

RESEARCH ARTICLE

An evaluation and spatial statistical analysis of China's regional sustainable development level

Mingran Wu

Abstract: Sustainability is an important factor of ecological civilization, and a reasonable sustainable development system is the basis for its enhancement. Based on the theory of sustainability science, we designed an evaluation index system comprising three subsystems: resource, environment and socio-economic development. Based on data from 30 provinces and cities in China from 2014 to 2016, we used the entropy method to evaluate the sustainable development level of different regions. In addition, we also summarized and classified different regions from the perspective of spatial statistical. The results show that the socioeconomic system has the greatest influence on the regional sustainable development system, indicating that the healthy and rapid development of the social economy is very important in sustainable development. In addition, China's sustainable development level is relatively low and varies greatly among different regions. Therefore, on the one hand, the government should reasonably strengthen and optimize environmental regulation and encourage the public to participate in supervision. On the other hand, it is necessary to improve the co-governance mechanism of different regions' ecological environment; improving the co-governance mechanism will serve not only to establish the cross-regional coordinated development management of institutions at the national level but also to establish a benefit-sharing and interest-compensation mechanism and find a balance of interests between regions. Finally, we should strengthen legal construction and clarify the rights and obligations of all parties to guide cross-regional coordinated development in line with laws and regulations.

Keywords: regional sustainable development, resource system, environmental system, socioeconomic system, environmental regulation, multiple governing mechanism

1 Introduction

With the development of industrial civilization, the traditional economic development model characterized by high consumption, high pollution and low efficiency has caused the continuous degradation of the ecological environment and has introduced severe challenges to the economic and social development of mankind. Since the World Commission on Environment and Development (WCED) proposed the viewpoint of sustainable development in 1992^[1], sustainable development has received international consensus, and cooperation between countries and regions has been continuously promoted. Since the reform and opening in 1978, China's economy has soared. In the past few decades, China has become one of the fastest growing countries in the world. Correspond-

ingly, China has also become one of the countries with the most serious resource consumption and environmental degradation in the world^[2]. At present, China's resource stock and environmental carrying capacity are both difficult to fit into the traditional economic growth model, and resource shortage and environmental pollution have become major obstacles to economic development^[3]. In 2014, the Chinese central government formally proposed the slogan "Declaration of War on Pollution"^[4], which greatly increased the severity of punishments for polluters and pollution behaviors and linked the performance of government officials with the achievements of environmental protection. Local governments have also made efforts to develop more than 30 innovative systems to actively promote the system design of sustainable development, including property rights management of natural resources, monitoring and early warning of the carrying capacity of resources and the efficient and economical utilization of resources^[4]. China has become one of the most insistent and positive countries in the world in improving the ecological environment. However, it should be noted that as a huge developing country, China still has relatively rigid demands for economic growth. There-

Received: February 11, 2020 **Accepted:** March 25, 2020 **Published:** March 31, 2020

Correspondence to: Mingran Wu. School of Business, Hohai University, Nanjing 210098, China; Email: wumr1992@163.com

Citation: Wu M. An evaluation and spatial statistical analysis of China's regional sustainable development level. *Resour Environ Econ*, 2020, 2(1): 112-125.

Copyright: © 2020 Mingran Wu. This is an open access article distributed under the terms of the [Creative Commons Attribution License](https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

fore, the Chinese government must consider the pressure of economic growth when protecting resources and the environment. It is impossible to completely ignore the economic growth rate when dealing with ecological environmental protection. In other words, China's future development should choose between maintaining economic growth and protecting resources and the environment in order to bring the two into an ideal state of balanced development. In addition, China is a mega-economy with various geographical conditions, ecological endowments and socioeconomic development levels in different regions^[5]; thus, areas should rely on their local conditions and implement different development concepts and strategies to achieve the maximize benefits. We believe that an improvement in national sustainable development capacity should be based on improving regional capacity, and the improvement of regional capacity must be based on an accurate understanding of the current condition of different regions^[6-8]. Therefore, the comprehensive evaluation of "sustainability" in different regions of China using scientific and reasonable evaluation methods is obviously an important aspect of sustainable scientific research. It is not only an important factor in analyzing regional competitiveness but also a necessary condition of regional development strategy.

2 Literature review

Following the industrial revolution and advances in industrialization, the relationship between human beings and nature worsened. In particular, after being continually exposed to global environmental events such as resource shortages, global warming, ecological degradation, serious desertification, population explosions and oil crises, people have developed a sense of crisis vis-a-vis the planet's ecological imbalance^[9]. The idea of sustainable development originated in 1962 with the publication of "Silent Spring" by the American biologist Rachel Carson, a book which illustrated the severity of the impact of modern pollution on the ecological environment and warned human beings to confront the serious consequences of their own production activities. The ecological issues raised by this popular scientific book have led to debates over the concept of development, marking the beginning of sustainability thinking^[10,11]. Ten years later, an informal international academic group, the Rome Club, published a research report, "The Limits of Growth", which triggered a fierce response from the international community^[11,12]. This report begins with a consideration of the earth's limited resources and energy, believing that human population growth and economic development are facing an insurmountable limit. This

research strengthened people's awareness of the crisis at hand and marked a major advancement in sustainability thinking^[11]. Later, in 1980, the International Union for the Conservation of Nature (IUCN) was entrusted by the United Nations Environmental Planning Group (UNEP) with the development of the World Natural Resources Conservation Framework, which preliminarily outlined the concept of sustainable development: The basic relationships in the natural, social, ecological, and economic development processes must be studied to ensure global sustainable development^[11,13]. In 1987, the World Commission on Environment and Development (WCED) published its famous report, "Our Common Future", which officially proposed this definition of sustainable development as: To meet the needs of the present, without causing harm to future generations^[11,14]. This definition has also become the most widely accepted definition of sustainable development worldwide. At the same time, the report pointed out that sustainable development is also a process of change in its use of resources, investment orientation, technological development and policy changes to continuously promote the potential to meet the needs of humanity now and in the future. In 1999, the National Research Council (NRC) published a report entitled "Our Common Journey: A Transition Toward Sustainability", which follows the concept of the WCED report and points out that sustainable development aims at "achieving long-term coordination between social development goals and environmental limits"^[11,15]. In 2012, the "Rio +20" summit adopted an outcome document, "The Future We Want", which launched a series of actions centered on the development of Sustainable Development Goals (SDGs)^[16]. A few years later, in September 2015, the United Nations adopted a series of important measures at the 70th UN General Assembly, namely, the Post-2015 Development Agendas (Post-MDGs). The establishment of these Post-MDGs has greatly changed the current global sustainable development governance model and mechanism, affecting future global development rules and even the development spaces among countries, and the issue has received extensive attention from the international community^[17]. The United Nations subsequently formed a number of influential recommendations around SDGs and Post-MDGs, such as "New Global Partnerships: Poverty Reduction and Economic Transformation through Sustainable Development"^[17,18] "Million Sounds: The World We Want"^[17,19], the "Global Sustainable Development Goals Recommendation"^[20], etc. Some civil think tanks and social groups have also built multiple research platforms around SDGs and Post-MDGs, and actively influence the direction of global sustainable development governance from a nongovernmental perspective^[17]. Cha^[11] believes

that from the mid-1980s to the mid-1990s the research methods of sustainable development focused mainly on static and qualitative research. From the mid-1990s to the early 21st century, sustainable development science was based on quantitative research methods and constructed the sustainable development evaluation index system and model.

