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Comprehensive Measurement of the Coordinated Development of China's Economic Growth, Energy Consumption, and Environmental Conservation

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Abstract: Since the Industrial Revolution, fossil fuels have become the main energy source for economic development. However, fossil fuels have also been linked to serious environmental impacts. China has recently undergone rapid economic growth, but its development model demands large amounts of energy and causes severe pollution. Therefore, there has been a recent shift toward the development of coordinated strategies to achieve economic growth while minimizing energy consumption and preserving the environment. This study sought to explore the spatiotemporal evolution of the coordination degree between economic growth, energy consumption, and environmental conservation (i.e., the "3E" system) in China, thus establishing a basis to improve coordinated development and minimize regional differences. This study evaluated 30 Chinese provinces using mathematical models. Between 2000 and 2019, the coordinated development level of the components of the 3E system in China increased steadily but remained generally low. Clear spatial agglomeration was also identified at the provincial scale, with the highest values occurring on the east coast and lower values occurring in the west and middle provinces.

Keywords: energy consumption; economic growth; ecological environment; coordinated development; China

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1. Introduction

1.1. Background and Purpose

After the Industrial Revolution, non-renewable energy sources such as coal, natural gas, and oil quickly became a key driving factor for economic development. However, fossil fuels also cause severe environmental problems [1], such as air and water pollution, as well as ecological degradation, all of which are becoming progressively worse. Therefore, there is a growing consensus that the current development model is fundamentally flawed. The concept of sustainable development came into being in this context and has since been widely accepted worldwide. Countries worldwide have embraced sustainable development as a new development model and have explored practical solutions from different perspectives [2]. Following the reform period and the opening of its economy, China's economic development has attracted worldwide attention. Nevertheless, China's resource-intensive development model has caused severe environmental impacts. This growing environmental pressure has highlighted the need to recognize the trade-offs between economic growth, energy consumption, and environmental conservation (hereinafter referred to as the "3E" system), which at least partially restricts the full realization of sustainable development strategies [3]. Additionally, China occupies a vast territory, and therefore the economic foundations, development models, and distribution of natural resources in different regions vary widely. Thus, the aforementioned trade-offs are also subject to regional variations at different scales [4]. Therefore, improving the coordinated development of the 3E system and minimizing regional gaps would facilitate the sustainable development of all regions, in addition to promoting a more comprehensive, healthy, and rapid development of China's economy.

Coordinated development is a systematic approach to optimize the trade-offs between the components of the 3E system. Specifically, the goal of this approach is to optimize the consumption of energy required for economic development, thereby minimizing environmental impacts. This study sought to characterize the spatiotemporal evolution of the coordination degree between the components of the 3E system in China. The findings thus provide a basis to improve the coordinated development of China and minimize regional variations.

1.2. Literature Review

Several studies have explored the coordinated development of the 3E system and have achieved some promising results. According to the size of the study area, these studies can be classified as large scale, mesoscale, and small scale.

At the large-scale level (national and above), James et al. constructed a global energy–environment–economic development model and explored the optimal path between the components of the 3E system [5]. Hirschfield et al. conducted a coupled analysis of the economic development and environmental conservation of a German watershed [6]. Fernández-Rodríguez et al. created a model to analyze the coupling between agricultural development and environmental conservation in a Spanish watershed [7]. Lu et al. calculated and analyzed the coupling coordination level of the 3E system and their temporal changes in China [8]. Wang et al. measured and analyzed the dynamic evolution of China's financial development, energy consumption, and economic growth [9]. Li et al. analyzed the coupling and coordinated development of China's 3E system [10]. Yu et al. measured the economy–energy–environment–technology coupling coordination level in China and analyzed its evolution [11]. Other related studies have also been conducted [12–20].

At the mesoscale level (province or region), Biswas et al. studied the constraints of social and economic development in Bangladesh and proposed the construction of a model to determine the rational utilization of ecological resources [21]. Keller et al. researched the coupling of sewage processing and biogas production in central Mexico from a coupled coordination perspective [22]. Ding et al. investigated the coupling coordination relationship between the economy and environmental conservation of Qinghai, China [23]. Chen et al. investigated the ecological and economic competitiveness of cities in Hunan, China [24]. Meng et al. investigated the coordinated development of the 3E system in Inner Mongolia, China, by applying a coupling coordination degree model [25]. Other related studies have also been conducted [26–30].

