Sustainability in Environment
ISSN 2470-637X (Print) ISSN 2470-6388 (Online)
Vol. 10, No. 3, 2025
www.scholink.org/ojs/index.php/se

Original Paper

Measurement of Efficiency in Rural Ecological Environment Governance, Regional Differences, and Characteristics of Dynamic Evolution—Evidence from China

Shuang Wang[1] & Junjie Wang[1]

[1] College of Economics and Management (College of Tourism), Dalian University, Dalian 116622, China

Received: June 24, 2025 Accepted: August 04, 2025 Online Published: August 20, 2025

doi:10.22158/se.v10n3p268 URL: http://dx.doi.org/10.22158/se.v10n3p268

Abstract

The article calculates the overall efficiency of rural ecological environment governance in 29 provinces of China from 2013 to 2022 using the super-efficiency SBM model. It describes the current development status of each province and employs the Dagum Gini coefficient method to reveal the spatial disparities and their sources and contributions across the four major geographic regions. Furthermore, it utilizes Kernel density estimation to depict the dynamic changes and evolutionary patterns of each province. The study reveals that the overall efficiency of rural ecological environmental governance in China is on a fluctuating upward trajectory, with a regional distribution pattern of eastern > western > central > northeastern areas. Significant inter-regional and intra-regional disparities in the efficiency of rural ecological environmental governance are observed, with the northeastern region exhibiting the greatest intra-regional variation, and the eastern region the least. Additionally, spatial imbalances between regions persist. Based on these findings, targeted policy recommendations are proposed to further enhance the efficiency of rural ecological environmental governance in China.

Keywords

Rural Ecological Environment Governance, Super-Efficiency SBM Model, Dagum Gini Coefficient, Kernel Density Estimation

1. Introduction

Ecological environment, serving as the foundation for human survival and development, plays a crucial role in the global ecosystem, socio-economic structures, and human well-being. The United States is advancing climate-smart agriculture through policies such as the Inflation Reduction Act, aiming to

stabilize soil ecosystems, enhance soil erosion resistance, mitigate water and soil loss, and ensure ecological balance in rural areas. Germany is vigorously developing ecological agriculture, encouraging farmers to use organic fertilizers, reduce the application of chemical pesticides, and implement crop rotation, thereby promoting the sustainable development of agriculture. The importance attached to ecological environment by China is increasingly prominent. As a crucial component of the ecosystem, the rural areas play a significant role in ecological environment governance, which is a key element of ecological civilization construction and is vital to the overall development of a beautiful China. Despite the improvement in the ecological environment of rural areas in China, the steady progress of green agricultural development, the significant enhancement of the rural living environment, and the continuous improvement of relevant institutional norms (Liu, 2024), issues such as imbalance between environmental infringement and redress, misalignment between prevention and regulatory management, and inadequate integration of pollution control protection with capacity building still persist (Chen, Lin, & Guo, 2021).

Moreover, the rural economic foundation is weak, lacking advanced pollution control technologies and managerial expertise, resulting in low efficiency of governance and difficulty in achieving anticipated outcomes. The primary challenges in the governance of rural ecological environments in China can be categorized into three aspects: the necessity to clarify the role of rural ecological governance for urban residents, the imperative to cultivate urban residents' enthusiasm for participating in rural affairs, and the importance of identifying the driving forces that promote rural engagement (Liu, 2024). Rural ecological environment governance constitutes a protracted, arduous, and complex undertaking, encompassing aspects such as "who will govern," "what to govern," and "how to govern" (Zhu, Liu, Peng et al., 2024). Investigating the current realities of rural ecological governance and promoting the sustainable development of rural ecological environments have become urgent practical issues that demand resolution (Chen, 2024). In 2022, the Chinese government will introduce the *"Action Plan for Agricultural and Rural Pollution Control (2021-2025)."* The goal is to complete the environmental remediation of 80,000 administrative villages by 2025, and the rural domestic sewage treatment rate will reach 40 %, basically eliminating a large area of rural black and odorous water bodies and other targets to improve the rural ecological environment. Bai et al. (2021) believe that on the one hand, rural ecological environment governance can show the subjective initiative of the government in rural construction, so that rural people can recognize the importance of ecological protection. On the other hand, it can also promote the construction of rural ecological civilization according to local conditions and stimulate farmers' enthusiasm for participating in ecological environmental protection. The governance of rural ecological environments can not only address environmental issues but also create conditions for the harmonious and stable development of rural societies (Bai, Xu, & Xie, 2023). On this basis, the evaluation of the efficiency of rural ecological environment governance is not only a key breakthrough in innovating the rural ecological environment governance system, but also promotes the continuous improvement and upgrading of the governance system. It is also a powerful measure to

promote the construction of ecological civilization. Strengthening rural ecological environment governance is of great practical significance for promoting the harmonious development of China's rural economy and society and promoting the process of rural modernization (Lu, 2024).

In order to enhance the efficiency of rural ecological environment governance in China, alleviate the contradiction between rural development process and ecological environment, and promote the rural ecological environment to enter the benign track of sustainable development, this paper will study from the following aspects :Firstly, the evaluation index system of rural ecological environment governance is constructed, and the data of rural areas in 29 provinces (autonomous regions and municipalities directly under the central government) from 2013 to 2022 are selected as the research object, and the efficiency value of rural ecological environment governance in rural areas of China is calculated and measured by super-efficiency SBM model. Secondly, the Dagum Gini coefficient method is used to measure the intra-regional differences, inter-regional differences and hypervariable density, and to reveal the sources of differences and their contributions. Third, the Kernel density estimation method is used to describe the dynamic evolution characteristics of rural ecological environment governance.

2. Literature Review

Under the increasingly important and urgent situation of rural ecological environment governance, the academic community has invested extensive and in-depth research. Through literature review, it is found that many experts and scholars have carried out comprehensive and detailed research and discussion, covering all key aspects of rural ecological environment governance, including the innovative construction and practice of governance mode, the formulation and improvement of policies and regulations, the evaluation of implementation effectiveness, and the stimulation and guidance of public participation awareness.

