



Evaluation of Governance Effectiveness of Ecological Environment Governance Measures on the Qinghai Tibet Plateau and Construction of Linear Regression Model

Guzhenzhen Hu^{1,*}

¹ Nanjing Foreign Language School, Nanjing 123456, Jiangsu, China

SUMMARY: *The large-scale industrial expansion has exacerbated the ecological vulnerability of the Qinghai Tibet Plateau and its surrounding areas. This study focuses on the Qinghai Tibet Plateau as the survey area and has carefully developed an evaluation index system suitable for the ecological vulnerability of the region. By integrating statistical data from 2015 to 2024, using the COWA operator method to scientifically weight different indicators, and utilizing multiple parallel regression analysis techniques, a linear regression model was established. This model is used to quantitatively examine the dynamic interaction and collaborative development trajectory between regional ecological environment and economic and social development system. The analysis results indicate that from 2015 to 2024, the overall comprehensive benefits of the ecological and social subsystems of the Qinghai Tibet Plateau have shown an upward trend, while the economic subsystems have shown a downward trend. Although the degree of coupling and coordination between ecological environment and economic and social development has improved, the type of coupling and coordination has shifted from mild imbalance to near imbalance. At the same time, the main constraints of coupling coordination have gradually shifted from the social subsystem to the economic subsystem. Although the ecological environment and economic and social development level of the Qinghai Tibet Plateau have generally improved, the degree of coupling and coordination is still relatively low. Given these observations, it is necessary to continuously improve the policy support framework for regional green development, establish and strengthen the effectiveness evaluation mechanism for green development, prioritize the cultivation and development of professional talent pools, and increase investment in technological innovation in the future.*

KEYWORDS: *Qinghai Tibet Plateau; Ecological environment governance; Evaluation of governance effectiveness; Linear regression; Green development; Ecological Restoration*

1 Introduction

The Qinghai Tibet Plateau and its surrounding areas are located at the intersection of the Indian Ocean Plate and the Eurasian Plate, sandwiched between the Tarim Platform, the Sino Korean Platform, the Yangtze Platform, and the Indian Platform. It is an area with frequent geological activities in China. The average altitude is 4000-5000m, belonging to the plateau and high mountain climate, controlled by the secondary high pressure and the Mongolian Siberian high pressure anticyclone center, far away from the ocean, severely eroded by wind, and widely distributed in deserts [1]. The Qinghai Tibet Plateau and its adjacent areas exhibit significant ecological sensitivity characteristics, manifested in the environmental state being prone to

*15950571635@163.com

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fluctuations, poor stability, weak resistance to external disturbances, and strong spatial mobility of ecological elements. Based on the above characteristics, it can be clearly concluded that the overall ecological environment system of the Qinghai Tibet Plateau and its surrounding areas exhibits high vulnerability characteristics.

For a long time, in the historical trajectory of traditional agriculture and animal husbandry in the Qinghai Tibet Plateau and its surrounding areas, continuous practices such as overgrazing of grasslands, deforestation, and overexploitation of land and wetlands (especially in steep slope areas) have led to a sharp decline in grassland and forest coverage. This in turn exacerbates the upgrading and expansion of desertification processes throughout the region. At the same time, in the process of the exploitation and utilization of energy and mineral resources in the region, the use of unscientific mining technology and predatory exploitation of shallow resources not only caused a lot of waste of mineral assets, but also highlighted the key problem of "high mining volume and low utilization efficiency". In addition, with the booming tourism industry in the Qinghai Tibet Plateau and its surrounding areas, some regions blindly pursue the maximization of economic benefits, ignoring the ecological carrying capacity of the surrounding environment, which has led to a sudden surge in ecological pressure. This unsustainable industrial development has further exacerbated the ecological vulnerability of the region, posing more severe ecological challenges to the Qinghai Tibet Plateau and its neighboring areas. Given the deteriorating ecological conditions of the Qinghai Tibet Plateau and its surrounding areas, the issue of ecological governance has attracted widespread attention from all sectors of society [2]. Considering the limited ecological self-recovery capacity and effectiveness of traditional governance strategies in the region, the core goal of ecological governance should shift towards promoting the transformation of regional industrial development models towards sustainability and efficiency. Specifically, it is necessary to use extensive industrial practice transformation as a springboard, guided by alleviating ecological poverty, actively explore and implement low-carbon industrial development paths, and regard it as a key strategy for governing the ecological environment of the Qinghai Tibet Plateau and its surrounding areas. Therefore, conducting multidimensional and multi-level analysis to propose countermeasures and suggestions for ecological governance in the region is not only urgent, but also has significant research value and practical significance.

The Qinghai Tibet Plateau and its adjacent areas are known as the "roots of rivers" and the "foundation of ecology". They not only occupy a crucial position in the international geopolitical landscape, but also serve as an indispensable security line in southwestern China. At the same time, they are strategic locations for maintaining ethnic unity, ensuring social stability, and containing abundant mineral resources. However, the fragility of the ecosystem in the region has triggered a series of chain ecological crises, which not only pose severe challenges to the economic and social development of the region, but also spread to a wider range due to their diffusion effects, exacerbating the complexity and severity of ecological problems, fully demonstrating the urgent need for governance of the ecological fragility of the Qinghai Tibet Plateau and its surrounding areas. Faced with such a severe ecological situation, implementing ecological governance has become the core strategy to slow down ecological degradation and optimize the ecological environment [3]. However, it is worth noting that the economic growth of the Qinghai Tibet Plateau and its surrounding areas has long relied excessively on industrial development, especially those extensive industrial models characterized by high pollution, high emissions, high energy consumption, and low energy efficiency. In view of this, reforming the development path at the industrial level and accelerating the decarbonization process of industries have become the only way to promote the ecological restoration of the Qinghai Tibet Plateau and its surrounding areas. In the current context where the "beneficiary pays" market mechanism still needs to be improved, exploring

innovative models for ecological self-restoration in ecologically sensitive and fragile areas such as the Qinghai Tibet Plateau, that is, promoting industrial decarbonization to promote natural restoration of ecosystems, is not only urgent, but also has profound practical value and strategic significance.

