A three-dimensional evaluation model for green development: evidence from Chinese provinces along the belt and road

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Abstract
The establishment of the green belt and road is an inevitable choice to conform to and lead the green and low-carbon cycle development and an inherent requirement for sustainable development. Therefore, we establish an evaluation system of green development oriented to carbon neutrality, and calculate the green development level (GDL) of the provinces along the belt and road in China from 2003 to 2018 by using a three-dimensional evaluation model. In addition, this paper employs the Obstacle Degree Model to identify the main obstacle factors that affect GDL, and provides targeted and differentiated countermeasures and suggestions for improving the regional GDL. Our results suggested that the overall GDL has improved, but not obvious, with a low level. The GDL and coordination degree between different regions exist certain differences, and its spatial pattern is characterized by “high in southeast and northeast, low in southwest and northwest’. From a regional perspective, innovation capacity is the key factor that affects the green development of the region in southeast, northeast, northwest and southwest China. Driving economic green transformation and promoting industrial energy conservation and emission reduction through technological innovation are the internal driving forces to achieve regional green sustainable development.

Keywords The belt and road · Green development · Carbon neutrality · Obstacle diagnosis model

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1 Introduction

In 2013, China first put forward a major initiative to build “the belt and road initiative (BRI)”, which attracts many countries attention and active responses. In 2019, the Chinese president Xi Jinping put forward at the opening ceremony of the second “the belt and road initiative” International Cooperation Summit Forum that “to take green as the background of the construction of BRI, the member countries should work together to create a good environment, strengthen ecological management, seek a new path of green development and build an ecological community of BRI.” Facing the increasingly severe ecological and environmental problems and global climate change challenges, building the green BRI is an important opportunity for member countries along the route to promote their healthy development and achieve comprehensive economic transformation and upgrading. At this special moment when all countries are fighting against the COVID-19 epidemic, the joint efforts of the international community have highlighted the importance and necessity of BRI international cooperation. This epidemic has caused the international community to think deeply about the harmonious symbiosis between human and nature. In the post-epidemic era, green recovery has become an important driving force for high-quality economic development. Therefore, building the green BRI is of great significance in promoting the economic recovery of the member countries and safeguarding the global ecological environment.

Green development becomes the theme of the ages. In recent years, scholars have done a great deal of research on building the green BRI from different angles. Some scholars have carried out research on resource consumption, environmental pressure, ecological risks and other aspects of the countries along the belt and road (Aung et al., 2020; Dong et al., 2015; Hu et al., 2021; Tracy et al., 2017). Yang et al. (2021) studied the distribution of ecological risk level of the countries along the belt and road by using the ecological risk index of land-use, and analyzed the spatial distribution of ecological risk with Kuwait as an example. Tian et al. (2019) evaluated the effects of the BRI on pollution and resource consumption from an international trade perspective, and found that the BRI has aggravated China’s environmental challenges. Some studies evaluated the ecological quality by using the ecological footprint method (Saud et al., 2020; Zhang & Ren, 2013). Yang and Fan (2019) evaluated the energy ecological footprint and economic contribution of the nine provinces along the Silk Road Economic Belt, and believed that the integration of energy and economic development was the basis of regional sustainable development. In order to promote the construction of the green BRI, the research on carbon emission reduction has become the focus of most scholars (Cai et al., 2018; Liu & Hao, 2018; Mahadevan & Sun, 2020). Hu et al. (2020) applied the Tapio decoupling model and Kaya-LMDI model to explore the spatial–temporal evolution of decoupling and drivers of carbon emissions of BRI countries from 1991 to 2016. Hussain et al. (2020) investigated the effect of natural resource depletion on energy use and carbon emissions for 56 BRI countries by using the STIRPAT model. Anwar et al. (2021) investigated the long-run and causal linkage between CO2, forest area and renewable energy consumption among 33 partner economies of BRI from 1986 to 2018, and the results suggested that developing renewable energy and increasing forestation will help to reduce the carbon emissions.

Some scholars have evaluated the green development level of the areas along the BRI. Cheng and Ge (2020) have constructed a green development system for countries along the Belt and Road from three aspects: socioeconomic development, consumption of natural resources and competitiveness of ecological environment, and investigated the
spatial characteristics of green development for countries. Lin (2016) analyzed the current situation and existing problems of green development in China’s provinces under the background of the “One Belt, One Road” strategy, and put forward some countermeasures and suggestions to promote green development. Chen et al. (2021) applied the super efficiency SBM model to evaluate the green development efficiency of Chinese provinces along the belt and road, and used Tobit model to extract the factors that affect the green development efficiency. Guo et al. (2022) used AHP entropy method to evaluate the green development index of the provinces along the belt and road in China, and analyzed the spatial and temporal differences of each region. Hang (2021) explored the industrial green development efficiency in provinces and cities along “the belt and road” in China, and found that the performance goal of green development generally showed a “U-shaped” trend of first decreasing and then rapidly increasing, and there was a big gap between the input–output efficiency of different regions. Huang and Li (2020) analyzed the impact of the BRI on participating countries’ green development. Gao (2019) studied the low-carbon and green development status for 52 countries along the belt and road from 1995 to 2016, and analyzed the socioeconomic factors affecting the growth of low-carbon and green TFP by panel regression in this area. Lan and Huang (2020) selected the economic aggregate index, industrial development index, economic sustainability index, resource endowment index, environmental stress index and environmental response index to construct a green belt and road indicator evaluation system, and used factor analysis to empirically evaluate and compare the green development levels of 42 countries along the BRI.

