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Has the level of green development in the northwestern provinces of China truly improved? A case study of Shaanxi

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ABSTRACT

Evaluating the actual progress in the green development of China's northwestern provinces can play a role in encouraging local governments to promote the reform of the ecological civilization system. By improving the "*green development indicator system*" formulated by the National Development and Reform Commission of China, the green development index (GDI) of Shaanxi Province from 2007 to 2016 was measured and compared with Shaanxi's ecological footprint (EF) and related indicators. The results showed that (1) the GDI in Shaanxi Province increased from 42.774 in 2007 to 64.971 in 2016, while during the same period, the per capita EF increased from 1.994 ha/cap to 2.719 ha/cap, the ecological deficit increased from 0.782 ha/cap to 1.500 ha/cap, and the ecological pressure index increased from 1.645 to 2.176. These results indicate that the green development of Shaanxi Province is still based on excessive ecological occupation. (2) A comparison between GDI and EF shows that the development of Shaanxi Province has changed from "low GDI, low EF" to "low GDI, high EF" to "high GDI, high EF". Thus, this study proposes countermeasures to change this trend, such as adjusting the energy structure, reducing carbon emissions, improving environmental capacity, and rigorous managing national land space.

1. Introduction

China's unique geographical environment leads to imbalancd development across its regions. Examining the distribution along the "Hu Huanyong Line", which is an important ecological barrier in China, 57% of China's land is northwest of the line but supports only 6% of the population (People's Network, 2019), as it mainly comprises grasslands, the Gobi desert, oases and snowy plateaus. This ecological vulnerability requires the northwestern provinces to improve their level of green development. Most of China's underdeveloped regions are located in the northwest of the country, and local governments there are pursuing economic development to eliminate poverty. As these economies become more developed, it becomes easier to solve the ecological problems that follow, and due to the excessive expansion of the western industry and the weak public awareness of environmental protection, it could be tempting to embark on the traditional road of treatment after pollution. However, at the start of the 21st century, people were finding that the means used to resolve development issues were causing manufacturing problems. Further, when the pace of development is slowed and governance carried out, the reduction in local fiscal revenue and living standards leads to a new round of poverty, and this places both the government and the public in an unprecedented dilemma. Today, people realize that the solution is urban green development (Ji, Li, & Jones, 2017), which has attained global consensus regarding its ability to achieve low-carbon economic transformation, maintain ecological security, and address climate change. Promoting green development in the northwestern provinces of China involves adjusting the industrial structure, energy structure, industrial layout, and national land space layout to match resources with production, consumption and other factors. It also means shifting way from the extensive production mode and consumption mode. Most importantly, it is necessary for the northwest regions to reduce pollutant emissions at the source, promote resource conservation and recycling, and achieve coordinated social and economic development along with ecological environmental protection (Zhang et al., 2019).

Since the 21st century, the "greenhouse effect", atmospheric ozone depletion, soil erosion, deforestation, land desertification and water pollution have increased the shortage of global environmental resources (Tsai, Lee, Yang, & Huang, 2016). Studies have shown that the future quality of life of humans will depend entirely on the transition to sustainable development (Soma, Dijkshoorn-Dekker, & Polman, 2018). The United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP) and the United Nations Environment Program (UNEP) have been focusing on greenhouse gas emissions and resource

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and environmental protection, which is challenging work. The World Bank (2012) describes green development as an environmentally friendly and socially inclusive growth model that aims to use natural resources efficiently and reduce pollution emissions. The Organisation for Economic Co-operation and Development (OECD, 2011) views green development as a solution to achieve economic growth while preventing environmental degradation, loss of biodiversity and the unsustainable use of natural resources. In recent years, some countries have actively implemented green development policies or actions, e.g., the United States investing in clean energy research and development, Nordic countries shifting to low-carbon energy, Germany implementing an “energy transformation” strategy with the goal of energy decarbonization, and Japan committing to building a “low-carbon society” (Chapman & Pambudi, 2018; Galvin, 2018; Skea & Nishioka, 2008; Urban & Nordensvärd, 2018). The increasing concern shown by countries and regions makes the assessment of the green development level not only an academic issue but also a problem that must be addressed in practice (Bare, 2014). As early as August 2002, Sweden’s Stockholm Environment Institute and the United Nations Development Programme jointly drafted *China’s Human Development Report 2002: Making Green Development a Choice.* This report defines the concept of green development in China and suggested taking a “green reform path”. The Chinese government accepted this proposal in 2011 and discussed the construction of a resource-saving and environment-friendly society for the first time in the *12th Five-Year Plan for National Economic and Social Development* with the theme of green development. China first published the *2016 National Ecological Civilization Construction Annual Evaluation Bulletin* on December 26, 2017 (National Bureau of Statistics, 2017), using the GDI to comprehensively demonstrate the green development status of each province and marking the Chinese government’s implementation of the green development strategy as a national policy.

The concept of a “green development, low-carbon economy” has brought rare opportunities for development to northwestern China, especially to Shaanxi Province (Shaanxi), which has a vast territory and rich resources. In the past 60 years, to city of Yulin, Shaanxi, has implemented the “Sand Control Afforestation” ecological construction project, which has become a global model exemplifying the control of deserts. The large-scale “Northern Sand Control and South Land” has continued to increase the forestry area and forest coverage of Yulin city from 40,000 ha and 0.9% in 1949 to 1.44 million ha and 33.1% in 2018 respectively (People’s Central Broadcasting Station, 2018). In 1999, Shaanxi took the lead in piloting “returning farmland, returning grazing, returning grass, and returning forests” in China and implemented the “beautiful landscape” ecological construction project in its northern reaches, which provides food and living subsidies to farmers who returned to maintaining farmland and grazing so that the local cultivated land, forest coverage and public living standards will continue to increase. Shaanxi’s unique resource advantages and location characteristics mean that its industrial structure is deeply rooted in fossil energy, resulting in a series of ecological and environmental problems. First, air pollution is a serious concern in Shaanxi. The number of days with excellent air quality in the 13 cities (districts) of Shaanxi was 157–331 days in 2018, and the average excellent rate was 66.5%, which is lower than the national average of 79.3%. The average respirable particulate matter was 103 $\mu g/m^3$, which was well below the secondary standard level of 10 $\mu g/m^3$. Second, the most important water environment in Shaanxi is the Wei River, which is polluted to varying degrees. In 2017, 52.6% of the mainstream of the Wei River was of water quality IV-V, and 5.3% was accounted for by inferior V water quality. Third, land use in the region is unsound, and soil pollution is serious. In 2018, the accumulated soil erosion area of Shaanxi was 7917.95 thousand ha, and the average annual soil erosion was approximately 735 million tons. The area of desertified land is 14,100 km^2, accounting for 6.9% of the province’s land area. (Shaanxi Provincial People’s Government, 2017). The overexploitation and utilization of farmland and the wind erosion of soil have intensified. Shaanxi has improved its ecological carrying capacity (EC) through ecological construction and restoration projects, but ecological damage and environmental pollution have also become increasingly serious. Therefore, has the level of green development in Shaanxi increased or decreased over the past 20 years? If it has improved, is this improvement sustainable? Faced with this question, a multi-perspective assessment of the level of green development becomes critical.

