manufacturing. The waste generated by industrial production is discharged into nature, which imposes a great environmental burden. Environmental constraints restrict industrial development, while the environment is both a cornerstone of industrial development and a place where resources are stored. Natural resources are the basic input for industrial production. Excessive consumption of resources causes environmental degradation, leading to unsustainable production and destroying the basic conditions for human survival. In contrast, economic growth caused by the development of industry and industrial technology can enhance citizens' quality of life and environmental protection awareness and delivery talent and funds toward the resource and environmental systems. Technological progress enables industry to achieve green production and reduce the pressure of resources and the environment that industry caused. The common goal of coordinated development is to maximize industrial output value and minimize pollutant emissions and coal consumption (Li et al., 2018) to create a highly efficient and sustainable economy with a solid economic foundation, abundant natural resources, and ecological livability. As China's industrialization and urbanization processes accelerate, the increasing demand for energy and the intensification of global warming have increased people's awareness of environmental protection issues. Therefore, it is extremely urgent to correctly understand the process of coordinated development among the industrial economy, resources and the environment, as this issue is of practical and theoretical significance for achieving sustainable development.

This study aims to make the following two contributions to the literature. First, it clarifies the relationship among the industrial economy, natural resources and environmental quality and uses this relationship as the research framework of the paper. Second, the coupling coordination model is used to analyze the coordinated development of industry, resources and environment, and then the spatial-temporal patterns of coupling relationships are explained through spatial analysis methods. The rest of this article is arranged as follows: Chapter 2 is a literature review of the industrial economy, resources and the environment; Chapter 3 introduces the methods and data used in this paper; Chapter 4 states the results and findings of this research; and the last part summarizes this research and discusses its policy implications.

## 2. Literature review

The literature review on the coordinated development of China's industrial economy, resources and environment mainly focuses on three aspects, including the influence of industrial development on resources and the environment, research on causal relationships among industrial development, resource consumption, and environmental quality, and studies focused on the coordinated development of the economy.

The processes of industrialization and urbanization have long been an academic focus. Scholars have reached a consensus on the destruction of resources and the environment caused by urbanization and industrial development (Cherniwchan, 2012;Ozcan et al., 2020; Sadorsky, 2013; Zhou et al., 2013; Nasrollahi et al., 2020; Cui et al., 2019). A great deal of empirical evidence shows that industrialization brings about enormous social changes and is accompanied by resource consumption and environmental deterioration. Industrialization and its production processes have led to the continuous expansion of national economies, increased $CO_2$ emissions and increased environmental pressure (Ozcan et al., 2020; Zhou et al., 2013). Rapid industrialization has reduced cultivated land (Kurucu and Chiristina, 2008). The transformation of industry from agricultural to industrial production is an essential factor in environmental quality change in economic development (Cherniwchan, 2012). Industrial activity in the Middle East and North Africa and some OECD countries has a negative impact on overall sustainable development (Nasrollahi et al., 2020), while for developed markets such as the US, improving energy efficiency and developing low-carbon clean energy are important measures to improve energy security and mitigate climate change (Pao et al., 2015). Studies have shown that renewable energy consumption has improved environmental quality in 16 EU countries (Bekun et al., 2019). Sadorsky (2013) pointed out that an increase in the level of industrialization in developing countries enhances energy intensity and that Chinese industrial growth has worsened the health of residents; for example, the discharge of industrial wastewater into densely populated areas has increased the cancer rate in China (Ebenstein, 2012). It can be seen that the tensions among industrial production, resources and the environment cannot be ignored.

A large number of empirical studies have examined the causal relationships among industrial growth, resource consumption, industrial pollution and so on. Ozcan et al. (2020) explored the relationship between economic development, resources and the environment in 35 OECD countries and proposed that sustainable development should be promoted through a coexistence mechanism rather than a trade-off mechanism related to energy consumption, economic growth and environmental degradation in each country. In some studies, machine learning has been used to analyze reciprocal relationships among the three; Kahouli-Brahmi (2008) discussed this method and proposed the direction of research. Regardless of whether growth occurs in the short term or long term, industrial production and energy consumption have a significant positive influence on carbon emissions. For instance, the growth of industrial production in Bangladesh has led to increased $CO_2$ emissions and energy consumption (Rahman and Kashem, 2017). Nonrenewable energy consumption and economic growth increase carbon emissions, while renewable energy consumption reduces $CO_2$ emissions (Bekun et al., 2019). Empirical evidence for China shows that in terms of the contribution of input factors to growth, technological progress plays the role of the first growth engine in most industries. China's industrial growth pattern has changed from the extensive mode after the reform and opening to the connotative expansion mode, characterized by improving quality (Chen, 2009). In addition, China's economic growth, energy structure and industrial pollution are spatially correlated, with different agglomeration areas in the spatial distribution

[3] Source: http://www.gov.cn/xinwen/2020-08/14/content_5534713.htm.

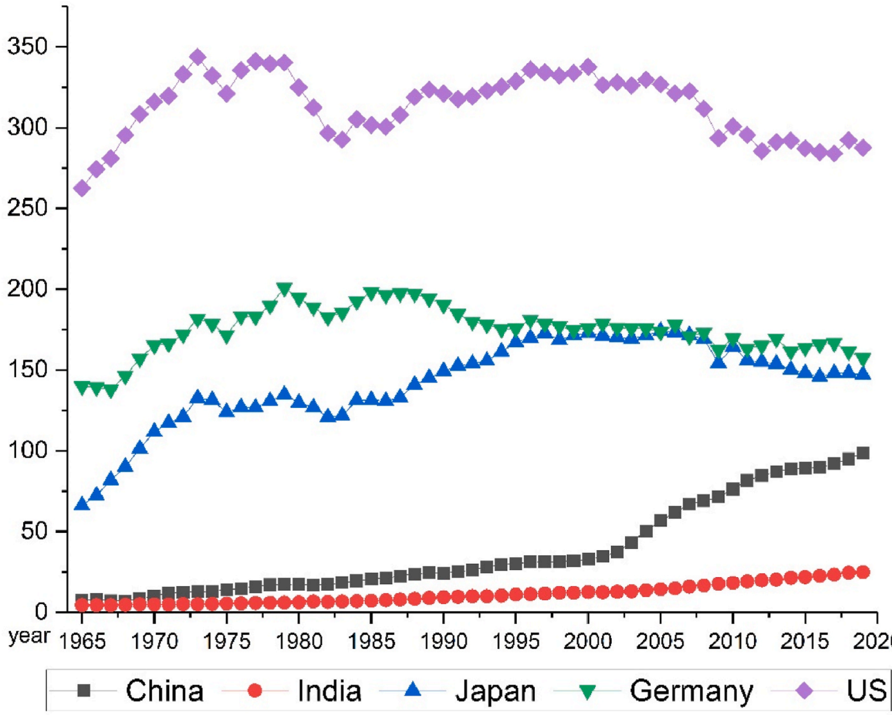


**Fig. 1.** Comparison of primary energy usage per capita of major countries (Data source: Statistical Review of World Energyhttp://dict.youdao.com/javascript:void(0);).