At the small-scale level (cities, counties, or below), ArzuAmar et al. evaluated the coupling coordination relationship of the environment and the economy in Hetian County, Xinjiang, China [31]. Lu et al. measured the coordinated development of tourism, the economy, and the environment in different cities in Gansu Province [32]. Chen et al. investigated the link between resources, the environment, and the economy and its temporal changes in Dingxi, China [33]. Cheng et al. studied the coordinated development of tourism and the environment in Chizhou [34]. Lu et al. studied the coupling of environmental pollution, resource consumption, and economic growth in Qingyang [35]. Moreover, other related studies have also been conducted [36–38].

In summary, research in this area has achieved many promising results, but there are still several critical shortcomings. First, from a research perspective, very few studies have explored the coupling and coordination of the 3E system. Furthermore, from a methodological perspective, the spatiotemporal characterization of the aforementioned factors using spatial analysis models and geographic information system (GIS) technology remains limited. This study sought to fill these gaps through the integration of GIS technology and the spatial analysis method. Specifically, it has constructed a model and index system to comprehensively explore the coordination degree of economic growth, energy consumption, and environmental quality in China from a spatiotemporal perspective. Therefore, the proposed approach significantly contributes to the development of the research field.

1.3. Contribution

The present study quantitatively examined 30 Chinese provinces using the coupling coordination degree model, global spatial autocorrelation model, and hotspot analysis model. Furthermore, it has constructed a measurement indicator system to analyze the spatiotemporal changes in the coupling between the components of the 3E system in China. All the methods used in this study were based on previously published literature (see Section 2 for more details). The findings indicated that the coordinated development of the 3E system of China tended to increase steadily but generally remained low. Clear spatial agglomeration was also observed at the provincial scale, with the highest values occurring on the east coast and lower values occurring in the west and middle areas.

The findings of this study could provide important theoretical and empirical insights into the factors that drive the energy economy, in addition to making important contributions to the fields of anthropogeography and sustainability. Furthermore, the findings would provide a basis to improve the coordinated development of economic growth, energy consumption, and environmental conservation in China, which would enable the construction of sustainable urban centers. The findings could also enable the enhancement of relevant policies by the local authorities to improve the development strategies and minimize regional variations in China and other countries.

2. Materials and Methods

2.1. Data Sources and Indicator System

A 3E coupling and coordinated development indicator system was established based on data from several regions of China [3,5,8,24,39,40] (Table 1). The research period spanned from 2000 to 2019. Particularly, the study focused on five typical years: 2000, 2005, 2010, 2015, and 2019. The data were obtained from the "China Statistical Yearbook", "China Environment Statistical Yearbook", "China Energy Statistical Yearbook", Statistical Yearbooks of different provinces, the Environmental Status Bulletin, the National Economy and Social Development Statistical Bulletin, and other related statistical data and literature.

Table 1. The 3E coupling and coordinated development indicator system.

Objective	Criteria	Indicator
Energy consumption	Overall size	Total energy production Growth rate of energy production Total energy consumption Increasing rate of energy consumption
	Structure	Proportion of coal in total energy consumption Proportion of crude oil in total energy consumption Proportion of natural gas in total energy consumption Proportion of wind power, nuclear power, and other power in energy consumption
	Quality	Energy consumption per unit of gross domestic product (GDP) Elastic coefficient of energy consumption Loss rate of energy processing and conversion Energy consumption per capita
Economic growth	Overall size	GDP Total import and export trade Total retail sales of social consumer goods Total investment in fixed assets
	Structure	Proportion of added value of secondary industry in GDP Proportion of added value of tertiary industry in GDP Proportion of social fixed asset investment in GDP
	Quality	GDP per capita Resident consumption level Total societal productivity Contribution rate of total assets of industrial enterprises Proportion of total local fiscal revenue in GDP

Table 1. *Cont.*

Objective	Criteria	Indicator
Ecological environment	Pollutant emissions	Sewage emissions Waste gas emissions Solid waste emissions
	Pollution treatment	Compliance rate of sewage emissions Comprehensive utilization rate of solid waste Capacity of waste gas treatment facilities Output value of "three wastes" comprehensive utilization products Proportion of environment governance investment in GDP
	Ecological protection	Proportion of afforestation area in the area under jurisdiction Control rate of water and soil loss Forest coverage Proportion of natural reserve area in total area