On the model and practice of rural ecological environment governance, Qu (2024) believes that in the practice of rural ecological environment governance, it is necessary to raise farmers' awareness of environmental protection and promote their active participation in environmental governance; strengthen the construction of rural infrastructure, improve the level of rural environmental sanitation; promote ecological agriculture technology, reduce agricultural pollution and other measures to continuously improve the governance effect of rural ecological environment (Qu, 2024). With the continuous implementation of the rural revitalization strategy, Zhang (2024) believes that we should focus on increasing the introduction of advanced agricultural production technology and equipment, make full use of cutting-edge high-tech agricultural technology, deeply explore and innovate the economic development model in line with rural reality, and comprehensively promote the rural economy to a healthy and sustainable development track (Zhang, 2024). At the legal level, Fu and Zhu (2024) think that we should build a new concept of the rule of law in rural ecological environment, improve the legislative system of rural ecological environment, and further play the function of soft law governance; straighten out the rural ecological environment law enforcement system and build a new

model of multi-governance; strengthen the judicial protection of rural ecological environment and improve the judicial protection mechanism of ecological environment (Fu & Zhu, 2025).

In the study of the measurement of rural ecological environment governance, Liang et al. (2024) used input variables (including industrial pollution control input, natural environment control input and domestic pollution control input) and output variables (including economic benefit output, social benefit output and ecological benefit output) as evaluation index system to detect China 's ecological environment governance, which has a certain explanatory effect on the measurement of governance. However, ecological governance is a dynamic process. The index system does not fully consider dynamic adjustment and cannot reflect changes in time, and the natural environment, economic development level and industrial structure in different regions are obviously different. It cannot accurately reflect the actual situation in each region (Liang & Chen, 2024). Huang et al. (2015) studied the input indicators of rural ecological environment governance mainly from the perspectives of rural resource and environment transformation, agricultural production environment governance investment, and rural living environment governance investment. The output indicators are composed of three aspects: social, economic and ecological benefits, taking into account the significant differences between rural and urban areas in terms of function and positioning, and industrial composition (Huang & Zhou, 2015). In terms of measurement methods, only a few scholars have conducted empirical research on the evaluation of rural ecological environment governance efficiency by combining DEA model. For example, Zhang et al. (2023) combined with the DEA-BBC model to evaluate the efficiency of the input-output index system of each city in Gansu Province, and analyzed it from the perspective of spatial heterogeneity (Zhang & Fan, 2023); Xie et al. (2024) used kernel density estimation and Dagum Gini coefficient to explore the spatial and temporal differences of rural human settlements environmental governance performance, and carried out research on rural human settlements environmental governance performance and influencing factors (Xie & Zhu, 2024).

Based on the above research, this paper is devoted to seeking improvement and breakthrough, in-depth study and exploration of the connotation and characteristics of rural ecological environment governance, starting from the efficiency, through the two elements of input and output, multi-dimensional construction of a new perspective of rural ecological environment governance evaluation index system. In terms of research objects, the existing literature mostly explores the rural ecological environment governance from the aspects of the advantages and disadvantages of governance and the impact of individual factors on the ecological environment, and fails to focus on the horizontal differences of dynamic or inter-regional governance in a period of time. The selection of China 's provinces as research objects has certain representativeness and universality, which is helpful for this paper to extract conclusions and inspirations with general significance. It can provide reference and reference for future ecological environment governance and promote regional coordinated development. In terms of research methods, the super-efficiency SBM model can make the final decision-making results more realistic and reliable. The Dagum Gini coefficient and its decomposition

method can identify the spatial gap and its changing trend in each region on the basis of avoiding the problem of data overlap. The Kernel density estimation method uses continuous density curves to describe the inter-regional distribution trend, which has strong stability. Using a single measurement method can easily lead to objective deviation of data quality, and the combination of the three methods enables this paper to carry out more exploration and innovation in rural ecological environment governance.

3. Research Design

3.1 Research Method

1) Super-SBM model

Different from the traditional DEA model, the super-efficiency SBM model directly incorporates the slack variables of input and output into the objective function, which can more comprehensively consider the non-efficiency factors of decision-making units, accurately measure the actual efficiency level of DMUs, and avoid the possible deviations of traditional models. The super-efficiency SBM model used in this paper can be expressed as:

Suppose there are n (j = 1, 2,..., n), each has m inputs (i = 1, 2,..., m), expected outputs y_{ij}^{g}(r = 1, 2,...,) and undesirable outputs (r = 1, 2,..., s_2). The fractional programming model can be expressed as:

$$\min\rho=\frac{\sum_{i=1}^{m} w_i x_{i0}-\sum_{i=1}^{m} s_i^-}{\sum_{i=1}^{m} w_i x_{i0}} \tag{1}$$

S.t. (2)

Among them, is the input weight, λ_i is the intensity variable, s_i^- is the input slack variable, s_i^{g+} is the expected output slack variable, s_i^{b+} is the undesired output slack variable. x_{io}, y_{r0}^{g}, y_{r0}^{b} respectively represent the input, expected output and undesired output of the evaluated decision-making unit, and $\min\rho$ is the SBM efficiency value.There is no upper limit to the efficiency value; a value greater than 1 indicates that the decision-making unit is not only effective but also has a relatively high efficiency level among all decision-making units, with a larger number indicating a more pronounced efficiency advantage for the decision-making unit; equal to 1 means that the decision-making unit has only reached the minimum level of efficiency; less than 1 is similar to the meaning of the SBM model, indicating that there is room for efficiency improvement for the decision-making unit.

2) Dagum Gini coefficient and its subgroup decomposition method

In this paper, the Gini coefficient method proposed by Dagum is used to investigate the spatial

differentiation degree of rural ecological environment governance. This method can deeply analyze the difference composition of rural ecological environment under different groups by decomposing the total difference into intra-group and inter-group differences. The basic definition of Gini coefficient is as follows:

$$G=\frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}|x_{ji}-x_{hr}|}{2n^2\mu} \tag{3}$$

Among them: (x_{hi}) represents the comprehensive index of rural ecological environment governance in l (h) province; k represents the number of geographical regions; n represents the number of cities; n_j(n_h) represents the number of cities contained in the geographical area of l (h).

