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REVIEW ARTICLE

Research progress and prospects of green development from the perspective of geography

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ABSTRACT

Influenced by global financial crisis in 2008, many countries around the world have realized the significance of sustainable development. And green development, as the most important pathway to sustainability, has been implemented by various countries. In this context, green development has drawn great attention from academic researchers both at home and abroad in recent years and has become an interdisciplinary-oriented research direction. As an applied basic research field for exploring the structural change of resources and environment as well as regional sustainable development, geography plays an essential role in the research of green development. Based on an intensive literature review, this article firstly summarized the connotation and analytical framework of green development. Secondly, it systematically outlined the progress of green development research from the perspective of geography and thus extracted seven themes, that is, the influencing factors of green development, assessment methods, spatial and temporal characteristics of green development, green development and industrial transformation, green transformation of resource-based cities, the effect of green development, and green development institutions and recommendations. Comments were made on the existing studies including their shortcomings. Finally, future research emphases were discussed, aiming to provide references for further study on green development from the perspective of geography in China.

Keywords: Green Development; Research Progress; Prospect; Perspective of Geography

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1. Introduction

After the industrial revolution, the continuous high-intensity economic activities have brought huge damage on our ecological environment. While reshaping the world economic geographical pattern, economic globalization promotes the flow of resource elements and environmental pollution on the global scale, and the spatial scale of the interaction between economic activities and environmental issues has also changed[1]. The interweaving of the 2008 international financial crisis and global climate change further promoted the reflection on the existing economic development mode, and governments have sought new economic development modes to get rid of the existing development crisis, in order to achieve long-term, stable and sustainable regional development. The philosophy of green development is just in line with that of sustainable development, both striving to explore a beneficial and environment-friendly economic development model. Since the proposition of Global Green New Deal (GGND) initiated by the United Nations Environment Programme (UNEP) in 2008, green development has been becoming a development consensus of more

and more countries and regions in the world and an important way to explore global sustainable development. Since the reform and opening up, China has taken just more than 30 years to complete the development tasks that western developed countries would accomplish in decades or even hundreds of years. The sharp compression of the spatial and temporal dimension had brought about China more complex regional development problems than any previous period, which also puts forward higher requirements for the government's governing power[2]. At present, China is experiencing an important period of economic transformation and upgrading as well as socialist modernization, with the conception of "promoting development through steady growth and structure reconstruction" as its main guidelines in economic development under the new normal situations. The scientific economic development will not only benefit our people, but also will have a far-reaching impact on the world development in the future. As an emerging civilization paradigm after industrial civilization, ecological civilization has become a strategic concept of realizing the sustainable development of the Chinese nation in the new era in recent years. Ecological civilization emphasizes the construction of a civilized society with production development, rich life and good ecology based on the carrying capacity of resources and the environment[3]. The fundamental direction of green development is to realize the symbiosis of economic, social and environmental development. Obviously, green development is the development concept and development model to meet the requirements of ecological civilization construction in the new era, while ecological civilization is the construction goal and objective result of green development.

With the increasingly recognition and popularization of the concept of green development, the academic research on the field of green development has also increased rapidly, attracting many scholars of various disciplines including geography, economics, sociology, environmental science, ecology, etc. Based on the core collection database of Web of Science, 438 papers, conference papers and reviewed literature of the subject—"green development" or "green economy" have been retrieved (**Figure 1**). It can be found that the number of documents on green development showed a rapid rise, especially since the outbreak of the international financial crisis in 2008, with the number of research papers in this direction increased by 12.03%. In the same way, 5,428 core journals and doctoral papers were retrieved in the CNKI database. Compared with the earlier boom of research on green development rising abroad, the relevant domestic research started relatively late, and the number of relevant documents began to increase after 2000, and increased significantly after 2008. It can be found that at present, green development has become a hot issue of research by scholars at home and abroad.

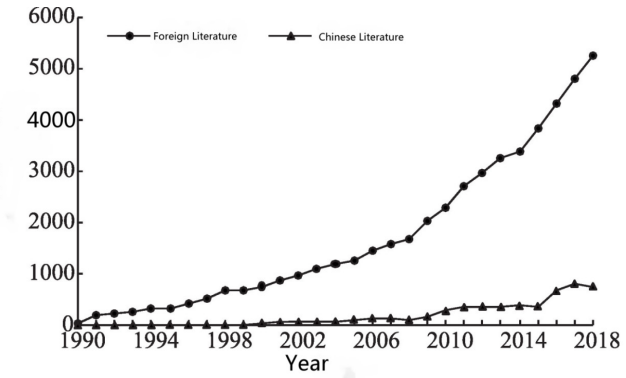

Figure 1. The number of publications on green development.