2.2. Research Method

2.2.1. Coupling Coordination Degree Model

The following steps were taken to calculate the coordination degree [8–10]:

Standardization of indicator values:

$$\text{Positive indicator}: \ y_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \tag{1}$$

$$\text{Negative indicator}: \ y_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \tag{2}$$

Calculation of the scale factor:

$$V_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}, 0 \le V_{ij} \le 1 \tag{3}$$

Calculation of information entropy:

$$e_j = -k\sum_{i=1}^{m} V_{ij}\ln V_{ij}, k = \frac{1}{\ln(m)}, k \ge 0, e_j \ge 0 \tag{4}$$

Calculation of information entropy redundancy:

$$d_j = 1 - e_j \tag{5}$$

Calculation of indicator weight:

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{6}$$

Calculation of comprehensive index:

$$X_n = \sum_{i=1}^{12} W_i I_{in} (n = 1, 2, \cdots, 30) \tag{7}$$

$$Y_n = \sum_{j=1}^{12} W_j I_{jn} (n = 1, 2, \cdots, 30) \tag{8}$$

$$Z_n = \sum_{q=1}^{12} W_q I_{qn} (n = 1, 2, \cdots, 30) \tag{9}$$

where X_n,Y_n and Z_n are the comprehensive indices of energy, economy, and the environment, respectively; W_i, W_j, W_q are indicator weights; and I_{in}, I_{jn}, I_{qn} are the standardized values of each indicator.

$$C = \left\{(X \times Y \times Z) / \left[(X + Y + Z)/3\right]^3\right\}^{1/3} \tag{10}$$

$$T = \alpha X + \beta Y + \gamma Z \quad (11)$$

$$D = \sqrt{C \times T} \quad (12)$$

where X, Y, Z are the comprehensive indices of energy, economy, and environment, respectively; C is the coupling degree; D is the coordination degree; T is the overall index of energy, economy, and the environment; and α, β, γ are weights, the three of which are equally important (i.e., 1/3).

According to the calculation results of the coordination degree, it is divided into ten grades (Table 2).

Table 2. Coordination degree classification.

Dysfunctional Recession		Coordinated Development	
Coordination Degree	**Type**	**Coordination Degree**	**Type**
[0,0.1)	Extreme dysfunctional recession	[0.5,0.6)	Minor coordinated development
[0.1,0.2)	Severe dysfunctional recession	[0.6,0.7)	Primary coordinated development
[0.2,0.3)	Medium dysfunctional recession	[0.7,0.8)	Medium coordinated development
[0.3,0.4)	Slight dysfunctional recession	[0.8,0.9)	Well-coordinated development
[0.4,0.5)	Minor dysfunctional recession	[0.9,1]	Highly coordinated development

2.2.2. Spatial Autocorrelation

(1) Global spatial autocorrelation Global spatial autocorrelation indicates whether the regional coordination degree between the components of the 3E system has a statistical agglomeration or dispersion in the whole region [41,42]:

$$I = \frac{n \sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} \left(Y_i - \overline{Y}\right)\left(Y_j - \overline{Y}\right)}{\sum_{i=1}^{n} \sum_{j=1}^{n} W_{ij} \sum_{i=1}^{n} \left(Y_i - \overline{Y}\right)^2} \quad (13)$$

where I is the global Moran's I index, n is the number of evaluation objects, $\overline{Y}$ is the average of the sample values of all the evaluation objects, Y_i and Y_j are the sample values of the evaluation object at i and j, respectively, and W_{ij} is the spatial weight matrix. A significance test for I was then conducted to further determine whether there is a spatial autocorrelation relationship:

$$Z = \frac{I - E(I)}{\sqrt{Var(I)}} \quad (14)$$

where Z is the test value of the global Moran's I, E(I) is the expectation of I, and Var(I) is the variance of I.

(2) Hotspot analysis (local Getis–Ord G* index) The hotspot analysis method was used to evaluate the dependence and heterogeneity of the regional coordination degree of the 3E system in local spaces, as well as to assess the local patterns of spatial autocorrelation [43]:

$$G_i^* = \frac{\sum_{j=1}^{n} W_{ij} x_j}{\sum_{j=1}^{n} x_j} (j \neq i) \quad (15)$$

where x_j is the sample value of the j-th evaluation object, n is the number of evaluation objects, and W_{ij} is the spatial weight matrix. The G_i^* value was significantly positive, which indicates that the values around the i region are relatively high and belong to a hotspot region; otherwise, the area is considered a "cold spot." Table 3 summarizes the equations used in this study.