Academia has carried out wonderful research on the relationship between the coordinated development of regional economy, society, resources and environment. Coastanza *et al.*^[21] and Wackernagel *et al.*^[22] believe that ecological carrying capacity research is built on a foundation of complex ecosystems, including resources, environment, human society and economic system, which complement each other. Western scholars' most representative research on sustainable development are as follows:

(1) Urban sustainable development, that is, the study on economic growth and the sustainability of human activities, resources and environment in the process of urban development. Calthorpe, a famous urban planning scholar, has clearly pointed out that urban sustainability means finding a balance among social, economic and ecological environments to ensure their continued existence^[23,24]. In recent years, with the acceleration of urbanization around the world and the increase in resource depletion, regional sustainable development has been greatly affected. Rapid urbanization has become an important cause of the deterioration of the ecological environment. As cities are regions where human activities exert the greatest pressure on the natural ecosystem, the urban ecological bearing capacity has far exceeded its own load^[25]. Resources and the environment are the basis of urban development. The protection, utility and recycling of resources and the environment are the basic principles of sustainable urban development^[26]. Urban development involves testing the sustainability of resource and environmental carrying capacity. Another important purpose of urban sustainable development research is to enhance the resilience of urban ecological functions and provide a better life for residents^[27,28]. In addition, Jin used the system dynamics method to construct an urban ecological sustainable development framework, simulated and predicted ecological footprint changes under different scenarios, and proposed corresponding countermeasures^[25,29]; Wang^[30] comprehensively explored the variability trajectory and spatial differentiation of Beijing's agricultural sustainable development capacity and analyzed the symbiotic relationship and interaction effect of factors influencing urban agriculture; Peng^[31] took 280 cities in 30 provincial administrative regions of China from 2003 to 2013 as research objects and studied the spatiotemporal difference characteristics of China's urban sustainable develop-

ment ability based on Data Envelopment Analysis (DEA) and Exploratory Spatial Data Analysis (ESDA). Taking Quanzhou as an example, and in keeping with the quantitative calculation of sustainable development level by using the energy value analysis method, Huang^[32] built the Sustainable Development Kuznets Curve Model (SDKC) to analyze the dynamic relationship between urban sustainable development level and economic growth, and then used the improved Gray Slope Correlation Model to discuss the causes of the curve. Most research results show that with the continuous improvement of a city's economy and basic functions, the conflicts among economic society, urban construction, population increase, resource shortage and the gradual improvement of people's requirements for the quality of the ecological environment will become more serious. However, current research on the long-term mechanism of sustainable urban development, especially the interaction between socioeconomic systems and resource-environment systems, remains very limited and must be further explored.

(2) Research on the Environmental Kuznets Curve. In 1955, economist Simon Kuznets^[33] studied the level of per capita income and the degree of fairness in distribution and proposed that the level of environmental pollution first increased and then decreased with economic growth, presenting the relationship shape of an inverted U-shaped curve. This means that when a country's economic development level is low, the degree of environmental pollution is relatively slight, but with the increase in people's income, environmental pollution becomes increasingly serious, and the degree of environmental deterioration increases with the growth of the economy. However, when the economy reaches a certain level, that is to say, a crucial "turning point", then with a further development in the economy, the degree of environmental pollution will gradually slow down, and the environmental quality will improve. In 1991, during the North American Free Trade Agreement negotiations, Americans worried that free trade would worsen the Mexican environment and affect the US domestic environment. American economists Grossman and Krueger^[34] discussed the relationship between environmental quality and per capita income for the first time, pointing out that the relationship between pollution and per capita income is "pollution increase with per capita GDP increase at low income levels, and decline with per capita GDP increase at high income levels". In 1993, Panayotou^[35] first referred to this inverted U-shaped relationship between environmental quality and per capita income as the environmental Kuznets Curve (EKC), which revealed that environmental quality initially declined with income increase, but after the income level rising to a certain extent (turning point), the envi-

ronmental quality will improve with the increase in income. In recent years, the academic community has also carried out a great deal of research on the relationship between regional economic growth and environmental pollution. The empirical analysis based on the environmental Kuznets Curve has been extremely rich^[36-41]. The study of the Kuznets Curve is a good indication of the long-term dynamic relationship between regional economic development and sustainable quality. However, due to the differentiation of indicator selection, different studies often lead to different results. Therefore, the selection of indicators requires further exploration.

(3) Regional sustainable development ability. This is the most common research area on sustainable science^[42-50]. The general research method is to design a set of evaluation index systems and then use a mathematical method to carry out comprehensive evaluation and scoring. Such research has great practical value. However, most of the evaluation indicators are too narrowly designed. Usually, only the resource and environmental carrying capacity of the region is considered, and the indicators of social and economic systems such as scientific and technological innovation are neglected. We believe that the capacity for regional sustainable development can not only be related to resources and environment but also to the quality and efficiency of economic growth and the benefits of regional science and technology innovation. In addition, due to the complexity of the system and the difficulty in obtaining historical data, most existing studies focus on static analysis using data from a single year while ignoring the change process of time factors thus affecting evaluation accuracy. Bartelmus^[51] suggested that regional sustainability is a dynamic process with a continuous evolution and development; therefore, a multiyear analysis can reflect the level more realistically. In this study, we adopt the entropy method and set the research duration as 3 years. We hope that the results will be more credible. In addition, considering the obvious regional differences in China's economic development, we focus on the spatial statistic of regional sustainable development capabilities and strive to provide a good reference for regional research and government decision-making.

3 Evaluation methods and index system

3.1 Evaluation methods: Entropy

The concept of entropy originated in classical thermodynamic theory. It was introduced into information theory by C. E. Shannon in 1948, was theorized and named "Information Entropy"^[52], which was used as a measure of uncertainty. The greater the entropy value of the indicator, the greater its impact on the overall evaluation. Therefore,

the index weight can be determined according to the entropy value of the information provided by each indicator observation. We assume that the original indicator data matrix $X = (x_{ij})_{m \times n}$ comprises m evaluation schemes and n evaluation indicators. For a certain indicator X_j , if the difference between the index value x_{ij} is larger, the role of the indicator in the comprehensive evaluation is greater; if the index values are all equal, then the indicator does not play a role in the comprehensive evaluation. The calculation steps of the entropy method are as follows:

(1) Because the entropy calculation method is based on the ratio of a certain indicator to the sum of the same indicator values of each scheme, there is no dimension effect and standardization is required. In addition, in order to avoid the meaninglessness of the logarithm when entropy is sought, data translation is required.