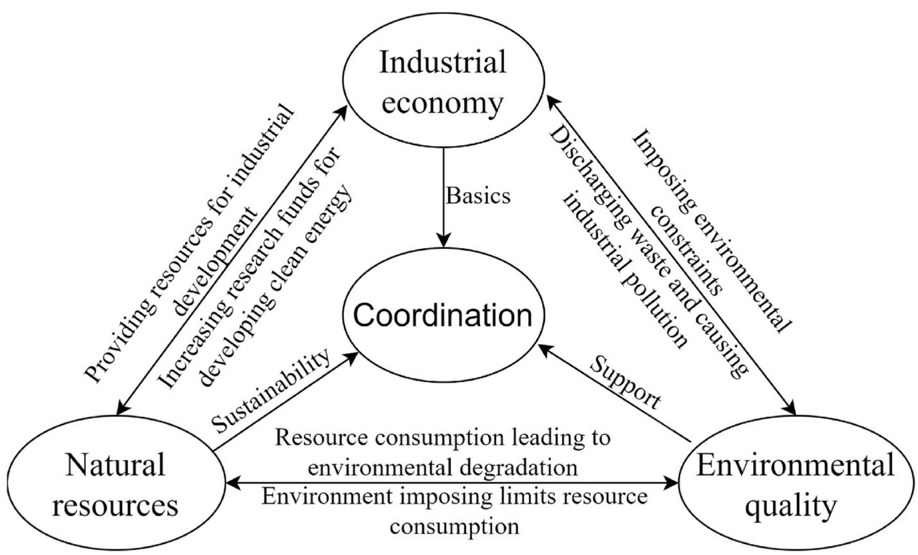


**Fig. 2.** The relationship among industrial economy, natural resources and environmental quality.

(Zhang et al., 2020). Meanwhile, there is spatial heterogeneity between industrial pollution and economic growth (He et al., 2014). Zhu et al. (2012) pointed out that resource shortages and environmental constraints have limited China's industrial development and agglomeration. Moreover, the rapid economic growth of emerging economies such as China and India has led to a significant increase in their industrial energy usage as a proportion of total energy consumption, especially coal consumption, and any reduction in coal consumption has a negative impact on industrial added value and economic growth in China and India (Shahbaz et al., 2015).

In addition, scholars have conducted in-depth and extensive research on sustainable development and coordinated development of economies. With the enhancement of public awareness of the environmental crisis, people from all social spheres have begun to focus on issues such as the environment and global warming; however, there is still a dilemma in the dynamic economic system between deepening economic development and addressing environmental change (He et al., 2014; Qian et al., 2019). Researchers have conducted empirical analysis on this subject from different perspectives, such as the connection of the economy and the ecological environment (He et al., 2017; Liu et al., 2020), the economy-resources-environment system (Sun et al., 2018), the coordinated development of urbanization with resources and the environment (Li et al., 2012; Azam and Khan, 2016; He et al., 2017), etc. Part of the studies analyzed the body of research to build an index system for regional economic development processes to analyze coordinated development. Zhang et al. (2018) constructed an index of urban sustainable development from the perspective of resource and environment carrying capacity constraints. Song et al. (2018) concluded that it is impossible for development to occur without energy consumption in the process of urbanization, so the coupling coordination level between low-carbon development and urbanization in China is not high. Moreover, many studies evaluate the coordinated development of China's economy, resources and environment, and some study the degree of coordinated development at the provincial level (Sun et al., 2018; Chen and Zhao, 2019;Wang et al, 2014) or analyze it from the perspective of carbon emissions (He and Zhang, 2018). Guan et al, (2011) simulated the development trend of economic growth, resources and the environment by using the coupled dynamics system and a GIS model. Wang et al. (2017) concluded that different policies should be adopted to develop different mining economic zones in China based on coupled and coordinated evaluation of the resources and environmental carrying capacity. Xing et al. (2019) combined the method and theory of system dynamics and the coupling coordination degree model and analyzed and evaluated simulation results on the Wuhan economy-resource-environment system. Wu and Ning, 2018 combined system dynamics modeling with the geographic information system to analyze the energy-environment-economy system and discussed the interaction among the three and the effects of key influencing factors.

The literature on this issue is mostly empirical research covering many countries and regions, and the results are basically consistent. Namely, industrial development, natural resources and environmental quality are processes that mutually influence each other and interact. Industrial development causes resource consumption and environmental degradation, but is constrained by the carrying capacity of resources and the environment, which makes it impossible to ignore the interactive relationship among these subsystems. However, most studies on sustainable development and coordinated development focus on the economy-environment, urbanization-environment, or economy-resources (energy)-environment systems, while few studies focus on industrial development and the coordinated development of resources and the environment. In fact, industrial economic development is an important factor in economic growth, which has a great influence on resources and the environment. Furthermore, developing countries increase their consumption of natural resources to achieve economic growth in the process of industrialization. Thus, the study of this issue has important theoretical and practical significance for the path of industrialization and urbanization in developing countries. This paper aims to provide empirical evidence for China on the theme of sustainable development from the perspective of coupling coordination among the industrial economy, resources and the environment to provide a reference for other developing countries seeking to achieve sustainable development in the process of industrialization. Based on panel data at the Chinese provincial level from 2004 to 2017, this paper constructs an index of coordinated development of the industrial economy, natural resources and environmental quality, while the entropy method, coupling coordination degree model and spatial autocorrelation method are used to analyze the temporal and spatial patterns and evolution characteristics of China's industrial development in relation to resources and the environment. The main contributions of this paper are as follows. Firstly, the interactive relationship among industrial economy, resources and environment is analyzed, which provide a new approach for coordinated development. Secondly, a comprehensive evaluation system of industrial economy, natural resources and environmental quality was constructed. Finally, the coupling coordination degree model and the spatial analysis method are used to discuss the evolution of its spatial and temporal pattern and the spatial agglomeration degree of the coupling coordination degree, which provide a more comprehensive developing pattern of coordinated development in China.

## 3. Materials and methods

### 3.1. Entropy method

The weight of each index must be determined before comprehensive evaluation of a subsystem is carried out. There are subjective and objective methods for determining weights. Among the objective weighting methods, this paper selects the entropy method to determine the weights.

① Since the constructed index system is a comprehensive evaluation index system, it cannot be treated directly due to its different dimensions. Therefore, the initial index must be standardized first. The standardized equations are as follows:

$$x_{ij}' = \frac{x_{ij}' - \min(x_{1j}, \ldots, x_{nj})}{\max(x_{1j}, \ldots, x_{nj}) - \min(x_{1j}, \ldots, x_{nj})} \quad (1)$$

$$x_{ij}' = \frac{\max(x_{1j}, \ldots, x_{nj}) - x_{ij}'}{\max(x_{1j}, \ldots, x_{nj}) - \min(x_{1j}, \ldots, x_{nj})} \quad (2)$$

where (equation (1) and (2)) $x_{ij}$ is the value of the $j$th indicator of the $i$th scheme and $x_{ij}'$ is the value after standardization. The subsystem has $m$ indicators and $n$ schemes to be evaluated. Among them, $x_{ij} \geq 0, 0 < i \leq n, 0 < j \leq m$. When the selected index has a positive sign, select (1) to standardize it, and when the selected index has a negative sign, select (2) to standardize it. In equations (1) and (2), $x_{ij}$ is the value of the $j$th indicator of province $i$, with a total of $n$ provinces and $m$indicators. Among them, $x_{ij} \geq 0, 0 < i \leq n, 0 < j \leq m$.

② The second step is to calculate the entropy value by using the entropy method. The equation is as follows:

$$e_j = -k\sum_{i=1}^{m}[p_{ij} \cdot 1\mathrm{n}(\mathrm{p}_{ij})] \quad (3)$$

Since $k = (\ln n)^{-1}$, we set $p(ij) = \frac{x_{ij}'+1}{\sum_{i=1}^{n}(x_{ij}'+1)}$ to avoid $\ln p_{ij}$ being meaningless.