Table 3. List of equations.

Equation Number	Description	Equation Number	Description
1, 2	Standardization of indicator values	7, 8, 9	Comprehensive index
3	Scale factor	10, 11, 12	Coordination degree
4	Information entropy	13	Global Moran's I index
5	Redundancy of the information entropy	14	Significance test of Global Moran's I
6	Indicator weight	15	Local Getis–Ord G* index

3. Results and Discussion

3.1. Measurement of Coupling and Coordinated Development

As shown in Table 4, the average coordination degree of the 3E system in China increased from 0.511 in 2000 to 0.566 in 2019. The coordinated development level exhibited an overall upward trend but generally remained low. The coordinated development level of all provinces also exhibited an overall upward trend but there were large differences among them. In 2000, the province with the lowest coordination degree was Gansu (0.426) and the highest was Shanghai (0.633). In 2019, the province with the lowest coordination degree was Ningxia (0.437) and the highest was Beijing (0.75). The findings thus demonstrated the occurrence of significant regional variations in coordinated development and these regional differences have a tendency to expand further. Upon analyzing the average coordination degree of each province, Beijing, Guangdong, and Shanghai exhibited the highest values, whereas Xinjiang, Gansu, and Ningxia had the lowest values. These observations were consistent with China's economic development trends. Particularly, in the eastern coastal areas, which are generally more developed, more funds and technologies have been invested in economic development, structural energy transformation, and environmental protection and governance. In turn, this was reflected as high values of coordinated development of the 3E system, whereas the opposite was true in the western inland areas.

Table 4. Coordination degree of the 3E system in China.

Province	2000	2005	2010	2015	2019	Average
Beijing	0.623	0.620	0.664	0.658	0.750	0.663
Tianjin	0.581	0.588	0.594	0.600	0.597	0.592
Hebei	0.481	0.465	0.509	0.495	0.540	0.498
Shanxi	0.468	0.477	0.440	0.454	0.573	0.482
Inner Mongolia	0.434	0.488	0.529	0.545	0.525	0.504
Liaoning	0.493	0.515	0.518	0.528	0.516	0.514
Jilin	0.507	0.467	0.489	0.486	0.508	0.492
Heilongjiang	0.504	0.485	0.504	0.490	0.502	0.497
Shanghai	0.633	0.614	0.627	0.665	0.670	0.642
Jiangsu	0.573	0.591	0.622	0.624	0.640	0.610
Zhejiang	0.556	0.590	0.614	0.628	0.651	0.608
Anhui	0.481	0.462	0.490	0.513	0.518	0.493
Fujian	0.526	0.550	0.556	0.602	0.604	0.567
Jiangxi	0.448	0.462	0.492	0.514	0.529	0.489
Shandong	0.547	0.554	0.636	0.580	0.590	0.581
Henan	0.455	0.476	0.515	0.515	0.561	0.504
Hubei	0.488	0.484	0.523	0.559	0.580	0.527
Hunan	0.473	0.475	0.531	0.569	0.571	0.524

Table 4. *Cont.*

Province	2000	2005	2010	2015	2019	Average
Guangdong	0.620	0.603	0.671	0.683	0.713	0.658
Guangxi	0.551	0.552	0.518	0.565	0.544	0.546
Hainan	0.553	0.533	0.545	0.618	0.568	0.564
Chongqing	0.517	0.533	0.577	0.598	0.606	0.566
Sichuan	0.561	0.549	0.517	0.560	0.592	0.556
Guizhou	0.442	0.443	0.456	0.533	0.512	0.477
Yunnan	0.502	0.506	0.506	0.538	0.525	0.515
Shanxi	0.472	0.466	0.532	0.553	0.568	0.518
Gansu	0.426	0.432	0.423	0.507	0.498	0.457
Qinghai	0.505	0.499	0.492	0.519	0.513	0.506
Ningxia	0.426	0.436	0.436	0.448	0.437	0.437
Xinjiang	0.491	0.471	0.444	0.492	0.480	0.476
Average	0.511	0.513	0.532	0.555	0.566	0.535