For positive indicators (bigger is better):

$$X'_{ij} = \frac{X_{ij} - \min(X_{1j}, X_{2j}, \dots, X_{nj})}{\max(X_{1j}, X_{2j}, \dots, X_{nj}) - \min(X_{1j}, X_{2j}, \dots, X_{nj})} + 1$$

$i = 1, 2, \dots, n; j = 1, 2, \dots, m$

(1)

For negative indicators (smaller is better):

$$X'_{ij} = \frac{\max(X_{1j}, X_{2j}, \dots, X_{nj}) - X_{ij}}{\max(X_{1j}, X_{2j}, \dots, X_{nj}) - \min(X_{1j}, X_{2j}, \dots, X_{nj})} + 1$$

$i = 1, 2, \dots, n; j = 1, 2, \dots, m$

(2)

(2) Calculate the proportion of the i_{th} plan under the j_{th} indicator:

$$P_{ij} = \frac{X_{ij}}{\sum_{i=1}^n X_{ij}} \quad (j = 1, 2, \dots, m)$$
(3)

(3) Calculate the entropy value of the j_{th} indicator:

$$e_j = -k \sum_{i=1}^n p_{ij} \ln(p_{ij}), \text{ and } k > 0$$

$$k = 1/\ln(n), \quad e_j \geq 0$$
(4)

(4) Calculate the coefficient of variation of the j_{th} indicator. For the indicator, the greater the difference between the indicator values is, the larger the impact on the evaluation of the program and the smaller the entropy value. Define the coefficient of variation:

$$g_j = \frac{1 - e_j}{m - E_e}, \text{ and } E_e = \sum_{j=1}^m e_j$$

$$0 \leq g_i \leq 1, \quad \sum_{j=1}^m g_j = 1$$
(5)

(5) Calculate the weightiness:

$$w_j = \frac{g_j}{\sum_{j=1}^m g_j} \quad (1 \leq j \leq m) \quad (6)$$

(6) Calculate the comprehensive scores of sustainable development capabilities in each region:

$$s_i = \sum_{j=1}^m w_j P_{ij} \quad (i = 1, 2, \dots, n) \quad (7)$$

3.2 Construction of the indicator system

This study takes resource conservation, environmental optimization and socioeconomic development as the three pillar systems of sustainable development and is based on the idea that there is a synergistic, symbiotic and balanced relationship among the three. Therefore, to assess the sustainability capacity, we must establish a quantitative evaluation index system with a comprehensive perspective. Based on existing research, we construct a regional sustainable development evaluation index system consisting of three subsystems, which includes 6 first-level indicators and 29 second-level indicators and judges the positive and negative attributes of each indicator (see Table 1).

(1) Resource system. Abundant resource supply is the material basis for sustainable development in the region. Whether it is the traditional or modern economic development model, investment in natural resources has always been the primary prerequisite and important guarantee of economic growth and social development. In this study, the resource system is divided into two subsystems: resource consumption and resource recovery and disposal. The former is a negative indicator, which is used to measure the consumption level of various important resources in the process of regional economic development. The latter is a positive indicator to measure how much the region improves the comprehensive utilization of resources in the process of economic development.

(2) Environmental system. A good ecological environment is a strong guarantee of sustainable development. Generally, regional economic development and environmental protection together constitute an interconnected system: environmental protection is the prerequisite for economic development, and only when the economy is developed to an ideal condition can the ecological environment be truly protected. In this paper, the environmental system is divided into two subsystems: pollution emission and ecological environment improvement. The former is a negative indicator that measures the damage to the ecological system caused by the discharge of various major pollutants, and the latter is a positive indicator that measures the extent to which the region improves the

environment.

(3) Social and economic system. Economic and social development is the overall driving force and ultimate goal of sustainable development in the region. A sustainable development system aims to realize the unification and promote the coordination of economic, social and ecological benefits in the development process and to further transform the economic development mode from extensive to intensive. In this study, the socioeconomic system also sets up two subsystems of economic and social development levels and scientific and technological innovation ability to investigate the impact of some important social conditions on sustainable development in the region.

4 Comprehensive evaluation

We take 2014-2016 as the research years and 30 Chinese mainland provinces and cities as the research objects. Due to a lack of relevant data, Tibet, Hong Kong, Macao and Taiwan are not included. The basic data come from the China Statistical Yearbook^[53] and the China Energy Statistical Yearbook^[54]. According to the entropy method, the score of the subsystems and comprehensive system of 30 provinces and municipalities are ranked as shown in Table 2. Considering the limited length of the article, all the numbers we calculated in this paper are the average value from 2014 to 2016.

We can see from Table 2 and Figure 1 that the scores of China's regional sustainable development system show complex and diverse characteristics, with different regions showing obvious distinctions, and the problems of protection and development coexisting. China has a large land area; thus, terrain and climatic conditions and land types are very complex and diverse, and the socio-economic development between regions are quite different. We can see from Table 2 that the province with the highest resource system score is Shandong (0.5607) and the lowest is Xinjiang (0.3099), with an average of 0.4538; the highest environmental system score is Hainan (0.6249) and the lowest is Shandong (0.3122), with an average of 0.5145; the highest score in the socioeconomic development system is Guangdong (0.6373) and the lowest is Jilin (0.0862), with an average of 0.2207; the highest score in the comprehensive system is Zhejiang (0.5931) and the lowest is Xinjiang (0.2632), with an average of 0.4112.

(1) Resource system. China's energy resources shortage and inequality distribution have increasingly become obstacles to economic development. In recent years, with the vigorous development of natural gas and power resources in the western region and the implementation of national-level projects such as "West-East Gas Trans-

Table 1. The index system of sustainable development ability evaluation

Target Layer	Indicator Type	Indicator Description	Indicator Unit	Indicator Property		
Regional capacity assessment system for sustainable development (A)	Resource System (B)	B11 Water Use	100 million cu.m	Negative		
		Resource Consumption (B1)	B12 Land for Agricultural Use	1,000 hectares	Negative	
			B13 Land for Construction	1,000 hectares	Negative	
			B14 Electricity Consumption	100 million kwh	Negative	
		Resource Disposal and Recovery (B2)	B2 Common Industrial Solid Wastes Comprehensively Utilized	10,000 tons	Positive	
			B22 Common Industrial Solid Wastes Disposed	10,000 tons	Positive	
			B23 Hazardous Wastes Utilized	10,000 tons	Positive	
			B24 Hazardous Wastes Disposed	10,000 tons	Positive	
			B25 Consumption Wastes Treatment Capacity	ton/day	Positive	
			B26 Treatment Rate of Consumption Wastes	%	Positive	
		Environment System (C)	Pollutant Emission (C1)	C11 Total Waste Water Discharged	10,000 tons	Negative
				C12 Sulfur Dioxide Emissions	10,000 tons	Negative
				C13 Nitrogen Oxides Emissions	10,000 tons	Negative
				C14 Smoke and Dust Emissions	10,000 tons	Negative
	C15 Common Industrial Solid Wastes Produced			10,000 tons	Negative	
	C16 Hazardous Wastes Produced			10,000 tons	Negative	
	Ecological Environment Improvement (C2)		C21 Forest Coverage Rate	%	Positive	
			C22 Total Area of Afforestation	hectare	Positive	
			C23 Area of Nature Reserves	10,000 hectares	Positive	
			C24 Proportion of Wetlands in Total Area of Territory	%	Positive	
	C25 Investment Completed in the Treatment of Industrial Pollution	10,000 yuan	Positive			
	Social and Economic System (D)	Social and Economic Development Level (D1)	D11 Total Population by Natural Growth Rate	‰	Positive	
			D12 Gross Capital Formation	100 million yuan	Positive	
			D13 Per Capita Disposable Income of Households	yuan	Positive	
D14 Per Capita Consumption Expenditure of Households			yuan	Positive		
Technological Innovation Ability (D2)		D21 Full-time Equivalent R&D Personnel	man-year	Positive		
		D22 R&D Expenditures	10,000 yuan	Positive		
		D23 R&D Projects	item	Positive		
		D24 Inventions in Force	piece	Positive		