③ The third step is to calculate $\omega_j$, the weight of the $j$th indicator:

$$\omega_j = \frac{1 - e_j}{m - \sum_{j=1}^{m} e_j} \quad (4)$$

④ The fourth step is to calculate the comprehensive score of each program. Once the comprehensive evaluations are carried out for the industrial economy, natural resources and environmental quality subsystems, the comprehensive scores are calculated as the sum of the product of each index and the index weight in the system. In other words, the equation to determine the contribution of the index to a subsystem is as follows:

$$U_i = \sum_{j=1}^{m}\left(\omega_j * x_{ij}'\right) \quad (5)$$

where $U_i$ is the comprehensive score of the industrial economy, natural resources or environmental quality system, $\omega_j$ is the weight of the index calculated by the entropy method, and $x_{ij}'$is the normalized value.

### 3.2. Coupling coordination degree model and development type

#### 3.2.1. Coupling coordination degree model

The notion of coupling degree derives from the physical sciences and refers to the degree of interaction in two or more systems. The coupling degree can be used to evaluate the interaction relationship of the system. On this basis, the coupling coordination degree model is introduced to evaluate the coordinated development degree of each province, to intuitively see whether the industrial economy, natural resources and environmental quality are coordinated. This paper refers to the Hashim Zameer et al. (2020) three-system (or three-element) coupling model. The model is shown in equation (6):

$$C_n = n\sqrt[n]{(u_1 \times u_2 \times \cdots \times u_n) \Big/ \prod (u_i + u_j)} \tag{6}$$

Based on this model, we build a coupling model of the three subsystems of the industrial economy, natural resources and environmental quality. The model is shown in equation (7):

$$C = \frac{3\sqrt[3]{U_1 \times U_2 \times U_3}}{U_1 + U_2 + U_3} \tag{7}$$

where (equation (7)) $C$ represents the degree of coupling, and $U_1$, $U_2$, and $U_3$represent the comprehensive evaluation index of the industrial economy, natural resources and environmental quality subsystems. The coupling degree model only shows the strength of the coupling and cannot reflect the level of coordinated development of the three systems. Therefore, based on the coupling degree, the coupling coordination degree model is constructed in equations (8) and (9):

$$D = \sqrt{C \times T} \tag{8}$$

$$T = \alpha U_1 + \beta U_2 + \gamma U_3 \tag{9}$$

where (equation (8) and (9)) $D$ is the evaluation result of the coupling coordination degree; $T$ is the comprehensive evaluation index of the three systems; and $\alpha$, $\beta$, and $\gamma$ are undetermined coefficients. When determining the coefficients, a combination of expert scoring and comprehensive investigation is adopted. Therefore, the undetermined coefficients are set as $\alpha = \beta = \gamma = 1/3$.

#### 3.2.2. Coupling degree and coupling coordination development type

To facilitate the analysis of the degree of coupling coordination among the three systems in the study area, different classifications of the coupling degree and coupling coordination degree are used in this paper (Table 1). This paper refers to the level of coordination degree of Xu and Hu (2020), the grading of the coordinated development of industrial economy, natural resources and environment are listed in Table 1.

### 3.3. Spatial autocorrelation analysis

According to Tobler's first law of geography, geographical things or attributes are correlated with each other in spatial distribution, and close things are more related than distant things. Many scholars have begun to focus on the spatial correlation of different attributes of different regions and for testing have selected the Moran $I$, which has been widely recognized in the literature. The equation of global Moran's I is as follows:

**Table 1**
Classification system of coordinated development of industrial economy, natural resources and environment.

| $C$ | Coupling type | $D$ | Coupling coordination |
|---|---|---|---|
| 0<C≤0.2 | Disorder-coupling | 0<D≤0.2 | Disorder |
| 0.2<C≤0.4 | Antagonistic phase | 0.2<D≤0.4 | Nearly-disorder |
| 0.4<C≤0.6 | Transitional phase | 0.4<D≤0.6 | Primary-coordination |
| 0.6<C≤0.8 | Moderate-coupling | 0.6<D≤0.8 | Moderate-coordination |
| 0.8<C≤1.0 | Advanced-coupling | 0.8<D≤1.0 | Advanced-coordination |

$$Moran'sI = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left(Y_i - \overline{Y}\right)\left(Y_j - \overline{Y}\right)}{S^2 \sum_{i=1}^{n}\sum_{j=1}^{n} W_{ij}} \tag{10}$$

where in (equation (10)) $S^2 = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \overline{Y}), \overline{Y} = \frac{1}{n}\sum_{i=1}^{n} Y_i$, $I$ represents the observed value of the $i$region, $n$ is the total number of regions, $Y$ represents the coupling coordination degree, and $W_{ij}$ represents the spatial weight matrix. The value range of the Moran $I$ is [-1,1]; if the value of $I$ is closer to 1, it shows that the regional attributes are positively correlated; if the value of $I$ is closer to −1, it shows that the regional attributes are negatively correlated; if the value of $I$ is 0, there is no correlation.

In addition, the local Moran's I (or LISA) is used to represent the local spatial autocorrelation of some regions, which is defined as

$$I_i = \frac{(x_i - \overline{x})}{S^2}\sum_{j=1}^{n} w_{ij}\left(x_j - \overline{x}\right) \tag{11}$$

The meaning of local Moran's I is similar to global Moran's I. A positive $I_i$ means region $i$with high(low) value is surroundings by regions with high(low) regions, which means a "high-high"("low-low") aggregation; and the negative $I_i$ represents region $i$ with high(low) value is surroundings by regions with low(high) regions, which means a "high-low"("low-high") aggregation.

## 4. Results and findings

### 4.1. Index system construction

To ensure the robustness of measurement of the coupling coordinated development, this paper divides the industrial economy system, natural resources system and environmental quality system into two first-level indicators and 8 s-level indicators, as shown in Table 3. All the data were taken from the 2005–2018 China Statistical Yearbook, China Industry Statistical Yearbook, China Statistical Yearbook on Environment and the statistical yearbooks from all provinces in China.

### 4.2. Explanation of the index system

#### 4.2.1. Variable selection for the industrial economy subsystem

Indicators to measure the development of industrial economic system should be comprehensive and representative, and describe the general situation of China's industrial economic development as far as possible. Chen and Zhao (2019) measured industrial economic structure from three aspects of industrial output structure, industrial employment structure and industrial investment structure. However, the structure of industrial economy is only one aspect of industrial economy, so the industrial economy subsystem is composed of two first-level indicators: industrial scale and industrial efficiency, in this paper, which can better reflect the actual situation of industrial economy development in China. Industrial scale measures the scale of regional industrial development with total current assets, total fixed assets, number of industrial enterprises above a designated size and the value of finished products of industrial enterprises above a designated size. The industrial efficiency indicator represents the benefits of regional industrial economic development, based on principal business revenue, total profits, paid-up capital and industrial added value.

#### 4.2.2. Variable selection for the natural resources' subsystem

In the research of coordinated development, the natural resources subsystem is added in many researches. At present, a set of index system for this system have been established. For example, Cui et al. (2019) measured natural resources by per capita resource stock and resource utilization efficiency. Besides, the resource size and efficiency are used to represent the natural resources in the study of Hashim Zameer et al.