Generally, some research achievements have been made on resources and environment, green development and emission reduction along the Belt and Road. In today’s world, “Carbon peak” and “carbon neutrality” have become the “hot words” and promoting the “carbon neutrality” will become an important part of the construction of the green “Silk Road.” “Carbon neutrality” has become the striving direction of “zero carbon emission” in all countries, and will also become the necessary way and means to promote the construction of the Green Silk Road. However, the existing research has not incorporated the idea of carbon neutrality into the assessment of green development along the BRI. Therefore, this paper integrated the concept of “carbon neutrality” into the evaluation framework of green development of the belt and road, so that we can have a comprehensive and clear understanding of GDL in provinces along the BRI, and it is of great significance to promote the establishment of the Green Silk Road and the early realization of the carbon neutrality. The contribution of this paper lies in: Firstly, this paper constructs a brand-new green development evaluation system facing “carbon neutral,” and evaluates the GDL of provinces and cities along the belt and road. Secondly, we build a three-dimensional evaluation model for green development, which can calculate the green development level, coordination degree and the deviation from the optimal development direction, make up for the deficiency of the coupling coordination degree model, and enable us to clearly recognize the gap between the development direction of the system and the optimal development direction, thus providing a direction for striving to improve the coordinated development level of each subsystem. Thirdly, the Obstacle Degree Model (ODM) is used to diagnose and analyze the obstacle factors that affect the green development, and different and targeted promotion suggestions are put forward to improve the regional green development.

The remainder of the paper is organized as follows. The next section of the paper introduces the evaluation method. Section 3 is the green development evaluation. Obstacle factor diagnosis of green development in Sect. 4, and the final section concludes this paper.
2 Evaluation method

2.1 Green development evaluation system

The concept of green development takes harmonious coexistence between man and nature as its value orientation, green low-carbon cycle as its main principle and sustainable development of economy, society and environment as its ultimate goal. At present, “carbon peaking” and “carbon neutrality” have become popular words frequently mentioned by various countries, and the low-carbon model has become a key issue that the government pays attention to. Therefore, based on the three-dimensional green development theory of economy, society and environment, this paper constructs a green development evaluation system facing “carbon neutrality” (Fig. 1) to boost the construction of a green and low-carbon “Silk Road.” Specific indicators are shown in Table 1.

Economic development is mainly manifested in five dimensions: development level, industrial structure, green production, innovation capability and economic openness. Specific indicators include GDP, per capita GDP, ratio of tertiary industry to GDP, energy consumption per unit of GDP, wastewater emission per unit of GDP, technology market turnover, number of per capita patent authorization and dependence on foreign trade.

Social development mainly focuses on measuring quality of life, medical services, education level and urbanization level. Specific indicators include the per capita disposable income of urban residents, per capita disposable income of rural residents, medical technical personnel per 1000 persons, beds of medical institutions per 1000 persons, ratio of high-quality talents, illiteracy rate and the ratio of urban population to total population.

The environmental development is mainly measured from the aspects of carbon balance, pollution emission, pollution treatment and greening level. Specific indicators include carbon neutralization coefficient, SO2 emissions, ammonia nitrogen emissions, total investment in the treatment of environmental pollution as percent of GDP, percentage of greenery coverage in built-up area and park green area per capita. It is worth mentioning the carbon balance index is characterized by carbon neutral coefficient in this paper. See carbon sink estimation in Sect. 3.3 for calculation. Carbon neutral means that carbon dioxide emissions and carbon dioxide absorption reach equilibrium within a certain period of time.