4. Kernel density estimate

Kernel density estimation is used to estimate the probability density function of random variables, which has better stability than traditional methods. The distribution trend is described by continuous density curve, and the result is more intuitive. The formula is as follows: where is the density function of rural ecological environment governance; n is the number of samples; is the sample value of independent distribution; x is the mean of the sample value; h is the bandwidth, and the estimation accuracy is inversely proportional to the bandwidth size.

$$f(x)=\frac{1}{nb}\sum_{i=1}^{n}k\left(\frac{x_i-x}{h}\right) \tag{4}$$

3.2 Construction of Index System

The evaluation of rural ecological environment governance efficiency is essentially a quantitative calculation of the ratio between the input and output of the governance task in the process of promoting ecological environment governance in rural areas. Its core goal is to optimize the allocation of resources. In terms of input index selection, referring to Chen et al. (2022), from the perspectives of capital, labor, natural resources, agricultural machinery investment, chemical substances and energy (Chen & Mu, 2022), but considering the uneven distribution of resources in rural areas of China and the ecological protection and restoration policies issued by the government, this paper selects five indicators from three aspects of capital, machinery and ecology as input indicators of rural ecological environment governance efficiency. In terms of output indicators, this paper draws on the division of output benefits by Zhang et al. (2023), and selects a total of 8 indicators from three aspects: ecological benefits, production benefits and social benefits (Zhang & Fan, 2023)

The input factors are divided into three dimensions: (1) The governance of rural ecological environment is inseparable from the support of funds. This paper selects the investment in rural landscaping and environmental sanitation as specific indicators and plays an important role in ecological environment governance. (2) Mechanization investment is becoming more and more important. It is the core power source in modern agricultural production. Agricultural machinery and water-saving irrigation facilities are selected as the standard of equipment investment. (3) In the ecological environment, the green coverage area is the most intuitive to reflect the governance situation. In this paper, the artificial afforestation area is used to represent the ecological environment input.

The output factors are also divided into three dimensions: (1) the area of soil and water loss control directly reflects the effectiveness of soil erosion control; greening coverage is a solid guarantee for the sustainable development of the natural environment; as an undesired output, the total amount of chemical oxygen demand discharged from agricultural wastewater is a key yardstick to measure the degree of agricultural non-point source pollution. Therefore, the three are used as representatives to show the ecological benefit output. (2) In the output of production efficiency, considerable grain output and agricultural output value mean that land use efficiency has entered a benign track. The use of chemical fertilizer and agricultural film to a certain extent indicates whether there is a short-sighted behavior of blindly destroying land due to excessive pursuit of output. (3) The rural domestic waste transfer station can see the impact of human life activities on the ecological environment, and select it as a representative of social benefit output. The specific indicators are shown in Table 1:

Table 1. Evaluation Index System of Rural Ecological Environment Governance Efficiency

Element	Dimension	Index	Index name and unit
Input	Capital input	x_1	Rural landscaping construction investment (ten thousand yuan)
		x_2	Rural environmental sanitation construction investment (ten thousand yuan)
	Equipment investment	x_3	Water-saving irrigation facilities investment (ten thousand sets)
		x_4	Investment in agricultural machinery (kilowatts)
	Ecological input	x_5	Artificial afforestation area (ten thousand hectares)
		y_1	Grain production (ton)
		y_2	Agricultural output value (hundred million yuan)

Output	Production efficiency output	y_3	Fertilizer consumption (million ton)
		y_4	Agricultural film use (ton)
	Social benefit output	y_5	Rural domestic waste transfer station (seat)
		y_6	Total discharge of chemical oxygen demand (COD) from agricultural wastewater (ton)
	Ecological benefit output	y_7	Green coverage (%)
		y_8	Soil erosion control area (thousand hectares)

3.3 Data Sources and Processing

This paper mainly measures the efficiency of rural ecological environment governance in rural areas of China from 2013 to 2022. The data are derived from “China Statistical Yearbook”, “China Rural Statistical Yearbook”, “China Environmental Statistical Yearbook” and “China Urban and Rural Construction Statistical Yearbook”. Considering the problem of missing data, the moving average method is used to replace and interpolate the missing data. In addition, in order to ensure the accuracy and effectiveness of data analysis, the data is standardized according to the Dearun software formula: 0.9 * (x-min) / (max-min) + 0.1.

4. Authentic Proof Analysis

4.1 Analysis of Rural Ecological Environment Governance Efficiency

Using maxdea software and super-efficiency DEA-SBM model, the efficiency value of rural ecological environment governance in China 's provinces from 2013 to 2022 is calculated, as shown in Table 2.

Table 2. Efficiency Value of Rural Ecological Environment Governance from 2013 to 2022

Province	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Bei Jing	0.43	0.43	1.04	1.04	1.01	1.00	1.12	1.02	1.10	1.04
Tian Jin	1.05	1.01	1.00	1.04	1.10	1.03	1.04	0.80	0.87	1.13
He Bei	1.00	1.01	1.01	1.01	0.73	0.47	0.63	0.60	1.03	1.01
Hai Nan	1.01	1.01	1.00	1.01	1.00	0.74	1.01	1.02	1.09	1.03
GuangDong	0.35	1.05	0.30	1.07	1.01	0.86	1.00	0.90	1.12	1.02
Shan Dong	0.17	0.17	0.18	1.02	1.01	1.02	1.11	0.19	1.02	1.00
Fu Jian	1.00	0.61	0.64	1.02	1.02	1.02	1.02	0.83	0.89	1.01