2 Related research

In the academic research field of the Qinghai Tibet Plateau, reference [4] provides a detailed record of the evolution trajectory of the industrial sector in the region, from the primary stage of primitive industry, to the rise and peak of traditional sectors, to subsequent decline, and to the emergence and strong expansion of modern industry. This series of changes has triggered profound thinking in the academic community about the future development trajectory of industry on the Qinghai Tibet Plateau. Based on the analysis of the natural ecological attributes and current environmental challenges of the Qinghai Tibet Plateau, reference [5] delves into the fundamental causes of ecological deterioration in the region and advocates for targeted industrial pathways that are conducive to the priority development of the Qinghai Tibet Plateau. Reference [6] focuses on the contemporary situation and internal conditions of industrial development on the Qinghai Tibet Plateau, and suggests that future industrial development should prioritize establishing large-scale agricultural production frameworks, creating unique energy and mineral resource development centers, and vigorously promoting the development of tourism. Reference [7] utilized an understanding of the inherent characteristics of resource-based assets to create a favorable market environment for the operation of the environmental resources industry, and successfully designed its organizational structure. Reference [8] deeply explores the impact of the unique ecological environment of the Qinghai Tibet Plateau on its development, and studies effective strategies for coordinating ecological protection and sustainable development. Reference [9] proposes a series of specific measures and suggestions aimed at restoring and protecting the ecology in response to the key strategic significance of the Qinghai Tibet Plateau and its increasingly severe ecological degradation. Reference [10] examined the industrial location advantages of the Qinghai Tibet Plateau, reexamined the essence of characteristic industrial economy, and systematically improved the characteristic industrial economic system of the Qinghai Tibet Plateau. Reference [11] analyzed the impact of ecological and environmental issues on the Qinghai Tibet Plateau from a broader macro perspective, including regional, national, and even global stages, and actively sought feasible ways to achieve sustainable development in the region. Finally, by summarizing the characteristics and challenges of characteristic industries in the Qinghai Tibet Plateau, reference [12] describes the future development direction of characteristic industries in the region.

In terms of research on ecological vulnerability, reference [13] suggests that vulnerability is a degree, which refers to the degree to which a system generates adverse responses during disaster events. The quality and quantity of adverse responses are controlled by the system's elasticity, which indicates the system's ability to inherit and recover from disaster events; Reference [14] suggests that vulnerability is a comprehensive measure of social welfare, which combines the defense capabilities of environmental, social, economic, and political systems against a range of potentially harmful disturbances; Reference [15] suggests that vulnerability refers to the sensitivity of fragile environments; The United Nations Disaster Relief Organization (1999) believes that vulnerability is a degree of loss, which refers to the extent to which a certain or a series of elements suffer losses when a natural phenomenon of a certain intensity occurs; Reference [16] divides the source areas of the Yangtze River and Yellow River into eight major regions, and uses principal component analysis to clarify the ecological

vulnerability of these eight regions; Reference [17] and others used Xiangjiang City in Hunan Province as an example to determine the weight of indicators using the Analytic Hierarchy Process, and evaluated its ecological vulnerability at a general level using the Grey Evaluation Method of the Triangular Whitening Weight Function; Reference [18] selected 31 indicators including risk, resistance, damage, and degradation based on SOPAC and UNEP, analyzed the impact of each indicator, and determined that the ecological vulnerability of Hainan Island is at a moderate level; Reference [19] established a "pressure state response" evaluation model and analyzed the ecological vulnerability of the Jiangsu coastal zone using AHP, and proposed suggestions for coastal zone ecological environment protection; Reference [20] selected 18 indicators from the aspects of environmental resource conditions, socio-economic level, and ecological balance, and used mean square error and analytic hierarchy process to conclude that the ecological vulnerability index of Anding District in Dingxi City showed a fluctuating downward trend. Based on the evaluation results, suggestions were put forward for further consideration.

In terms of research on ecological restoration issues, reference [21] categorizes ecological compensation models into six types: ecological compensation tax (fee), ecological compensation guarantee deposit system, fiscal subsidy system, preferential credit, trading system, and domestic and foreign funds; Reference [22] summarizes the exploration process of ecological restoration in southern, northern, and Inner Mongolia pastoral areas in China, and proposes new ideas for soil and water conservation ecological construction in ecological restoration; On the basis of clarifying the definition of ecological restoration, reference [23] analyzed the supporting measures for ecological restoration implementation, taking the ecological restoration pilot projects in Jiangxi Province in the past three years as an example; Reference [24] suggests that ecological compensation can be divided into national compensation, regional compensation, departmental compensation, industrial compensation, etc; Reference [25] divides China's ecological measures into two categories: government measures and market measures; Based on the analysis of the concepts of ecosystem degradation, ecological restoration, and ecological restoration, reference [26] examines the influencing factors and principles of ecological restoration; Reference [27] suggests that the ecological compensation standard is a comprehensive assessment of four aspects: cost estimation, increase in ecological service value, willingness to pay, and ability to pay; Reference [28] comprehensively reviewed the research and application progress of ecological restoration technology, and clarified the future development direction of ecological restoration. The research on ecosystem restoration in China focuses on the causes of ecosystem degradation, solutions, restoration and reconstruction techniques, and the ecological effects during the ecological restoration process.