Geography is an applied basic discipline researching on resources, environmental structural changes and regional sustainable development, which can not only tell us what had happened in the past, but also can provide us ways to deal with the current issues and future events[4]. Its main task is to study the major theoretical and practical problems faced by the sustainable development of contemporary human society[5]. Since the 1980s, related theory, methods and technology of geography have become the foundation to solve related issues[6]. Due to its discipline characteristics as comprehensiveness, regionality and interdisciplinary geography owns some incomparable advantages in the field of green development. In this context, this paper expounds the origin, connotation and analysis framework of green development research, and summarizes the research progress and existing problems related to green development at home and abroad from the perspective

of geography. Through systematic summary and review, this paper hopes to provide relevant guidelines for the future research of Chinese geography in the field of green development, so as to provide corresponding reference for better understanding the research direction and purifying the research issues.

2. Origin, connotation and framework of green development research

2.1 Origin of the study

As a paradigm change of the economic development, green development can be traced back to the Spacecraft Economy Theory proposed by American scholar Bolding in the 1960s and a series of discussions on steady-state economy, green economy and ecological economy advocated by Daley and Pierce[7]. In the early stage, it was mostly applied to guide the development of ecological industry, and then gradually expanded to the whole economic system. As early as 2002, the United Nations Development Programme[8] developed the green development concept to research on Chinese issues. Since then, in order to solve the increasingly severe contradiction between the rapid economic growth and the environmental resources in the Asia-Pacific region, the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) has put forward the green development strategy[9]. In the post-financial crisis era, green development, as a new economic development model addressing the human development crisis and providing beneficial solutions, has attracted increasing attention from international institutions such as Organization for Economic Co-operation and Develop (OECD), United Nations Commission on Sustainable Development (UCSD), United Nations Environmental Programme (UNEP) and World Bank etc. At the United Nations Conference on sustainable development in 2012 in Rio de Janeiro, Brazil, green development was formally established as one of the important means to achieve the sustainable development. Since the reform and opening up, with the rapid development of China's economy and society and high-intensity resource development, the evolution of Chinese man-earth relations has shown a diversified, complex and tenser characteristic[10]. In the 21st century, the Chinese government was committed to the harmonious and unified development of economic construction and ecological environment, and successively put forward the development concept of "Scientific Outlook on Development" and the construction of "Resource-conserving Society and Environmental-friendly Society". In 2009, Circular Economy Promotion Law of the People's Republic of China was implemented to promote sustainable development in the form of law. In May 2013, when President Xi Jinping presided over the sixth collective study of the Political Bureau of the Party of CPC Central Committee, he pointed out that "we should properly handle the relationship between economic development and ecological and environmental protection, and more consciously promote green, circular and low-carbon development". The Fifth Plenary Session of the 18th CPC Central Committee upgraded green development into one of the five development concepts guiding China's economic and social development during the 13th Five-Year Plan. As the concept of green development gradually became a global consensus (**Figure 2**), the relevant research has also entered a new stage.

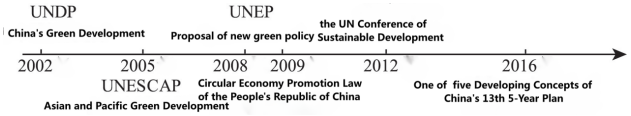

Figure 2. Green Development: global consensus.

2.2 Connotation and analysis framework

Green development belongs to the second generation of sustainable development concept (strong sustainable development), which is a reflection on the thought of "weak sustainable development", that is, the thinking of ecological limit is added on the basis of weak sustainable development, emphasizing that natural capital cannot be completely replaced by artificial capital, and it is necessary to achieve non-zero growth of key natural capital[11-12]. With the deepening of green development research and the integration of different disciplines, the connotation of green development is also constantly changing, from harmonious and unified development between the economy and ecology[8,13] at early stage to a more

multi-dimensional direction of evolution. The current mainstream is to define it from the perspective of regional economic system coping with resources and environmental problems and improving human well-being. UNEP pointed out that green economy is an economic activity aimed at improving human well-being in the long term while avoiding bringing about significant environmental risks and ecological scarcity to our next generation, with characteristics of low carbon, resource availability and social inclusiveness[14-15]. The World Bank[16] sees green growth as a way of making efficient use of natural resources while minimizing environmental pollution and influence and effectively dealing with natural disasters. Zhu Dajian[17] believes that two important dimensions of scale and fairness has been added on the green economy adds based on the traditional efficiency-oriented economic model, with the characteristics of economic efficiency, scale controllability and social inclusiveness.

Although different institutions and scholars have different perspectives and emphases on the connotation of green development, an agreement is reached on the essence of green development, that is, under the constraints of resources and environment, it shall strive to realize the symbiotic development of economy, social and natural system by developing low-carbon economy and circular economy so as to maximize the development benefits.

In terms of green development, many international institutions and organizations have put forward their analysis frameworks for green development according to their actual situations. Among them, the green growth framework established by OECD is widely adopted and applied[18]. The framework consists of four aspects: environmental and resource productivity, natural asset base, environmental factors related to life quality and policy response. Its biggest feature is taking other goods and services as production factors by taking full consideration of the value of natural resources, focusing on using a low-cost and high-effective way to relieve environmental stress. In addition, scholars and researchers began to put emphasis on constructing analysis framework of green development and there had emerged some valuable research fruits. For example, Hu Angang[19] put forward the "three circles model" for green development, including three systems of economy, society, and nature. And the symbiosis of the three systems formed coupling relationships among the green growth, green wealth and green welfare. In general, theories related to green development have been effectively expanded, gradually forming a comprehensive and coordinated theoretical description and framework construction of "economy-environment-society", and the research of such composite system is attracting the attention of scholars and researchers at home and abroad.