Fig. 1 Theoretical system of “three-dimensional” green development
| Target layer       | Level-1 indicators | Level-2 indicators | Level-3 indicators | Unit          | Impact | Reference source                                                                 |
|-------------------|--------------------|--------------------|--------------------|---------------|--------|-----------------------------------------------------------------------------------|
| Green development | Economy            | Level of development (LD) | GDP (E1)           | 100 million yuan | +      | Long et al. (2021), Yang et al. (2019), Sun et al. (2018), Cheng and Ge (2020), Huang and Li (2020), Zhang et al. (2020) and Li et al. (2020) |
|                   |                    |                     | Per capita GDP (E2) | 10,000 yuan    | +      | Yang et al. (2019), Sun et al. (2018), Yang and Huang (2019), Cheng and Ge (2020), Zhang et al. (2020) and Li et al. (2020) |
|                   |                    | Industrial structure (IS) | Ratio of tertiary industry to GDP (E3) | % | + | Sun et al. (2018), Yang and Huang (2019), Cheng and Ge (2020), Huang and Li (2020), Zhang et al. (2020) and Li et al. (2020) |
|                   |                    | Green production (GP) | Energy consumption per unit of GDP (E4) | Tce/10000 yuan | – | Sun et al. (2018), Yang and Huang (2019), Cheng and Ge (2020), Huang and Li (2020), Zhang et al. (2020) and Li et al. (2020) |
|                   |                    |                     | Waste water emission per unit of GDP (E5) | Ton/100000 yuan | – |                                                                                   |
|                   |                    | Innovation capacity (IC) | Technology market turnover (E6) | 100 million yuan | + | Huang and Li (2020), Zhang et al. (2020), Li et al. (2020), Weng et al. (2020) and Fang et al. (2020) |
|                   |                    |                     | Number of per capita patent authorization (E7) | Piece/100000 people | + |                                                                                   |
|                   | Economic openness (EO) | Dependence on foreign trade (E8) | – | + | Huang and Li (2020) |
|                   | Society            | Quality of life (QL) | Per capita disposable income of urban residents (S1) | Yuan | + | Sun et al. (2018), Yang and Huang (2019) and Weng et al. (2020) |
|                   |                    |                     | Per capita disposable income of rural residents (S2) | Yuan | + |                                                                                   |
|                   | Medical services (MS) | Medical technical personnel per 1000 persons (S3) | Person | + | Long et al. (2021), Huang and Li (2020), Weng et al. (2020) and Fang et al. (2020) |
| Target layer       | Level-1 indicators | Level-2 indicators | Level-3 indicators       | Unit | Impact | Reference source                                                                 |
|-------------------|--------------------|--------------------|--------------------------|------|--------|-----------------------------------------------------------------------------------|
|                    |                    |                    | Beds of medical institutions per 1000 persons (S4) | Beds | +      | Yang et al. (2019), Cheng and Ge (2020), Huang and Li (2020), Weng et al. (2020) and Fang et al. (2020) |
| Education level (EL) |                    |                    | Ratio of high-quality talents (S5) | %    | +      |                                                                                  |
|                    |                    |                    | Illiteracy ratio (S6) | %    | −      |                                                                                  |
| Urbanization level (Urban) |                |                    | Ratio of urban population to total population (S7) | %    | +      | Huang and Li (2020), Weng et al. (2020) and Fang et al. (2020) |
| Environment        | Carbon balance (CB) |                    | Carbon neutral coefficient (EN1) | −    | +      |                                                                                  |
|                    | Pollution discharge (PD) | SO2 emission (EN2) | 10,000 ton | −    |        | Long et al. (2021), Yang et al. (2019), Sun et al. (2018), Yang and Huang (2019), Cheng and Ge (2020) and Zhang et al. (2020) |
|                    |                    | Ammonia nitrogen emission (EN3) | 10,000 ton | −    |        |                                                                                  |
| Pollution treatment (PC) | Total investment in the treatment of environmental pollution as percent of GDP (EN4) | % | + | Long et al. (2021), Sun et al. (2018), Yang and Huang (2019) and Weng et al. (2020) |
| Greening level (GL) | Percentage of greenery coverage in built-up area (EN5) | % | + | Long et al. (2021), Yang et al. (2019), Yang and Huang (2019), Zhang et al. (2020) and Li et al. (2020) |
|                    | Per capita park green area (EN6) | m² | + |                                                                                  |
The larger the carbon neutral coefficient is, the stronger the regional carbon balance capacity is and the lower the regional carbon dioxide level is. Under the framework of the Paris Agreement, many countries have put forward the goals of “carbon neutrality.” Therefore, integrating the concept of carbon neutrality into the framework system of green development assessment of the belt and road is of great significance for regional low-carbon development, sustainable development and promoting the construction of the green Silk Road.

2.2 Green development assessment model

A three-dimensional model of green development evaluation based on economy, society and environment is established (Fig. 2). The three-dimensional model of green development evaluation included three steps: dimensionless standardization, weight determination and green development evaluation.

Step 1 Standardize the indicators. Assuming that there are m samples and n indexes, then the sample set is \( (x_{ij})_{m \times n} \), where \( i = (1,2,\ldots,m), j = (1,2,\ldots,n) \). Because the units of the original indicators are different, it is necessary to convert the original data into dimensionless, standardized and order-of-magnitude values, so as to eliminate the influence caused by different attributes among different indexes and facilitate subsequent data processing and calculation. The extreme value method is the simplest method to eliminate the influence of variable dimension and range. Therefore, the extreme value method (Fang et al., 2020) is used for standardization.

Positive indicator : 
\[
X_{ij} = \frac{x_{ij} - \min (x_{ij})}{\max (x_{ij}) - \min (x_{ij})}
\]  
(1)

Negative indicator : 
\[
X_{ij} = \frac{\max (x_{ij}) - x_{ij}}{\max (x_{ij}) - \min (x_{ij})}
\]  
(2)

where \( X_{ij} \) is the standardized value; \( x_{ij} \) denotes the original value.

Step 2 Determine the index weight. The entropy method determines the index weight according to the degree of change of each index value, which is an objective weighting method and avoids the deviation caused by human factors. Compared with the analytic hierarchy
process (AHP), it eliminates the influence of people’s subjective consciousness and can objectively reflect the weight of indicators. In order to avoid the deviation caused by subjective consciousness, this paper applied the entropy method to determine the indicator weights (Li et al., 2021; Wang et al., 2018, 2020; Zhang et al., 2006). The calculations are listed as follows:

\[ Y_{ij} = \frac{X_{ij}}{\sum_m X_{ij}} \]  

\[ E_j = -\frac{1}{\ln n} \sum_1^m (Y_{ij} \ast \ln Y_{ij}) \]  

\[ \alpha_j = \frac{1 - E_j}{\sum (1 - E_j)} \]

where \( Y_{ij} \) represents the proportion of \( i \)-th evaluation object under the \( j \)-th indicator; \( E_j \) is the entropy for the \( j \)-th indicator; and \( \alpha_j \) is the weight value of the \( j \)-th indicator.

**Step 3** Assessment of Green Development. The three-dimensional evaluation model can not only calculate the green development level and coordination degree, but also calculate the angle between the actual development behavior vector and the optimal development behavior vector, and can clearly identify the deviation degree between the actual development direction and the optimal development direction of each region. Therefore, we use this method to assess the degree of green development. The specific steps are as follows. Firstly, according to the first two steps, the economic, social and environmental development index are calculated with the following formula:

\[ X_i = \sum_{j=1}^{8} P_j I_{ij}; Y_i = \sum_{j=1}^{7} W_j S_{ij}; Z_i = \sum_{j=1}^{6} R_j D_{ij} \]

where \( X_i \), \( Y_i \) and \( Z_i \) represent the economic, social and environmental development indices of each region, respectively. \( P_j \), \( W_j \) and \( R_j \) represent the weights of economic, social and environmental development indicators, respectively. \( I_{ij} \), \( S_{ij} \) and \( D_{ij} \) represent the standard values of economic, social and environmental indicators, respectively.