3 Data sources and research methods

3.1 Overview of the research area

The Qinghai Tibet Plateau is a vast area. Its southern end extends to the Himalayas, and its northern end connects with the Qilian Mountains and the northern foot of the Kunlun Mountains. It spans about 1500 kilometers from north to south, and its geographical coordinates are roughly between $26^{\circ} 00'$ and $39^{\circ} 47'$ north latitude. The western end starts at the intersection of the Karakoram Mountains and the Pamir Plateau, and is connected to the Loess Plateau and the Qinling Mountains to the east. It stretches for about 2800 kilometers from east to west, with a geographic longitude roughly within the range of $73^{\circ} 19'$ to $104^{\circ} 47'$ east longitude. The total

area of the Qinghai Tibet Plateau is about 2.5 million square kilometers, and the terrain and landforms are extremely complex, covering various types such as plateaus, valleys, basins, and numerous mountain ranges. The diversity of this terrain has also led to significant differences in the internal climate conditions of the Qinghai Tibet Plateau, with distinct regional characteristics in the climate of each region.

In order to maintain consistency and improve the feasibility of data analysis, this survey will focus on specific areas of the Qinghai Tibet Plateau, including Qinghai Province, Xizang Autonomous Region, Diqing Tibetan Autonomous Prefecture in Yunnan Province, Gannan Tibetan Autonomous Prefecture in Gansu Province, Aba Tibetan and Qiang Autonomous Prefecture in Sichuan Province, and Ganzi Tibetan Autonomous Prefecture. For data collection, this study mainly utilized time series statistical data from different cities and counties within the prescribed research scope from 2015 to 2024. The compilation of relevant data in the Qinghai Tibet Plateau region involves integrating information from multiple cities and states, using statistical techniques such as summation, averaging, and weighting to obtain comprehensive insights. We systematically compiled and organized data on the total population, economic growth rate, and industrial composition of each city and state using authoritative sources such as the China Statistical Yearbook, Urban Statistical Yearbook, and National Economic and Social Development Bulletin released annually from 2015 to 2024. Similarly, data on per capita water resources and annual precipitation were extracted from various statistical yearbooks and water resources bulletins published by various cities and prefectures during the same period. The newly introduced ecological indicators, such as comprehensive control areas for soil erosion, afforestation area, and forest coverage, are compiled based on the "Ecological Environment Development Bulletin" issued by various cities and prefectures from 2015 to 2024, as well as statistical data released by relevant government agencies such as the Bureau of Statistics, the Meteorological Bureau, and the Forestry Bureau. In the case of discovering data gaps in certain cities and states on the Qinghai Tibet Plateau, this study uses interpolation techniques to supplement and improve the incomplete dataset. For situations where there is no data at all, estimates are obtained by averaging relevant data from neighboring cities and states to ensure the robustness and completeness of the research dataset.

3.2 Research methods

Project performance evaluation mainly includes evaluation objectives, evaluation subjects, evaluation objects, evaluation systems, evaluation models, evaluation standards, and other main contents. In the actual operation process of the ecological governance project on the Qinghai Tibet Plateau, due to professional requirements and the limitations of the abilities of the project participants, the project operation management party is unable to dynamically track and evaluate the overall and partial aspects of the project, making it difficult to timely identify and efficiently solve problems, and unable to effectively achieve post project operation and maintenance.

The performance evaluation of the Qinghai Tibet Plateau ecological governance project during the operation period is an objective evaluation of the overall project, and the construction of a hierarchical, interrelated, and relatively independent evaluation index system is a prerequisite for ensuring the scientificity of the evaluation results. Therefore, the first step is to clarify the evaluation objectives and objects, establish a preliminary indicator system, determine the weights of indicators, construct an evaluation model based on this, calculate the evaluation values of each indicator and rank them, and provide feedback and correction to the indicator system to obtain scientifically reasonable evaluation results. The performance evaluation framework is shown in Figure 1.

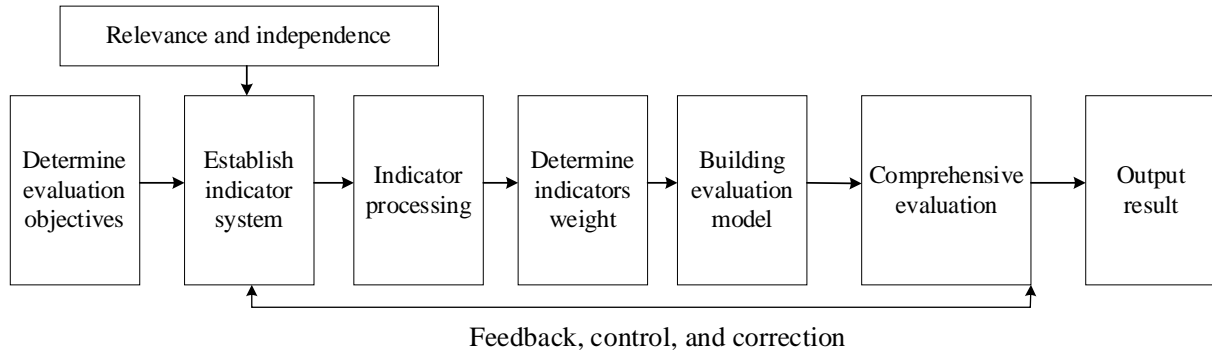


Figure 1: Performance evaluation framework for the operation period of the Qinghai Tibet Plateau ecological governance project

The rationality of selecting performance evaluation indicators has a significant impact on the effectiveness of evaluation results. There are many factors that affect the performance level in the actual operation of the Qinghai Tibet Plateau ecological governance project. This article follows the principles of scientificity, representativeness, comprehensiveness, practicality, relative independence, and operability, and combines the characteristics and management points of the operation period of the Qinghai Tibet Plateau ecological governance project to collect evaluation indicators on the operation period of the Qinghai Tibet Plateau ecological governance project from multiple perspectives.