3. Main research topics for green development

3.1 Factors affecting green development

Study on the factors influencing green development is one of the main research directions of green development research, which directly reveals the causes and mechanism of action affecting green development level, and provides a decision-making basis for predicting the future regional development and formulating corresponding countermeasures. The existing studies mainly analyzed the factors affecting green development based on such approaches as regression model, obstacle degree model and geographical detector and so on. Overall, regional green development is affected at any period by multiple driving forces. Its influencing factors can be roughly divided into two categories of natural factors and social-economic factors. But the study on natural factors is relatively rare, and many studies focus on social-economic factors, always combining natural factors with current development. For example, Feng *et al.*[20] pointed out that people living in low altitude areas always has a relatively positive attitude in dealing with global climate change, and their corresponding regional green development level is higher.

In the Anthropoid period of Earth, as the social economic factors is becoming more active and easier to detect, how the social-economic factors affect human activities like economic development, industrial structure, financial instruments, environmental reg-

ulation, public behavior and other aspects has been highly valued (**Figure 3**). It is generally believed that the region with a good economic foundation always has a relatively high level of green development. However, the studies from Mu Xueying *et al.*[21] showed that the economic foundation is a necessary but inadequate condition for green development, and the regions with a good foundation for economic development do not necessarily have a high level of green development. After the international financial crisis, the global macro economy shows an uncertainty, which also affects the implementation of the green development strategy to a certain extent. Jin *et al.*[22], taking China as an example, pointed out that macroeconomic uncertainty has little impact on the green development level in developed and coastal cities, but it has an obvious inhibitory effect on the green development level in less developed cities. Technological progress and its bias are an important breakthrough to realize the coordinated development of economic growth and environmental improvement. The research of Sun Caizhi *et al.*[23] showed that the labor bias and capital bias in technological progress can promote the growth of local green economy, while capital bias can also drive the growth of green economy in neighboring areas, indicating the importance of increased human capital As the main link of human economic activities in the ecological environment, the rationality and advance of industrial structure are conducive to promoting the improvement of regional green development[24]. From the perspective of industrial scale, industrial agglomeration and regional green development efficiency show a "U"-shaped relationship. With the enhancement of industrial agglomeration, the green development efficiency will decrease at first and then increase[25].

In recent years, the research on the relationship

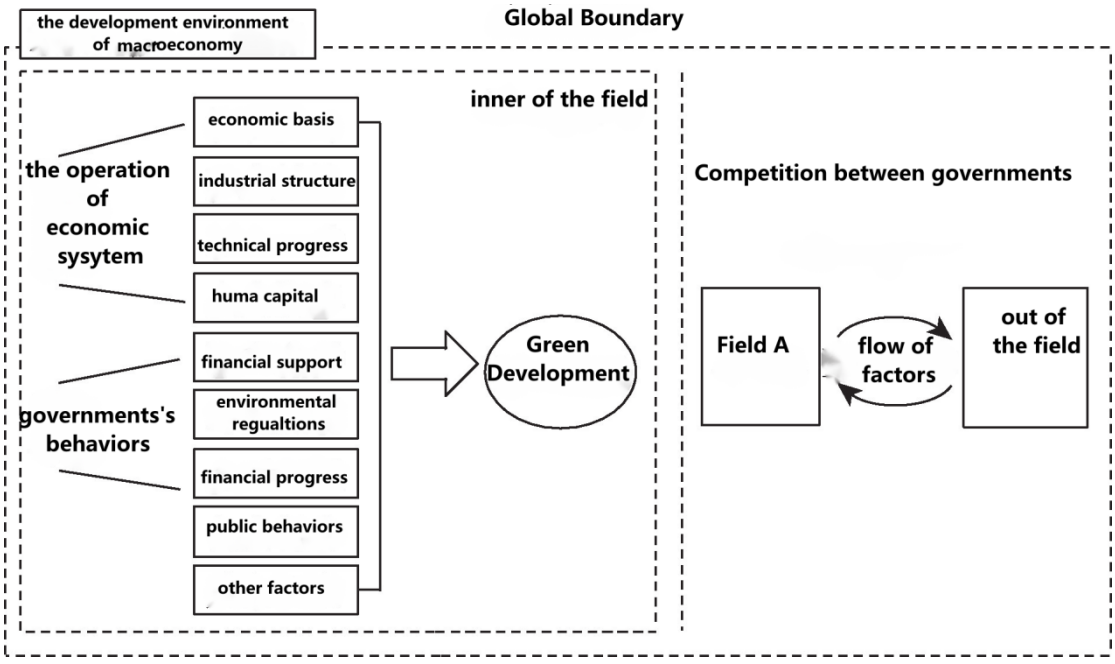

Figure 3. Main social-economic factors driving the change of green development.