Secondly, by calculating the cosine of the angle (refer to \( \angle t_n t_{ij} \) in Fig. 2) between the actual development behavior vector of the region and the diagonal of the green development evaluation three-dimensional model (Set each side length to 1), the coordination degree of the green development in this region is finally obtained (Lu et al., 2015).

GDL refers to the ratio of the module length of the actual development behavior vector projected on a diagonal line to the module length of the optimal development behavior vector, that is, the ratio of the modulus of the projection \( t_n t_{ij} \) of the vector \( t_n t_{ij} \) to the optimal development behavior vector \( t_n t_{ij} \) (see Fig. 2). The specific formulation are as follows:

\[ C_i = \cos \alpha_i \]  

\[ D_i = \frac{\sqrt{X_i^2 + Y_i^2 + Z_i^2} \ast \cos \alpha_i}{\sqrt{3}} \]
where $C_i$ denotes coordination degree; $D_i$ is the green development level; and $\alpha_i$ is the angle between the actual development behavior vector and the optimal development behavior vector for each region. $X_i$, $Y_i$ and $Z_i$ represent the economic, social and environmental development indices of each region, respectively.

### 2.3 Estimation of carbon emissions and carbon sinks

#### 2.3.1 Carbon emissions

At present, there are many accounting methods for carbon emissions. Scholars mainly uses the following four methods to measure carbon emissions: life cycle assessment, general structure, bottom-up and top-down method. The “bottom-up” and “top-down” proposed by the IPCC are widely used carbon emission accounting methods at present. In contrast, the “top-down” carbon emission accounting method is relatively simple, which is favored and widely used by scholars. (Hu et al., 2020; Liu et al., 2021). Therefore, this paper adopts the “top-down” method to calculate carbon emissions, and the formula is as follows:

$$ E = \sum_i \left( E_n \times V_i \times F_i \right) \times \frac{44}{12} \quad (9) $$

where $E$ represents the carbon emissions; $E_n$ denotes the $i$-th fuel consumption; $V_i$ is the standard coal conversion coefficient of the $i$-th fuel; and $F_i$ is the carbon emission coefficient of the $i$-th fuel. See Table 2 for specific parameters.

#### 2.3.2 Carbon sinks

According to the United Nations Framework Convention on Climate Change, carbon sink refers to the process, activity, or mechanism of removing carbon dioxide from the atmosphere (Guo et al., 2017; Yang et al., 2012). Referring to the IPCC and existing relevant research (Zhang et al., 2018; IPCC, 2006, 2007), the carbon sink coefficients of different land-use types are determined (see Table 3). The carbon sinks formula used is as follows:

$$ \text{Carbon}_\text{Sink} = \sum m_i \times \sigma_i \quad (10) $$

| Table 2: Carbon emission calculation parameters |
|-----------------------------------------------|
| Fuel       | $V_i$ (Standard coal conversion coefficient) | $F_i$ (Carbon emission coefficient) |
|------------|---------------------------------------------|------------------------------------|
| Coal       | 0.7143                                      | 0.7559                             |
| Coke       | 0.9714                                      | 0.8550                             |
| Crude oil  | 1.4286                                      | 0.5857                             |
| Gasoline   | 1.4714                                      | 0.5538                             |
| Kerosene   | 1.4714                                      | 0.5714                             |
| Diesel fuel| 1.4571                                      | 0.5921                             |
| Fuel oil   | 1.4286                                      | 0.6185                             |
| Natural gas| 1.3300                                      | 0.4483                             |
| Electricity| 0.1229                                      | 0.6027                             |


where \( \text{Carbon}_\text{Sink} \) is the carbon sinks of a region; \( m_i \) denotes the area of \( i \)-th land-use type; \( \sigma_i \) is the carbon sink coefficients of \( i \)-th land-use type; \( E \) is the carbon emissions; and \( \text{CNC} \) refers to the carbon neutral coefficient of a region, which is used to express the degree of carbon neutral or carbon balance of a region.

2.4 Kernel density estimation method

Kernel density estimation is a density function used to estimate unknown functions in probability theory, which belongs to one of the non-parametric test methods (Sun et al., 2018; Zhang et al., 2012). The application of kernel density estimation method can more intuitively describe the overall evolution of green development level along the BRI in China. The calculation method is shown in Eq. (4):

\[
f(x) = \frac{1}{nh} \sum_{i=1}^{n} k\left(\frac{x - X_i}{h}\right)
\]

where \( n \) is the number of samples; \( k\left(\frac{x - X_i}{h}\right) \) is the kernel function. The choice of bandwidth \( (h) \) follows the basic idea of minimum integral mean square error, which is related to the smoothness of the kernel density distribution. Based on the change of nuclear density curve, the evolution characteristics of green development performance for the provinces along the belt and road in China were analyzed: (1) When the shape and extension of the density curve remain unchanged and the position changes, the overall level of green development will change, while it will decrease when moving to the left and rise when moving to the right. (2) When the shape and position of the density curve remain unchanged, and the extensibility changes, it indicates the change of regional green development level difference. The curve “steeper and thinner” indicates that the difference is narrowing, and “getting shorter and fatter” shows that this difference is expanding. (3) When the position and extension of the density curve remain unchanged and the shape changes, it indicates the regional difference in the horizontal distribution of green.