With the implementation of a green development strategy, research investigating green development evaluation index systems has attracted increasing attention from all walks of life. Therefore, it is particularly important to construct a green development evaluation system. The OECD (2011) has designed an indicator system that includes environmental and resource productivity, the natural asset base, quality of life and policy response with the goal of economic growth. Kondyli (2010) applied systematic analysis and composite indicators to assess the sustainability of the northern Aegean Islands at different points in time. Although China’s research on green development evaluation is relatively late, it has already achieved relevant results with regard to emission reduction targets, for example, constructing an indicator system from the perspective of resources and the environment to evaluate the level of urban green development (Wang, Zhao et al., 2018; Yang, Ling, Zhang, & Yao, 2018; Zhang, Liu, Wu, & Wang, 2018), constructing a comprehensive evaluation index system to assess China’s level of green development (Guo, Mi, & Zhao, 2015; Sun, Tong, & Zou, 2018; Tian, Zang, Xu, & Chen, 2018; Wang, Li, & Yu, 2018), and noting the relationship between green economic efficiency and the green development level, green GDP and the EF (Huang, Hu, & Qiao, 2018; Wang, Wang, & Liang, 2019). However, in these studies, the selection of green development indicators and information on their data sources are opaque, and it is difficult to obtain approval from the public and the local government on these indicators, the evaluation results are also difficult to verify. Even the “2016 National Ecological Civilization Construction Annual Evaluation Bulletin” first published in 2017 in China only shows the green development status of the northwestern provinces in 2016, making it difficult to see the evolutionary characteristics of the green development level over time. To this end, based on the GDI in the 2016 National Ecological Civilization Construction Annual Evaluation Bulletin published by the Chinese government combined with the geographical characteristics and development level of Shaanxi, an adjusted green development evaluation index system is adopted here based on publicly available statistics. The data were used to calculate the GDI of Shaanxi from 2007 to 2016, and its evolutionary characteristics were analysed. The EF method was then used to verify the reliability of the GDI results (Fig. 1), which provides a scientific basis upon which the local government can formulate relevant policies.

2. Methods and data

2.1. Study area

Located in the hinterland of northwestern China (Fig. 2), Shaanxi has a land area of 205,800 km^2 and contains Qinling, an important ecological security barrier in China. From north to south, the province can be divided into three distinct regions based on geography, social economy, and culture. The northern part includes Yan’an city and Yulin city, with a land area of 81,000 km^2, accounting for 39.4% of the province. It is the largest loess area in the world and is also located on the edge of the Mu Us Desert. Northern Shaanxi is rich in energy, but the soil loss is serious, and the ecology is fragile. It is the key implementation area of ecological construction projects. The central part includes Xi’an city, Tongchuan city, Baoji city, Xianyang city, Weinan city, the Yangling Agricultural High-tech Industry Demonstration Zone and other Guanzhong cities, accounting for 63.1% of the province’s population. This region is the most densely populated area in Shaanxi, due to the industrial concentration, and its GDP accounted for 62.4% of

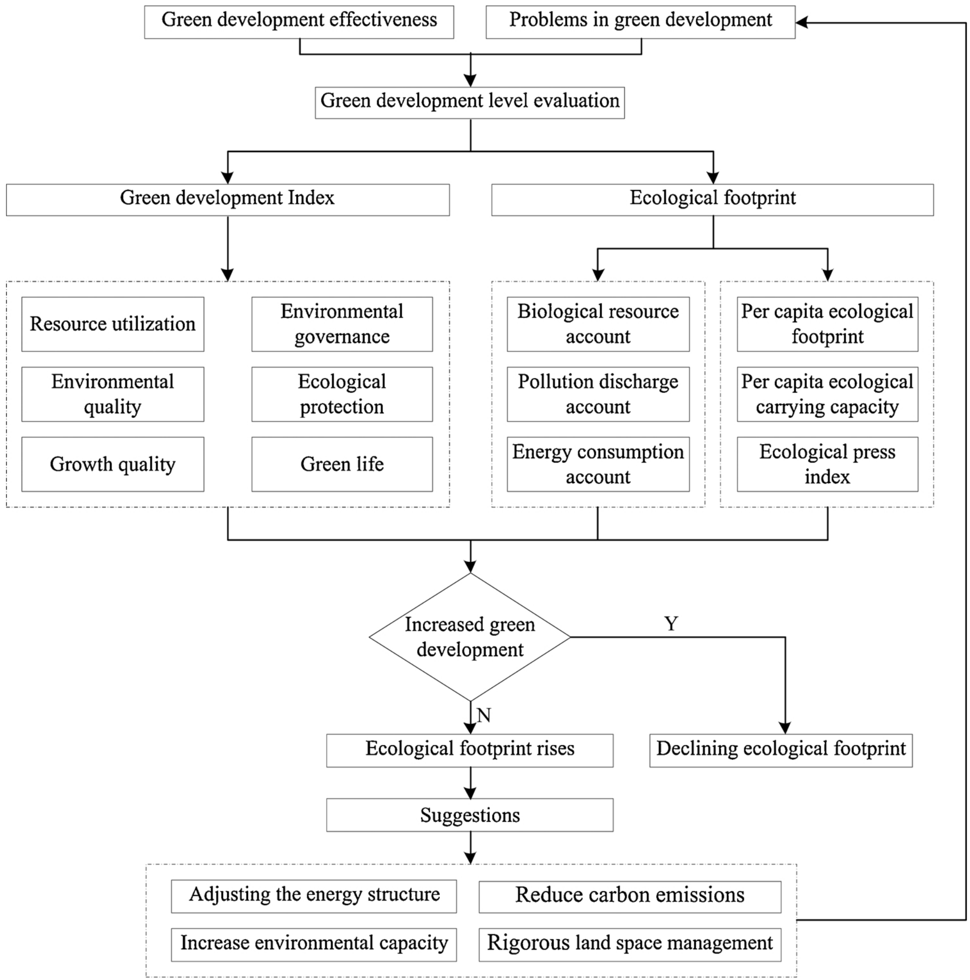


Fig. 1. Research framework.

that of the province in 2018. However, the water resources are in short supply in Guanzhong, the Wei River has serious pollution, and the air quality is declining. The south includes Hanzhong city, Ankang city, and Shangluo city. Southern Shaanxi has abundant ecological resources, with a forest coverage rate of 56.5%. It has 12 national nature reserves and 13 national forest parks. However, socio-economic