between environmental regulations, financial development and green development has gradually increased. Wang *et al.*[26] believed that both formal and informal environmental regulations can promote the level of regional green development, but there are significant differences in the mode of action. Peng Xing *et al.*[27] divided environmental regulations into three types including command control, economic incentive and voluntary consciousness, pointing out that the enhancement of economic incentive-oriented environmental regulation and voluntary consciousness-oriented environmental regulation can significantly improve the level of green technology innovation and promote industrial green transfor-

mation. Financial development affects the regional green development from four aspects: capital support, resource allocation, enterprise supervision and green finance[28]. Compared with foreign countries, the economic development system dominated by the Chinese government determines the importance of local governments in regional development. He Aiping *et al.*[29] believes that the competition between local governments will curb the improvement of green development level, and the fluctuation of the government's choice between economic catch-up and environmental regulations, making China's green development efficiency continuously fluctuate at a low level. In recent years, the public has experienced a transition from passive response to active participation, and as an important supplement to environmental governance tools, non-governmental organizations (NGOs) play an increasingly important role in global climate change and environmental governance, and the effect of public participation depends on the level of public education and the determination of government governance[30].

3.2 Measurement for the level of green development

Research on the measurement for green development level will not only help scholars and deciders understand the current status of regional green development, but will also help explore factors influencing the improvement of green development level and formulate differentiated development countermeasures, which is crucial for the realization of green development goals. At present, a large number of methods have been used to explore the measurement for level of green development, which can be roughly divided into three categories: green efficiency evaluation, single index evaluation and comprehensive index evaluation.

Compared with the traditional method of efficiency evaluation, the green efficiency evaluation takes the environmental pollution caused by the operation of the economic system into consideration, emphasizing to invest less resource to obtain higher economic returns while producing less environmental pollution. At present, there are many methods of calculating green development efficiency, and the most commonly used method is data envelope analysis (DEA). After years of development, the DEA model has been continuously improved. Such methods as DEA model[31], SBM model[32], Super-SBM model[33] and Malmquist-Luenberger[34] have been widely used. In addition to the green efficiency measurement of the macroeconomic system, geographers have also conducted empirical studies on various industrial departments focusing on land use green efficiency[35], water resource green efficiency[36], and green innovation efficiency[37]. With the gradual enrichment of the measurement content, the selection for green efficiency model indicators also takes factors as technology, environmental protection[38] and haze[39] and so on into consideration based on the traditional input (labor, capital, resources) and output (economic benefits and environmental pollution).

The single index method is analyzed based on a certain side of green development from a certain framework, represented by green GDP accounting, decoupling index and carbon profit and loss. Green GDP includes resources and environmental costs as economic costs into the national economic production accounting according to the disadvantages of traditional national economic accounting, which is widely used in practice. Lei Min *et al.*[40] analyzed the green GDP of resource-based cities according to the SEEA2003 accounting system formulated by the United Nations; Zhang Hong *et al.*[41] calculated the green GDP of Fujian Province based on the SEEA2003 accounting system. Kunanutakij *et al.*[42] established a green GDP model based on the environmental extended input-put model (EIO-LCA) and took Thailand as an example. Decoupling originated in the field of physics and was later applied to resource and environmental research, which OECD[43] defines as breaking the association of environmental load and economic development. Lu Qiang *et al.*[44] took the decoupling index as a dynamic index of industrial green transformation and upgrading, and conducted the empirical analysis with Guangdong Province as an example. With people's increasing attention to carbon emissions, the concept of carbon source/sink is introduced, and the carbon profit and

loss caused by this has become an important basis for the regional policy formulation. Zhao Rongqin *et al.*[45] studied the carbon revenue and expenditure and the spatial differences of carbon balance in the Central Plains Economic Zone; Wang Xi *et al.*[46] analyzed the spatial and temporal changes of carbon profit and loss in Henan Province based on energy consumption data, the number of major industrial products and remote sensing data.

The comprehensive index evaluation method can comprehensively reflect the level of regional green development, and help understand the various factors affecting green development, so it is widely applied in practice. According to the different research subjects, the comprehensive evaluation index system of green development is increasingly rich. Hou Chunguang *et al.*[47] build a green evaluation index system including five aspects: economic growth system, green welfare system, green wealth system and green governance system; Kim *et al.*[48] have constructed the OECD national green development evaluation index system from five aspects: environment and resource production rate, environmental and resource production rate, ecological efficiency improvement, natural asset base, environmental quality, life quality and economic responses in the production process;; based on the information entropy and dissipation structure theory, Hou Caizhi *et al.*[49] established the regional green development evaluation index system in the perspective of support input entropy, pressure output entropy, prototype metabolic entropy and oxidative metabolic entropy; Based on the "P-S-R" model, Guo Fuyou *et al.*[50] have built a green development index system of restricted development zone from three aspects of green development pressure, green development state and green development response.

In general, the abovementioned three methods gradually enriched their research methods by absorbing research methods from economy and ecology in the process of application Due to the subjectivity of index selection and weight determination, it is difficult to compare the efficiency of relevant studies based on the efficiency evaluation and comprehensive index evaluation, while the index methods represented by green GDP accounting have a certain comparability. When selecting methods, the actual situation of the research area and research purpose need to be fully considered, so as to achieve the best evaluation effect. However, each method is faced with a series of problems and challenges, such as single data source, poor timeliness, and difficulty in applying at the micro scale.