Firstly, by searching literature and reviewing multiple actual cases collected, preliminary evaluation indicators were formulated. Based on this, expert consultation and screening were conducted to remove indicators with weak representativeness and optimize the establishment of an evaluation indicator system to ensure that the constructed indicator system is more scientific and reasonable. Finally, based on on-site investigations of multiple projects and the selection criteria for ecological vulnerability indicators in the Qinghai Tibet Plateau and its peripheral areas, quantifiable indicators related to the ecological vulnerability of the Qinghai Tibet Plateau and its peripheral areas were collected. Through systematic clustering analysis, low-level related indicators were removed and high-order related indicators were retained. The selected indicators were carefully classified, and the following complete and comprehensive evaluation index system was established (see Table 1).

Table 1: Ecological Environment Vulnerability Index System of the Qinghai Tibet Plateau and Its Borderlands (Part)

First level indicator layer (B)	Secondary indicator layer (C)	Third level indicator layer (D)
Stress indicator (B1)	Natural indicator (C1)	Per capita water resources (D11)
		Available grassland area (D12)
		Per capita cultivated land area (D13)
		Area of desertified land (D14)
		Living forest storage area (D15) Year-end inventory of large livestock (D16)
	Environmental indicators (C2)	Area affected by natural disasters (D17)
		Wastewater discharge volume (D42)
		Exhaust emissions (D43)
Potential indicator (B2)	Natural indicators (C3)	Industrial solid waste emissions (D44)
		Precipitation (D51)
		Newly added grass planting area in that year (D52)
		Increase in cultivated land area this year (D53)
		Forest coverage rate (D54)
		Forest storage volume (D55)
		Total water resources (D56)
	Environmental indicators (C4)	Soil erosion control area (D57)
		Year-end slaughter of large livestock (D58)
		Afforestation area (D81)
		Wastewater treatment investment (D82)
		Waste gas treatment investment (D83)
		Investment amount for industrial pollution control (D84)

3.3 Determination of indicator weights based on COWA operator weighting

The commonly used weighting methods in the evaluation process, such as tomographic analysis, use expert scoring raw data for calculation, and there may be some extreme values of experts that affect the objectivity of indicator weighting. OWA (ordered weighted averaging) is a weighting method that uses data sequences to recombine and weight them based on location, treating the data differently and weakening the impact of extreme adverse values. The improved COWA (Combination ordered weighted averaging) method based on the OWA operator reorders the ecological environment indicator data sequence of the Qinghai Tibet Plateau and weights it according to its own position, which can reduce the influence of subjective factors of experts on weight calculation to a certain extent, making the results more accurate and objective. Invite n experts to assign values to various levels of indicator factors and calculate indicator weights based on the COWA operator [29]. The specific steps are as follows:

Step 1: Invite n experts to score the importance of ecological environment indicators on the Qinghai Tibet Plateau at the same level using a 10-point scoring method. Obtain the original scoring dataset $(a_1, a_2, \dots, a_j, \dots, a_n)$ for each indicator from n experts. After sorting and ranking the raw data from large to small, number them from 0 in order, and obtain $b_0 \geq b_1 \geq b_2 \geq \dots \geq b_j \geq \dots \geq b_{n-1}$.

Step 2: Set the original data b_j weight of the sorted ecological environment indicators on

the Qinghai Tibet Plateau to θ_{j+1} , and use the combination number to weight them. The calculation formula is as follows:

$$\theta_{j+1} = c_{n-1}^j / \sum_{j=0}^{n-1} c_{n-1}^j = c_{n-1}^j / 2^{n-1} \quad (1)$$

where, $\sum_{j=0}^{n-1} \theta_{j+1} = 1$; c_{n-1}^j is the number of combinations of j elements extracted from $n-1$ elements.

Step 3: Weighting the sorted ecological environment indicator data b_j of the Qinghai Tibet Plateau to obtain the absolute weight value \bar{w}_i of each indicator factor, that is:

$$\bar{w}_i = \sum_{j=0}^{n-1} \theta_{j+1} b_j \quad (2)$$

where, m is the number of indicator factors, $\theta_{j+1} \in [0, 1]$.

Step 4: Calculate the relative weights w_i of various ecological environment indicators on the Qinghai Tibet Plateau, namely:

$$w_i = \bar{w}_i / \sum_{i=1}^m \bar{w}_i \quad (3)$$

4 Evaluation based on multiple regression indicators

This evaluation model closely combines the unique attributes of ecological environment indicators on the Qinghai Tibet Plateau and makes forward-looking predictions on its evaluation results. In the carefully constructed sample set D , we use ${}^p X_i$ to specifically refer to the ecological environment indicator characteristics exhibited by the i -th sample on the Qinghai Tibet Plateau, while ${}^c T_i$ is used to accurately represent the actual evaluation value of the ecological environment index corresponding to the i -th sample on the same plateau. Given that the evaluation values of ecological environment indicators on the Qinghai Tibet Plateau included in sample set D are constantly changing, and fully considering the real-time needs of the evaluation values of ecological system indicators on the Qinghai Tibet Plateau in practical application scenarios, this study has decided to adopt the advanced method of multiple parallel regression modeling.