Table 2. Evaluation results and ranking of sustainable development capacity of different regions in China in 2014-2016

Area	B: Resource System		C: Environment System		D: Social and Economic System		A: Comprehensive System	
	Score	Ranking	Score	Ranking	Score	Ranking	Score	Ranking
Beijing	0.4797	8	0.5742	4	0.3023	6	0.5101	4
Tianjin	0.475	9	0.561	6	0.2325	9	0.4647	8
Hebei	0.5223	3	0.3583	29	0.2009	13	0.3513	25
Shanxi	0.5476	2	0.3891	28	0.1209	25	0.3536	24
Inner Mongolia	0.431	22	0.5041	21	0.1473	20	0.3508	26
Liaoning	0.501	5	0.4335	25	0.1589	16	0.3663	22
Jilin	0.448	16	0.5467	12	0.0862	30	0.3634	23
Heilongjiang	0.3506	29	0.5437	16	0.0872	29	0.2848	29
Shanghai	0.4967	6	0.6019	2	0.3513	5	0.5659	2
Jiangsu	0.4448	18	0.4117	27	0.5791	2	0.5071	5
Zhejiang	0.5047	4	0.5458	13	0.4732	3	0.5931	1
Anhui	0.4373	19	0.4858	23	0.2215	10	0.3793	18
Fujian	0.4477	17	0.5948	3	0.2668	7	0.4817	6
Jiangxi	0.4242	26	0.5447	15	0.1488	18	0.3736	21
Shandong	0.5607	1	0.3122	30	0.4631	4	0.4756	7
Henan	0.4267	23	0.4182	26	0.2543	8	0.3415	27
Hubei	0.4251	24	0.5325	19	0.2184	12	0.3993	14
Hunan	0.432	21	0.5469	11	0.2185	11	0.415	11
Guangdong	0.4249	25	0.472	24	0.6373	1	0.5589	3
Guangxi	0.4231	27	0.5568	9	0.148	19	0.3805	17
Hainan	0.472	10	0.6249	1	0.1248	24	0.4533	9
Chongqing	0.4698	11	0.5576	7	0.1495	17	0.4186	10
Sichuan	0.4351	20	0.5225	20	0.1647	14	0.3749	19
Guizhou	0.4542	14	0.5455	14	0.1007	27	0.3746	20
Yunnan	0.4666	12	0.5538	10	0.1299	22	0.4044	13
Shaanxi	0.4801	7	0.5346	17	0.1415	21	0.4077	12
Gansu	0.4062	28	0.5569	8	0.0906	28	0.339	28
Qinghai	0.4534	15	0.5696	5	0.1153	26	0.3975	15
Ningxia	0.4641	13	0.5332	18	0.1264	23	0.3862	16
Xinjiang	0.3099	30	0.5037	22	0.1612	15	0.2632	30
Average	0.4538	-	0.5145	-	0.2207	-	0.4112	-

mission” and “West-to-East Power Transmission”, the regional distribution and utilization of China's energy resources have improved, but have not yet achieved an optimum level. Therefore, China must further strengthen and control its total energy and water resource consumption and land area construction; further, China must implement the strict farmland protection, land conservation and water resource management policies. In addition, different regions should strengthen research on resource technologies and introduce them according to their characteristics, vigorously develop and utilize new and renewable clean energy, and improve the efficiency of energy utilization in order to achieve the sustainable development of regional energy and economy.

(2) Environmental system. The environmental system scores are not good and show large regional differences. Therefore, in further measures, the Chinese government should not only strengthen the regional coordination of environmental protection but must also carry out the environmental assessment of key areas, river basins and industries to adjust and optimize the industrial layout, scale and structure that do not conform with the ecological environment construct function, strictly controlling environmentally risky projects. Moreover, the government must also raise pollution discharge standards, increase the elimination of outdated production capacity in key industries such as iron and steel, and encourage all administrative regions to enact policies to eliminate outdated production capacity using a wider scope and stricter standards. Further, they must vigorously develop energy conservation and environmental protection industries, clean production industries, and clean energy industries; thus, the government must strengthen the guidance of scientific and technological innovation, focus on guiding green consumption, raise the level of technology and equipment in green industries such as energy conservation, environmental protection, and resource recycling, and foster and develop a number of high-tech enterprises.

(3) The social and economic system. The healthy and rapid development of the social economy is crucial to promoting regional sustainable development. However, from the perspective of the entire evaluation system, the average score of the socioeconomic development system is the lowest. The relationship between economic development and environmental protection is extremely complicated, and there is inevitably a contradiction between the two. To a certain extent, economic development comes at the expense of destroying the ecological environment. In developing countries, including China, this problem is more serious. At present, developing countries basically depend on industry and even heavy industry as the pillars of economic development. The exhaust gas, dust

and sewage discharged from industrial production will follow the ecological cycle, causing pollution in a wider area, which creates a confrontation between economic development and environmental protection. However, environmental protection is fundamentally a development issue. A highly developed economic level is also a positive factor in protecting the environment. Therefore, we should not only focus on economic development but also make it consistent with environmental protection.

(4) The comprehensive system. The comprehensive system score represents the comprehensive capability of regional sustainable development. As shown in Figure 1, from 2014 to 2016, all provinces in China scored unsatisfactorily in the system. However, by comparing the original data, we can conclude that, first the average level of sustainable development in the eastern region leads the rest of the country, showing a declining trend from the eastern coast to the inland region. Most of the provinces and cities showing excellent performance are concentrated in the economically developed eastern region. Second, there is a positive correlation between the level of regional sustainable development and the regional economic aggregate, population growth rate and per capita disposable income of residents. Overall, cities with a higher GDP, larger population and greater land size have performed better in sustainable development. Lastly, regional innovation capabilities are highly correlated with the level of integrated sustainability. Along with an improvement in regional innovation capability, the overall level of sustainable development of the region has increased significantly.