2.5 Obstacle degree model

The ODM is a model for identifying some obstacles factors of the evaluation objects because of its scientific and objective characteristics and strong adaptability, which have been adopted in many disciplines. This paper applies the ODM (Han et al., 2021) to
identify the obstacle factors that restrict the regional green development, so as to find a way out for studying the regional green development and provide scientific and objective decision-making suggestions.

\[ P_{ij} = 1 - X_{ij} \]  

(13)

\[ M_{ij} = \frac{R_j \times P_{ij}}{\sum_{j=1}^{n} (R_j \times P_{ij})} \times 100\% \]  

(14)

where \( M_{ij} \) is the obstacle degree of region \( i \) at \( j \)-th indicator; \( R_j \) is the weight of each indicator, indicating the contribution of the obstacle factor; \( P_{ij} \) represents deviation between indicators and development goals; and \( X_{ij} \) is the standardized value of indicators.

### 2.6 Data resources

In view of the availability of data, this paper collected 17 provinces and cities along the belt and road (except Tibet) in China from 2003 to 2018, including Shanghai, Yunnan, Fujian, Guangdong, Zhejiang, Hainan, Guangxi, Chongqing, Jilin, Xinjiang, Shaanxi, Gansu, Liaoning, Ningxia, Qinghai, Heilongjiang and Inner Mongolia. All of the original data were from the “China Statistical Yearbook,” “Regional Statistical Yearbook,” “Environmental Statistical Yearbook” and “China Energy Statistical Yearbook.” Due to the differences in economic development and geographical location, we have divided the study area into four regions, southeast, southwest, northeast and northwest (Fig. 3), in order to facilitate subsequent research.
3 Green development evaluation

3.1 Development evaluation of economic, social and environmental subsystem

From the perspective of development trend, during the research period, the development trend of each subsystem generally showed an upward trend, and the social subsystem has been greatly improved, from 0.3374 in 2003 to 0.4330 in 2018 (Fig. 4). After the implementation of the belt and road strategy, that is, after 2013, the social subsystem has shown a trend of first increasing and then decreasing and tends to be flat, and the social development level (0.441) after the implementation of the belt and road strategy is generally higher than that before the implementation (0.375). The economic and environmental subsystems have developed steadily after the implementation of the belt and road strategy. In addition, we found that the economic development index is not high among the three sub-systems, mainly due to the evaluation of green economic development paid more attention to green production level. At present, green production has become the key to the transformation from traditional economy to green economy. Overall, the development level of the three subsystems after the implementation of the belt and road strategy is generally higher than before. This does not mean that the implementation of the belt and road strategy has promoted the green development level of the provinces along the belt and road, but it reflects that the development trend of these provinces is gradually improving, which is beneficial to the construction of the Green Silk Road. What’s more, the average values of the economic, social and environmental development are 0.4068, 0.3997 and 0.5060, respectively, indicating that the development level of each subsystem is not high, and there is still room for improvement. Therefore, the green development of the regions along the belt and road in China should not only focus on promoting the green economy development, but also pay attention to the steady development of society and environment.

Figure 5 shows the regional distribution characteristic of economic, social and environmental development. The development level of economic, social and environmental has obvious regional differences. In terms of economic development, from the perspective of economic development level, Shanghai has the highest level of economic
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development, reaching 0.8642, while Ningxia (0.2142) has the lowest level. The economically developed areas are mainly distributed in the southeast, while the economic development in the northwest is relatively backward (Fig. 5). It can be seen that the development level of green economy in the provinces along the BRI presents a development pattern of high in the southeast and low in the northwest, which is consistent with the trend of regional economic development level in China.

With respect to social development, the top five regions are Shanghai (0.8993), Liaoning (0.5849), Zhejiang (0.5419), Jilin (0.4841) and Heilongjiang (0.4567), which are mainly concentrated in the southeast and northeast regions. The regions with low social development level are mainly distributed in the southwest and northwest, such as Yunnan, Gansu and Qinghai. The reason for this phenomenon is mainly due to the superior geographical position, developed economy, high infrastructure conditions and people’s living standard in the eastern coastal areas of China. However, the level of medical services and education in the southwest and northwest regions is relatively low, resulting in their low social development index.

With respect to ecological environment, the evaluation order of the top five are Hainan (0.6802), Ningxia (0.6674), Qinghai (0.6125), Fujian (0.5544) and Xinjiang (0.5226), which are mainly distributed in the northwest and southeast regions. The high environmental development index in northwest China is mainly due to the sparse population, low level of economic development, low utilization of natural resources and the environment in northwest China, resulting in relatively low environmental pollution and pressure. Hainan has the highest level of environmental development, which is mainly due to its tourism development, no heavy polluting industries, high greening level and good environmental protection.

Fig. 5 Regional distribution characteristics of economic, social and environmental subsystem
3.2 Evolution characteristics of green development level

In this paper, the kernel density estimation method is used to analyze the temporal evolution of green development level, and reveal its changing characteristics and trends. Figure 6 shows the distribution of kernel density in different years (2003, 2008, 2013 and 2018), revealing the evolution of green development.