**Table 3**
The index system of industrial economy, natural resources and environment.

| Subsystem | Level 1 | Level 2 | Units | Attributes |
|---|---|---|---|---|
| Industrial economy subsystem | Industrial scale | Total current assets | 100 million yuan | + |
| | | Total fixed assets | 100 million yuan | + |
| | | Industrial enterprises above a designated size | a | + |
| | | Finished products of industrial enterprises above a designated size | 100 million yuan | + |
| | Industrial efficiency | Principal business revenue | 100 million yuan | + |
| | | Total profits | 100 million yuan | + |
| | | Paid-in capital | 100 million yuan | + |
| | | Industrial added value | 100 million yuan | + |
| Natural resources subsystem | Resource scale | Total surface water supply | 100 million $m^3$ | + |
| | | Forest area | Ten thousand hectares | + |
| | | Forest coverage rate | % | + |
| | | Construction land area | One thousand hectares | + |
| | Resource efficiency | Per capita water resources | $m^3$/person | + |
| | | Per capita generating capacity | kwh/person | + |
| | | Per capita agricultural land area | $m^2$/person | + |
| | | Energy consumption per unit of GDP | Tons of standard coal/ten thousand yuan | – |
| Environmental quality subsystem | Environmental pollution | Industrial wastewater discharge | Ten thousand tons | – |
| | | Industrial $SO_2$ discharge | Ton | – |
| | | Chemical oxygen demand | Ten thousand Tons | – |
| | | $PM_{2.5}$ concentration | mg/m3 | – |
| | Environmental governance | Investment in industrial pollution control | Ten thousand yuan | + |
| | | Complete project investment for wastewater treatment | Ten thousand yuan | + |
| | | Complete project investment for waste gas treatment | Ten thousand yuan | + |
| | | Investment in environmental pollution control as a proportion of GDP | % | + |

(2020). Similar to the relevant literature, the natural resources subsystem is composed of the resource endowment and resource efficiency indicators in this paper. The former measures the total amount of regional resources, based on four secondary indexes: total surface water supply, forest area, forest coverage rate, and construction land area. The latter represents the efficiency of resource usage based on per capita water resources, per capita generating capacity, per capita agricultural land area, and energy consumption per unit of GDP.

#### *4.2.3. Variable selection for the environmental quality subsystem*

When describing the environmental system, many researches measure the environmental subsystem from the perspective of environmental quality and environmental regulation. For example, Cui et al. (2019) used environmental quality and environmental governance to measure the system. While Chen and Zhao (2019) builds an indicator system to measure the ecological environment from three aspect: pressure, state and response. Hashim Zameer et al. (2020) refined the ecological efficiency in China and various regions into four primary indicators including environmental pollution, resource consumption, economic benefits and a circular economy. Therefore, the environmental subsystem is evaluated by two first-level indicators: environmental pollution and environmental governance in this paper. This paper selects four secondary-level indicators—industrial wastewater discharge, industrial $SO_2$ discharge, chemical oxygen demand, and $PM_{2.5}$ concentration—to measure environmental pollution and four additional secondary-level indicators—investment in industrial pollution control, complete project investment for wastewater treatment, complete project investment for waste gas treatment and investment in environmental pollution control as a proportion of GDP—to estimate the environmental governance level.

### *4.3. Analysis of the subsystem results*

#### *4.3.1. Industrial economy subsystem*

Based on the formula and index system above, this paper calculates the industrial economic development level of the 30 provincial-level administrative regions in China, shown in Fig. 3. The overall development of the industrial economy in China and its three major regions shows an increasing trend year by year: the national average increased from 0.0655 in 2004 to 0.2559 in 2017, with an average annual growth rate of 1.46%, which means that the industrial economy, an important engine of regional economic development in China, has developed rapidly in recent decades. It can be seen that the level of industrial economic activity is highest in the east, followed by the middle and the western regions. Moreover, the growth rate of the eastern region is obviously higher than that of the central and western regions. The comprehensive scores of the industrial economy in the eastern, central and western regions were 0.1268, 0.0434 and 0.0202 in 2004, respectively, while they evolved to 0.4135, 0.2216 and 0.1232 in 2017, and the difference between the eastern region and the other two regions shows a gradually expanding trend. Part of this faster growth of the industrial economy in the eastern region in recent decades can be attributed to the region's relatively complete infrastructure, continuous inflows of capital and talent, and high level of openness to the outside world, while the central and western regions have seen a gradually

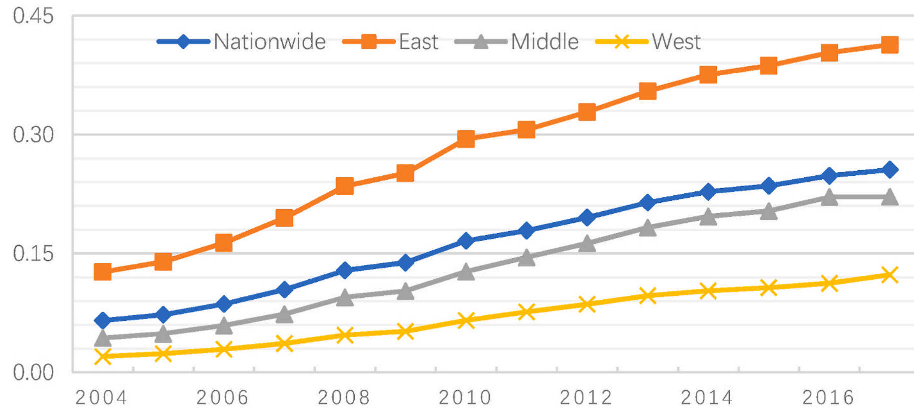


**Fig. 3.** The temporal evolution of regional industrial economic development scores.

widening gap between their industrial economic development and that of the eastern region due to their relatively backward infrastructure, outflows of capital and talent and other factors.

*4.3.2. Natural resources subsystem*

Based on the formula and index system above, this paper calculates the state of the natural resources subsystem for the 30 provincial-level administrative regions in China, shown in Fig. 4. As shown in the figure, the overall value of the national natural resources system showed a rising trend year by year, with the national average rising from 0.2491 in 2004 to 0.3278 in 2017, with an average annual growth rate of 0.61%. The value of this subsystem grew slowly until 2008, increased significantly in 2009, and then showed a slow growth trend. The trend is highest in the central region, followed by the western region and the eastern region, in a pattern that basically aligns with the national conditions of China. The natural resource endowment and per capita level of natural resources in the central and western regions are obviously higher than those in the eastern region due to the resource abundance of these regions. Moreover, the gap between the central and western regions' natural resources scores has been decreasing, while the disparity between the eastern region and midwestern area has been increasing year by year, indicating that the eastern region is increasingly constrained by natural resources in the process of rapid economic development. In particular, an extreme shortage of water resources and a tight use of land resources have become obstacles to the economic development of the region.

*4.3.3. Environmental quality subsystem*

Based on the above formula and index system, this paper calculates the environmental quality subsystem scores of the 30 provincial-level administrative regions in China, as shown in Fig. 5. The environmental quality score has shown a fluctuating growth trend for the country overall and the three regions: the national average increased from 0.4334 in 2004 to 0.4726 in 2017, with an average annual growth rate of 0.3%. In terms of the overall trend, the environmental quality score decreased from 2004 to 2006, slowly increased from 2006 to 2008, combined with a decreasing trend year by year from 2008 to 2011, then increased year by year from 2011 to 2016, but has decreased significantly since 2016. In addition, the environmental quality subsystem score is highest in the western region, second highest in the eastern region and lowest in the central region. Moreover, the gap between the central region and the western region first expanded and then decreased during the observation period. But the eastern, central and western region environment index still exist a certain difference. The score of environmental quality decreased slightly after 2008. Hashim Zameer et al. (2020) pointed out that China had to put forward the policy of a high-level investment of 400 million yuan due to the financial crisis in the United States in 2008, and the large amount of investment had a certain impact on the environmental system. Besides, the scores of environmental quality in the central region fluctuated greatly. Actually, in recent decades, due to the rapid development of the industrial economy, the consumption of a large number of natural resources and the destruction of the natural environment in the central region, environmental quality has been lowest in the central region. With a significantly serious haze problem, most of the cities with the worst air quality in the country are located in this region.