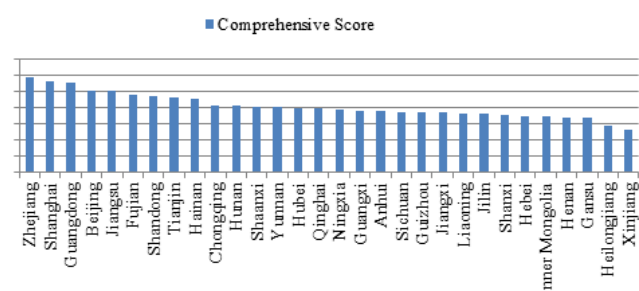


Figure 1. Ranking of sustainable development capacity in different regions of China from 2014 to 2016

5 Spatial statistical analysis

To further explore the spatial statistic characteristics of China's regional sustainable development, we use the spatial statistical method to classify different provinces. With reference of Li & Guo (2017), this paper constructs the spatial weight matrix, and then analyzes the spatial distribution of the whole region with global spatial autocorrelation, and then reveals the correlation of spaces

through Moran scatter diagram and local spatial autocorrelation analysis.

5.1 Global spatial autocorrelation

Global spatial autocorrelation analysis is used to describe the spatial distribution characteristics of subjects in the whole region and analyze whether they have aggregation. This paper adopts the index as the measure method, which is not easily affected by deviation from normal distribution. The calculation formula is as follows:

$$I = \frac{n \times \sum_{i=1}^n \sum_{j=1}^n W_{ij}(x_i - \bar{x})(x_j - \bar{x})}{(\sum_{i=1}^n \sum_{j=1}^n W_{ij}) \times \sum_{j=1}^n (x_i - \bar{x})^2} \tag{8}$$

In formula, W_{ij} is the spatial weight. The value range of *Moran's I* is [-1 1]. When the value of *Moran's I* is greater than 0, there is a positive correlation between the sample areas, and the observed values of each area tend to converge. The study area presents a spatial distribution pattern of "agglomeration", and the phenomenon of "agglomeration" becomes more obvious with the value becomes greater. When the value of *Moran's I* is less than 0, there is a negative correlation between sample regions, and the observed values in each region have different trends. There is a spatial pattern of "competition" between observation regions. When the value of *Moran's I* is 0, the study area showed an independent random distribution, with small differences among each area, and the observation areas tended to be evenly distributed. Through GeoDa software, the average data of sustainable development levels of 30 provinces and cities from 2014 to 2016 are imported into analysis. After calculation, the *Moran's I* value of regional sustainable development in China from 2014 to 2016 is 0.3921, indicating that sustainable development in different regions has been showing positive spatial autocorrelation, showing a spatial distribution pattern of agglomeration.

5.2 Local spatial autocorrelation

The Moran scatter diagram is used to show the instability of local space, and the local spatial connection situation can be recognized more intuitively by visual two-dimensional graph. The spatial relationship represented by Moran scatter diagram is shown in Table 3.

In addition, we often use the local indicators of spatial association (LISA) to study local spatial autocorrelation. Generally speaking, LISA is an indicator to describe the degree of spatial agglomeration between regional units with significant similar values. The calculation formula of local Moran index is:

$$I_i = \frac{(x_i - \bar{x})}{m_0} \sum_j^n W_{ij}(x_j - \bar{x}) \tag{9}$$

If the value of I_i is greater than zero, it means units with similar sustainable development level have spatial agglomeration. If the value of I_i is less than zero, it indicates that there is no spatial agglomeration.

The Moran scatter diagram of sustainable development levels of 30 provinces and cities in China from 2014 to 2016 is shown in Figure 2. It can be seen from Figure 2 that the scatter diagram distribution during the study period has similar characteristics: Provinces distribution mainly concentrates in the quadrant I and III, indicated that space effect type mainly belonging to positive correlation; The provinces and cities located in quadrant I are mainly in eastern coastal areas, and located in quadrant III are mainly in the central and western areas.

Therefore, we know that the spatial distribution of China's inter-provincial sustainable development level is polarized, forming a high level of eastern provinces and cities convergence and a low level of eastern and western provinces and cities convergence.

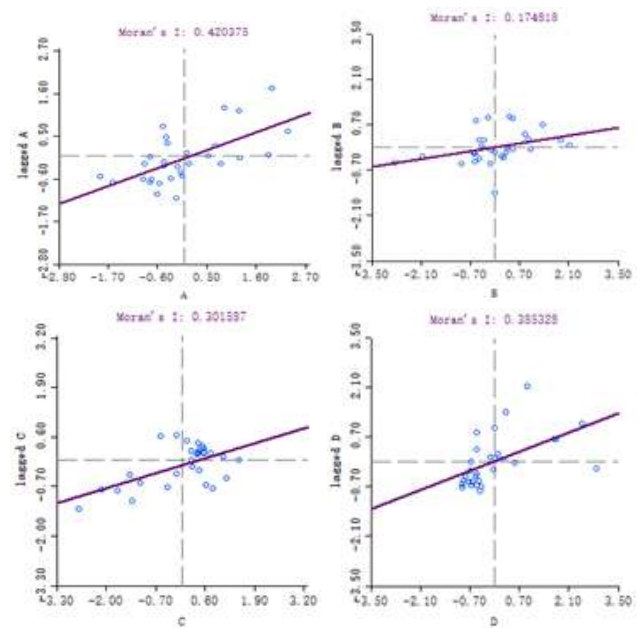


Figure 2. The Moran scatter plot of sustainable development system (A), resource system (B), environment system (C) and social and economic system (D) of China between 2014 and 2016

Through LISA analysis by GeoDa software, we can get the Moran aggregation diagram of different spatial autocorrelation types represented by different colors, as shown in Figure 3.

In order to further identify the local spatial clusters of China's inter-provincial sustainable development level

Table 3. Spatial relationship characteristics of Moran scatter plot

Quadrant	The local spatial relationship
I	The sustainable development level of provinces and surrounding provinces are both high (High-High agglomeration, H-H)
II	The sustainable development level of the province is low, but the surrounding level is high (Low-High agglomeration, L-H)
III	The sustainable development level of provinces and surrounding provinces are both low (Low-Low agglomeration, L-L)
IV	The sustainable development level of the province is high, but the surrounding level is low (High-Low agglomeration, H-L)

Table 4. Regional aggregation of sustainable development level in China from 2014 to 2016

System	H-H	L-H	L-L	H-L
Sustainable Development System (A)	Jiangsu, Zhejiang, Shanghai, Fujian	Jiangxi	Jilin, Inner Mongolia, Qinghai	-
Resource System (B)	Hebei	Henan, Jiangsu	Qinghai	-
Environment System (C)	-	-	Hebei, Henan, Shanxi, Anhui, Shandong	-
Social and Economic System (D)	Jiangsu, Anhui, Zhejiang, Shanghai, Fujian	Jiangxi	Xinjiang, Sichuan, Gansu, Inner Mongolia	-

from 2014 to 2016, this paper screened the four quadrants of *Moran's* scatter diagram to eliminate the insignificant provinces, and acquired the local cluster result, as shown in [Table 4](#).

In general, in these significant provinces and cities, the H-H type is all economically developed places in the eastern region, the L-H type mainly contains Jiangxi, Henan and Jiangsu, while the L-L type is mainly in the central and western regions. In addition, no Chinese provinces and cities belong to the H-L type.