Furthermore, as the input data of this evaluation model is a (871×1) dimensional feature matrix composed of ecological environment indicators of the Qinghai Tibet Plateau, and the output data covers the predicted results of biological environment indicators of the Qinghai Tibet Plateau (presented in a 3×1 dimensional form) and their corresponding evaluation values, the model is clearly defined as a supervised multi input ternary output regression model. As clearly shown in Figure 2, we have tailored three parallel regressors for the three output variables ${}^c v_x$, ${}^c v_y$, and ${}^c v_z$ to ensure their accuracy and efficiency in prediction.

The ecological environment indicators of the Qinghai Tibet Plateau exhibit a non-linear correlation with their actual evaluation values. Based on the unique attributes of the ecological environment indicators of the Qinghai Tibet Plateau presented by sample set D [30], this study constructed a linear regression model with multiple input and three output characteristics, aiming to achieve scientific evaluation of the ecological environment indicators of the Qinghai Tibet Plateau.

$$\mathbf{V} = \mathbf{XB} + \varepsilon \quad (4)$$

where, d represents the number of samples in the training sample set, and $\mathbf{X} = \begin{bmatrix} {}^p X_1 & {}^p X_2 & \cdots & {}^p X_d \end{bmatrix}^T$ represents the characteristic matrix of the ecological environment indicators of the Qinghai Tibet Plateau in the training sample set.

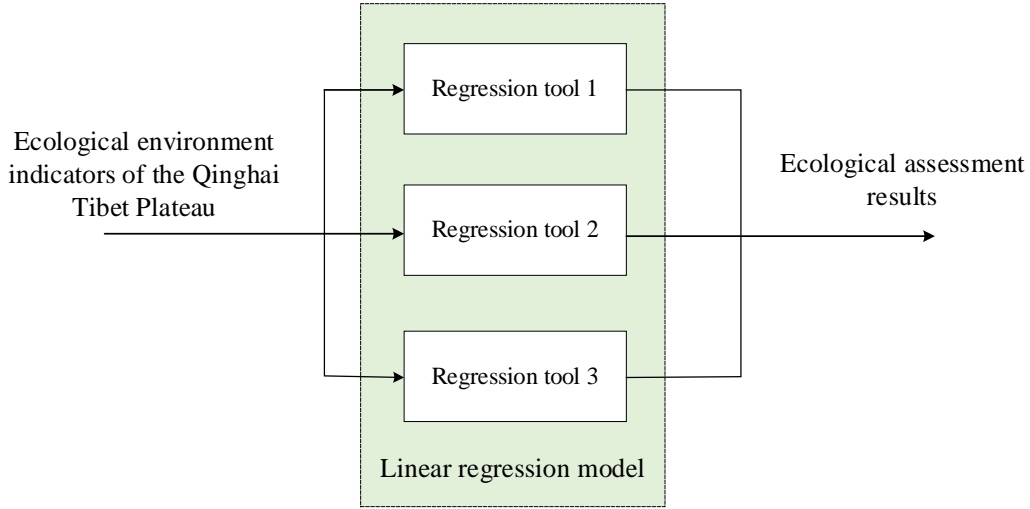


Figure 2: Structure of the Ecological Environment Index Evaluation Model

In the ecological environment index evaluation system of the Qinghai Tibet Plateau, the response matrix corresponding to the constructed evaluation model can accurately reflect the actual labeling situation of the ecological system index evaluation values of the Qinghai Tibet Plateau. The specific calculation presentation form is as follows:

$$\mathbf{V} = \begin{bmatrix} \mathbf{V}_x \\ \mathbf{V}_y \\ \mathbf{V}_z \end{bmatrix}^T = \begin{bmatrix} c \mathbf{v}_{x_1}^{\text{truth}} & c \mathbf{v}_{x_2}^{\text{truth}} & \cdots & c \mathbf{v}_{x_i}^{\text{truth}} \\ c \mathbf{v}_{y_1}^{\text{truth}} & c \mathbf{v}_{y_2}^{\text{truth}} & \cdots & c \mathbf{v}_{y_i}^{\text{truth}} \\ c \mathbf{v}_{z_1}^{\text{truth}} & c \mathbf{v}_{z_2}^{\text{truth}} & \cdots & c \mathbf{v}_{z_d}^{\text{truth}} \end{bmatrix}^T \quad (5)$$

The regression coefficient matrix represents the weight values of various characteristics of ecological environment indicators on the Qinghai Tibet Plateau, calculated as follows:

$$\mathbf{B} = \begin{bmatrix} \mathbf{B}_x \\ \mathbf{B}_y \\ \mathbf{B}_z \end{bmatrix}^T = \begin{bmatrix} b_{x_1} & b_{x_2} & \cdots & b_{x_{n+1}} \\ b_{y_1} & b_{y_2} & \cdots & b_{y_{ni}} \\ b_{z_1} & b_{z_2} & \cdots & b_{z_{ni}} \end{bmatrix}^T \quad (6)$$

Since the evaluation model of ecological environment indicators on the Qinghai Tibet Plateau predicts the evaluation values of ecological environment indicators on the Qinghai Tibet Plateau, that is, the prediction of specific values $c \mathbf{v}_x^{\text{truth}}$, $c \mathbf{v}_y^{\text{truth}}$, and $c \mathbf{v}_z^{\text{truth}}$, the loss function is defined as the sum of the squared Euclidean distances between the true value of the ecological environment indicator evaluation values on the Qinghai Tibet Plateau and the predicted location of the ecological environment indicators on the Qinghai Tibet Plateau. In order to minimize the loss function of the model, the optimization objective of the model is:

$$\begin{cases} \operatorname{argmin}_{B_s} \|V_x - XB_x\|_2^2 \\ \operatorname{argmin}_{B_s} \|V_y - XB_y\|_2^2 \\ \operatorname{argmin}_{B_s} \|V_z - XB_z\|_2^2 \end{cases} \quad (7)$$

Due to the unknown optimal hyperparameters of the model, it is not possible to directly assign them through prior knowledge. In this paper, grid search and K -fold cross validation are used to obtain the optimal hyperparameters α' and q' . The steps are as follows:

1) Split the training sample set into k subsets through cross validation, where the scale ratio of each training set to the test set is set to $(k-1)$ to 1. Specifically, the training set is responsible for model training, while the testing set is used to evaluate the trained model. When evaluating the performance of the model, the evaluation metric used is Root Mean Square Error (RMSE).