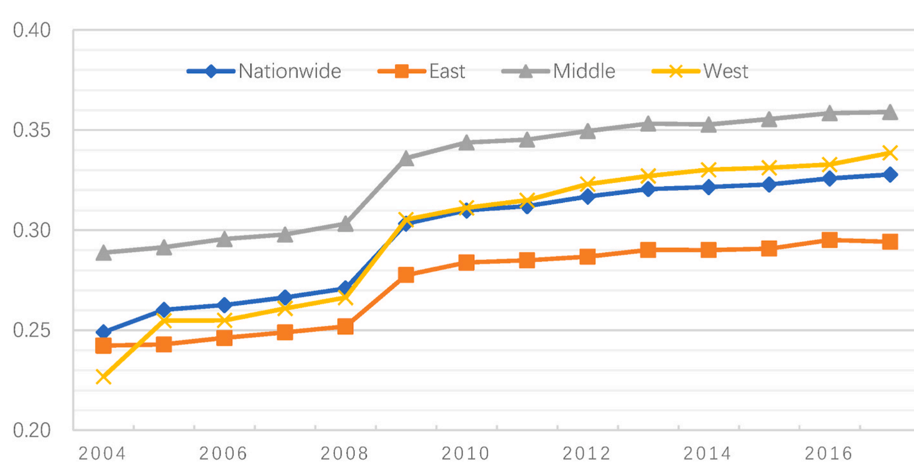


**Fig. 4.** The temporal evolution of regional natural resources scores.

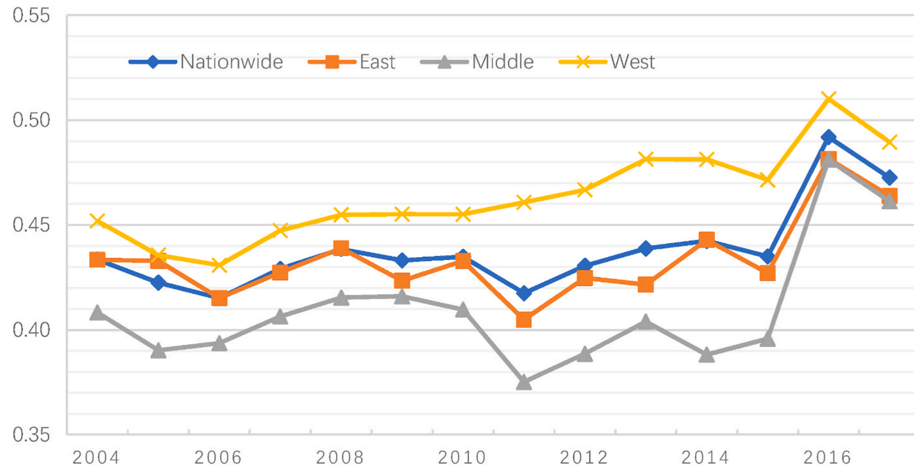


**Fig. 5.** The temporal evolution of regional environmental quality scores.

### 4.4. Analysis of the coupling coordinated development of China's industrial economy, resources and environment

#### 4.4.1. Analysis of the coupling coordination degree

(1) Temporal evolution of national coupling coordinated development

According to the aforementioned formula, this paper calculates the national score of the industry, resources and environment subsystems, the coupling degree value, the coupling coordinated degree score and the corresponding development type from 2004 to 2017, which can be seen in Table 4. As seen in this table, the national coupling degree of the three subsystems increased from 0.77 in 2004 to 0.986 in 2017, with coupling in the run-in stage in 2004 and 2005 and in the high coupling stage from 2005, indicating that the coupling level of the industrial economy, natural resources and environmental quality was constantly improving. In addition, the coupling coordination degree has also been on a continuously improving trend; the value increased from 0.4381 in 2004 to 0.5839 in 2017, with an average annual growth rate of 1.12%. However, coupling coordination was of the moderate type across all years, which means that there is still much room for improvement in the coupling coordination of the three subsystems.

(2) Spatial pattern of regional coupling coordination

Based on the division of the coupling coordination type above, this paper used ArcGIS to draw a spatial-temporal evolution map of the industrial economy, natural resources and environmental quality subsystems in China's 30 provincial administrative regions for the years 2004, 2008, 2012 and 2017, as displayed in Fig. 6.

As shown, the coupling coordination level of all provinces and regions in China was relatively low in 2004, with all of them in the range of medium to low coupling coordination. From the perspective of spatial distribution, provinces with moderate coupling coordination were distributed in the eastern coastal region and the central region, while provinces with low coupling coordination were mainly distributed in the northwest and southwest regions. Jilin, Beijing, Tianjin, Anhui and Jiangxi were of the low coupling coordinated development type. For 2008, the spatial picture shows a large change; some eastern coastal provinces, such as Shandong, Jiangsu, Zhejiang and Guangdong, upgraded to the high coupling coordination type, many regions in China remain moderate coupling coordination, and many regions in China, including Beijing, Hainan, Ningxia, Gansu, Qinghai, Chongqing and Guizhou, maintained low coupling coordination classifications. For 2012, the spatial pattern changes little compared with that of 2008: only Beijing, Gansu, Chongqing and Guizhou upgraded from low to medium coupling coordination. By 2017, Henan, Hubei, Fujian and Sichuan had improved enough to be classed within the high coupling coordination type. On the other hand, although the coupling coordination degree of most of the other provinces increased, their coordination types did not change much.

Based on the above analysis, it can be found that the evolution of the spatial pattern of coupling coordination has the following characteristics. First, the coupling coordination development level of the regional industry, resource and environment subsystems showed an increasing trend, but it was still at a relatively low level. Guangdong Province, which in 2007 had the highest coupling coordination value in the

**Table 4**
The national coupling coordinated degree and development type in China.

| Year | Industry | Resources | Environment | Coupling degree | Type | Coupling coordinated degree | Type |
|---|---|---|---|---|---|---|---|
| 2004 | 0.065 | 0.249 | 0.433 | 0.770 | Moderate-coupling | 0.4381 | Primary-coordination |
| 2005 | 0.073 | 0.260 | 0.423 | 0.794 | Moderate-coupling | 0.4473 | Primary-coordination |
| 2006 | 0.086 | 0.263 | 0.415 | 0.829 | Advanced-coupling | 0.4596 | Primary-coordination |
| 2007 | 0.104 | 0.266 | 0.429 | 0.857 | Advanced-coupling | 0.4781 | Primary-coordination |
| 2008 | 0.129 | 0.271 | 0.438 | 0.888 | Advanced-coupling | 0.4982 | Primary-coordination |
| 2009 | 0.139 | 0.303 | 0.433 | 0.902 | Advanced-coupling | 0.5129 | Primary-coordination |
| 2010 | 0.166 | 0.310 | 0.435 | 0.928 | Advanced-coupling | 0.5308 | Primary-coordination |
| 2011 | 0.179 | 0.312 | 0.417 | 0.943 | Advanced-coupling | 0.5345 | Primary-coordination |
| 2012 | 0.195 | 0.317 | 0.431 | 0.951 | Advanced-coupling | 0.5466 | Primary-coordination |
| 2013 | 0.214 | 0.321 | 0.439 | 0.959 | Advanced-coupling | 0.5579 | Primary-coordination |
| 2014 | 0.228 | 0.322 | 0.442 | 0.964 | Advanced-coupling | 0.5647 | Primary-coordination |
| 2015 | 0.235 | 0.323 | 0.435 | 0.969 | Advanced-coupling | 0.5665 | Primary-coordination |
| 2016 | 0.248 | 0.326 | 0.492 | 0.961 | Advanced-coupling | 0.5842 | Primary-coordination |
| 2017 | 0.256 | 0.328 | 0.473 | 0.968 | Advanced-coupling | 0.5839 | Primary-coordination |