The kernel density curves of 2003 and 2008 present obvious bimodal distribution, which reveals a polarization trend in the GDL for the provinces along the belt and road in China in the early stage of the study, and there are more regions with low green development level. In the later stage of the study, the kernel density curves changed from bimodal distribution to unimodal distribution, which indicated that the green development level of the provinces along the BRI in China was gradually concentrated, and the regional gap was narrowed to some extent. From 2003 to 2013, the first peaks moved to the right significantly, indicating that the green development level tended to increase, and the gap between the low-value area and the high-value area began to narrow. In addition, we found that after the implementation of the belt and road strategy, the nuclear density curves in 2013 and 2018 shifted significantly to the right relative to those in 2003 and 2008, indicating that the green development level after the implementation of the belt and road strategy has an upward trend. Overall, the average of GDL has increased from 0.4166 in 2003 to 0.4597 in 2018. The overall GDL for the provinces along the belt and road in China has improved, but the improvement is not significant and is at a low level, indicating that there is still room for improvement in green development for the provinces along the belt and road in China.

3.3 Spatial heterogeneity of green development performances

In this paper, using ArcGIS 10.2 software, the green development level in 2003, 2008, 2013 and 2018 was visually expressed (see Fig. 7). The green development level is divided into four grades: low level, medium–low level, medium–high level and high level. The red circle in Fig. 7 represents the coordination degree of green development, and the larger the circle, the better the coordination. The blue bar graph represents the angle between the green development direction and the optimal development direction, and is an auxiliary
variable to judge the coordination degree of green development. The higher the bar graph is, the larger the angle is, the greater the deviation from the optimal development direction is, and the worse the coordinated development is.

In terms of space, there are some differences in GDL between different regions, with a pattern of higher in the east and lower in the west. There are few areas with medium–high and high GDL, but more areas with medium–low and low green development levels (Fig. 7). Specifically, in 2003, there were one high-level and one medium–high level area, namely Shanghai and Guangdong, and three low-level areas, namely Guangxi, Chongqing and Gansu. The remaining 12 regions are at the middle-low levels. In 2008, the grade of green development in Zhejiang, Guangdong and Chongqing was improved. Only green development grade in Yunnan has dropped from middle-low level to low level, mainly because the economic and environmental development index of Yunnan has decreased during this period, resulting in a slight decline in its green development level. By 2013, that is, the belt and road strategy was implemented, we found that the number of areas with low GDL was 0, indicating that the overall GDL has improved to a certain extent, and the number of areas with medium–high levels has increased. In 2018, Shaanxi’s green development was improved and joined the ranks of medium–high level development, and other regions did not change. Generally speaking, the green development level has improved during the study period, and exist regional differences, with the highest level in southeast region (0.5441), followed by northeast region (0.4493), southwest region (0.3615) and northwest region (0.3235).

With respect to coordination degree of green development, the coordination degree is higher in the southeast and northeast regions, but lower in the southwest and northwest regions. The highest coordination degree in southeast China is Zhejiang, which is as high
as 0.9919. The deviation degree from the optimal development direction decreased from 6.9021 in 2003 to 5.5368 in 2018, indicating that the coordination degree of Zhejiang has been improved during the study period. In term of northeast China, the coordination degree in Jilin and Heilongjiang has improved, and their development direction is gradually approaching to the optimal development direction. The coordination degree of all provinces in southwest China has been improved to a certain extent. Among them, Yunnan has improved greatly, and the angle deviation from the optimal development direction has dropped from 34.9467 in 2003 to 18.8624. The reason for this phenomenon is that the improvement of Yunnan’s social development index, which makes the economic, social and environmental development of the region more balanced. Qinghai, Ningxia and Gansu provinces have the lowest coordination degree in northwest China, and the angle deviation from the optimal development direction are 30.5904, 27.1754 and 22.4909, respectively, which is mainly due to the unbalanced development of economic, social and environmental subsystems in these areas, resulting in a low coordinated degree development. Therefore, the green development should not only promote the development of economic, social and environmental subsystems, but also balance and coordinate the development of each subsystem, avoiding the “short board effect” and ensure the balanced, coordinated and steady development of each subsystem. Only in this way, all regions can achieve green, sustainable and long-term development.

4 Obstacle factor diagnosis of green development

4.1 Obstacle factors analysis of subsystem

Based on the ODM, the key obstacle factors affecting the green development of provinces and cities along the belt and road in China are investigated from economic subsystem, social subsystem and environmental subsystem (Fig. 8).

As shown in Fig. 8, the economic subsystem has the greatest obstacle degree, followed by social subsystem and environmental subsystem. From the changing trend, the obstacle degree in economic and environmental subsystem showed a fluctuating upward
trend during the study period, with an increase of 0.09% and 0.57%, respectively. From 2003 to 2018, the obstacle degree of social subsystem declined slowly, from 4.82% in 2003 to 4.23% in 2018, with an average annual decline of 0.93%. The main obstacle factors of social subsystem are S1, S2 and S7. By 2012, the obstacle degree of the economic sub-system had increased to the maximum, at 6.64%, and the top three obstacle factors that affected economic subsystem are the per capita patent authorization, the turnover of technology market and the dependence on foreign trade. Carbon neutral coefficient, total investment in the treatment of environmental pollution as percent of GDP and per capita park green area are the main obstacle factors affecting the development of the environmental subsystem. After the implementation of the “Belt and Road” strategy, the degree of barriers of the economic and environmental subsystems has been increased, indicating that we should focus on identifying the barriers of the economic and environmental subsystems and reducing the degree of barriers, so as to promote the green development level of the economy and environment subsystems. In order to improve the regional GDL, it is necessary to further reduce the obstacles of indicators under the economic subsystem and the environmental subsystem. On the one hand, enhancing the regional innovation capacity and promoting the green economic transformation are the necessary means. On the other hand, it is necessary to save energy and reduce emissions, improve the greening level, enhance the regional carbon balance capacity and achieve sustainable development.