2) Input the hyperparameter space generated by the permutation and combination of $A' = [\alpha'_x \ \alpha'_y \ \alpha'_z]^T \in R^{3 \times l}$ and $Q' = [q'_x \ q'_y \ q'_z]^T \in R^{3 \times m}$ into the ecological environment index evaluation model of the Qinghai Tibet Plateau, and conduct $(k \times l \times m)$ rounds of model training.

3) For each set of hyperparameter combinations, calculate the mean of k ecological environment indicator model evaluation data for the Qinghai Tibet Plateau. Among them, the i -th set of hyperparameters corresponds to:

$$\bar{E}_i = \begin{bmatrix} \bar{E}_{xi} \\ \bar{E}_{yi} \\ \bar{E}_{zi} \end{bmatrix} = \begin{bmatrix} \frac{1}{k} \sum_{s=1}^k \left(\frac{1}{n_k} \sum_{j=1}^{s_i} |v_{x_j}^{\text{trath}} - v_{x_j}^c|^2 \right) \\ \frac{1}{k} \sum_{l=1}^k \left(\frac{1}{n_k} \sum_{j=1}^{s_l} |v_{y_j}^{\text{trath}} - v_{y_j}^c|^2 \right) \\ \frac{1}{k} \sum_{n=1}^k \left(\frac{1}{n_k} \sum_{j=1}^{n_i} |v_{z_j}^{\text{trath}} - v_{z_j}^c|^2 \right) \end{bmatrix} \quad (8)$$

where, n_k is the number of samples in the test set. Ultimately, the model evaluation metric corresponding to the hyperparameters of $(l \times m)$ group is $\bar{E} = [\bar{E}_x \ \bar{E}_y \ \bar{E}_z]^T$.

4) Obtain the corresponding optimal hyperparameters α' and q' based on the minimum values of \bar{E}_x , \bar{E}_y , and \bar{E}_z in the evaluation index \bar{E} .

5 Empirical analyses

The comprehensive benefits of the ecological, economic, and social subsystems of the Qinghai Tibet Plateau from 2015 to 2024 are intuitively represented by a curve graph (see Figure 3 for details). This graphical description effectively illustrates the development trajectory of these three subsystems within a specified time range. The analysis of the graph shows that the overall comprehensive benefit level of the ecological and social subsystems is on the rise, while the comprehensive benefit level of the economic subsystem is on the decline. Specifically, from 2015 to 2017, the comprehensive benefit level of the ecological subsystem steadily increased from 0.115 to 0.140, indicating a continuous improvement in the regional ecological environment during this period. However, there was a significant decline in 2018, with the comprehensive benefit level of the ecosystem plummeting to 0.075, the lowest point in previous years, posing a considerable threat to the ecological environment. However, in the following

years, due to the continuous promotion of national park pilot projects and the establishment of ecological civilization highlands, ecological protection and restoration work have been strengthened, and the ecological environment has been continuously improved. Therefore, the comprehensive benefit level of the ecological subsystem soared from 0.075 in 2018 to 0.245 in 2021, showing a significant growth rate, indicating that the regional ecological environment has reached a favorable state. However, by 2024, the comprehensive benefits of the ecological subsystem will once again decline, indicating that the ecological environment is once again facing challenges.

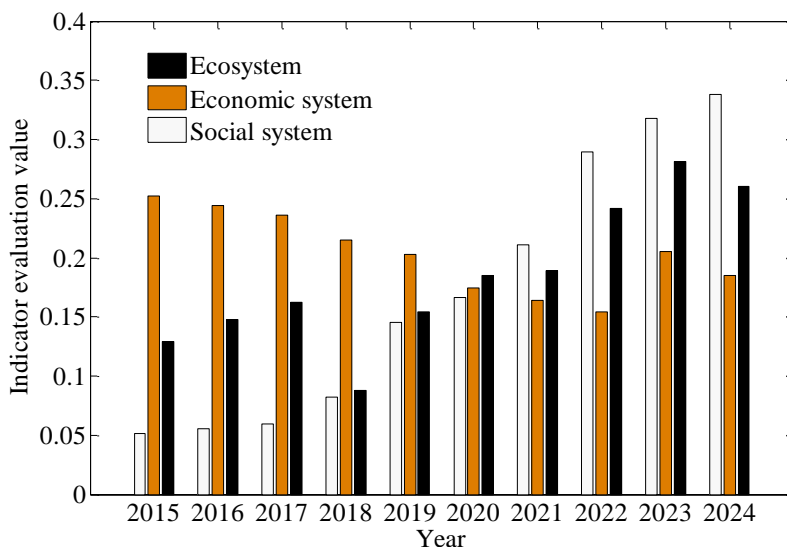


Figure 3: Comprehensive Benefit Level of Ecological, Economic, and Social Subsystems on the Qinghai Tibet Plateau from 2015 to 2024