For sustainable development system, Jiangsu, Zhejiang, Shanghai and Fujian are belonging to the H-H type. The four H-H type provinces and cities are the most economically developed areas on the southeast coast of China and together form one of the regions with the strongest sustainable development capabilities. The commonality of this zone is the scores of the socioeconomic system, which are ranked top in the country, and the comprehensive score of sustainable development ability is also among the highest in the country. This shows that the socioeconomic system plays an important role in the overall system, indicating how important the healthy and rapid development of the social economy is to regional sustainability. The most typical is Jiangsu, the resource

system score (0.4448, ranked 18) and environmental system score (0.4117, ranked 27) are not very well, but the sustainable development comprehensive score (0.5071, ranking 5) is very good. With years of economic development and industrial upgrading, these regions have good industrial structures. High-energy-consumption and high-environment-pollution industries have been transferred to areas where the prices of production factors and environmental protection intensity are relatively small. In their ensuing development, these regions should continue to play their geographical advantages, focus on the development of high-tech emerging industries with high added value, and intensify their research into green technology to become a powerful high-tech industry center. Jiangxi belongs to the L-H type. Jilin, Inner Mongolia and Qinghai are belonging to the L-L type. All these provinces are located in the inland areas of central and western China. Although the scores of each system are very different, their common feature is that their socioeconomic system scores are not satisfactory (the highest score being Jiangxi at 0.1488, ranking 18 in the country). Some provinces scored ideally in a certain system, such as Qinghai in the environmental system (0.5696, ranking 5). However, they do not perform well in other systems. The poor

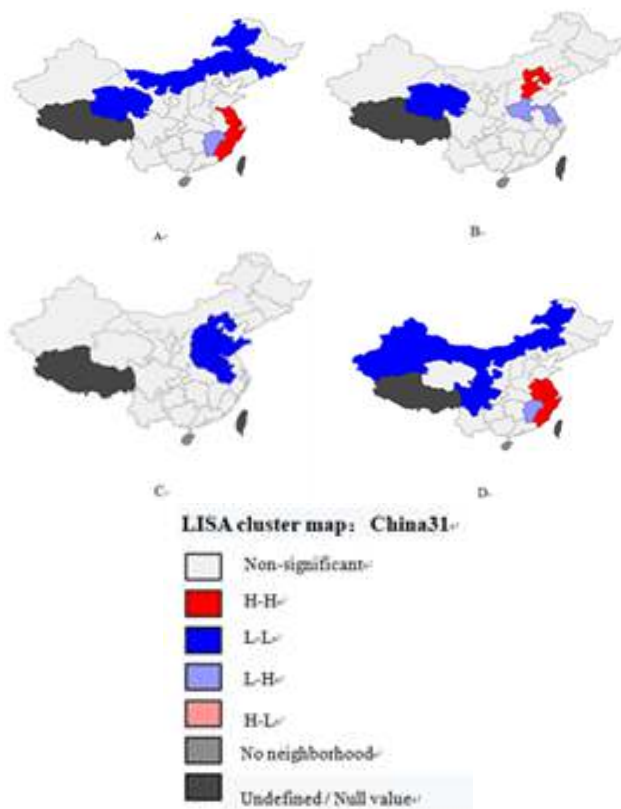


Figure 3. Moran aggregation map of Chinese regional sustainable development level

performance of these provinces in the socioeconomic system has led to an unsatisfactory performance in overall sustainable development. Therefore, in future steps, these regions should vigorously develop their economy, contribute to the welfare of residents through economic growth, and enhance regional strength and social wealth. In addition, they should adopt scientific economic growth methods and rely more on scientific and technological progress to improve the quality of economy.

For the resource system and environment system, China has a very bad performance. Most prominent provinces are L-H and L-L types. As the largest developing country in the world, China has few per capita resources and serious imbalance regional development. Moreover, extensive development mode has great dependence and damage on natural resources and environment. China is one of the most resource-constrained countries in the world. First, with the continue increase of population, the pressure on the shortage of land resources will become increasingly serious. Second, most parts of central and western China are short of water, so that when rainfall is uneven or dry, the potential danger of water shortage is obvious. Third, China's existing traditional energy consumption is very fast, the external demand for energy imports is increasing.

What's more, the current energy structure is still dominated by coal, which has a significant impact on atmospheric quality, and the pollution is obvious^[55]. In China, heavy industry accounts for a huge proportion of industrial output value. Oil pollution, petrochemicals, chemical raw materials manufacturing, ferrous metal smelting and other polluting industries are relatively developed, and structural and regional environmental risk prevention pressures are gradually increasing. The total energy consumption of coal-based energy continues to develop, and the proportion of clean energy and purchased electricity is also relatively small. Therefore, the task of improving energy structure and reducing total coal consumption is arduous^[56]. Therefore, it is necessary for China not only to strengthen the ecological transformation of traditional industries but also to vigorously cultivate strategic emerging industries and reduce the dependence of its economic development on resources and environment.

Social economic system is the most important subsystem of sustainable development system. The H-H provinces are mainly in the eastern region, have strong productivity ability, and are also ideal in the ranking of various indicators, showing a good ability for sustainable development. Some eastern regions have even reached the level of moderately developed countries. In comparison, the economic development in the central and western regions is backward, the industrial structure is gratuitous, and the level of people's income and scientific and cultural literacy are also not well, which is the reason why most L-L cluster provinces were in the central and western regions. Therefore, in future development, these regions should vigorously develop their economy, contribute to the welfare of residents through economic growth, and enhance regional strength and social wealth. In addition, they should adopt scientific economic growth methods and rely more on scientific and technological progress to improve the quality of economy.

6 Conclusions

This paper constructs an evaluation index system for regional sustainable development and uses statistics from 2014 to 2016 to analyze the sustainable development capability of 30 provinces in China. The first conclusion is that the socio-economic system has the greatest influence on the whole system, indicating that the healthy and rapid development of the social economy is very important to sustainable development; second, regional differences are quite significant, the highest-ranking being Zhejiang (0.5931) and the lowest-ranking being Xinjiang (0.2632); lastly, China's overall ability is poor and most regions have different kinds of sustainable development pressures,

except for a few provinces and cities such as Zhejiang, Shanghai, Guangdong, *etc.*

7 Discussion

Optimize environmental regulation rationally. The relationship between environmental regulation and technological innovation and socio-economic development has always been an important issue of academia. Magat^[57] first pointed out that technological innovation is an important determinant of the trade-off between environmental protection and economic development. In the early 1990s, Michael Porter^[58,59] proposed the "Porter Hypothesis", arguing that a rationally environmental regulation policy can stimulate enterprises to undertake technological innovation, generate innovative compensation, and make up for and even exceed the cost of environmental regulation to achieve a "win-win" status for both environment and economy. At present, China's environmental regulation is relatively weak and cannot meet the requirements of ecological civilization construction and sustainable development. Therefore, the government must first continuously enrich the tools for regional environmental regulation to establish a fair, diverse and sophisticated policy tool system. Transferring environmental regulation tools from a reliance on administrative measures to a comprehensively dependence on legal, economic, technological and necessary administrative measures would strengthen the application of complex environmental regulation tools, promote their coordination and optimization, and encourage the public to participate in governance. Second, the government must strengthen the relevance of regional policies and implement differentiated environmental regulations, such as strengthening the synergy between regional environmental policies and regional development policies as well as connecting policies between regional environmental and economic development. More specifically, in terms of the regional resource and environmental endowment and ecological carrying capacity, the government should determine the focus and direction of environmental regulation in each region and promote the unification of regional development goals and environmental regulation policies. Based on scientific analysis, it should rationally determine different environmental policy objectives and strengthen the policy docking of common environmental issues. Lastly, a scientific and effective environmental supervision system based on regional differences is needed. Under the premise of strictly implementing the total amount control, various pollutant discharge standards and sewage charges can be subdivided according to regional differences. The government also needs to establish a national vertical and unified envi-

ronmental supervision system to constrain the short-term behavior of local governments.