An analysis of the spatial distribution of coordinated development levels (Figure 1) demonstrated that only Beijing, Shanghai, and Guangdong achieved a primary coordinated development level in 2000. A total of 13 provinces (e.g., Heilongjiang, Shandong, Jiangsu) reached a minor coordinated development level. The remaining 14 provinces were in a minor dysfunctional recession state and were mainly located in the central and northwestern regions. In 2005, Beijing, Shanghai, and Guangdong were still the only provinces that had achieved a primary coordinated development level. The number of provinces that had achieved a minor coordinated development level decreased to 11. The remaining provinces were in a state of minor dysfunctional recession, with a concentrated contiguous distribution in the northeast, central, and northwest regions. In 2010, Shandong, Jiangsu, and Zhejiang also achieved a primary coordinated development level in addition to Beijing, Shanghai, and Guangdong, accounting for a total of six provinces. The number of provinces that had reached a minor coordinated development level had increased to 15, mainly in the northeast, central, and southwest regions. The remaining nine provinces were in a state of minor dysfunctional recession. In 2015, the number of provinces that had achieved a primary coordinated development level reached eight, and all of these provinces were concentrated in the eastern coastal areas. The number of provinces that had reached a minor coordinated development level had increased to 16, and they were all concentrated in the central and southwestern regions. The remaining six provinces were in a minor dysfunctional recession. In 2019, Beijing and Guangdong reached a medium coordinated development level. Furthermore, five provinces (e.g., Jiangsu, Shanghai, Chongqing) achieved a primary coordinated development level. The number of provinces that reached a minor coordinated development level increased to 20, and were mainly distributed in the northeast, central, and southwest regions. Xinjiang, Gansu, and Ningxia, which are located in the northwest region, were in a state of minor dysfunctional recession. Overall, the areas with the highest 3E coordinated development level in China were largely concentrated on the east coast, whereas the regions with a lower coordinated development level were mainly located in the underdeveloped central and western regions. In summary, coordinated development decreased gradually from east to west, and the gap between the regions has increased.