3.3 Spatiotemporal evolution of green development

Spatiotemporal evolution analysis is a common content of geography. For a long time, scholars at home and abroad have carried out a large number of case studies in different regions, focusing on the spatiotemporal evolution of green development. Based on the evaluation of green development level, multi-timing statistics data were used to depict the spatial patterns and evolution laws of green development by such approaches as the spatial autocorrelation model[51], convergence model[52], nuclear density function[53] and other methods. Foreign researches on the spatiotemporal evolution of green development started earlier, but it mostly reflects the spatiotemporal characteristics of green development worldwide at macro level. Kumar's[54] study on green development efficiency in 41 countries worldwide from 1971 to 1992 shows that countries with active response to the global climate changes are always performed better in the green development. Lin *et al.*[55] also analyzed the green development efficiency of 70 countries from 1981 to 2007. The study pointed out that the global green development efficiency has been improved significantly during this period, and the green development efficiency of developed countries and emerging industrialized countries was higher than that of developing countries. In addition, most of the relevant researches are carried out in the following regions and organizations including East Asia[56], Latin America[57], inner of the European Union[58], OECD[59] and G20[60]. Compared with foreign countries, China's unique development environment also provides good empirical materials for green development research. Although the relevant research started late, it has achieved fruitful research

results and the research scale is relatively perfect. Compared with foreign countries, Sun *et al.*[61] found that although the level of green development in China has improved from 2000 to 2014, the level of green development was still at a relatively low level, and the level of green development was greatly different between the east, central and western areas. In addition to exploring the spatiotemporal evolution of green development at national and municipal administrative regional scales as city[62] and county[63], it also involved typical regions such as urban agglomeration[64], Yangtze River Economic Belt[65], old industrial bases[66], and resource-based cities[67]. A large number of research results show that the green development level of different countries and regions shows relatively different change trends in different periods, with obvious regional, dynamic and differential characteristics. Due to the impact of the international financial crisis, the level of green development declined after 2008. However, with the transformation of economic development mode and the strengthening of environmental policies, the level of green development began to rebound.

With the deepening of the research, scholars gradually began to explore the grid-scale green development evaluation research. For example, Yun Yinjuan *et al.*[68] conducted detailed studies on the spatial distribution of carbon sources/sinks in Shiyang River Basin based on MODIS-NDVI data; Liu Junhui *et al.*[69] designated important carbon fixation areas of typical Chinese land ecosystems based on land restoration data. With the continuous rise of earth big data, the grid research will become the mainstream research in the future.

3.4 Green development and industrial transformation

Green industry is an important branch of green economy, an effective entry point and an important driving force for the realization of green development goals. Green industry can be realized through two ways of industrial green transformation and the construction of new green industries[70], which reflects the different ideas to develop green industry.

Industrial green transformation refers to the transformation of industrial mode toward a more resource-saving and environmental-friendly direction both in its structures and efficiency[71], which is an innovation of the existing industrial development mode. The measure of industrial green degree is the key to industrial green transformation. Most of the studies were carried out based on such methods as decoupling models, EKC curves, and environmental entropy and so forth. For example, Wang Junhua *et al.*[72] used Tapio decoupling model to analyze the decoupling relationship between economic growth and CO_2 emissions in China; Fujii *et al.*[73] measured the greening degree of nine industries in OECD countries using EKC curves; Liu He *et al.*[74] took the SO2 emissions as an example to construct the industrial environmental entropy and the regional environmental entropy to study the industrial structure greening degree of Chengdu-Chongqing economic zone. The path of industrial green transformation is also the focus of scholars. Relevant research can be roughly divided into two categories: One discusses industrial structure optimization from a static perspective. For example, the linear planning model under the triple constraint of energy-environment and employment construction written by Song Tao *et al.*[75] have analyzed the industrial optimization path in the Beijing-Tianjin-Hebei region; The other analyzes the dynamic evolution of industrial structure adjustment based on the dynamic perspective. For example, Zhu Yongbin *et al.*[76] simulate the direction of industrial structure optimization and carbon emission trend in China by constructing a cross-stage optimization model. On this basis, some scholars further positioned the industrial development based on the actual situation of the regional development so as to guide the spatial layout of the industry[77–78].

In terms of the new green industry, scholars mainly conduct relevant research on the spatial layout and its influencing factors. However, since the statistical departments of various countries have not issued an officially recognized statistical caliber for the development of green industry, it also brings certain difficulties to explore the development of new green industry. To this end, scholars began to explore "bottom-up" data collection methods. In addition to

professional statistical databases, Shapira *et al.*[79] proposed a search method that combines linguistic text to identify green businesses and conducted empirical studies using UK small and medium green food businesses as an example. Based on South Korean business survey database data, Park *et al.*[80] analyzed the distribution of the new green industry during 2006–2012. The research pointed out that while the new green industries in South Korea tend to be located in the traditional manufacturing concentrated areas, they also form new green industry clusters. The green city industrial sectors tend to be located in or near big cities, while the new energy industries tend to be far away from big cities. Yi *et al.*[81] analyzed the spatial distribution of green enterprises in China based on the Dun & Bradstreet million dollar database. The study found that there is significant imbalance in the spatial distribution of green industries in China. Compared with other cities, cities that practice the clean energy policy own 54.3% of green jobs and 61.8% of green enterprises. In general, the definition of new green industries and the lack of relevant data are to a large extent restricting the new research on green industry.