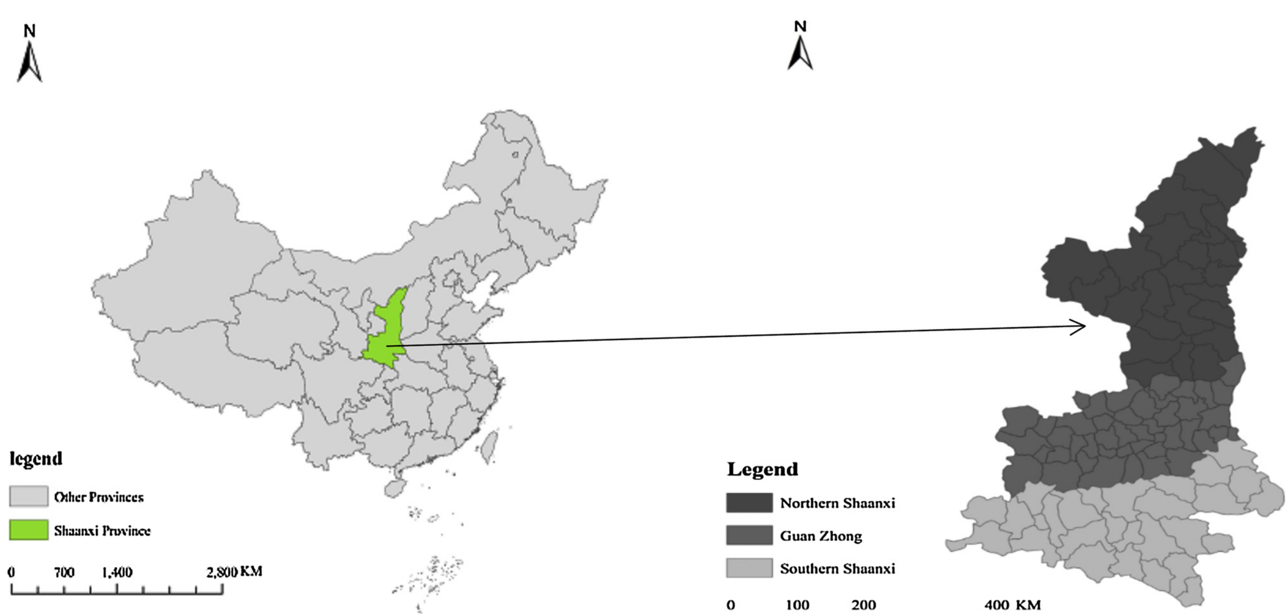


Fig. 2. Research area.

development is slow, and its industrial structure needs further improvement.

In terms of resource utilization, the total energy consumption in Shaanxi has continued to rise, from 67,750 thousand tons of standard coal equivalent in 2007 to 121,200 thousand tons of standard coal equivalent in 2016. The resource output rate was 2500 US$/t in 2016. Although this value increases each year, the overall output rate is still low. In terms of environmental management, the total amount of chemical oxygen demand, total ammonia and nitrogen emissions, total sulphur dioxide emissions, and total nitrogen oxide emissions are decreasing each year. The utilization rate of hazardous waste treatment and the harmless treatment rate of domestic garbage are continuously increasing, from 20.1% and 67.3% in 2007 to 55.1% and 98.5% in 2016, respectively. Environmental quality and air pollution are serious concerns. The ratio of days with good air quality at the prefecture level and above decreased from 84.1% in 2007 to 62.9% in 2016. The water quality of centralized drinking water sources at the prefecture level and above is at or above the category III ratio and remains above 99.1%. Further, the amount of chemical fertilizer and pesticides used per unit of cultivated land have increased continuously, from 559.1 kg/ha and 3.8 kg/ha in 2007 to 799.6 kg/ha and 4.5 kg/ha in 2016, respectively. In terms of ecological protection, forest coverage increased from 37.3% in 2007 to 41.4% in 2016. The area of new mine restoration and management has also increased significantly, reaching 2188 ha in 2016, which was 12 times greater than the area in 2015. In terms of the quality of growth, the per capita GDP growth rate is declining, and economic growth is slow, declining from 21.1% in 2007 to 7.1% in 2016. In terms of green living, urban green area is increasing, and the per capita park green area has increased from 8.10 m^3 in 2007 to 12.30 m^3 in 2016 (Fig. 3). According to the *2016 National Ecological Civilization Construction Annual Evaluation Bulletin* promulgated by the Chinese government, the level of green development in Shaanxi lags behind the national average. Exploring the evolution of green development in Shaanxi and its influencing factors clearly holds practical significance for the scientific formulation of ecological management and environmental policies.

2.2. Methods

2.2.1. Green development index calculation

The GDI characterizes the green development level of a region, including resource utilization, environmental governance, environmental quality, ecological protection, growth quality and green living. The "*green development indicator system*" (National Development & Reform Commission, 2016) formulated by the National Development and Reform Commission, the National Bureau of Statistics, and the Ministry of Ecology and Environment uses a comprehensive index method that is calculated by the weighted average of 45 indicators (Table 1). These indicators are divided into positive and negative indicators according to the evaluation function. They are also divided into absolute numbers and relative numbers according to the nature of the index data, and the values must be dimensionless. The treatment method converts an absolute number index into a relative number indicator, converts a reverse index into a forward indicator, and then calculates the individual index. The GDI calculation formula is as follows:

$$GDI = \sum_{i=1}^{N} W_i Y_i (i = 1, 2, \ldots, 45) \tag{1}$$

In Formula (1), *GDI* is the green development index, Y_i is the individual index of the indicator, W_i is the weight of the Y_i index, and *N* is the number of indicators.

2.2.2. Ecological footprint and related index calculation

As a research method for evaluating sustainable development (Rees, 1992), the EF transforms sustainable development from an abstract concept to an operational practice (Wackernagel et al., 2002), introducing regional resources by including "equalization factors" and "yield factors". The ecological footprint used in the paper was revised on the basis of the Global Footprint Network. This work has two amendments: first, we have increased the pollution discharge accounts to included waste gas, waste water and solid waste. Second, seven subjects—chestnut, walnut, poultry egg, silkworm cocoon, pepper, palm and lacquer—that reflect the characteristics of Shaanxi and have statistical data are added to the biological resource account.

This approach converts resources and energy consumption into an estimate of the productive land area necessary to provide such material flow. Then, this result is compared with the productive land area that is available in the region by calculating the difference between the supply and demand of the ecological load and judging whether production and consumption activities are within the ecosystem's carrying capacity (Xu, Cheng, & Zhang, 2006). The per capita EF is the ratio of the total bio-productive land to population. The formula for calculating the EF is:

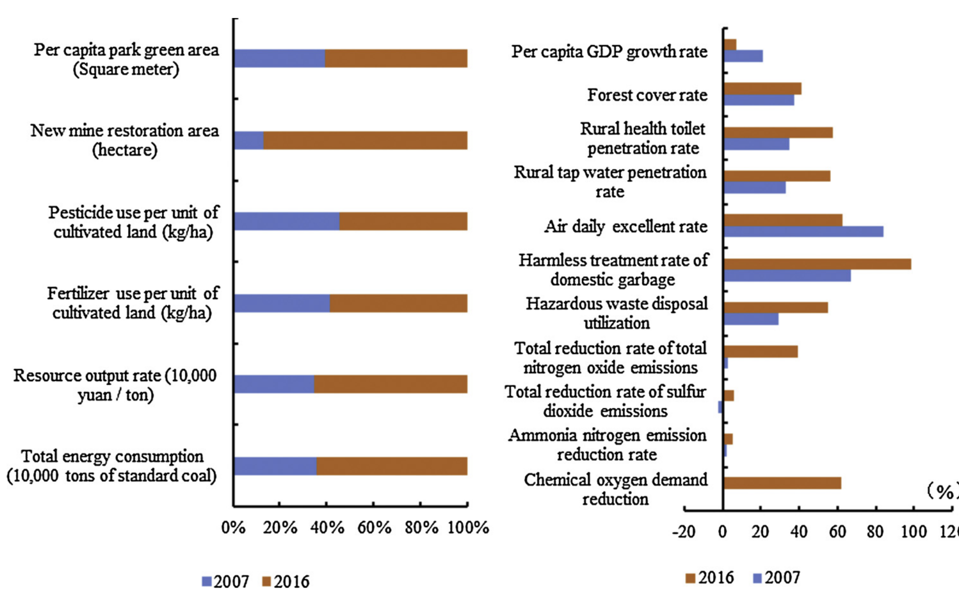


Fig. 3. Relevant indicators of green development in Shaanxi Province in 2007 and 2016.