Jiang Su	1.01	0.64	1.00	1.02	1.01	1.01	1.03	0.50	0.73	1.02
Zhe Jiang	0.29	0.29	0.29	0.29	0.27	0.28	0.30	0.30	0.32	0.32
Liao Ning	0.37	0.37	0.33	1.05	1.03	1.32	1.00	1.00	1.07	0.88
Ji Lin	1.02	1.00	1.00	1.04	1.00	0.64	1.03	1.01	1.04	1.18
Hei Longjiang	1.01	1.02	1.01	1.15	1.13	1.01	1.23	0.71	1.10	1.02
An Hui	0.22	0.23	0.26	0.25	0.24	0.22	0.23	0.23	0.23	0.23
Jiang Xi	1.01	0.66	0.44	0.51	0.44	0.41	1.00	1.41	1.37	1.27
He Nan	1.01	1.00	1.01	1.20	1.08	1.06	1.02	1.00	1.00	1.02
Hu Bei	0.35	0.44	0.38	0.45	0.36	0.27	0.31	0.30	0.35	0.37
Hu Nan	0.89	1.00	1.00	1.02	1.00	0.74	0.71	0.69	0.68	1.00
Shan Xi	0.53	0.56	0.31	1.05	1.07	1.03	1.00	0.79	1.00	1.01
Guang Xi	0.33	0.30	0.27	0.35	0.29	0.28	0.37	0.20	0.24	0.37
ChongQing	1.04	1.03	1.04	1.12	1.01	1.08	1.08	0.78	0.89	1.05
Si Chuan	1.01	1.00	1.00	1.11	0.75	1.04	1.09	0.37	0.65	1.06
Gui Zhou	1.04	1.00	0.60	1.08	1.00	0.65	1.03	0.31	0.65	1.04
Yun Nan	0.72	0.71	0.36	0.53	0.40	0.33	0.45	0.25	0.85	1.01
Shaan Xi	1.06	1.01	1.04	1.06	1.03	1.04	1.21	0.84	1.02	1.06
Gan Su	1.00	1.00	0.89	1.20	1.01	1.00	1.00	1.10	1.00	1.02
Qing Hai	1.01	1.12	1.06	1.16	1.33	1.05	1.00	0.76	1.03	1.05
Ning Xia	0.39	0.40	0.41	0.43	0.46	1.01	1.02	1.03	1.04	1.11
Xin Jiang	1.03	1.06	1.12	1.17	1.05	1.06	1.09	0.80	1.02	1.03
Nei Meng	1.01	1.29	0.19	0.20	1.02	1.01	1.00	0.87	1.02	1.01
Mean Value	0.77	0.77	0.69	0.88	0.86	0.82	0.90	0.71	0.88	0.94

It can be seen from the above table that the average efficiency of ecological environment governance in each stage is less than 1, indicating that China still needs to strengthen governance in rural ecological environment. Although the country has paid more and more attention to the management of rural ecological environment in recent years, the 18 National Congress of the Communist Party of China has raised the construction of ecological civilization to a new height as a basic national policy and implemented the strategy of rural revitalization, it is still necessary to use various resources to improve the rural ecological environment.

From the dynamic trend point of view, the cities in the 10 years in a small increase or maintain the original development trend; among them, Shandong Province had the largest increase between 2013 and 2022. The difference between 2013 and 2022 was 0.83, but its fluctuation was more obvious. In contrast, Xinjiang and Inner Mongolia did not increase significantly despite fluctuations. It shows that

the growth trend of rural ecological environment governance efficiency in Xinjiang and Inner Mongolia is quite different from that in other provinces. The reason is that Xinjiang and Inner Mongolia are representative cities in the western region. Xinjiang has a large arid area, accounting for 83.3 % of Xinjiang 's land area. The average annual precipitation is only 147 mm, the vegetation is sparse, the forest coverage is low, and the ecological environment self-healing ability is poor. Most areas of Inner Mongolia belong to arid and semi-arid areas, and the grassland ecosystem is fragile. Once destroyed, it is difficult to restore. Activities such as overgrazing can easily lead to grassland degradation and land desertification, resulting in a small increase compared with other provinces.

During the study period, the provinces with efficiency values below 1 in 2022 are: Zhejiang, Liaoning, Anhui, Hubei, and Guangxi, as shown in Figure 1 below. Among them, Liaoning has the largest degree of fluctuation, and even reached an efficiency value greater than 1 in 2016-2021, exceeding the national average. The reason may be related to the number of enterprises punished for illegal emissions in Liaoning in 2016 reached 200, effectively curbing the damage of industrial pollution to the rural ecological environment and ensuring the results of rural ecological environment governance. At the same time, the promotion area of ecological agriculture technology in Liaoning Province reached 5 million mu in 2016, which not only reduced agricultural non-point source pollution, but also promoted rural economic development, achieved a win-win situation between ecology and economy, and improved governance efficiency. However, in 2022, rural domestic waste and sewage in Liaoning Province are basically in a state of disorderly discharge. The rural domestic waste and human feces in the province reach 8.4 million tons, and the domestic sewage is 600 million tons, which flows into and soaks into rivers and groundwater, seriously polluting the water body. The province 's annual output of 20 million tons of crop straw, only part of it is used, and the rest is piled up in disorder, affecting environmental governance. Among the provinces, Guangxi has the lowest efficiency value in 2020, only 0.2. As of 2020, the rural domestic sewage treatment rate in Guangxi is only 9.2%, which is still far from the national average rural domestic sewage treatment rate of 25%. From 2016 to 2019, the sales volume of chemical fertilizers in the region increased by 25.7 %, and the utilization rate was low, which led to problems such as soil and water pollution. It can be seen that improving governance efficiency is affected by many factors and requires multi-party cooperation and coordinated development.