3.5 Green transformation of resource-based cities

In the post financial crisis era, there emerged a great number of heated researches on "urban transformation" all around the world. Different with garden city, compact city, ecological city and low-carbon city, green city is a dynamic, harmonious and efficient comprehensive development model, which aims to promote the green growth of urban economy by reducing the negative externality of environment and reducing the negative impact on natural resources and ecosystem[82–83]. Resource-based cities refer to cities rapidly developed relying on their resource advantages. Due to excessive emphasis on the development of resource-based industries and the lack of long-term overall planning, resource-based cities are generally faced with problems such as resource depletion and the lack of alternative industries[84]. Since the 1960s and 1970s, the transformation and development of resource-based cities have been the focus of the government and academia. The transformation of resource-based cities started earlier in some foreign countries, and the concept of green development was fully reflected in the transformation process, for example, the new industrialization policy represented by the diversification strategy in the field of environmental technology implemented by Ruhr district, Germany in the 1980s[85]; the industrial diversification development strategy and high-tech industrial development model of Kitakyushu, Japan[86]. They all provided good ideas for the green transformation of resource-based cities.

Since 2001, China has piloted the transformation of resource-based cities. In 2008, Taiyuan City, Shanxi Province issued the Regulations of Taiyuan City on Promoting Green Transformation (Draft), becoming the first city in China to promote green transformation in the form of local legislation. And the National Sustainable Development Plan for Resource-based Cities (2013–2020) issued by the State Council in 2013 took green development as the guiding ideology for the development of resource-based cities.

In this context, Chinese scholars combined the green development theory with the transformation of resource-based cities, and deeply discussed the connotation, timing and path of green transformation of resource-based cities.

Generally speaking, the green transformation of resource-based regions is a process of gradual transition from the traditional "black" development model to the ideal "green" development model. The core is to promote the greening of industrial development and economic growth mode. The integration of resource-based economy and green-innovation is the driving mechanism to promote green transformation. And the construction of green transformation system constitutes the guarantee mechanism of green transformation[87]. The realization of green economy is not only to avoid "mining-exhaustion and urban-decline", but also to explore how to effectively use resources for sustainable development[88]. Due to the differences in life cycles among resource-based cities, it is difficult to regulate the life cycle of resource-based cities only by strictly controlling the

development intensity of leading resources. Thus, it is necessary to formulate comprehensive and systematic life-cycle optimization and regulation measures[89]. Therefore, the green transformation of resource-based cities is to seek for a more optimized development mode[90]. The green transformation of resource-based cities should be carried out in the growth period, mature period and early recession[91], and the coexistence of three modes of "resource continuation + resource substitution + undertaking industrial transfer" can be adopted to realize industrial transformation and upgrading[92]. For cities with overcapacity or poor environmental conditions, it is of great significance to control the industrial scale[93].

The green transformation performance of resource-based cities is also a hot issue concerned by scholars. Li *et al.*[94] studied the green development efficiency of 116 resource-cities in China and pointed out that at present, most resource-exhausted cities still have problems of development inefficiency. Zeng Xiangang *et al.*[95] studied the green transformation performance of 16 coal-resource-exhausted cities, which showed that the green transformation of coal-resource-exhausted cities is still in the primary stage, and the difference in selecting transformation path makes the transformation performance different among different types of cities. In terms of policy implementation, Guo Shufen *et al.*[96] analyzed the impact of the "comprehensive supporting reform pilot zone for resource-based economic transformation" on resource-based areas in Shanxi Province. The research showed that the establishment of the pilot zone promotes the quality of economic development by promoting the diversified development of industrial industries, but the effect of tertiary industry diversification is still not obvious, and the effect of policy implementation lags behind.

3.6 A study on the green development effect

As a common choice for governments to deal with multiple crises and challenges, green development will inevitably bring about a series of impacts on economic development, ecological environment and social life in the process of strategy implementation, which will form a complex feedback relationship between green development and economic-environment-social system. How and to what extent the implementation of green development strategy affects the development of human society has attracted scholars' attention.

Generally speaking, the green development strategy mainly affects the economic system by affecting the industrial structure, industrial operation form and industrial operation environment, and promotes the transition of economic development mode from traditional "brown economy" to "green economy". These all can bring the vitality of new economic growth. On the one hand, in the process of promoting green transformation, we need to pay the costs, including incremental investment and macroeconomic losses caused by the implementation of energy-saving and environmental protection technologies. And there are still some sunk costs in the green behavior of resource-based enterprises; On the other hand, it will generate energy-saving benefits and create new economic growth points[97]. Taking China as an example, Feng Chao *et al.*[98] studied the cost-benefit problem of transformation. The results showed that the economic benefits brought by the transformation of development mode are greater than the costs, and it can realize the win-win development of environmental economy. This economic effect accounts for about 3%–10% of GDP. Hall *et al.*[99] analyzed the economic effects brought by the development of new green industries in the United States, and the results showed that the development of new green industry promotes the improvement of economic benefits.