Table 1
Shaanxi Province Green Development Indicator System.

Secondary index	Three-level indicator ("-" indicates a negative indicator, "+" indicates a positive indicator)	Data Sources
Resource utilization	Total energy consumption (-), Unit GDP energy reduction rate (+), CO_2 emission reduction rate per unit of GDP (+), Non-fossil energy as a share of primary energy consumption (+), Total water use (-), 10,000 yuan GDP water consumption decline rate (+), Unit industrial added value water consumption reduction rate (+), Cultivated land holdings (+), New construction land scale (-), Unit GDP construction land area reduction rate (+), Resource output rate (+), General industrial solid waste comprehensive utilization rate (+).	*Shaanxi Statistical Yearbook. China Environmental Statistics Yearbook. China Energy Statistics Yearbook.*
Environmental governance	Chemical oxygen demand reduction (+), Ammonia nitrogen emission reduction rate (+), Total reduction rate of sulphur dioxide emissions (+), Total reduction rate of total nitrogen oxide emissions (+), Hazardous waste disposal utilization (+), Harmless treatment rate of domestic garbage (+), Sewage centralized treatment rate (+), Environmental pollution control investment accounts for the proportion of GDP (+).	
Environmental quality	Ratio of days with good air quality at prefecture level and above (+), Daily average of inhalable particles (-), Proportion of river section of water quality I-III (+), Proportion of rivers with inferior V waters (-), The water quality of centralized drinking water sources at or above the prefecture level is higher or higher than the proportion of Class III (+), Fertilizer use per unit of cultivated land (-), Pesticide use per unit of cultivated land area (-).	
Ecological protection	Forest cover rate (+), Forest stock (+), Grassland comprehensive vegetation coverage (+), Wetland protection rate (+), Land area of nature reserve (+), New soil erosion control area (+), New mine restoration management area (+).	
Growth quality	Per capita GDP growth rate (+), Resident per capita disposable income (+), The added value of tertiary industry as a share of GDP (+), The value added of strategic emerging industries as a share of GDP (+), Research and experimental development expenditures as a share of GDP (+).	
Green life	Per capita daily water consumption (-), Per capita park green area (+), Green travel (public transport passenger traffic per 10,000 population) (+), Urban built-up area green rate (+), Rural tap water penetration rate (+), Rural health toilet penetration rate (+).	

$$EF = \sum EF_i/N = \sum (r_i \times \frac{C_i}{p_i})/N \tag{2}$$

In Formula (2), EF is the per capita EF, EF_i is the EF of the i-th consumer good, N is the total population of the region, r_i is the equilibrium factor, C_i is the consumption of the i-th commodity, P_i is the first average production capacity of the i type of consumer goods, and i is the category of consumer goods.

The EC refers to the sum of the areas of bio-productive land that can be provided to humans in the region. Assessing human activities based on the EC is very important for regional ecosystem sustainability (Graymore, Sipe, & Rickson, 2010). The per capita EC is calculated as:

$$EC = \sum EC_j/N = \sum (a_j \times r_j \times y_j)/N \tag{3}$$

In Formula (3), EC is the per capita ecological carrying capacity, EC_j is the ecological carrying capacity of the jth biological production land, a_j is the area of the jth biological production land, r_j is the equilibrium factor, and y_j is the production factor.

The per capita ecological profit and loss is the difference between the EC and the EF. The formula is as follows:

$$ED = EC - EF \tag{4}$$

When $ED < 0$, there is an ecological deficit, which indicates that the ecological environment has been overloaded. When $ED > 0$, there is an ecological surplus.

The ecological stress index (*EPI*) reflects the intensity of the disturbance to the ecosystem due to human activities. It is expressed as the ratio of the EF to the EC (Shi & Wang, 2016), and the calculation is as follows:

$$EPI = EF/EC \tag{5}$$

When $EPI < 1$, the intensity of human activity-caused disturbance to the ecosystem does not exceed the internal-feedback threshold of the regional ecosystem under certain conditions, and the ecosystem remains in equilibrium (Wang, Mao, & Wang, 2002).

2.3. Data sources and their dimensionless processing

The green development indicator system includes the six secondary indices of resource utilization, environmental governance, environmental quality, ecological protection, growth quality and green living, and these indices include 55 three-level indicators, such as total energy consumption, total reduction in chemical oxygen demand, urban air quality excellent days ratio, forest coverage rate, per capita GDP growth rate and green area rate in urban built-up areas. Because some indicator data are difficult to obtain, the following processing is performed.

First, explicitly eliminate indicators or indicator data instead of reasons and distribute their weights to their peers. In the secondary index of resource utilization, the following were excluded due to missing data for two non-binding indicators, "effective utilization coefficient of farmland irrigation water" and "comprehensive utilization of crop straw". In the secondary index of environmental management, due to the partial missing data for the "total nitrogen oxide reduction" and "hazardous waste disposal utilization" indicators, the respective values were replaced by the lowest value in 2008–2017. In the secondary index of environmental quality, the "proportion of water quality in the coastal waters (I, V) ratio" was excluded because Shaanxi is an inland province. Due to incomplete basic statistics, the "safe utilization rate of contaminated cultivated land" and the "water quality compliance rate of important rivers and lakes" were excluded. Additionally, "fine particulate matter (PM2.5) with substandard land and above urban concentration", "surface water reach or better than class III water body" and "surface water inferior V water body ratio (%)", which are clearly defined and have data sources in the *Statistical Yearbook*, were used to replace the "daily average of inhaled particles", the "proportion of river section of water quality I-III (%)" and the "proportion of rivers with lower V waters (%)". In the secondary index of ecological protection, the "natural shoreline retention rate" and "marine protected area" indicators were excluded because Shaanxi is an inland province. The "rate of governance of desertified land" was also excluded due to lack of data. "Grassland area as a ratio of administrative areas" and "wetland area as a ratio of administrative areas", which are clearly defined and have data sources in the *Statistical Yearbook*, were used to replace "prairie integrated vegetation coverage rate" and "wetland protection rate". Due to data quality or access difficulties, also excluded were "new energy vehicle ownership growth rate", "per capita energy consumption reduction rate, green product market share (high-efficiency energy-saving product market share)" and "green building in the proportion of new construction", but the secondary index of green living was supplemented by the indicators of "per capita daily water consumption" and "per capita park green area".