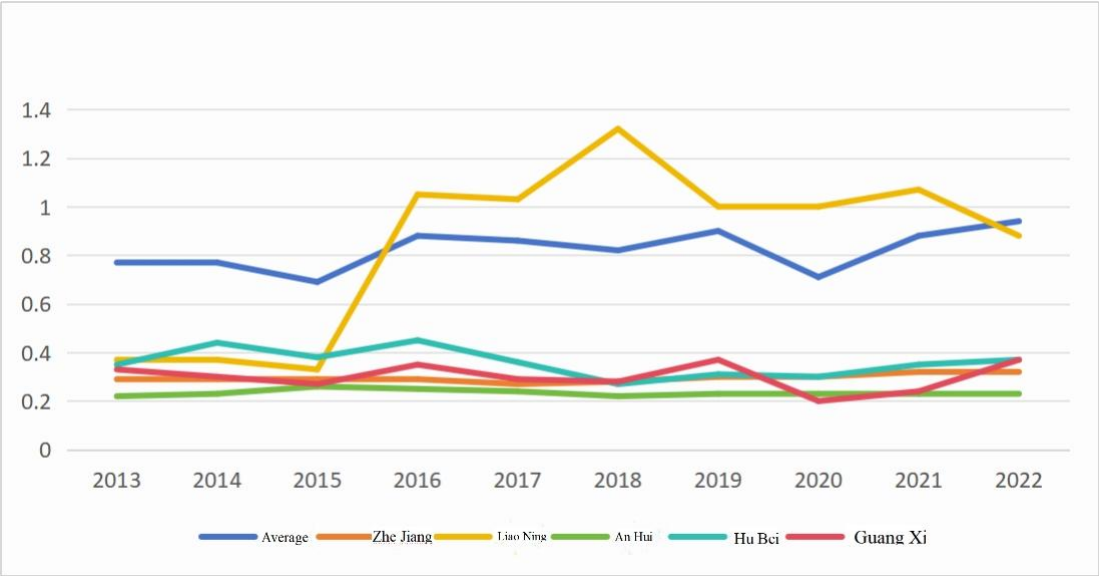


Figure 1. The Average Value of China's Rural Environmental Governance Efficiency in Four Regions

As shown in Figure 2, the high efficiency of rural ecological environment governance in China gradually shifted from the western region to the eastern region from 2013 to 2022. The provinces (autonomous regions, municipalities directly under the central government) with darker colors in the graph have higher efficiency values. From various years, the provinces with higher efficiency values in 2013 were mainly Xinjiang, Shaanxi, Chongqing, and Guizhou, while Shandong, Anhui, and Guangxi had lighter colors; In 2013, among the four major regions in China, the efficiency of rural ecological environment governance in the western region was relatively high, with Xinjiang and Shaanxi ranking in the top two with efficiency values greater than 1. Shandong, Anhui and other regions had lower efficiency values, with efficiency values below 0.35. In 2017, the efficiency value of Northeast China significantly improved, with Heilongjiang being the most significant. In 2020, the efficiency value of Hunan Province in the central region significantly increased, while the efficiency value of Hubei and other places decreased. In 2022, the overall efficiency of rural ecological environment governance in China has improved, and both the central and local governments have increased their funding for rural ecological environment governance, improving the quality of rural ecological environment. It can be seen that different regions have different development trends in different years.

4.2 Analysis of Regional Differences in Rural Environmental Governance Efficiency in China

Through the analysis of 4.1 on the efficiency of rural ecological environment governance at the provincial level, it can be seen that there are spatial differences in the efficiency of rural ecological environment governance in China. In order to further analyze the sources of regional differences in the efficiency of rural ecological environment governance, this paper will use the Dagum Gini coefficient method to measure and analyze the causes of regional differences from the perspective of intra-regional differences, inter-regional differences and super-variable density according to the four major regions of the eastern, northeastern, central and western regions based on China 's regional division standards. The

eastern region includes Beijing, Tianjin, Hebei, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong and Hainan. The northeast region includes Liaoning, Jilin, Heilongjiang; the central region includes Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan; the western region includes Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang.

4.2.1 Overall Differences and intra-regional Differences

As far as the overall difference analysis is concerned, the spatial difference of rural ecological environment governance efficiency between 2013 and 2022 has not changed much as a whole. The Gini coefficient is between 0.118 and 0.269, and it decreases from 0.215 to 0.118 during the sample period, maintaining a slight fluctuation state. The trend is relatively gentle, and it reaches the minimum value of 0.118 in 2022, as shown in Table 3 below. In terms of the regional differences in the efficiency of rural ecological environment governance, the difference in the northeast region is the largest, with an average of 0.308, and the difference in the east is the smallest, 0.115. The overall trend of decline in various regions shows that the regional synergy of modern service industry development is gradually increasing in recent years.

Table 3. Dagum Gini Coefficient Decomposition Results

Years	Overall difference	Intra-region difference			
		Eastern part	Northeastern part	Midportion	Western part
2013	0.215	0.163	0.348	0.297	0.137
2014	0.225	0.203	0.224	0.248	0.145
2015	0.269	0.222	0.214	0.319	0.206
2016	0.184	0.103	0.329	0.172	0.166
2017	0.180	0.050	0.342	0.181	0.195
2018	0.202	0.121	0.349	0.226	0.171
2019	0.153	0.070	0.337	0.159	0.126
2020	0.251	0.121	0.294	0.312	0.260
2021	0.166	0.058	0.309	0.193	0.143
2022	0.118	0.040	0.336	0.135	0.068

4.2.2 Inter-provincial Differences

Further analysis of the inter-regional differences in the efficiency of rural ecological environment governance in China at various stages shows that (see Table 4), the average difference between the northeast region and the eastern region is the largest, which is 0.355, which may be related to the differences in natural conditions and economic development levels. The difference between the northeast region and the central region is the smallest, which is 0.123. It can be seen that there are

similar phenomena in the rural ecological environment governance in the northeast and central regions, indicating that the rural areas in the northeast and central regions are relatively close in the ability and level of ecological environment governance.

Table 4. Interregional Differences in the Efficiency of Rural Ecological Environment Governance in China at Different Stages

Years	Intra-region difference					
	East-Northeast	East-Central	East-West	Northeast-Central	Northeast-West	Central-West
2013	0.336	0.256	0.350	0.154	0.339	0.253
2014	0.397	0.233	0.394	0.184	0.424	0.211
2015	0.399	0.313	0.334	0.220	0.384	0.306
2016	0.346	0.154	0.343	0.149	0.357	0.176
2017	0.347	0.138	0.339	0.140	0.350	0.192
2018	0.353	0.204	0.342	0.154	0.345	0.212
2019	0.343	0.126	0.333	0.102	0.342	0.150
2020	0.325	0.243	0.380	0.209	0.332	0.299
2021	0.360	0.141	0.377	0.111	0.343	0.179
2022	0.337	0.095	0.342	0.059	0.336	0.110

4.2.3 Sources and Contributions of Regional Differences

Table 5 reflects the contribution sources of spatial differences in rural ecological environment governance in the four regions. The inter-regional contribution to the spatial difference of rural ecological environment governance is the largest, with an average contribution of 0.077, followed by the super variable density, with an average contribution of 0.072. The contribution within the region is the smallest, with an average contribution of 0.047; all three show a slight fluctuation, and the trend is stable. The regional differences are the main source of spatial differences. The contribution of inter-regional super-variable density means that the cross-terms between various geographical regions are an important reason for the unbalanced characteristics of rural ecological environment governance. Therefore, there is a more obvious differentiation phenomenon in the rural ecological environment governance in each region. Therefore, it is necessary to promote the development of lagging areas as soon as possible to take the road of differentiated governance and enhance the coordination and linkage of regional governance.