Regarding the social subsystem, its overall benefit indicators have shown a continuous upward trend, rising from 0.047 in 2015 to 0.299 in 2024, highlighting a strong and noteworthy growth pattern. This progress means that the living standards and environmental conditions of the local people have substantially improved. In sharp contrast to the ecological and social subsystems, the overall efficiency level of the economic subsystem is showing a significant downward trend. From 2015 to 2022, the comprehensive efficiency index of the economic subsystem decreased from 0.221 to 0.136, reflecting the continuous slowdown of economic growth and the increasing necessity of economic structural adjustment and development. In 2020, due to the impact of the epidemic, economic development significantly declined. Although the comprehensive efficiency index of the economic subsystem briefly rebounded to 0.180 in 2023, this growth has been proven to be unsustainable, with the index recovering to 0.163 in 2024, indicating that the basic elements of regional economic development remain largely unchanged. Throughout the entire research period, the Qinghai Tibet Plateau remained committed to the construction of ecological civilization and made significant progress in ecological environment protection, with continuous improvement in ecological quality. The improvement of the ecological environment, coupled with a certain degree of economic development, has promoted substantial progress in the social development pattern of the Qinghai Tibet Plateau, and the living standards of the people have steadily improved. At the same time, as the crucial role of ecological environment in regional development becomes increasingly evident, economic activities on the Qinghai Tibet Plateau are facing increasingly severe constraints brought about by ecological factors. Therefore, the economic growth rate has

significantly slowed down and entered a challenging transitional stage.

Table 2 comprehensively decomposes the coupling and coordination dynamics between the ecological environment and comprehensive economic and social development of the Qinghai Tibet Plateau from 2015 to 2024, and identifies their respective coupling and cooperation categories.

Table 2: Coupling and Coordination Types of Ecological Environment and Economic and Social Development on the Qinghai Tibet Plateau from 2015 to 2024

Year	Coupling degree C	Coupling coordination degree D	Coordination type
2015	0.352	0.336	Mild dysregulation and decline
2016	0.373	0.363	Mild dysregulation and decline
2017	0.384	0.373	Mild dysregulation and decline
2018	0.367	0.345	Mild dysregulation and decline
2019	0.487	0.416	On the brink of imbalance and decline
2020	0.516	0.431	Facing imbalance and decline
2021	0.576	0.459	Facing imbalance and decline
2022	0.681	0.516	Reluctantly imbalanced decline
2023	0.735	0.557	Reluctantly imbalanced decline
2024	0.754	0.557	Reluctantly imbalanced decline

From 2015 to 2024, the coupling strength between the ecological environment and the comprehensive economic and social development of the Qinghai Tibet Plateau has shown a significant upward trend. It is worth noting that the coupling index has increased from 0.3517 in 2015 to 0.754 in 2024, indicating a substantial interconnection between ecological environment and economic and social progress. From 2015 to 2017, the coupling metric increased from 0.3517 to 0.388, reflecting the uneven development of coupling patterns. At this stage, the interrelationships between ecological, economic, and social subsystems are relatively weak, and the impact of regional production and living activities on the ecological environment is limited. In 2018, the coupling index slightly decreased to 0.367. However, during the period of 2018 to 2019, the coupling index significantly upgraded, soaring from 0.367 to 0.487, while the coupling type underwent a transformation, indicating an increase in the degree of integration between ecological, economic, and social subsystems. In the following years, the coupling index continued to maintain positive growth, rising from 0.487 in 2019 to 0.754 in 2024. Since 2021, the coupling and coordination type has entered a stage of harmonious development, with high interconnectivity among ecological, economic, and social subsystems. The mutual influence between these systems has intensified, creating an orderly development environment within each subsystem.

Meanwhile, from 2015 to 2024, the coupling and coordination degree between the ecological environment and economic and social development of the Qinghai Tibet Plateau has shown a continuous upward trend, shifting from a mild imbalance state to other states. In 2017, the coupling coordination index reached its lowest point of 0.336, indicating a mild imbalance and deterioration in coordination types, reflecting insufficient coordination between ecological, economic, and social subsystems. Economic and social expansion have had significant adverse effects on the ecological environment, and regional development comes at the cost of ecological degradation. This pattern continued until 2018. In 2019, the coupling coordination index rose to 0.416, and the coordination between ecological, economic, and social subsystems was strengthened, transitioning to a nearly unbalanced and declining coordination type, which continued until 2020 and 2021. By 2022, the coupling coordination index will further increase

to 0.516, and the coordination between ecological, economic, and social subsystems will continue to strengthen, significantly reducing the impact of economic and social development on the ecological environment and improving the quality of regional development. The coordination type transforms into an unbalanced but constantly improving state. Throughout the research period, the coupling and coordination between the ecological environment and economic and social development of the Qinghai Tibet Plateau have been continuously optimized and steadily improved, highlighting the practical effectiveness of relevant policy interventions. This is mainly attributed to the continuous deepening of the construction of the ecological civilization highland on the Qinghai Tibet Plateau, which regards ecological environment protection and restoration as key strategic priorities, and strives to establish a green circular economy framework. Through a series of measures such as actively promoting industrial restructuring and innovating mechanisms for realizing the value of ecological products, the comprehensive benefits of economic and social development have gradually improved. From 2015 to 2024, the challenges faced by the ecological environment and economic and social development system of the Qinghai Tibet Plateau in achieving coupling and coordination have undergone significant changes. The obstacle levels of ecological, economic, and social subsystems have increased from 34.145%, 22.608%, and 43.236% in 2015 to 32.087%, 53.279%, and 14.082% in 2024, respectively. The main obstacle factors have shifted from the social subsystem to the economic subsystem (see Figure 4 for details).