Then, the change of jobs is the most intuitive embodiment of the green development strategy. With the transformation and upgrading of traditional industries with "high pollution, high energy consumption and high water consumption" and labor-intensive industries, there will be a large number of job losses brought by the traditional manufacturing sectors, while the development of green industry can bring about new employment opportunities. Yi[100] systematically analyzed the impact of state and local clean energy and climate policies on employment in metropolitan areas of the United States since 2006.

The results showed that the implementation of state and local policies has a positive impact on employment at the urban level. For each additional policy, green employment in metropolitan areas will increase by 1%; Lehr *et al.*[101] simulated the impact of renewable energy on German employment under different scenarios. Almost all scenarios show a positive net employment effect. According to the prediction, the total employment will increase from 340,000 in 2009 to 500,000 ~ 600,000 in 2030.

At the same time, with the greening of economic development, the environmental effects brought by the implementation of green development strategy are gradually revealed, represented by reduction of carbon emission, reduction of major pollutant emissions and improvement of environmental quality, especially in areas with dense traditional industrial layout. Musango *et al.*[102] simulated the development of green economy in South-Africa under four investment development scenarios. The research results showed that green economy intervention measures can not only significantly reduce carbon emissions, the dependence of industries, especially the power industry relying on fossil fuels, but also promote the sustainable utilization of natural resources. Zhou Xiongyong *et al.*[103] took Fujian Province as an example to analyze the impact of different policies on energy conservation and emission reduction. The research pointed out that different policies have different effects on energy conservation and emission reduction. Tax, environmental protection and industrial policies have the most obvious effects on energy conservation and emission reduction, while financial, department of treasury, science and technology policies have weak effects on energy conservation and emission reduction. Rivera *et al.*[104] analyzed the impact of carbon tax on the carbon emission in Mexican. The result showed that without economic compensation, the implementation of carbon tax will reduce carbon emissions by 75% in 2050.

3.7 Advice on green development

Green system is the institutional projection of green civilization and also a way to promote the harmonious coexistence between human and nature[105]. If various restrictive factors as policy, economy and culture are not well considered, the green development strategy will not achieve ideal results[106–107]. Therefore, the improvement of green development system is of great significance to promote the transformation of economic development mode and ensure the realization of green development goals.

Government promotion and policy support are the basic characteristics of green development. Guiding with strategic planning, countries around the world have issued guiding policies in industry, finance and energy utilization to promote the establishment of green development system. Firstly, the green development route and action plan should cover the key factors of all dimensions of sustainable development, and clarify the short-term, medium-term and long-term objectives and binding indicators to be achieved[108]. Secondly, as an innovation of the current development model, the government should clearly analyze the fundamental interests of all groups in the process of green reform to make the development goals more inclusive[109]. In the specific policy-making process, Mathews[110] took South Korea as an example and pointed out that the government-led industrial green policy is completely feasible in democratic countries; and Ringel *et al.*[111] pointed out that active and effective energy policy is the key to realize green transformation, so energy policy should play an important role in the overall strategy formulation process; Dulal *et al.*[112] believed that the regional green development strategy should include active and effective fiscal policies. The introduction of market-oriented mechanism can form a “double-wheel-driving” development mechanism of green development. On the basis of clarifying the ownership and distribution of the government’s ownership, usufruct and income right of environmental resources, the market-oriented mechanism mainly determined the market-based resource and environmental property right trading system, and established diversified ecological compensation and environmental payment mechanisms, such as green tariff, carbon emission trading, carbon tax, etc., in which carbon tax has achieved better results in reducing carbon emission[113]. However, if it is unfeasible or

difficult to collect carbon tax in the region, it shall use the renewable energies to replace the high carbon-emission energies[114].

Laws and regulations are important bases for ensuring and standardizing the green development system. At present, relevant foreign laws and regulations are becoming more and more perfect and concrete. Since the 21st century, the Chinese government has successively improved relevant laws on ecological environment protection and has promoted the development of circular economy, such as "renewable energy law", "Circular Economy Promotion Law", "Ten items on protecting the atmosphere", "Ten items on protecting water resource", and "Ten items on protecting land resource", and so on. However, compared with Western developed countries, China has not yet formed a coordinated and perfect legal and policy system for green economy development[115]. Yang Jiejun[116] believed that in the future, China shall further promote green development from policy guidance and policy action to legal adjustment and implementation, so as to upgrade green development policy into legal mechanism, and it shall pay attention to the unity of policy guidance and legal guidance. At this stage, China's green development legislation should focus on such fields as climate change, energy issues and green finance[117]. In addition, a good ecological environment supervision system is a good supplement to the green development system. It is necessary to gradually establish an ecological environment supervision system dominated by government supervision and supplemented by non-governmental organization supervision.