Second, the adjusted indicator system consisted of 45 indicators (Table 1). The raw data of each indicator were taken from the *Shaanxi*

Statistical Yearbook, *China Environmental Statistics Yearbook* and *China Energy Statistics Yearbook* in 2008–2017. Among them, the carbon dioxide reduction per unit of GDP was calculated according to the extended Kaya identity (Kaya, 1990). In the energy consumption structure, because non-fossil energy such as hydropower accounts for only 3.1% of the total, only carbon dioxide emissions from coal, oil and natural gas were considered. The calculation formula is as follows:

$$CO_2 = \sum_{i=1}^{n} C_i = \sum_{i=1}^{n} E_i \times \frac{C_i}{E_i} = \sum_{i=1}^{n} E_i \times \Psi_i \tag{6}$$

In Formula (6), CO_2 indicates the total amount of carbon dioxide emissions, C_i indicates the amount of CO_2 energy consumed by the i-th energy, E_i which is the energy consumption of the i-th type and $\Psi_i$is the CO_2 emission coefficient of the *i*-th energy type. According to the *Guidelines for the Preparation of Provincial Greenhouse Gas Inventories* (National Development & Reform Commission, 2011), the emission coefficients of coal, oil and natural gas are 1.903 kg-CO_2/kg, 3.0202 kg-CO_2/kg and 2.1622 kg-CO_2/kg, respectively.

Third, due to differences between data units, dimensionless processing is required. Data standardization is used to obtain a result in the [0,1] interval (Zhang, Luo, Cheng, & Wang, 2016), which is then converted into a dimensionless value to facilitate the comparison and weighting of indicators of different units or magnitudes. The formulas for calculating the positive and negative indicators are as follows.

The formula for calculating the positive indicator is:

$$X' = \frac{X - MIN}{MAX - MIN} \tag{7}$$

The formula for calculating the negative indicator is:

$$X' = \frac{MAX - X}{MAX - MIN} \tag{8}$$

In Formulas (7) and (8), X' is the value after normalization, *MAX* is the maximum value of the index sample data, and *MIN* is the minimum value of the index sample data.

3. Results analysis

3.1. Green development index results analysis

The calculation results for Formula (1) show that Shaanxi's GDI increased from 42.774 in 2007 to 64.971 in 2016, which is an increase of 51.9% (Fig. 4). Except for the declines in 2011 and 2014, the indices are increasing overall. Among all indices, the secondary indices of environmental governance, ecological protection, growth quality and green living are also increasing, and of these, ecological protection and green living contribute the most to GDI growth. Secondary indicators such as resource utilization and environmental quality are declining (Fig. 5).

Examining the three-level index, the increased reduction in the total amount of chemical oxygen demand emissions, the reduction rate in total nitrogen oxide emissions, the harmless treatment rate of domestic garbage, and the centralized treatment rate of sewage led to an increase in the environmental governance index (Fig. 6a). For example, the reduction in total chemical oxygen demand emissions increased from -0.3% in 2007 to 61.7% in 2016, which was an increase of 100.5%. The centralized sewage treatment rate increased from 38.6% in 2007 to 91.4% in 2016, which was an increase of 57.7%. These findings indicate that environmental governance in Shaanxi has been quite effective. The increase in forest cover, forest stocks, grassland integrated vegetation cover, and wetland area as a percentage of administrative area is driving the increase in the ecological protection index (Fig. 6b). For example, forest cover increased from 37.3% in 2007 to 41.4% in 2016, representing an increase of 10.04%. The forest stock volume increased from 338 million m^3 in 2007 to 396 million m^3 in 2016, representing an increase of 17.15%. The per capita disposable income of residents, the added value of tertiary industry as a share of GDP, the added value of strategic emerging industries as a share of GDP, and the proportion of research and experimental development expenditures to GDP have increased slightly, from US$1594.50, 37.8%, 41.5%, and 2.11% in 2007 to US$4123.33, 35.1%, 47.5%, and 2.2% in 2016, respectively, representing increases of 164.24%, 11.9%, 14.5%, and 2.4%. However, the sharp decline in the per capita GDP growth rate is the main indicator keeping the growth quality index low, and it declined by 66.2%, indicating that Shaanxi's economic growth momentum is insufficient (Fig. 6c). The increase in the rural tap water penetration rate and the increase in the rural health toilet penetration rate is the main driver of the increase in the green living index (Fig. 6d), which increased from 33.2% and 35.1% in 2007 to 56.1% and 57.6% in 2016, representing increases of 68.9% and 64.6%, respectively.

However, the quality of resource utilization and the growth of environmental quality in Shaanxi are still insufficient. As the three-level indicator shows, the increases in total energy consumption and CO_2 reduction per unit of GDP are the main indicators leading to the decline in the resource utilization index (Fig. 6e). For example, energy consumption increased from 67,748.6 thousand tons of standard coal equivalent in 2007 to 121,201.4 thousand tons of standard coal equivalent in 2016, which was an increase of 44.1%. Carbon dioxide

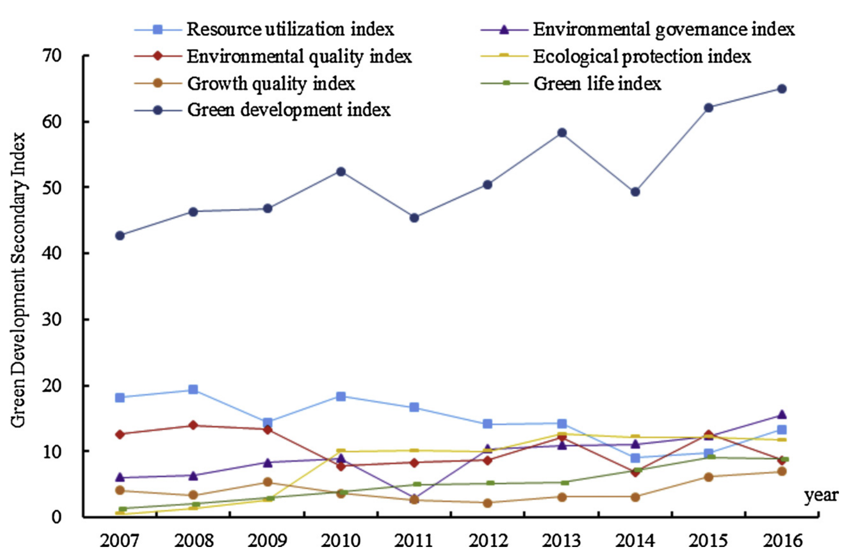
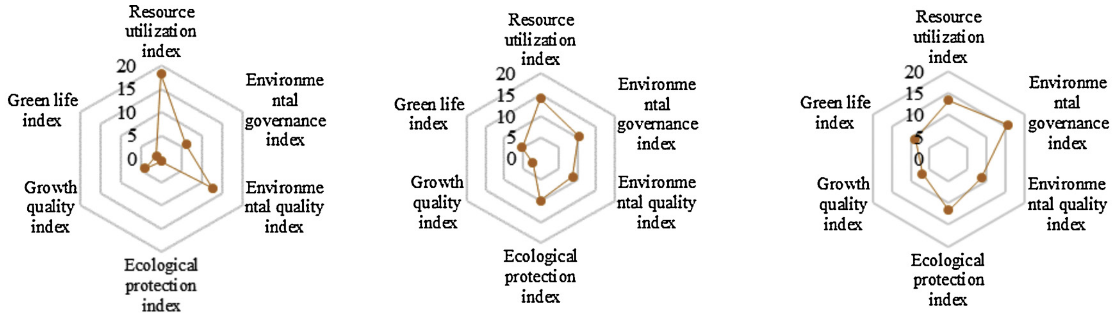