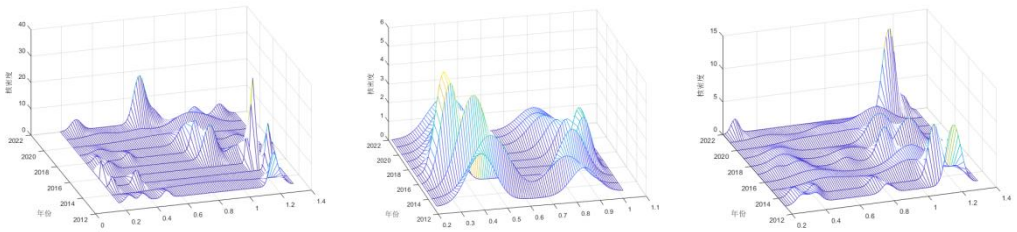
Table 5. Spatial Difference Contribution of Rural Ecological Environment Governance in Four Major Regions

Years	Contribution values

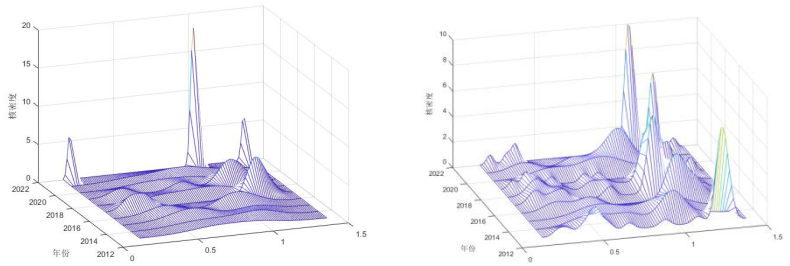
	Within the region	Inter-regional	Ultra-density variation
2013	0.052	0.084	0.079
2014	0.055	0.086	0.084
2015	0.070	0.098	0.102
2016	0.045	0.057	0.082
2017	0.043	0.082	0.055
2018	0.050	0.083	0.069
2019	0.035	0.071	0.047
2020	0.065	0.072	0.114
2021	0.037	0.076	0.053
2022	0.022	0.061	0.034
Mean Value	0.047	0.077	0.072

4.3 The Dynamic Evolution Characteristics of Rural Ecological Environment Governance

In order to continue to explore the dynamic information of rural ecological environment governance, this paper uses Kernel density estimation method to analyze the distribution characteristics of rural ecological environment governance in the whole country and four major regions, as shown in figure 3.From the perspective of the overall evolution characteristics of the country, the nuclear density in 2022 has been greatly improved, and there is no single peak phenomenon, indicating that the governance efficiency among various regions in China has been improved, but there are still differences. In terms of sub-regions, there is no trailing phenomenon in each region. The nuclear density curve of the efficiency of rural ecological environment governance in the northeastern region shows an obvious main peak and multiple small sub-peaks, with an obvious right-shift trend. The central point of 2014-2017 is relatively high and concentrated; from 2020 to 2022, the location of the center point has declined and the distribution range has changed, indicating that the difference in the northeast region has gradually decreased. The moving range of the eastern center point on the vertical axis is larger, from the low point of close to 0 to close to 20, indicating that the rural ecological environment governance is significantly different between different years. The main peak of the central and western regions in 2013-2020 tended to be stable, and the main peak suddenly increased in 2021-2022, indicating that the level of rural ecological environment governance in the two years was obvious.



Eastern region Northeastern region West region



Central region National

Figure 3. The Nuclear Density Level of Rural Ecological Environment Governance

5. Discussion

Firstly, from the perspective of the effect value of rural ecological governance, the average efficiency of the whole country is less than 1, and the value has changed in the past ten years, roughly between 0.69 and 0.94, which is in a relatively stable but slightly fluctuating state, but there is a gap between provinces. Zhejiang, Liaoning, Anhui, Hubei and Guangxi belong to cities with low efficiency values; Beijing and Tianjin stand out among many provinces, and their average efficiency is far ahead. In addition, some cities (such as Inner Mongolia, Guangdong, Shandong, etc.) showed large fluctuations during the study period, which is worthy of attention.

Although Zhejiang is located in the developed areas of eastern China, its efficiency value is low. The reason is that the industry in rural areas of Zhejiang is developing rapidly. Some small enterprises and workshops have problems such as imperfect environmental protection facilities and substandard pollutant emissions, which have caused certain pollution to the rural ecological environment. At the same time, some rural areas have introduced some enterprises with high pollution and high energy consumption in the process of undertaking industrial transfer, which further aggravates the pressure of rural ecological environment. The efficiency values of Beijing and Tianjin are higher. Tianjin has not only issued a series of policy documents such as ' Tianjin Municipal People 's Government General Office forwarded the notice of the Municipal Agricultural Commission, the Municipal Construction Commission and the Municipal Environmental Protection Bureau on improving the rural living environment of our city to accelerate the implementation of the beautiful rural construction ', clarified the objectives, tasks and measures of rural ecological environment governance, and provided strong policy guidance for governance work. In 2022, it will arrange special funds for rural environmental remediation of 7.26 million yuan to support rural environmental remediation projects such as Wuqing District. Inner Mongolia reached a peak of 1.29 in 2014, the reason for which was that in 2014, General Secretary emphasized that Inner Mongolia should be built into an important ecological security barrier in northern China, and won 590 million yuan of special funds for environmental protection from the central government, 430 million yuan of special funds for environmental protection arranged by the

autonomous region, and the total scale of grassland construction remained at more than 40 million mu.