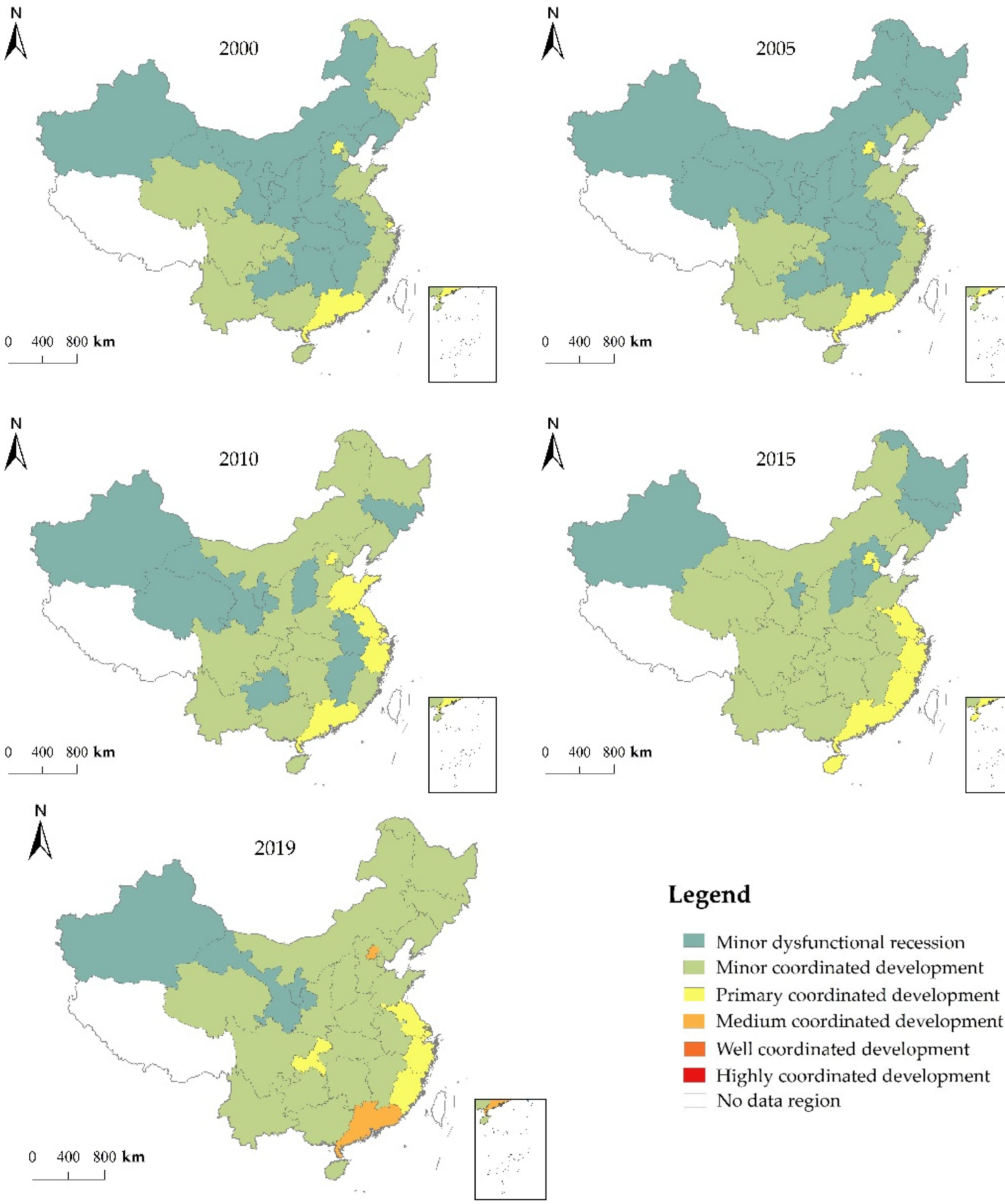

Figure 1. Coordinated development of the 3E system in China.

3.2. Spatial Pattern of Coupling and Coordinated Development

3.2.1. Global Spatial Autocorrelation

Table 5 summarizes the global Moran's I index of the coordination degree of the 3E system in China in 2000, 2005, 2010, 2015, and 2019 (Table 5). All of the index values of the past years were positive, and all z test values exceeded the critical value of 2.58, which were significantly correlated at a 0.01 level. Therefore, the coordinated development level of China exhibited a positive spatial autocorrelation, with clear clustering at the provincial scale. In other words, the coordinated development level had a high (or low) regional spatial aggregation and was not randomly distributed. Provinces with a higher coordinated development tended to neighbor higher-level provinces. Similarly, those with a lower coordinated development level tended to be near to lower-level provinces. Furthermore, the global Moran's I index exhibited only small fluctuations, indicating that the spatial autocorrelation degree was not very stable. In other words, the spatial agglomeration distribution in provinces with a high or low coordinated development level fluctuated to a certain extent.

Table 5. Global Moran's I index of the 3E coordination degree in China.

Year	Moran's I	Z	P
2000	0.23700	3.61602	0.00029
2005	0.24969	3.79100	0.00015
2010	0.24446	3.70517	0.00021
2015	0.21186	3.27822	0.00104
2019	0.24091	3.66335	0.00024

3.2.2. Local Spatial Autocorrelation

Further local spatial autocorrelation analyses of the coordinated development level in China were conducted, and the local Getis–Ord G* index of the coordination degree was calculated using the "cold spot", "secondary cold spot", "secondary hotspot", and "hotspot" categories to quantify the association between the values of each spatial unit and its adjacent spatial unit to explore the local spatial relationships (Figure 2).

In 2000–2005, the number of hotspot areas increased to six, all of which were located on the east coast. The number of sub-hotspot areas decreased to six, all of which were scattered in the east and west. The number of sub-cold spot areas decreased to six, mainly in the western and northeastern regions. The number of cold spot areas increased to 12, with a contiguous distribution in the central western regions. In 2005–2010, the number of hotspot areas remained unchanged, while the number of sub-hotspot areas decreased to four, and these two types of areas were primarily located on the east coast. The sub-cold spot and cold spot areas changed significantly, as most provinces changed from cold spot areas to sub-cold spot areas, and the number of sub-cold spot areas increased to 15, all of which were located in the central, western, and northeastern regions. The number of cold spot areas decreased to five and were mainly located in the western region. In 2010–2015, the number of hotspot areas decreased to three, whereas the number of sub-hotspot areas increased to six. Furthermore, these two types of areas were mainly located on the east coast. The number of sub-cold spot areas decreased to 10, all of which were concentrated in the central and western regions. The number of cold spot areas increased to 11 and were mainly located in the northwestern and northeastern regions of the central area. In 2015–2019, the number of hotspot areas remained unchanged (i.e., still three) and the number of sub-hotspot areas increased to seven. These two types of areas were mainly located on the east coast and the southwestern Sichuan–Chongqing area. The number of sub-cold spot areas decreased to eight and these were concentrated in the central area. The number of cold spot areas increased to 12 and they were primarily located in the western and northeastern regions.