Improve the co-governance mechanism of the ecological environment. Ecological problems are fluid, cross-regional and long-term. Therefore, ecological governance must be integrated and requires greater cooperation between the central government and local governments and between different local governments. However, due to the "administrative district economy", a region's cooperation and economic relations with the surrounding areas often aim at maximizing its own interests; this lack in synergy awareness and holistic perspective makes coordination and development difficult across different regions and leads to a reduction in the quality of development and overall benefits. Therefore, it is necessary to establish and improve the coordination mechanism, reconcile the interests of cross-regional development, and guide the division of labor and coordinated development of trans-regional areas. This is both the rule of regional economic development and the essence of scientific development. In this regard, we may need to establish a management institution of cross-regional coordinated development at the national level which would be responsible for formulating relevant policies and promulgating the laws and regulations of cross-regional coordination across the country. In addition, we must find a balance of interests among regions and actively construct a benefit-sharing and interest-compensation mechanism for the coordinated development of cross-regional cities. We can also construct a framework of laws and regulations to remit the present lack of legal safeguards for coordinated development and cooperation. At the same time, it is necessary to strengthen law management, clarify the enforcement power of coordinated to contracting parties, and guide coordinated cross-regional development with laws and regulations.

References

- [1] WCED. Our common future: The world commission on environment and development. Oxford, UK: Oxford University Press, 1987.
- [2] Wu MR and Zhao M. Measurement on Regional Ecological Efficiency in China and Analysis on Its Influencing Factors: Based on DEA-Tobit Two-stage Method. *Technology Economics*, 2016, **35**(3):75-80.
- [3] Xi YQ. Research on Mechanism and Policy of Circular Economy Development. National Achievements Library of Philosophy and Social Sciences, Beijing: Social Sciences Academic Press, 2014.
- [4] Wu MR and Zhao M. Research on Chinese Different Regional Sustainable Development Capacity and its Spatial Differentiation. *Shanghai Journal of Economics*, 2016, **10**: 84-92.

- [5] Wu MR and Zhao M. The Comprehensive Evaluation and Spatial Difference Analysis on China's Regional Innovation Competitiveness. *Shanghai Economy*, 2018, **1**: 78-90.
- [6] Parris TM and Kates RW. Characterizing and measuring sustainable development. *Annual Review of Environment and Resources*, 2003, **28**: 559-586.
<https://doi.org/10.1146/annurev.energy.28.050302.105551>
- [7] Ness B, Urbel-Piirsalu E, Anderberg S, *et al.* Categorising tools for sustainability assessment. *Ecological Economics*, 2007, **60**: 498-508.
<https://doi.org/10.1016/j.ecolecon.2006.07.023>
- [8] Wu JG and Wu T. Sustainability indicators and indices: An overview. In: Christian NM, Madu CK, *et al.* *Handbook of Sustainable Management*. London: Imperial College Press, **2012**: 65-86.
https://doi.org/10.1142/9789814354820_0004
- [9] Niu WY. The Theoretical Connotation of Sustainable Development: The 20th Anniversary of UN Conference on Environment and Development in Rio de Janeiro, Brazil. *China Population, Resources and Environment*, 2012, **22**(5): 9-14.
- [10] Rachel Carson. *Silent Spring*. UK: Penguin Classics, 1962.
- [11] Cha N, Wu JG and Yu RB. Analysis of subject trends in research on sustainable development. *Acta Ecologica Sinica*, 2013, **33**(9): 2637-2644.
<https://doi.org/10.5846/stxb201201160096>
- [12] Donella H. Meadows, Dennis L. Meadows, Jorgen Randers, and William W. Behrens. *The Limits to Growth*. New York: University Books, 1972.
- [13] IUCN. *World Conservation Strategy: Living Resource Conservation for Sustainable Development*. Gland: Switzerland, **1980**: 18-19.
<https://doi.org/10.2305/IUCN.CH.1980.9.en>
- [14] World Commission on Environment and Development. *Our common future: The world commission on environment and development*. Oxford, UK: Oxford University Press, 1987.
- [15] National Research Council. *Our Common Journey: A Transition toward Sustainability*. Washington, DC: National Academies Press, 1999.
- [16] United Nation Conference on Sustainable Development. *The Future We Want*, 2012.
- [17] Peng SZ and Sun XZ. Post-2015 Global Governance for Sustainable Development and China's Strategy. *China Population, Resources and Environment*, 2015, **25**(7): 1-5.
- [18] High-level Panel of Eminent Persons on the Post-2015 Development Agenda. *A New Global Partnership: Eradicate Poverty and Transform Economies Through Sustainable Development*, 2013.
- [19] United Nations Development Group. *A Million Voices: The World We Want*, 2013.
- [20] Open Working Group on Sustainable Development Goals. *Outcome Document: Proposal of Open Working Group for Sustainable Development Goals*, 2014.
- [21] Coastanza R, Arge R, Groot R, *et al.* The value of the world ecosystem services and nature. *Nature*, 1997, **387**: 253-260.
<https://doi.org/10.1038/387253a0>
- [22] Wackernagel M and Galli A. An overview on ecological footprint and sustainable development: a chat with Mathis Wackernagel. *International Journal of Ecodynamics*, 2007, **2**(1): 1-9.
<https://doi.org/10.2495/ECO-V2-N1-1-9>
- [23] Calthorpe P and Ryn SV. *Sustainable Communities: A New Design Synthesis for Cities, Suburbs and Towns*. San Francisco: Sierra Club Books, 1986.
- [24] Yang ZS and Ding Y. Progress in Urban Sustainable Development Research: An International Perspective. *Economic Geography*, 2016, **36**(7): 9-18.
- [25] Zhou J and Guan WH. Study on sustainable development in Nanjing based on ecological footprint model. *Acta Ecologica Sinica*, 2012, **32**(20): 6471-6480.
<https://doi.org/10.5846/stxb201107281104>
- [26] Houghton G. *Sustainable Cities*. London: Jessica Kingsley Publishers, 1996.
- [27] Daily GC, Polasky S, Goldstein J, *et al.* Ecosystem Services in Decision Making: Time to Deliver Frontiers. *Ecology and Environment*, 2009, **7**(1): 21-28.
<https://doi.org/10.1890/080025>
- [28] Niemelä J, Saarela SR, Söderman T, *et al.* Using the Ecosystem Services Approach for Better Planning and Conservation of Urban Green Spaces: A Finland Case Study. *Biodiversity and Conservation*, 2010, **19**(11): 3225-3243.
<https://doi.org/10.1007/s10531-010-9888-8>
- [29] Jin W, Xu LY and Yang ZF. Modeling a policy making framework for urban sustainability: incorporating system dynamics into the Ecological Footprint. *Ecological Economics*, 2009, **68**(12): 2938-2949.
<https://doi.org/10.1016/j.ecolecon.2009.06.010>
- [30] Wang D, Lin XQ, Liu X, *et al.* Dynamic variation assessment and improvement strategies of urban agricultural sustainable development in Beijing at the county level. *Geographical Research*, 2014, **33**(9): 1706-1715.
- [31] Peng C, Chen ZF, Wu RH, *et al.* Spatial-temporal Differentiation of Urban Sustainable Development in China based on ESDA. *China Population, Resources and Environment*, 2016, **26**(2): 144-151.
- [32] Huang X and Huang MS. Relationship between sustainable urban development and economic growth based on energy analysis: a case study of Quanzhou City. *Progress in Geography*, 2015, **34**(1): 38-47.
- [33] Kuznets SS. Economic Growth and Income Inequality. *American Economic Review*, 1955, **45**(1): 1-28.
- [34] Grossman GM and Krueger AB. Environmental impact of a North American free trade agreement. NBER Working Paper No. 3914, 1991.
<https://doi.org/10.3386/w3914>
- [35] Panayotou T. *Empirical tests and policy analysis of environmental degradation at different stages of economic development*. Geneva, Switzerland: International Labor Office, 1993.
- [36] Paudel KP and Schafer MJ. The Environmental Kuznets Curve Under a New Framework: The Role of Social Capital in Water Pollution. *Environmental and Resource Economics*, 2009, **42**(2): 265-278.
<https://doi.org/10.1007/s10640-008-9215-y>
- [37] Lin BQ and Jiang ZJ. The Prediction and Influencing Factors Analysis of Environmental Kuznets Curve of Carbon Dioxide in China. *Management World*, 2009, **4**: 27-36.
- [38] Xu GY and Song DY. An Empirical Study of the Environmental Kuznets Curve for China's Carbon Emissions: Based on Provincial Panel Data. *China Industrial Economics*, 2010, **5**: 37-47.