Secondly, from the Dagum Gini coefficient analysis of regional differences and their sources and contributions, it can be concluded that the overall difference decreased by 0.097, indicating that the rural ecological environment governance was further enhanced in terms of coordination. According to the division of China 's four major regions, it can be found that the average difference between the northeast and the west of the rural ecological environment governance level is the largest, 0.355; the reason is that on the one hand, the level of economic development in the northeast region has certain advantages over the west, facing economic transformation, and local finance has financial support for rural ecological environment governance. The economy of the western region is relatively backward, the fiscal revenue is low, the investment in rural ecological environment governance is seriously insufficient, and many rural areas lack basic environmental protection facilities; on the other hand, the northeast region is dominated by plains, and the terrain is flat and open, which is conducive to the centralized development of ecological environment management projects, such as large-scale sewage treatment plants, landfill construction and farmland pollution control. The terrain in the western region is complex, with more plateaus, deserts and gobi in the northwest, more mountains, plateaus and karst landforms in the southwest. The rural areas are scattered, the transportation is inconvenient, the cost of governance is high, the transportation and installation of governance technology and equipment are difficult, and it is difficult to achieve centralized governance in some areas. The difference between northeast and central is the smallest, which is 0.123. The economic development level of the northeast region and the central region is in the middle position in the country, the local fiscal revenue and the income level of rural residents are similar, and the capital investment ability in rural ecological environment governance is equivalent, and the northeast region and the central region are important agricultural production areas in China. The rural economy is mainly agricultural production, the industrial development lags behind the eastern region, and the industrial structure is relatively single, which makes the difference in governance efficiency between the two regions the smallest.

Thirdly, it can be seen from the Kernel density estimation dynamic evolution feature map that there is no single peak phenomenon in the overall evolution characteristics of the country, and the governance efficiency between various regions in China has been improved. This research result is consistent with the previous conclusion of the Gini coefficient, indicating that the coordination of rural ecological environment governance in various regions has been strengthened. The height of the peaks in the central and western regions will increase in 2021 as a whole, and the distribution of rural ecological environment governance in these two regions will generally show a concentrated trend. The kernel density curve of rural ecological environment governance efficiency in the northeast region shows a regular rightward trend, which indicates that the governance level in the northeast region has an upward trend. Each region presents different characteristics and trends in the process of governance. It is necessary to combine its own advantages, adjust measures to local conditions, and strive to achieve coordinated development.

6. Conclusion and Suggestions

6.1 Conclusion

Based on multiple dimensions, this paper constructs an evaluation index system for the efficiency of rural ecological environment governance. According to the panel data of 29 provinces from 2013 to 2022, the super-efficiency DEA-SBM model, Dagum Gini coefficient method and Kernel density are used to measure the efficiency of rural ecological environment governance in China and analyze its regional differences. The evolution trend of rural ecological environment governance efficiency is described, and the following conclusions are drawn:

(1) According to the analysis results of the comprehensive index of rural ecological environment governance efficiency, the effectiveness of rural ecological environment governance in China shows very different characteristics at the national and provincial levels. From a national perspective, China 's overall effect in rural ecological environment governance has been improved, which fully demonstrates the country 's firm determination in the field of ecological civilization construction and the effective implementation of a series of policy measures. However, when exploring at the provincial level, it is found that there is a certain gap between provinces. In terms of regional governance efficiency, it shows a pattern of eastern > western > central > northeast. It is worth noting that even within each region, the governance situation is not uniform, and there are cities with governance efficiency lower than 1 in each region. In addition, affected by many factors, the efficiency of rural ecological environment governance in individual cities fluctuates greatly.

(2) From the analysis of regional differences, the overall trend of the Gini coefficient of rural ecological environment governance efficiency in 29 provinces is relatively flat, with no significant fluctuations. In terms of regional differences, the gap between the northeast and the east is the largest, and the problem of spatial imbalance between regions still exists. The Gini coefficient decomposition shows that the inter-regional contribution to the spatial difference of rural ecological environment governance is the largest, indicating that the spatial imbalance between regions is the main reason for the overall difference, and the secondary reason is the super variable density. The difference within the four regions contributes the least to the overall difference.

(3) From the analysis of the evolution characteristics of the national rural ecological environment governance efficiency, it can be concluded that at the national level, there is no single peak phenomenon in the year of investigation, showing a trend of differentiation. In terms of regions, each has its own characteristics but there is no tailing phenomenon. The nuclear density curve in the northeastern region shows a main peak with multiple small sub-peaks, indicating that there is no obvious polarization in the region; the eastern region has significant differences in governance in different years; the main peak of the central and western regions in 2013-2020 tended to be stable, and the main peak suddenly increased in 2021-2022, indicating that the level of rural ecological environment governance in these two years was obvious.

6.2 Suggestion

First of all, for provinces and cities with low governance efficiency, the government should play a leading role and give policy and financial support. The general infrastructure construction in rural areas is relatively weak, and the investment and construction of infrastructure should be increased. By improving the infrastructure such as the construction of rural domestic waste treatment plants and the construction of domestic sewage centralized treatment plants, it can not only effectively improve the rural ecological environment, reduce the pollution of garbage and sewage to soil, water and air, but also lay a solid foundation for the sustainable development of rural areas.

Secondly, it is necessary to promote the coordinated development of rural ecological environment governance, cross-regional cooperation, and form a good situation of synergy. The eastern region should unreservedly export advanced environmental protection technology to the central and western regions, and share the valuable experience accumulated in the process of rural ecological environment governance. Through technical assistance and experience exchange, we can help other regions to improve the ability of rural ecological environment governance, narrow the gap of governance efficiency between regions, and promote the balanced development of rural ecological environment governance in China. Other regions should further explore the new path of environmental protection and economic development in line with their own development characteristics, and strive to find the best balance between the two. Combined with the local resource endowment, industrial structure and ecological characteristics, the rural ecological environment governance strategy is formulated. Through unremitting efforts, we will gradually realize the catch-up and surpassing of rural ecological environment governance, continuously improve the efficiency of governance, and finally achieve the benign interaction and common prosperity of ecological environment and economic development in various regions.

Finally, strengthen supervision and evaluation. To formulate regulatory standards for the construction and operation of rural ecological governance infrastructure, and to clarify the responsibilities and powers of the regulatory authorities. Strengthen the quality supervision of the project construction process to ensure that the construction quality of infrastructure such as domestic waste treatment plants, domestic sewage pipe networks and treatment plants meets the standards. The performance evaluation index system of rural ecological environment governance project is established, and the project is evaluated from the aspects of ecological environment improvement effect, economic benefit and social benefit, so as to further improve the efficiency of rural ecological environment governance.