4. Review and prospect

(1) It is widely acknowledged that the green development is of great importance in helping achieve the overall goals of sustainable development. As a discipline studying the relationship between human and earth, geography owns incomparable advantages in researching green development. Scholars have done a lot of research and practice on green development from the perspective of geography, including influencing factors, calculation methods, spatiotemporal evolution pattern, green development and industrial transformation, green development of resource-based cities, green development effects and institutional suggestions, etc., which has important reference for future researches. Compared with foreign countries, although the research on green development in China started late, it has achieved fruitful research results. It is not difficult to find that due to the different economic basis and development problems faced at home and abroad, there are some differences in green development goals. For example, foreign economies and institutions began to pay attention to the role of green development in coping with global climate change and poverty reduction earlier. While at home, it emphasized on economic development and ecological environment protection and then turned to increase people's well-being. In this context, there are some differences in the research of green development at home and abroad, including the selection of research methods, research scale and so on. Although the research fields of green development are increasingly rich, there are still some shortcomings in the existing research due to the complexity of green development and the imperfection of relevant research methods. With the continuous advancement of ecological civilization and the construction of a beautiful China, under the background of the new era, China shall made a further exploration and study in the following aspects in terms of geography researches: Green development is a multi-dimensional and complex system involving three subsystems: economy, environment and society. "Process-pattern-mechanism" is the basic method and way of comprehensive geographical research. The existing studies have described spatiotemporal evolution of green development in detail as well as its related influencing factors. However, there are relatively few studies on the systematic analysis of green development mechanism by coupling "process" and "pattern". Due to the distinct comprehensiveness of geography, it is urgent to establish an analysis framework with local characteristics based on geography. Then each scale is nested, and the interaction mechanism between the elements of green development is analyzed. The analysis of green development mechanism helps scholars better

simulate the evolution trend of regional green development under different scenarios, and provides decision-making basis for relevant policy-making.

(2) The relationship between human and earth is the core research issue of geography, which runs through all stages of geography. In recent years, with the change of the external development environment, as a bridge between "human" and "environment", human-earth relationship has drawn much attention from scholars and has been endowed with new connotations with the advances of the times. In the context of the new era, how to further apply the theory of human-earth relationship into practical research and application is an issue that geographers should focus on. Green development research also pays attention to the economic and social development and the changes of resources and environment, so as to pursue the harmonious development of human and nature. The future research on green development should take this as the starting point to strengthen the integration and coupling of green development with human-earth elements under different time and space scales, and apply relevant research results into the decision-making and management of green development.

(3) In recent years, China has put forward a series of initiatives and strategies as "The Belt and Road", "Urban Agglomeration", "The Yangtze River Economic Belt" and "The Revitalization of the Old Industrial Bases in Northeast China" etc. to further promote the economy development in such regions, which has brought about new opportunities and forces for the overall economy development of China. However, at this stage, all policy radiation areas are facing varying degrees of resource and environmental pressure, and it is urgently necessary to convert the old kinetic energy into new ones to achieve high-quality development. Geography is a practical discipline. Compared with foreign countries, China's geography has made great contributions to the decision-making related to major national development and has also effectively guided China's economic development and construction. Therefore, in order to optimize China's future economic development pattern and give full play to the effectiveness of development initiatives and strategic policies, it is necessary to further refine the research on green development in typical areas from the perspective of geography.

(4) Green development research needs the combination of multi-angle analysis and multi-research means. At present, the research on green development mainly uses socio-economic statistical data to obtain the information needed to understand the influencing factors and spatiotemporal evolution of green development. In recent years, although professional statistical databases, remote sensing data and questionnaire survey data have been applied in the research of green development, the application is far from being desired. In terms of research methods, descriptive analysis and quantitative means are mostly used to analyze the functional relationship of various elements of green development, but there is still a lack of comprehensive integration of traditional methods and new technical means. Due to the lack of research methods and data, the existing research did not take the scale and accuracy well into consideration. It is suggested that relevant departments should formulate statistical norms and standards for green industry as soon as possible and establish a more complete data database. In recent years, with the progress of Internet and remote sensing geographic information technology, it is possible to obtain large-scale and high-precision spatiotemporal data to represent human activities. In this context, it is worthy of continuous attempts for scholars to use the spatiotemporal big data to analyze and predict the spatiotemporal revolution of green development. (5) Green development is an interdisciplinary research topic involving many disciplines. From the perspective of geography, green development research has made some research achievements and formed seven main research topics, but there are still some deficiencies on the whole. In recent years, when analyzing and studying related problems, geography has introduced disciplines and methods such as economics, ecology and management in the research process, and has achieved ideal results. In the future, it is still necessary to strengthen interdisciplinary research to form a systematic and overall research perspective,

so as to further promote the research of green development and related fields. For example, in terms of system suggestions for green development, we should carry out multi-disciplinary researches according to the actual situation of China's existing green development system, so as to strengthen the top-level design and put forward perfect solutions to better promote green development.

Conflict of interest

The authors declare that they have no conflict of interest.

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