4.2 Diagnosis of regional and provincial obstacle factors

In this paper, the first five indicators of obstacle degree are selected as the basis for identifying major obstacle factors, and three periods, 2003, 2011 and 2018, are selected to reflect the changes of regional obstacle factors at different periods (Table 4). In addition, the main obstacle factors of the provinces studied in 2003 and 2018 were identified (Figs. 9, 10).

With respect to southeast China, in 2003, the main factors hindering the green development in southeast China were EN4, E7, EN1, E1 and E8. Among them, the highest obstacle degrees of EN 4 and EN 1 index is Shanghai (see Fig. 9), with 24.09% and 25.82%, respectively, which indicates that pollution treatment and carbon balance are the main obstacle factors to the green development of Shanghai. E7 becomes the first obstacle factor in Zhejiang, Fujian, Guangdong and Hainan, which indicates that innovation capacity has become the primary factor restricting the green development of these provinces. In 2011 and 2018, the main factors that hindered the southeast region were the same. At this time, the primary obstacle to Guangdong’s green development is no longer E7 but EN4 and EN1. Generally speaking, the main obstacle factors in southeast China involve the environmental subsystem and the economic subsystem, among which pollution treatment, carbon balance and innovation capacity are the main obstacle affecting the green development of this region. Therefore, strengthening regional pollution treatment, reducing carbon emissions and improving the innovation capacity are the key driving forces to promote regional green development in southeast China.

In terms of northeast China, there are four same obstacle factors in the period of 2003, 2011 and 2018, namely E7, E6, S1 and E8. This phenomenon shows that during the study period, innovation capacity, residents’ quality of life and regional economic openness have been the main obstacle factors to the green development in northeast China. Therefore, in the future development, the region needs to pay more attention to technological innovation, strengthen regional trade and exchanges, improve residents’ quality of life and reduce the obstacle degree of major factors, so as to enhance the
regional green development. From the perspective of the provinces studied, the main obstacles restricting Liaoning, Jilin and Heilongjiang in 2003 were E7 and E8. By 2018, E7 remained the primary constraint in the three provinces, while the degree of obstacle to E8 decreased.

With respect to southwest China, the main obstacle factors to the green development in this region are E7, E8 and S1. During the study period, the three indicators increased and decreased in different degrees. E7 increased from 11.45% in 2003 to 12.56% in 2018, representing an increase of 9.69%. Among them, the obstacle degree of E7 in Guangxi, Chongqing and Yunnan all increased from 2003 to 2018 (Figs. 9, 10). The obstacle degree of S1 has also increased, which indicates that the obstacle degree of S1 to hinder the green development of southwest China has increased. The E8 dropped from 11.67% in 2003 to 7.61% in 2018, with a drop of 34.79%. Although the obstacle degree of E8 declined during the study period, the status of its main obstacle did not change much. Therefore, reducing the obstacle degree of the E8 is still the direction of future efforts in southwest China. Generally speaking, E7 is the primary factor that restricts Guangxi, Chongqing and Yunnan, so improving the innovation level in this region is the key to promoting the green development in southwest China.

| Region   | Year | Category | Ranking of indicators |
|----------|------|----------|-----------------------|
|          |      |          | 1  2  3  4  5         |
| Southeast 2003 | Obstacle Factors | EN4  E7  EN1  E1  E8 |
| Obstacle degree/% | 10.66  10.25  9.33  7.64  7.55 |
| 2011 Obstacle Factors | E6  EN1  EN4  E7  E1 |
| Obstacle degree/% | 10.57  10.48  9.92  9.82  7.60 |
| 2018 Obstacle Factors | EN4  EN1  E6  E7  E1 |
| Obstacle degree/% | 10.95  10.24  8.14  6.99  6.98 |
| Northeast 2003 | Obstacle Factors | E7  E8  S1  E6  S2 |
| Obstacle degree/% | 12.73  12.32  9.83  8.38  7.47 |
| 2011 Obstacle Factors | E7  E6  E8  S1  E1 |
| Obstacle degree/% | 14.77  11.59  9.88  7.34  6.41 |
| 2018 Obstacle Factors | E7  E6  S1  E8  E2 |
| Obstacle degree/% | 13.83  9.69  9.09  8.74  7.08 |
| Southwest 2003 | Obstacle Factors | E8  E7  S1  S2  E2 |
| Obstacle degree/% | 11.67  11.45  7.56  7.49  7.45 |
| 2011 Obstacle Factors | E7  E6  E8  E1  S1 |
| Obstacle degree/% | 13.78  11.98  9.26  6.85  6.22 |
| 2018 Obstacle Factors | E7  E6  S1  E8  E1 |
| Obstacle degree/% | 12.56  11.12  8.35  7.61  6.99 |
| Northwest 2003 | Obstacle Factors | E7  E8  S1  E6  S2 |
| Obstacle degree/% | 11.96  11.71  8.82  8.72  7.76 |
| 2011 Obstacle Factors | E7  E6  E8  E1  S1 |
| Obstacle degree/% | 14.34  11.17  9.44  7.27  6.88 |
| 2018 Obstacle Factors | E7  E6  E8  S1  E1 |
| Obstacle degree/% | 13.33  9.93  8.81  8.60  7.78 |
The E7, E6, E8 and S1 are the main obstacle factors affecting northwest China in the period of 2003, 2011 and 2018. The obstacle degree of E7 and E6 has increased in the research period as a whole, indicating that technological innovation has become the key obstacle factor restricting the green development in the northwest region. Among them, the obstacle degree of E7 obstacle factor in Inner Mongolia increased the most, from 12.14%
in 2003 to 15.07% in 2018. In addition, during the study period, both the S1 and E8 have declined to varying degrees. Generally speaking, E7 has become the first major obstacle to the green development in northwest China.