References

Bai, L. T., Xu, J. H., & Xie, X. J. (2023). Deficiencies and Countermeasures of Rural Ecological Environment Pollution Control Under the Background of Rural Revitalization. *Agricultural Economy*, (08), 34-37.

Chen, M. Y. (2024). Problems and Countermeasures of Rural Ecological Governance Under the Background of Rural Revitalization. *Rural Economy and Technology*, *35*(23), 70-73.

Chen, Y., & Mu, H. Z. (2022). Research on the Measurement and Influencing Factors of China's Agricultural Ecological Efficiency. *Statistics and Decision Making*, *38*(23), 101-106.

Chen, Z., Lin, Y., & Guo, J. (2021). Practical Issues and Optimization Ideas of China's Rural Ecological Environment Governance under the Background of "Rural Revitalization Promotion Law". *Modern Law Research*, *2*(4).

Ding, G. F., & Jiang, M. (2022). The Legal Logic of High-Quality Rural Ecological Environment Governance in China. *Administrative Forum*, *29*(06), 118-126.

Feng, X. (2021). Construction of Rural Ecological Environment Governance Community in Rural Revitalization. *Gansu Social Sciences*, (03), 167-173.

Fu, C. L., & Zhu, Y. L. (2025). Legalization of Rural Ecological Environment Governance: Value Review, Practical Obstacles, and Practical Approaches. *Public Governance Research*, 1-14.

He, W., & Tang, J. B. (2022). "Idle Rotation" of Rural Environmental Policies and Its Correction—Based on a Fuzzy-Conflict Analysis Framework]. *Journal of Yunnan University (Social Sciences Edition)*, *21*(01), 116-123.

Huang, Y., Zhou, Z., & Huang, J. (2015). Comparative Analysis of Regional Rural Ecological Environment Governance Efficiency Based on DEA. *Arid Zone Resources and Environment*, *29*(03), 75-80.

Jiang, Y., Huang, L., Liu, Y., & Wang, S. (2024). Impact of Digital Development and Technology Innovation on the Marine Fishery Economy Quality. *Fishes*, *9*, 266.

Li, C. (2022). Research on the Modernization Policy Development of Rural Ecological Environment Governance in China. *Academic Exploration*, (08), 45-51.

Liang, T., & Chen, Z. (2024). Measurement, Regional Differences, and Convergence Characteristics Analysis of China's Ecological Environment Governance Efficiency. *Statistics and Decision Making*, *40*(07), 93-97.

Liu, H. (2024). Tapping and Cultivating the Main Force of Rural Ecological Environment Governance. *Advances in Social Science and Culture*, *6*(4).

Liu, S. X., & Li, J. W. (2024). The Dilemma and Relief Path of Rural Ecological Environment Governance in China. *Environmental Protection*, *52*(15), 69-71.

Liu, Y. Q., Meng, Q. L., Jia, X. Y. et al. (2024). The Current Situation and Governance Path of Rural Ecological Environment from the Perspective of Rural Revitalization Strategy. *Rural Economy and Technology*, *35*(18), 34-37.

Lu, M. (2024). The Problems and Countermeasures of Current Rural Ecological Environment Governance. *Agricultural Studies*, *8*(1).

Qu, Z. (2024). Research on the Practical Dilemmas and Countermeasures of Rural Ecological Environment Governance. *Environment and Life*, (10), 91-93.

Shuang, W., Yafei, L., Zenghui, L. et al. (2022). Analysis on Energy Conservation and Emission Reduction Efficiency and Influencing Factors for Ports around Bohai in China under the Low Carbon Target. *Sustainability*, *14*(22).

Wen, N. (2021). Pluralistic Co-governance: Rural Ecological Environment Governance under the Background of Rural Revitalization. *Journal of Yunnan Minzu University (Philosophy and Social Sciences Edition)*, *38*(03), 115-120.

Wen, W., Zhang, H. S., & Zhang, Q. W. (2022). Evaluation of Rural Financial Ecological Environment Based on EWM-DEA Model—Taking 12 Prefecture-Level Cities in Heilongjiang Province as an Example]. *Agricultural Economics and Management*, (02), 92-102.

Wen, Y., & Zhu, Q. W. (2021). Symbiotic Governance of Rural Ecological Environment: Mechanism, Evolution, and Challenges. *Journal of Guangxi University (Philosophy and Social Sciences Edition)*, *43*(05), 93-101.

Xie, H. Q., & Zhu, X. F. (2024). Measurement and Spatiotemporal Evolution of Rural Human Settlement Environment Governance Performance in China. *Resource Development and Market*, *40*(07), 970-978.

Zhang, B., & Mei, Y. Y. (2023). Rural Ecological Environment Governance in the Context of Comprehensive Rural Revitalization: Policy Evolution and Path Selection. *Journal of Nanjing Agricultural University (Social Sciences Edition)*, *23*(02), 112-120.

Zhang, C. (2024). Research on the Dilemmas and Countermeasures of Rural Ecological Environment Governance under the Background of Rural Revitalization. *Digital Agriculture and Intelligent Farm Machinery*, (11), 53-55.

Zhang, W. C. (2021). Efficiency Evaluation and Improvement Strategies of Rural Ecological Environment Governance Based on DEA Model. *Agriculture and Technology*, *41*(20), 113-116.

Zhang, X., & Fan, G. H. (2023). Efficiency Evaluation and Spatial Heterogeneity Analysis of Rural Ecological Environment Governance in Gansu Province. *Territory and Natural Resources Study*, (06), 37-42.

Zhang, Z. S. (2020). Pluralistic Co-governance: Innovative Models of Rural Ecological Environment Governance under the Perspective of Rural Revitalization Strategy. *Journal of Chongqing University (Social Sciences Edition)*, *26*(01), 201-210.

Zhu, J., Liu, X., Peng, Y. et al. (2024). "Joint Creation" Perspective on Rural Ecological Environment Governance Mechanism Research. *Environmental Science & Technology*, *47*(S2), 13-18.