Fig. 4. Trends in various indexes of green development in Shaanxi Province from 2007 to 2016.



a Trends of various indexes of green development in Shaanxi Province in 2007

b Trends of various indexes of green development in Shaanxi Province in 2012

c Trends of various indexes of green development in Shaanxi Province in 2016

Fig. 5. Contribution of Shaanxi Province Green Development Secondary Index in 2007, 2012 and 2016.

per unit of GDP exhibited a greater reduction from 11.9% in 2007 to −2.5% in 2016, which represents a 120.7% increase in the reduction rate. The decrease in the ratio of days with good air quality at the prefecture level and above and the increases in the amount of fertilizer per unit of cultivated land and the use of pesticides are the main indicators leading to the decline in the environmental quality index (Fig. 6f). For example, the ratio of days with air quality at the prefecture level and above decreased from 84.1% in 2007 to 62.9% in 2016, which was a decrease of 25.2%, indicating that air pollution in Shaanxi is a very serious concern. The amount of fertilizer and pesticide used per unit of cultivated land increased from 559.01 kg/ha and 3.77 kg/ha in 2007 to 799.64 kg/ha and 4.52 kg/ha in 2016, respectively, representing increases of 43.1% and 16.6%.

3.2. Analysis of the ecological footprint results

3.2.1. Analysis of the ecological footprint calculation results

The EF of Shaanxi from 2007 to 2016 was calculated according to Formula (2) (Table 2). The results show a clear increase in the EF in Shaanxi from 1.994 ha/cap to 2.719 ha/cap. Among the calculations, the EF of the energy consumption accounts is particularly prominent, which also reflects the practical significance of actively promoting clean energy.

In the energy consumption account, the EF of coal is dominant, from 0.656 ha/cap to 1.178 ha/cap, with an average annual growth rate of 7.9%. The EF of oil is second only to coal; this value increased from 0.221 ha/cap to 0.351 ha/cap, and the average annual growth rate is 8.4%. The decline began in 2015. In 2015 and 2016, the EF of oil was 0.321 ha/cap and 0.246 ha/cap, respectively. Shaanxi's energy consumption structure continues to be dominated by high-polluting energy sources such as coal and oil, while the use of clean energy, such as natural gas and hydropower, is low, although hydropower has a low EF.

In the pollution discharge account, the water pollution EF does not occupy a dominant position, but it has increased each year, i.e., from 0.073 ha/cap in 2007 to 0.120 ha/cap in 2016, and the average annual growth rate is 6.4%. The EF of air pollution is stable and has declined each year since 2012, indicating that waste gas treatment work in Shaanxi has achieved some results. Except for a slight decline in 2009, the EF of solid waste pollution increased in all years, i.e., from 0.152 ha/cap to 0.236 ha/cap, for an average annual growth rate of 5.5%.

In the biological resource account, the EF of cultivated land and grassland is dominant; the amount of cultivated land has increased from 0.557 ha/cap to 0.730 ha/cap, while grassland is basically stable at between 0.210 and 0.260.

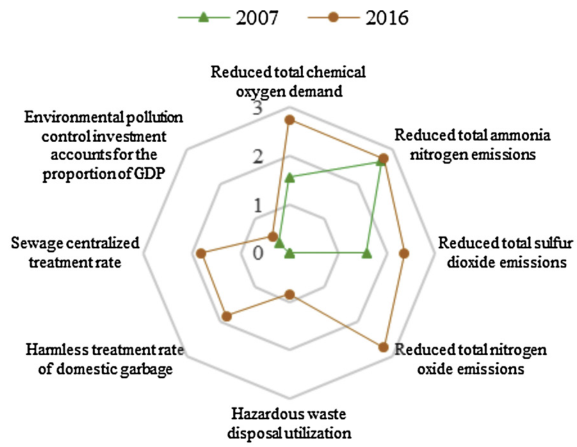
3.2.2. Analysis of results for the ecological footprint-related index

The Shaanxi EC results (Fig. 7) were calculated according to Formula (3), and the values were stable between 1.2 ha/cap and 1.3 ha/cap. According to Formula (4), the results for the ED in Shaanxi increased from 0.78 ha/cap to 1.50 ha/cap, which was an increase of 91.8%. According to Formula (5), the Shaanxi EPI (Fig. 7) increased from 1.65 to 2.18, which was an increase of 32.3% and indicates that the ecological environment problems in Shaanxi are becoming increasingly serious, leading to structural disorder, dysfunction and declines in biological productivity.

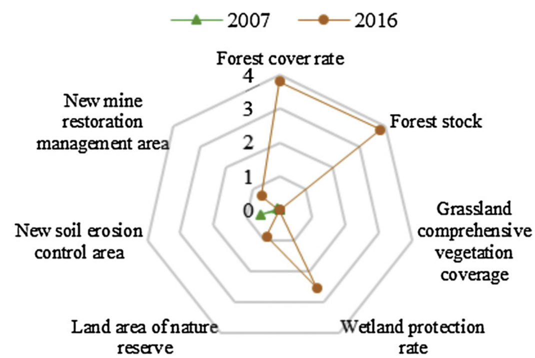
3.3. Comparative analysis of the ecological footprint and green development index results

Using the EF on the horizontal axis and GDI on the vertical axis, an EF of 2.25 ha/cap and a GDI of 55 are taken as the intermediate values of the calculation results, and the coordinate axes are divided into four quadrants (Fig. 8). Moving counter-clockwise from quadrant I to quadrant IV, the quadrants are sequentially expressed as "high GDI, high EF", "high GDI, low EF", "low GDI, low EF" and "low GDI, high EF". Normally, under the same level of green development, reducing or slowing the EF growth rate is consistent with the green development goal. The results show that the green development level of Shaanxi has transitioned from quadrants III and IV to quadrant I and has not yet reached the optimal state of "high GDI, low EF". The energy consumption structure in the EF account shows that fossil energy, such as coal and petroleum, as well as water pollution and solid waste pollution basically reflect the low resource utilization and poor environmental quality indicated by the GDI. This result shows that due to a lack of ecological considerations in the GDI, it is still necessary to include the EF to reflect the level of green development.