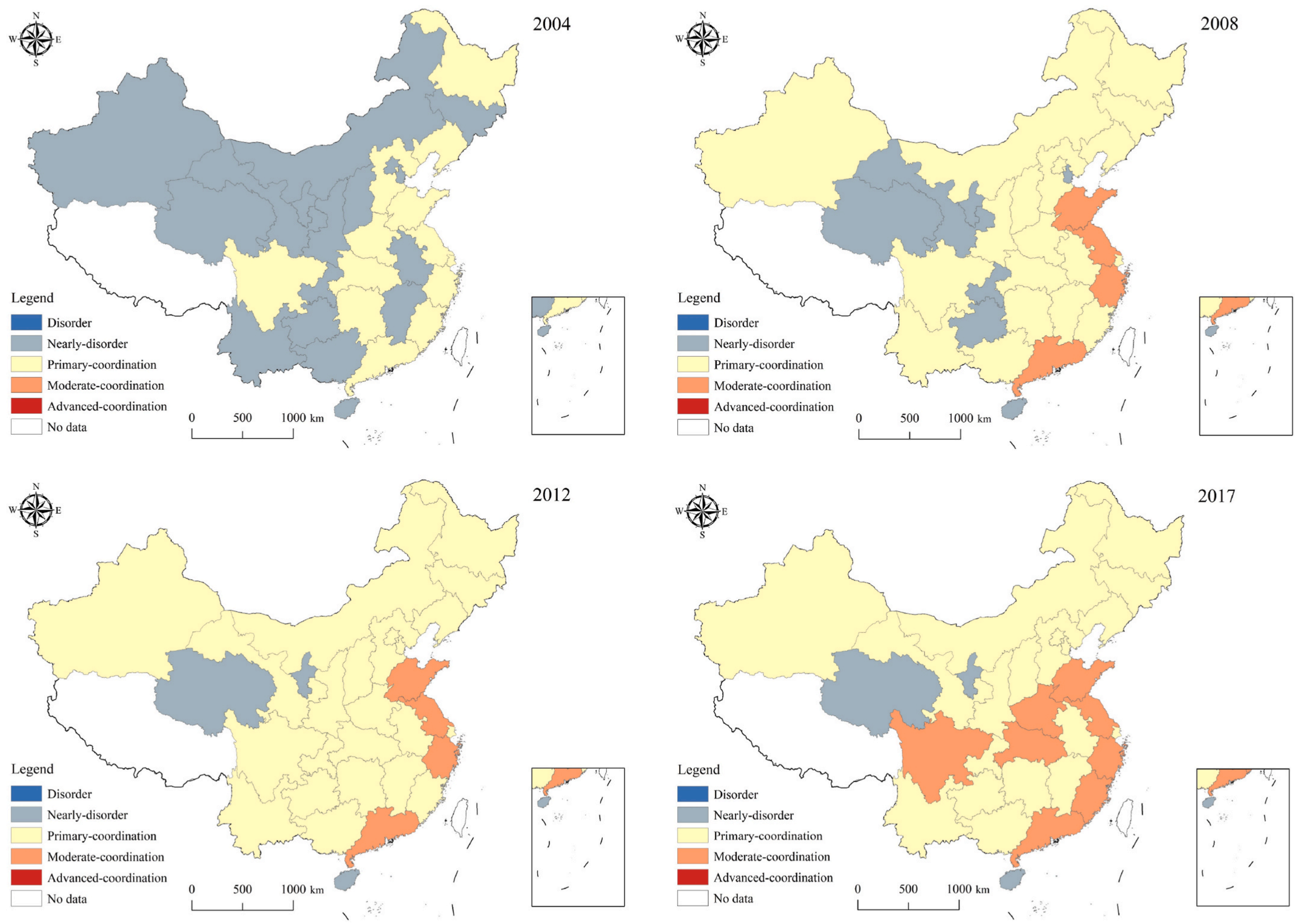


**Fig. 6.** The spatial-temporal pattern of the coupling coordinated degree of three systems.

observation period (0.7449), is still at a high coupling coordination level but has not reached an extremely high coupling coordination level. Second, from the perspective of east and west, the spatial pattern of coupling coordinated development shows a decreasing trend from the eastern region to the midwest regions; the southeast coastal region, on the other hand, had the highest level of coupling coordinated development, followed by the central and western regions. Third, from the point of view of north and south, the coupling coordinated development level of the southern provinces was generally higher than that of the north, which was related to the more active economic development and better environmental quality in the south.

### 4.4.2. Analysis of spatial autocorrelation

According to the degree of coupling coordination of industry, resources and the environment, this paper uses Geoda to calculate the spatial autocorrelation of regional coupling coordinated development, with the results shown in Table 5. The Moran I values for the coupling coordination degree range from 0.25 to 0.30, and all pass the significance test of 5%, indicating that the degree of coupling coordination among industry, resources and the environment displays positive spatial autocorrelation obviously, which means that the regions with a high coordination degree cluster together, as do the regions with a low coordination degree. In its early stage, development of the regional industrial economy causes excessive consumption of resources and a decline in environmental quality. With the improvement of industrial technology and pollution control capacity, regional energy consumption gradually declines, and environmental quality also tends to improve. However, there is a large gap in industrial development among different regions in China. The industrial economy of the eastern coastal areas is well developed. Resource consumption and environmental quality have also reached a high level due to the advantages of opening to the outside world and policy. However, as industrial development in the midwestern regions remains in the stage of rapid growth, the demand for resources and the impact on the environment are still evident. The fluctuation range is not large, which indicates that the pattern of coordinated development among provinces in China has not changed much.

**Table 5**
The Moran's I index of industry, resources and environment coupling coordination from 2004 to 2017.

| Year | Moran I | P-value | Year | Moran I | P value |
|---|---|---|---|---|---|
| 2004 | 0.2833 | 0.007 | 2011 | 0.2419 | 0.024 |
| 2005 | 0.2555 | 0.013 | 2012 | 0.2367 | 0.022 |
| 2006 | 0.2555 | 0.013 | 2013 | 0.2278 | 0.013 |
| 2007 | 0.2459 | 0.017 | 2014 | 0.2216 | 0.020 |
| 2008 | 0.2497 | 0.015 | 2015 | 0.2654 | 0.007 |
| 2009 | 0.2579 | 0.015 | 2016 | 0.2805 | 0.005 |
| 2010 | 0.2554 | 0.018 | 2017 | 0.2517 | 0.017 |

In addition, in order to compare the local characteristics of the coupling coordination degree between the three systems, the local Moran index of the coupling coordination degree is calculated, the scatter plots and Lisa plots of 2004 and 2017 are drawn, as shown in Fig. 7. Most of these provinces are located in the first and third quadrants, but even though there is significant spatial autocorrelation