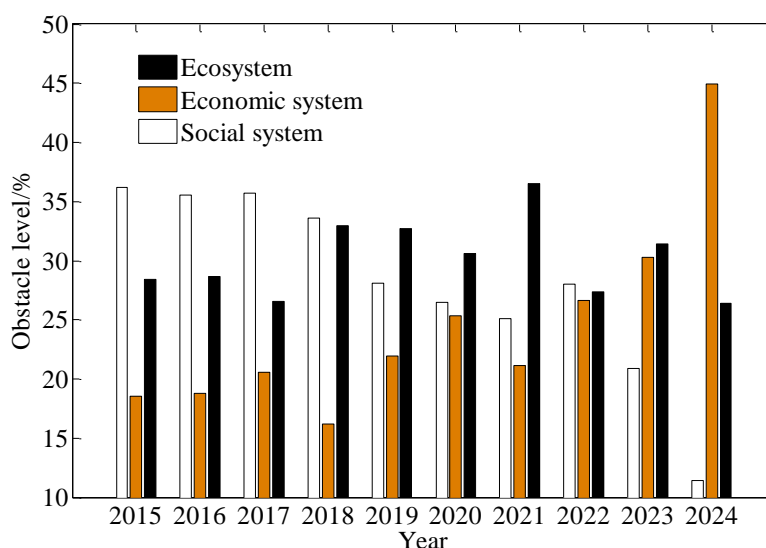


Figure 4: Obstacles at the System Layer of Coupling and Coordination between Ecological Environment and Economic and Social Development on the Qinghai Tibet Plateau

Further analysis shows that although there has been a certain degree of increase in the level of obstacles at the ecological subsystem, economic subsystem, and social subsystem levels, the increase is relatively small, and the overall situation is relatively stable. This is in line with the ecological environment of the Qinghai Tibet Plateau, whose unique natural conditions make it difficult to achieve significant improvement in the regional ecological environment in the short term. The degree of obstacles at the level of economic subsystems has shown an increasing trend year by year, and the growth rate is relatively high, especially after 2021, the growth rate has significantly accelerated, rapidly rising from 33.569% to 53.817%, an increase of over 60%. This reflects the slowing down of economic development in the Qinghai Tibet Plateau, while the increasingly prominent constraining effect of ecological protection and restoration projects on economic development has had a significant impact on the development of economic

subsystems. The degree of obstacles at the level of social subsystems has been decreasing year by year, with a significant decrease from 43.24% to 14.083%, a decrease of nearly 30 percentage points. Especially after 2022, with the comprehensive victory of poverty alleviation work, the speed of eliminating obstacles at the level of social subsystems has significantly accelerated. This indicates that with the gradual improvement of the ecological environment, sustained economic development, and effective implementation of national strategies such as poverty alleviation, significant progress has been made in the social development of the Qinghai Tibet Plateau, and the social subsystem has transformed from the largest obstacle factor to the smallest obstacle factor.

6 Conclusion

This study takes the Qinghai Tibet Plateau as the research area and uses ecological environment sample data from 2015 to 2024. It adopts quantitative analysis techniques to deeply study the coupling and coordination dynamics between the ecological environment and the comprehensive economic and social development system in the region. Subsequent research has yielded the following key insights: (1) Regarding the development process, from 2015 to 2024, the ecological environment and overall economic and social development level of the Qinghai Tibet Plateau have shown a continuous upward trajectory. However, there are still significant differences in the development trajectories of ecological, economic, and social subsystems. Specifically, these differences are evident in the disparity between the level of development of economic subsystems and the level of development of ecological and social subsystems. Despite significant progress in the ecological and social subsystems, there has been a slight decline in the economic subsystem. In addition, the impact of economic subsystems on the coupling and coordination between the ecological environment and economic and social development of the Qinghai Tibet Plateau is becoming increasingly significant. (2) From the perspective of coupling coordination, the overall coupling coordination scenario between the ecological environment and economic and social development of the Qinghai Tibet Plateau from 2015 to 2024 is relatively optimistic. The coupling coordination degree increased from 0.336 to 0.557, and the coordination type shifted from a mild unbalanced state to a state close to mild equilibrium. However, the coupling and coordination process between the ecological environment and economic and social development of the Qinghai Tibet Plateau is still in the transitional stage and has not yet reached the stage of harmonious development. At present, the coupling and coordination level between regional ecological environment and economic and social development is still relatively low, and there is great potential for improvement.

During the research period, significant progress has been made in ecological environment protection and economic and social development on the Qinghai Tibet Plateau. However, there is still a considerable gap between the regional economic and social development level and the national average level. Regional development policies, population size, and technological level are still the main factors restricting regional development. The Qinghai Tibet Plateau should continue to optimize regional green development support policies. One is to establish a green development assessment mechanism, construct an economic development evaluation system oriented towards green, low-carbon, and circular economy, enhance the weight of factors such as resources and environment in the economic development evaluation system, increase the proportion of indicators such as resource conservation, environmental friendliness, and ecological protection, and gradually realize the transformation of economic accounting methods to GEP accounting methods; Secondly, we attach great importance to the construction of talent teams, guided by demand, continuously increase investment in talent cultivation, continuously optimize talent cultivation methods, strengthen the cultivation and introduction of urgently

needed and scarce talents, continuously promote the "campus talent introduction" activity, and effectively improve the quality of regional talent team construction; The third is to increase investment in science and technology, implement a strategy driven by technological innovation, create a leading force in technological innovation, develop high-tech industries, improve resource utilization efficiency through technological innovation, use technological innovation to drive economic development, and embark on a transformation path driven by innovation and endogenous growth, in order to achieve coordinated development of environmental protection and regional economy.

Author's Profile

Guzhenzhen Hu was born in Nanjing, Jiangsu, China, in 2009. She is currently studying at Nanjing Foreign Language School. She is currently interested in Mathematical modelling and the environment.

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