In summary, the coordinated development level in China exhibited an obvious spatial agglomeration distribution, exhibiting a clear spatial dependence and spatial unevenness. During the study period, both the hotspot and cold spot areas exhibited fluctuations, demonstrating that the level of coordinated development varied not only regionally but also temporally. This was consistent with a previous analysis of Global Moran's I index. Particularly, the hotspot agglomeration area was mainly located on the east coast, whereas the cold spot agglomeration area was primarily located inland, in the central and western regions. Moreover, it is identified an east-to-west transition from hotspot to cold spot areas. Therefore, the coordinated development level in China generally tended to decrease from east to west, resulting in significantly distinct distribution patterns between the east coast and the inland provinces.

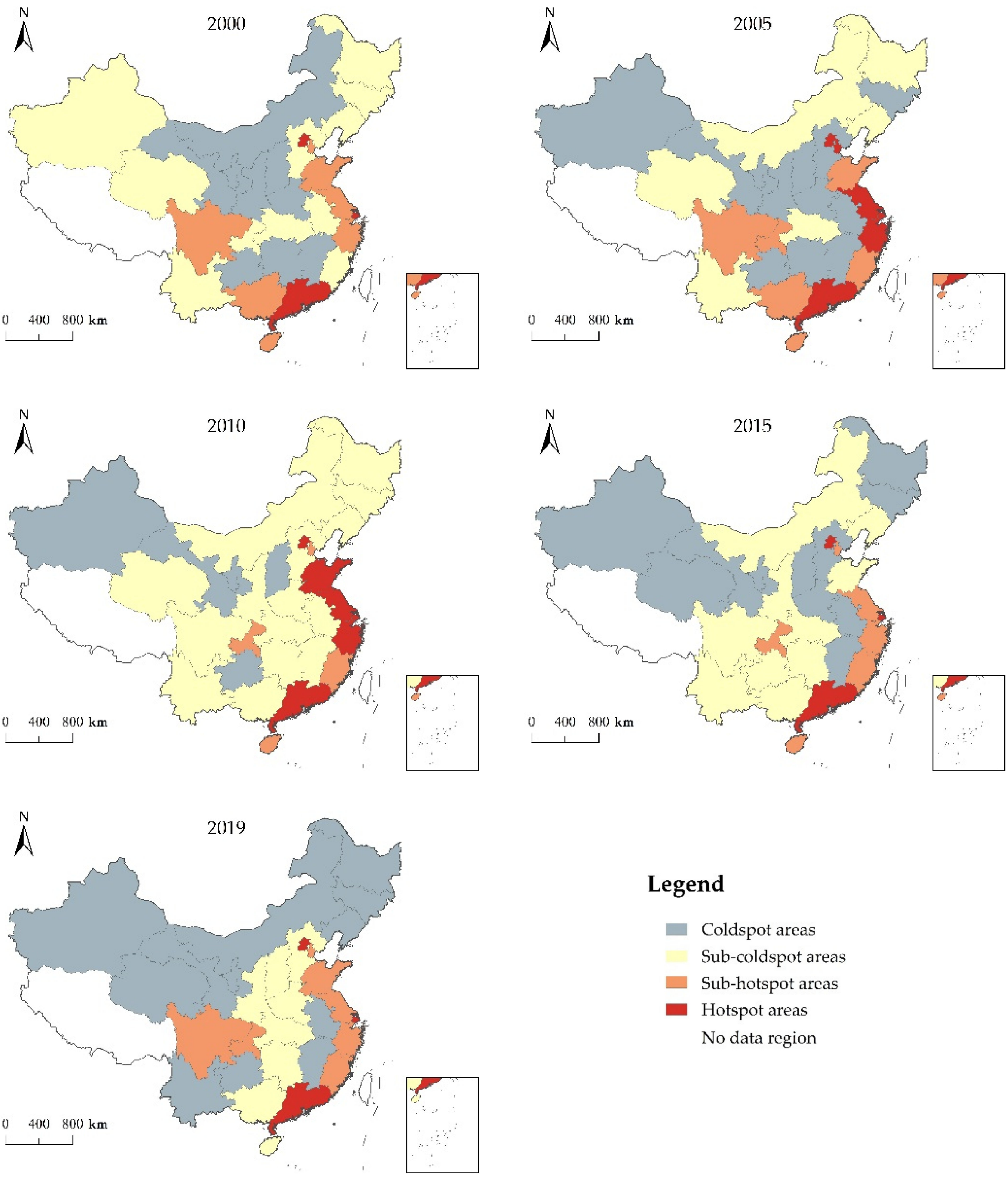

Figure 2. Spatial evolution of a cold spots and hotspots of coordinated development in China.

3.3. Discussion

Other recent studies have also explored the links between the components of the 3E system. However, such related studies remain quite limited. For instance, Lu et al. [8] reported that the components of the 3E system in China were intimately related. Rehman et al. [44] evaluated economic parameters to explore the link between economic growth, energy consumption, and environmental quality in Pakistan, and the authors reported that decreasing energy consumption and greenhouse gas emissions provided important socioeconomic benefits such as reducing investment costs. Li et al. [10] examined the spatiotemporal distribution of the coordinated development of China's provincial 3E system and reached similar conclusions to those described herein. Specifically, the authors reported that there was a clear spatial agglomeration distribution of the coordinated development level of China's provinces. Moreover, Liu et al. [29] used the distance-based coupling coordinated degree (CCD) model and dynamically comprehensive coordination degree model coupled with the 3E index system to evaluate the coordinated development levels of 11 provinces in the Yangtze River Economic Belt. The CCD model could thus provide indicators to evaluate regional variations in the 3E system. Luo et al. [45] proposed a comprehensive evaluation index system to analyze the temporal changes in the coordination degree of China's 3E system. The authors also indicated that the development stage of provinces must be taken into account when exploring the coordinated development of the 3E system, as this would help minimize regional differences and improve coordinated development.

The study had several crucial limitations that will be addressed in the future. Particularly, this study was only conducted at the provincial level. Therefore, future studies should be conducted on a finer scale (cities, municipalities, and counties) to gain more granular insights. Moreover, due to data unavailability, the study only spanned from 2000 to 2019. Future studies should thus include data from 2020 and later.