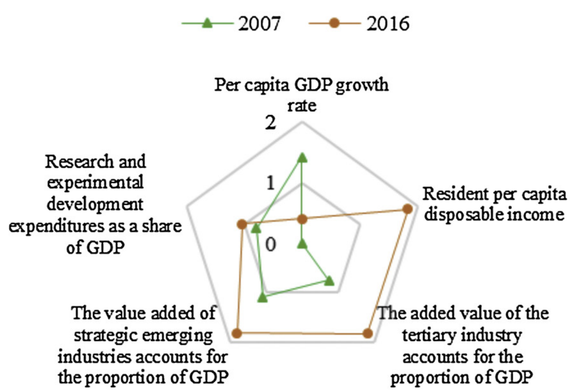
Fig. 8 shows that the GDI and the EF basically grow at the same rate before 2010, which shows that the improvement in the level of green development in Shaanxi is at the expense of resources and energy. GDI began to decline in 2011, but the EF is still increasing because in the process of accelerating industrialization, Shaanxi has accelerated the use of coal, oil, natural gas and rock salt with a focus on the North Shaanxi Energy and Chemical Industry Base and the Weibei Energy Connection Zone. With the development of resources, energy consumption not only puts pressure on the ecological environment but also causes air pollution and sewage pollution that reduces the quality of environmental governance. From 2011–2013, the growth rate of the GDI was greater than that of the EF; the growth rate of the EF declined because the Shaanxi Provincial Government adhered to both ecological protection and pollution prevention during this period; promoted the control of atmospheric, water and soil pollution; implemented ecological restoration by returning farmland to forests and grasslands;



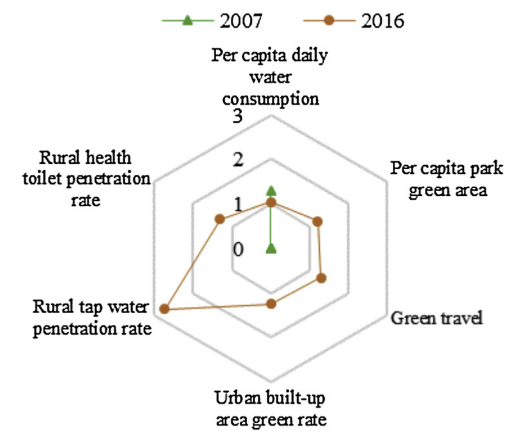
a. Environmental governance three-level indicator contribution



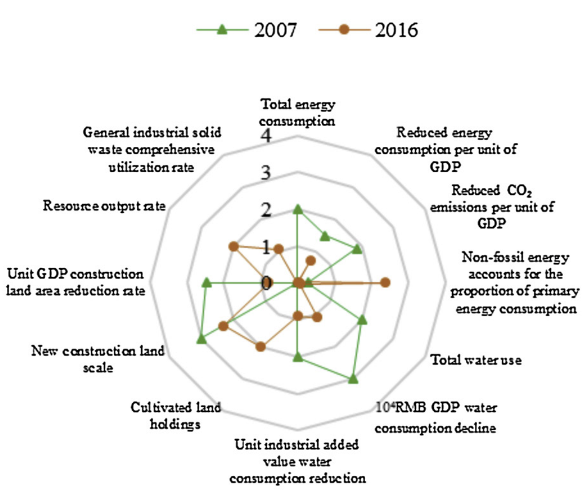
b. Ecological protection three-level indicator contribution



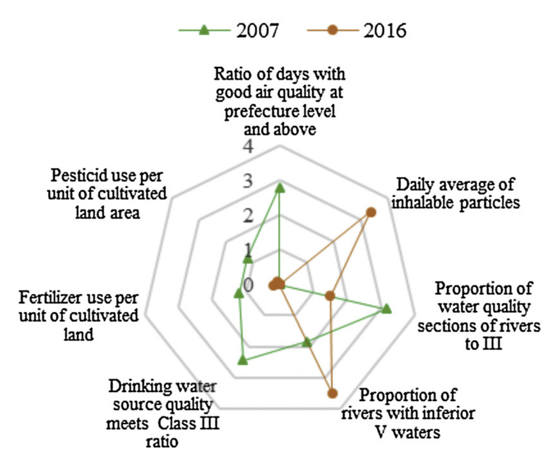
c. Growth quality three-level indicator contribution



d. Green life three-level indicator contribution



e. Resource utilization three-level indicator contribution



f. Environmental quality three-level indicator contribution

Fig. 6. Contributions of the three-level indicator of green development in Shaanxi Province in 2007 and 2016.

Table 2
Changes in the per capita ecological footprint of Shaanxi Province from 2007 to 2016.

Ecological footprint account		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Biological resource account	Agricultural products (arable land)	0.299	0.319	0.339	0.352	0.356	0.375	0.367	0.362	0.373	0.373
	Forest products (forest land)	0.024	0.028	0.030	0.032	0.037	0.040	0.041	0.044	0.046	0.049
	Grass product (grass)	0.217	0.250	0.227	0.232	0.228	0.240	0.248	0.256	0.254	0.247
	Aquatic products (waters)	0.017	0.019	0.019	0.021	0.028	0.036	0.047	0.047	0.059	0.062
	Total	0.557	0.616	0.615	0.637	0.648	0.691	0.703	0.709	0.733	0.730
Pollution discharge account	Water pollution	0.073	0.076	0.081	0.087	0.089	0.094	0.096	0.106	0.121	0.120
	Air pollution	0.255	0.243	0.223	0.214	0.252	0.226	0.213	0.202	0.179	0.057
	Solid waste pollution	0.152	0.168	0.154	0.194	0.199	0.200	0.207	0.239	0.255	0.236
	Total (Contaminated area)	0.480	0.487	0.458	0.495	0.540	0.520	0.516	0.547	0.555	0.413
Energy consumption account	Coal (Fossil energy land)	0.656	0.678	0.749	0.768	0.861	0.949	1.001	1.057	1.103	1.178
	Oil (Fossil energy land)	0.221	0.283	0.292	0.298	0.302	0.328	0.344	0.351	0.321	0.246
	natural gas (Fossil energy land)	0.077	0.099	0.095	0.107	0.118	0.116	0.130	0.143	0.158	0.181
	Hydropower (Building land)	0.003	0.004	0.005	0.007	0.007	0.007	0.009	0.010	0.013	0.012
	Total	0.958	1.065	1.141	1.181	1.288	1.400	1.484	1.560	1.594	1.617
Total	–	1.994	2.168	2.214	2.313	2.477	2.611	2.703	2.816	2.883	2.760

Unit: ha/cap.