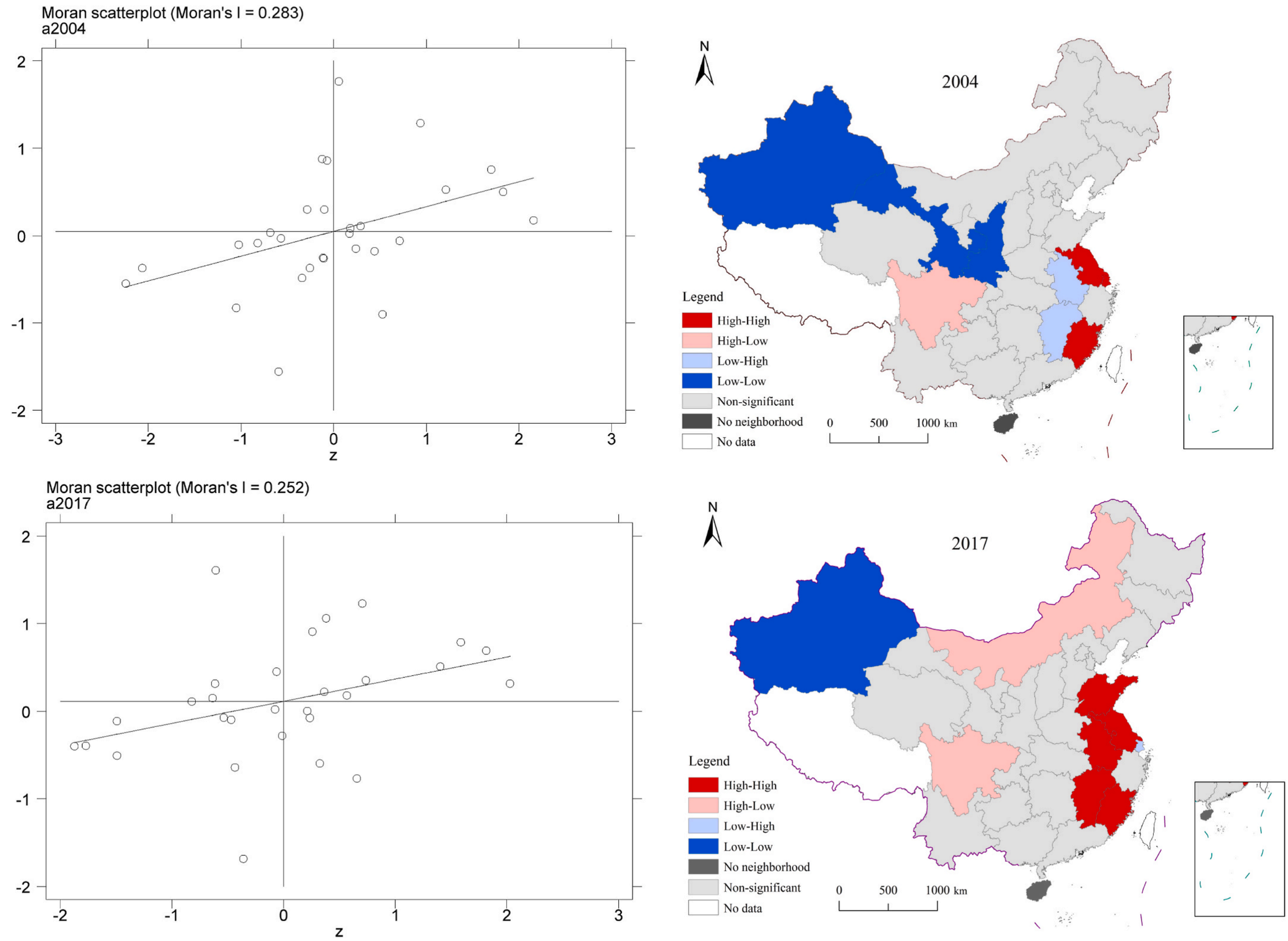


**Fig. 7.** The local spatial analysis of industrial economy, natural resources and environment.

overall, many provinces still do not have significant local correlation, which indicates that there are spatial differences in the coordinated development of provinces in China. As a result, from the perspective of spatial autocorrelation in the coupling coordination degree, the provinces with high coupling coordination are concentrated in the eastern coastal areas, while the provinces with low coupling coordination are mainly distributed in the midwestern regions.

It is worth noting that the "high-high" cluster expanded from 2004 to 2017, while the "low-low" cluster decreased. In 2004, Jiangsu and Fujian were "high-high" clusters, and by 2017, the central provinces like Anhui and Jiangxi were also high. In 2003, in the western region, Xinjiang, Gansu and Ningxia were in low-low concentration, while in 2017, only Xinjiang was the region with low-low concentration. It can be seen that the spatial change trend of the coordinated development pattern of all provinces in China from 2003 to 2017. The spatial pattern of the coordinated development degree in the eastern region did not change much, while the central and western regions changed greatly. Part of the reason can be attributed to the advantages of the reform and opening up system, natural resources, environment and special geographical location, the eastern region has always been a relatively developed region in China, and its status in China's economic development has not changed greatly. In contrast, the central and western regions were relatively backward at the beginning of their economic development. However, China's subsequent emphasis on sustainable development and the improvement of infrastructure enabled the coordinated and orderly development of various regions, thus making some central and western regions stand out.

## 5. Conclusions and policy recommendations

With the rapid development of industrialization and informatization, China has become the world's largest manufacturing country, paying the price of resource depletion and environmental degradation. As China's economic development has moved from a high-speed growth stage to a high-quality development stage, the extensive growth mode of the industrial economy has been unable to adapt. It is necessary to take a sustainable development path in which economic growth is coordinated with the natural resources and environment subsystems. Calculating the degree of development coordination between the industrial economy and the resource and environment subsystems not only contributes to promoting the optimization and adjustment of regional economic development and the upgrade of the industrial energy structure but is also conducive to formulating sustainable industrial development policies to achieve high-quality regional economic development. Based on Chinese provincial panel data from 2004 to 2017, this paper uses the entropy method, coupling coordination degree model and spatial autocorrelation analysis to analyze and evaluate the spatial-temporal patterns and evolution characteristics of the degree of coupling coordination among China's industrial economy, resources and environment. The results show the following: (1) From the perspective of the subsystem development trend, overall development of the industrial economy, natural resources and environmental quality in China and its three major regions is increasing year by year, but the growth modes of the three subsystems are different, with linear, segmented and fluctuating trends, respectively. Therefore, there are differences in the development of subsystems in the three regions. (2) Overall, the coupling coordination degree shows an upward trend throughout the sample period, but it remains at a low level. Its spatial pattern shows a downward trend from the eastern region to the central and western regions. The southeast coastal region has the highest level of coupled coordinated development, followed by the central region, and the western region has the lowest level. In terms of the north and south areas, the level of coupling coordinated development in the southern provinces is generally higher than that in the north. (3) The degree of coupling coordination of the industry-resource-environment system shows positive spatial autocorrelation. The provinces with high coupling coordination and agglomeration are mainly distributed in the eastern coastal areas, and the provinces with low coupling coordination and agglomeration are mainly distributed in the western regions.

This research has important policy implications for the coordinated development of industry, resources and the environment in China and other developing countries. First of all, the development of subsystems in different regions is quite different. The eastern region has a higher level of industrial economic development, while the central region has more abundant natural resources. The environmental quality in the western region is better, while the environmental quality in the eastern and central regions is below the national average. The development of these three systems has significantly affected the pattern of regional economic development in China. Therefore, the eastern and central regions should pay attention to environmental quality due to the coordinated development of the three systems in different regions. The western region should continue to develop economy and strengthen regional industrial economic development. Secondly, the coordination degree of China's industry, resources and environment is on the rise, which indicates that China's resources and environmental regulation policies play a certain role in achieving coordinated development. The western region has the lowest degree of coordination. Therefore, the western region should pay attention to the coordinated development of industrial economy, attract industrial enterprises to settle in and develop regional industrial economy while maintaining its excellent environmental quality level. Finally, the coupling coordination degree among provinces presents a significant positive spatial correlation, and the western region presents a low-low concentration. Consequently, the well-developed cities in western China should play a leading role in promoting the coordinated development of neighboring provinces and cities.