- [39] Zou XQ. An Analysis on the Correlation Between Land Finance and Economic Development: Based on Land Finance Kuznets Curve Hypothesis and Panel Data Evidence. *China Land Science*, 2013, **27**(5): 14-19.
- [40] Zhu R, Zhao MZ and Xue JB. Industrial Transfer, Economic Growth and Environmental Pollution: An Inspiration from the Environmental Kuznets Curve. *Ecological Economy*, 2018, **34**(7): 68-73.
- [41] Tang X and Hu AG. Achieve innovative and ecological modernization: tunneling through the Environmental Kuznets Curve. *China population resources and environment*, 2018, **28**(5): 1-7.
- [42] Li CF, Wang AJ, Chen XJ, *et al.* Regional Distribution and Sustainable Development Strategy of Mineral Resources in China. *Chinese Geographical Science*, 2013, **23**(4): 470-481.
<https://doi.org/10.1007/s11769-013-0611-z>
- [43] Zhang W, Duan XJ and Zhang WY. Evaluation and Evolution of Sustainable Development in Yangtze River Delta. *Resources and Environment in the Yangtze Basin*, 2013, **22**(10): 1243-1249.
- [44] Wang ZQ, Luo YZ, Zhang MH, *et al.* Quantitative Evaluation of Sustainable Development and Eco-Environmental Carrying Capacity in Water-Deficient Regions: A Case Study in the Haihe River Basin, China. *Journal of Integrative Agriculture*, 2014, **13**(1): 195-206.
[https://doi.org/10.1016/S2095-3119\(13\)60423-2](https://doi.org/10.1016/S2095-3119(13)60423-2)
- [45] Di QB and Han YX. Analysis of the Sustainable Development Capacity of China's Marine Ecosystem from the Perspective of Entropy. *Scientia Geographica Sinica*, 2014, **34**(6): 664-671.
- [46] Zheng DF, Liu XX, Wang YY, *et al.* Spatiotemporal evolution and driving forces of natural capital utilization in China based on three-dimensional ecological footprint. *Progress in Geography*, 2018, **37**(10): 1328-1339.
- [47] Tan FF and Lu ZH. Sustainable development assessment based on NLPCA-GSO: a case study of the Bohai Rim region. *Acta Ecologica Sinica*, 2016, **36**(8): 2403-2412.
<https://doi.org/10.5846/stxb201411042166>
- [48] Yang JY. Analysis of Urbanization Healthy and Sustainable Development in Major Grain Producing Areas-Taking Henan Province as an Example. *Chinese Journal of Agricultural Resources and Regional Planning*, 2015, **36**(2): 9-16.
- [49] Nie Y. Sustainable Development of New Rural Finance in China. *Asian Agricultural Research*, 2012, **4**(9): 81-86.
- [50] Zheng D and Dai EF. Environmental Ethics and Regional Sustainable Development. *Journal of Geographical Sciences*, 2012, **22**(1): 86-92.
<https://doi.org/10.1007/s11442-012-0913-6>
- [51] Peter B. Dematerialization and capital maintenance: Two sides of the sustainability coin. *Ecological Economics*, 2003, **46**(1): 61-81.
[https://doi.org/10.1016/S0921-8009\(03\)00078-8](https://doi.org/10.1016/S0921-8009(03)00078-8)
- [52] Shannon CE. A mathematical theory of communication. *The Bell System Technical Journal*, 1948, **27**(3): 379-423.
<https://doi.org/10.1002/j.1538-7305.1948.tb01338.x>
- [53] National Bureau of Statistics. *China statistical yearbook*, Beijing, 2017.
- [54] Department of Energy Statistics. *China energy statistical yearbook*, Beijing, 2017.
- [55] Liang GL, Zhang LB, Li DQ, *et al.* Experiences and Suggestions for Ecological Civilization Construction in Fujian Province. *Engineering Sciences*, 2017, **19**(4): 74-78.
<https://doi.org/10.15302/J-SSCAE-2017.04.012>
- [56] Yuan QM and Cui DJ. Evaluation on Sustainable Development of Tianjin based on DPSIR Model. *Commercial Research*, 2013, **3**: 27-32.
- [57] Magat WA. Pollution control and technological advance: a dynamics model of the firm. *Journal of Environmental Economics and Management*, 1978, **5**(1): 1-25.
[https://doi.org/10.1016/0095-0696\(78\)90002-5](https://doi.org/10.1016/0095-0696(78)90002-5)
- [58] Porter ME. America's green strategy. *Scientific American*, 1991, **4**: 1-5.
- [59] Porter ME. Linde CToward a new conception of the environment-competitiveness relationship. *Journal of Economic Perspectives*, 1995, **9**(4): 97-118.
<https://doi.org/10.1257/jep.9.4.97>