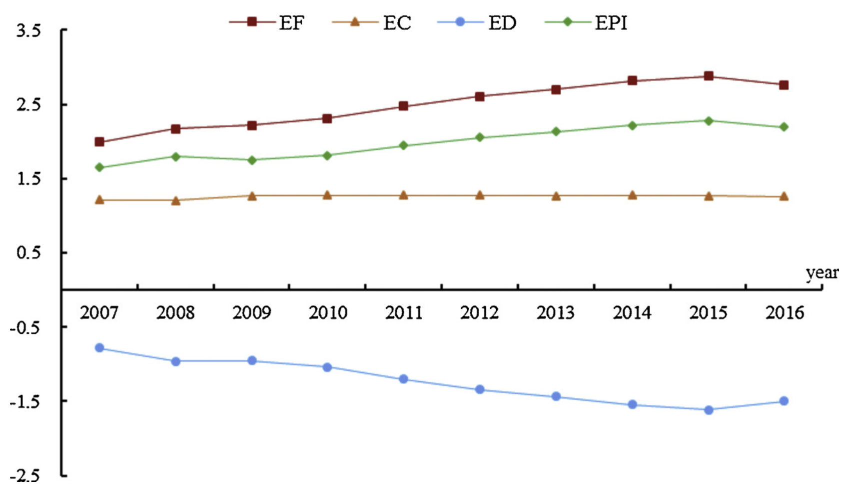


Fig. 7. Changes of ecological footprint per capita, ecological carrying capacity per capita and ecological deficit per capita and ecological press index in Shaanxi from 2007 to 2016.

implemented water pollution control in the Han River, and implemented air pollution control in the Guanzhong area. A series of ecological projects led to a significant increase in the GDI in 2011–2013. In 2014, the EF continued to grow at a low rate, while the GDI declined due to the inefficient use of resources. In 2014–2016, the GDI and the EF were inversely related, and while the GDI continued to grow, the EF gradually declined. This pattern occurs because Shaanxi has achieved good results in optimizing and upgrading the industrial structure given the background of the national ecological environmental policy and environmental supervision. However, overall, the growth rate of the GDI is greater than that of the EF, suggesting that resource and energy consumption in Shaanxi is gradually becoming more efficient. These results indicate that under the multiple effects of urbanization, industrialization, industrial structure optimization and upgrading, and policy adjustment, although the level of green development in Shaanxi has increased while its EF has been reduced, Shaanxi is changing the way in which the level of green development is increased to increase the EF.

4. Conclusion and suggestions

4.1. Conclusion

In the past ten years, the green development of the western region has realized a transformation from the local government to the national will, from isolated treatment to addressing the system, and from the government to pluralistic governance. This transition has played an important role in ecological construction and environmental protection. Shaanxi is a microcosm of China’s ecological civilization construction and green development. The “2016 National Ecological Civilization Construction Annual Evaluation Bulletin” published by the Chinese government only has data for 2016, and it cannot offer a longitudinal comparative analysis of successive years. Therefore, the main work goal is to explore the dynamic characteristics and evolution of the green development level in Shaanxi Province from 2007 to 2016 and to use the EF method for verification. The purpose is to observe the changing trend of GDI and EF to judge whether the improvement in the green development level is the premise for improving the utilization of ecological resources, which would provide a scientific basis for formulating ecological construction and environmental protection policies. The main conclusions of the study are as follows:

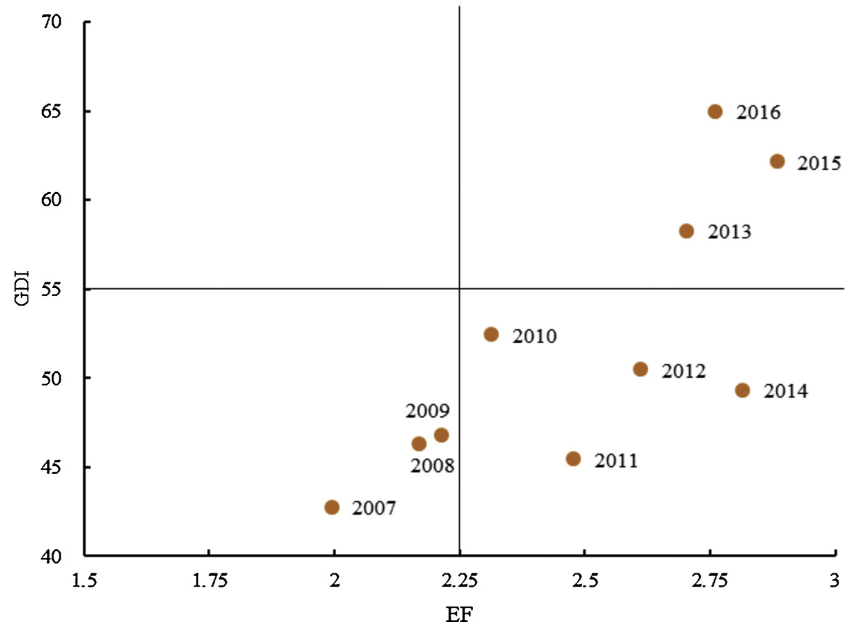


Fig. 8. Trends in per capita ecological footprint, ecological stress index and green development index in Shaanxi Province from 2007 to 2016.

First, the GDI and the EF in Shaanxi showed growth in 2007–2016, indicating that improvement in the level of green development in Shaanxi is occurring at the cost of increasing ecological occupancy, but the growth rate of occupancy is slowing down.

Second, from the secondary index that constitutes GDI, secondary indices such as environmental governance, ecological protection, green living and growth quality have made outstanding contributions to Shaanxi's GDI, whereas secondary indices such as resource utilization and environmental quality are clearly making insufficient progress.

Lastly, the ED and EPI in Shaanxi are both growing, which is inconsistent with the change in GDI in Shaanxi, indicating that the level of green development in Shaanxi has increased but the ecological pressure has also increased annually.

4.2. Suggestions

Based on the actual context of Shaanxi, a GDI system was established to evaluate the overall level of green development in Shaanxi and verify the green development level using the EF. The results show that the quality of green development in Shaanxi still needs improvement based on ecological occupation. Improvement is not sustainable. Strengthening ecological construction is the fundamental measure of the implementation of green development in the northwest and should be the basic strategy for promoting the sustainable use of natural resources in the region. This conclusion not only expands the application field of EF methods in the evaluation of green development levels but also broadens the significance of ecological science and environmental science in social and economic development. This approach has important practical significance for exploring the effectiveness of low-carbon development and green development paths and for formulating ecological construction and environmental protection policies. To this end, the following countermeasures and recommendations are proposed:

First, optimize the energy structure, reduce the proportion of coal consumption, accelerate the pace of the "gasification of Shaanxi", promote the development of clean energy, implement "coal to gas" and "oil to gas" projects, promote electric energy replacement projects, and reduce carbon emissions.

Second, reduce the dependence of economic growth on the energy and chemical industry and accelerate the comprehensive utilization of resources. Additionally, reduce the environmental capacity through structural emission reduction, eliminate outdated production capacity, reduce excess capacity, improve the governance level of key industries such as cement, coking, steel, nonferrous metals, glass, ceramics and brick, and integrate relevant enterprises into the emergency reduction list and the peak production range.

Lastly, rigorous land space management establishes a national land space development and protection mechanism. Strictly control the ecological protection red line to realize supervision of the whole process for the landscape–forest–lake–grass system. Improve the farmland protection system, water resources management system, and environmental protection system to improve environmental capacity.

It should be noted that because the evaluation method and statistical basis of the green development indicator system must still be improved, there is no agreement among various stakeholders. Shaanxi has adopted the corresponding data to replace a consensus because of the difficulty in obtaining data in a unique geographical location. We study Shaanxi Province because it has typical significance for green development in northwestern China. The framework and technical route of our work can be replicated in different regions, but the adjustment of individual indicators will depend on identifying a data source recognized by the local government and the public. We will explore these issues in depth in future research. Therefore, the accuracy of the calculation results and extensions can be further improved.

Declaration of Competing Interest

The authors declare no conflict of interest. No conflict of interest exists in the submission of this manuscript, and it has been approved by all authors for publication.

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