4.3 Discussion on the future action direction of regions

Figure 11 shows the main obstacle factors of green development in provinces during the study period. According to the main obstacle factors in each province, this paper discusses the future development direction of each province, and divides the future development direction of provinces into three types: openness and innovation oriented, low-carbon economy oriented and low-carbon innovation-oriented (Fig. 12).

Figure 12 shows that most provinces are openness and innovation-oriented, while few provinces are low-carbon economy-oriented and low-carbon innovation-oriented. The top three major obstacle factors in Shanghai are carbon neutral coefficient (EN1), total investment in the treatment of environmental pollution as percent of GDP (EN4) and GDP (E1). Therefore, carbon balance and economic development are the main obstacle factors to the green development in Shanghai. Therefore, Shanghai should control the regional carbon emission level to improve the regional carbon balance capacity, promote the green economic transformation and take the road of low-carbon economic development. The main obstacle factors in Guangdong are the number of per capita patent authorization (E7), the treatment of environmental pollution as percent of GDP (EN4) and the carbon neutral coefficient (EN1). Technology market turnover (E6), carbon neutral coefficient (EN1) and the dependence on foreign trade (E8) are the major obstacles to green development in Zhejiang. Thus, innovation and carbon balance are the main obstacles to the green development of Zhejiang and Guangdong. Therefore, the two provinces need to improve the level of technological innovation, research and develop green technologies, reduce pollution
emissions and take the road of innovation and low-carbon development. The technology market turnover (E6), the number of per capita patent authorization (E7) and the dependence on foreign trade (E8) are the main factors that hinder the green development of other provinces. In the future development, these provinces need to pay more attention to technological innovation, develop green technologies, strengthen regional exchanges, promote green trade and improve their own green development level.

5 Conclusion and implications

5.1 Conclusion and discussion

This paper used the data of 17 provinces along the belt and road in China from 2003 to 2018, applied three-dimensional evaluation model to investigate the GDL of the provinces, and employed the ODM to examine the main obstacle factors affecting the improvement of the green development. The main conclusions are as follows.

The GDL for the provinces along the belt and road in China shows a spatial distribution pattern of “high in the east and low in the west.” The obstacles to green development of provinces along the belt and road mainly come from economic subsystem, followed by the social subsystem and finally the environmental subsystem. In terms of regional obstacle degree, there are some differences among the main obstacle factors in different region. The pollution treatment, carbon balance and innovation capacity are the main obstacle factors restricting the green development in southeast China. The main obstacle factors in north-east China, southwest China and northwest China focus on innovation capacity, quality of life and economic openness, but the order ranks of obstacle factors are different among different regions. The future development of Shanghai should focus on emission reduction and take the road of low-carbon economy development. Zhejiang and Guangdong should
strengthen technological innovation, control emissions and take the road of low-carbon innovation. Other provinces should attach importance to technological innovation, develop green technology, promote green trade and develop toward a more open and more innovative society.

This study has some limitations that merit mention. This paper only calculates the carbon emissions from energy consumption, while other sources of carbon emissions such as human respiration and cropland-soil respiration are excluded from the scope of this study. Such exclusion may result in low estimation of regional carbon emissions. Therefore, in future research, the carbon emissions of human respiration and cropland-soil respiration can be considered to improving the accuracy of regional carbon emissions.

5.2 Implications

In this paper, we can get some suggestions and implications.

(1) Balanced the development of each subsystem. Our study found that the development level of the environmental subsystem had a large gap with the economic and social subsystems, and the coordination degree need to be further improved. The coordination between the subsystems in southwest China and northwest China is low, which is mainly due to the unbalanced development of the subsystems in economy, society and environment. Unbalanced development of each subsystem will not only affect the overall green development level, but also affect the deviation between the development direction of the system and the optimal direction. Therefore, green development should not only promote the development of economic, social and environmental subsystems, but also balance and coordinate the development of each subsystem, avoiding the “short board effect” and ensure the balanced, coordinated and steady development of each subsystem. Only in this way, all regions can achieve green, sustainable and long-term development.

(2) Regional carbon balance cannot be ignored, which has become a major obstacle factor to green development in some areas. We found that the carbon neutral coefficient has a great effect on the green development of southeast China, especially in Shanghai, where the obstacle degree of carbon neutral coefficient was as high as 21.19%. Due to the limited land area and the small area occupied by carbon-fixing vegetation in Shanghai, the carbon sink potential in the region is weak. In addition, due to the high economic development, dense population and relatively increased carbon emissions, the carbon balance in this area is weak. Therefore, on the one hand, the region should increase the vegetation coverage rate and promote the regional carbon sink potential. On the other hand, it is necessary to develop new energy sources, improve the utilization rate of clean energy, promote energy conservation and emission reduction in the industry, and motivate people to take green on the trip, thus reducing regional carbon emissions.

(3) Increase investment in scientific research to promote scientific and technological innovation. With respect to regional obstacle factor, in 2018, the innovation (E7 and E6) has become the first obstacle in northeast, southwest and northwest China and the third obstacle in southeast China. Therefore, it is necessary to promote the green transformation of economy by scientific and technological innovation, and promote industrial energy conservation and emission reduction by scientific and technological innovation, which plays an important role in driving regional low-carbon and green development.
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