4. Conclusions

Between 2000 and 2019, the coordinated development level of the 3E system in China tended to increase steadily, albeit remaining relatively low. The coordinated development level of all provinces showed an upward trend. However, there were marked differences between provinces. Several provinces were still in a minor dysfunctional recession stage, whereas most provinces reached higher coordinated development levels. Nevertheless, only a few provinces reached the medium coordinated development level or above, and most of them were at a minor or primary coordinated development level. Overall, the areas with a high coordinated development level were mainly concentrated on the east coast, whereas the areas with a lower coordinated development level were primarily located inland in the central and western regions. This trend gradually decreases from east to west, and the gap between the regions increases.

Between 2000 and 2019, the coordinated development level in China showed clear spatial agglomeration distribution characteristics at the province level, with an obvious spatial dependence and spatial unevenness. Provinces with a higher coordinated development level tended to neighbor other higher-level provinces, whereas those with a lower coordinated development level tended to be close to lower-level provinces. During the study period, the degree of the spatial agglomeration of coordinated development fluctuated. Hotspot agglomeration areas were primarily observed in provinces with high levels of coordinated development, which in turn were mainly located on the east coast. In contrast, cold spot agglomeration was primarily observed in the inland regions. Therefore, the findings indicated that coordinated development tended to markedly decrease from east to west, resulting in distinct differences between the eastern and western provinces.

The findings provided insights into the unique strengths and weaknesses of each province, thus allowing for the creation of coordinated development strategies based on the characteristics of each region. The eastern region should take advantage of its rapid economic growth to further strengthen technological innovation and efficient energy utilization. For the central region, additional efforts should be made to improve green policies and promote coordinated development. Achieving this will also require investment in green industries, in addition to supporting green financial policies. For the western region, industrial infrastructure must be maintained/upgraded to promote coordinated development and green policies must be urgently enacted to prioritize the sustainable development of underdeveloped provinces.

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