## Author statement

Wang Jiankang: Conceptualization, Methodology, Writing-Review & Editing, Funding acquisition, Han Qian: Software, Writing - Original Draft, Visualization, Wu Kexin: Writing - Original Draft, Data Curation, Xu Zetao: Writing - Original Draft, Resources, Liu Peng: Writing - Original Draft, Resources.

## Declaration of competing interest

The authors declare no conflict of interest.

## References


Azam, M., Khan, A.Q., 2016. Urbanization and environmental degradation: evidence from four SAARC countries—Bangladesh, India, Pakistan, and Sri Lanka. Environ. Prog. Sustain. 35, 823–832.

Bekun, F.V., Alola, A.A., Sarkodie, S.A., 2019. Toward a sustainable environment: nexus between $CO_2$ emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. Sci. Total Environ. 657, 1023–1029.

Chen, S., 2009. Energy consumption, CO2 emission and sustainable development in Chinese industry. Econ. Res. J. 44 (4), 41–55 (Chinese).

Chen, Y., Zhao, L., 2019. Exploring the relation between the industrial structure and the eco-environment based on an integrated approach: a case study of Beijing, China. Ecol. Indicat. 103, 83–93.

Cherniwchan, J., 2012. Economic growth, industrialization, and the environment. Resour. Energy Econ. 34, 442–467.

Cui, X., Fang, C., Liu, H., Liu, X., 2019. Assessing sustainability of urbanization by a coordinated development index for an Urbanization-Resources-Environment complex system: a case study of Jing-Jin-Ji region, China. Ecol. Indicat. 96, 383–391.

Ebenstein, A., 2012. The consequences of industrialization: evidence from. Rev. Econ. Stat. 94, 186–201.

Guan, D., Gao, W., Su, W., Li, H., Hokao, K., 2011. Modeling and dynamic assessment of urban economy-resource-environment system with a coupled system dynamics - geographic information system model. Ecol. Indicat. 11, 1333–1344.

He, C., Huang, Z., Ye, X., 2014. Spatial heterogeneity of economic development and industrial pollution in urban China. Stoch. Environ. Res. Risk Assess. 28, 767–781.

He, J., Zhang, P., 2018. Evaluating the coordination of industrial-economic development based on anthropogenic carbon emissions in Henan Province, China. Int. J. Environ. Res. Publ. Health 15.

He, J., Wang, S., Liu, Y., Ma, H., Liu, Q., 2017. Examining the relationship between urbanization and the eco-environment using a coupling analysis: case study of Shanghai, China. Ecol. Indicat. 77, 185–193.

Kahouli-Brahmi, S., 2008. Technological learning in energy-environment-economy modelling: a survey. Energy Pol. 36, 138–162.

Kurucu, Y., Chiristina, N.K., 2008. Monitoring the impacts of urbanization and industrialization on the agricultural land and environment of the Torbali, Izmir region, Turkey. Environ. Monit. Assess. 136, 289–297.

Li, L., Lei, Y., Wu, S., He, C., Yan, D., 2018. Study on the coordinated development of economy, environment and resource in coal-based areas in Shanxi Province in China: based on the multi-objective optimization model. Res. Pol. 55, 80–86.

Li, Yangfan, Li, Yi, Zhou, Y., Shi, Y., Zhu, X., 2012. Investigation of a coupling model of coordination between urbanization and the environment. J. Environ. Manag. 98, 127–133.

Liu, Y., Yang, L., Jiang, W., 2020. Coupling coordination and spatiotemporal dynamic evolution between social economy and water environmental quality – a case study from Nansi Lake catchment, China. Ecol. Indicat. 119, 106870.

Nasrollahi, Z., Hashemi, M. sadat, Bameri, S., Mohamad Taghvaee, V., 2020. Environmental pollution, economic growth, population, industrialization, and technology in weak and strong sustainability: using STIRPAT model. Environ. Dev. Sustain. 22, 1105–1122.

Ozcan, B., Tzeremes, P.G., Tzeremes, N.G., 2020. Energy consumption, economic growth and environmental degradation in OECD countries. Econ. Modell. 84, 203–213.

Pao, H.T., Chen, H.A., Li, Y.Y., 2015. Competitive dynamics of energy, environment, and economy in the. U.S. Energy 89, 449–460.

Qian, X., Wang, D., Wang, J., Chen, S., 2019. Resource curse, environmental regulation and transformation of coal-mining cities in China. Res. Pol. 101447.

Rahman, M.M., Kashem, M.A., 2017. Carbon emissions, energy consumption and industrial growth in Bangladesh: empirical evidence from ARDL cointegration and Granger causality analysis. Energy Pol. 110, 600–608.

Sadorsky, P., 2013. Do urbanization and industrialization affect energy intensity in developing countries? Energy Econ. 37, 52–59.

Shahbaz, M., Farhani, S., Ozturk, I., 2015. Do coal consumption and industrial development increase environmental degradation in China and India? Environ. Sci. Pollut. Res. 22, 3895–3907.

Song, Q., Zhou, N., Liu, T., Siehr, S.A., Qi, Y., 2018. Investigation of a "coupling model" of coordination between low-carbon development and urbanization in China. Energy Pol. 121, 346–354.

Sun, Q., Zhang, X., Zhang, H., Niu, H., 2018. Coordinated development of a coupled social economy and resource environment system: a case study in Henan Province, China. Environ. Dev. Sustain. 20, 1385–1404.

Wang, Q., Yuan, X., Cheng, X., Mu, R., Zuo, J., 2014. Coordinated development of energy, economy and environment subsystems - a case study. Ecol. Indicat. 46, 514–523.

Wang, R., Cheng, J., Zhu, Y., Lu, P., 2017. Evaluation on the coupling coordination of resources and environment carrying capacity in Chinese mining economic zones. Res. Pol. 53, 20–25.

Wu, D., Ning, S., 2018. Dynamic assessment of urban economy-environment-energy system using system dynamics model: a case study in Beijing. Environ. Res. 164, 70–84.

Xing, L., Xue, M., Hu, M., 2019. Dynamic simulation and assessment of the coupling coordination degree of the economy–resource–environment system: case of Wuhan City in China. J. Environ. Manag. 230, 474–487.

Xu, M., Hu, W., 2020. A research on coordination between economy, society and environment in China: a case study of Jiangsu. J. Clean. Prod. 258, 120641.

Zameer, H., Yasmeen, H., Wang, R., Tao, J., Malik, M.N., 2020. An empirical investigation of the coordinated development of natural resources, financial development and ecological efficiency in China. Res. Pol. 65, 101580.

Zhang, J., Zhang, K., Zhao, F., 2020. Spatial effects of economic growth, energy consumption and environmental pollution in the provinces of China—an empirical study of a spatial econometrics model. Sustain. Dev. 28, 868–879.

Zhang, M., Liu, Y., Wu, J., Wang, T., 2018. Index system of urban resource and environment carrying capacity based on ecological civilization. Environ. Impact Assess. Rev. 68, 90–97.

Zhou, X., Zhang, J., Li, J., 2013. Industrial structural transformation and carbon dioxide emissions in China. Energy Pol. 57, 43–51.

Zhu, Y., Yang, L., Lv, H., Shen, Xi, 2012. Research on resource shortage, environmental damage and industrial agglomeration Effect—based on the empirical analysis of

China's provincial industrial agglomeration in the 21st century. Manag. World (11), 28–44 (Chinese).