ISSN: 1813-4890

Evaluation and Prediction of Carbon Emissions on Land Use in Inner Mongolia

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Abstract

Taking the land use carbon emission security as the starting point and Inner Mongolia as the research area, a pressure-response model based evaluation index system of land use carbon emission security was constructed by using land use change data and social-economic statistical data from 2001 to 2021, and the temporal characteristics of land use carbon emission security were analyzed.The GM(1,1) model was used to predict land use carbon emissions. The results show that: (1) From 2001 to 2021, net carbon emissions of land use in Inner Mongolia increased by a large amount, among which agricultural land had the highest carbon emissions, followed by construction land carbon emissions； (2) The fluctuation of land use carbon emission security index in Inner Mongolia decreased from 2001 to 2021, and reached the highest point in 2003, which was at the sub-safety level. The total carbon emission of agricultural land occupies a dominant position in the carbon emission of land use type and is the key factor affecting the security of land use carbon emission. (3) From 2022 to 2031, the safety index of land use carbon emission in Inner Mongolia approximately plummeted, and the safety level decreased from critical safety to unsafe, and the safety state continued to weaken. On the premise of recognizing the security situation of land use carbon emission in this region, targeted carbon emission reduction measures should be taken from relatively sensitive indicators.

Keywords

Land use carbon emissions GM(1,1) model Inner Mongolia.

1. Introduction

Climate change poses great challenges to human survival and development[1]. The causes of global climate change can be divided into two categories: one is the impact of human behavior on the environment,the other is the climate change caused by environmental change, in which the increase of carbon emissions caused by human activities is the main cause of climate change[2]. Since the Industrial Revolution, the massive burning of fossil energy, the excessive reclamation of land and the irrational use of grassland are the key factors of global warming caused by human activities[3]. Global warming causes the rise of the water level, the loss of living space for many organisms, biodiversity is seriously threatened, environmental deterioration will bring many chain reactions, the expansion of the ozone layer, the aggravation of desertification, frequent flood and drought disasters, directly threaten the survival and development of human beings. Therefore, research on land use carbon emissions is helpful for human to understand the safety level of regional carbon emissions and the development trend of carbon emission control. The current domestic research on land use carbon emissions mainly focuses on land cover and the impact of land use change on carbon emissions[4].

In view of this, this paper takes Inner Mongolia as the research area, uses the data of main land use types in Inner Mongolia from 2001 to 2021, combines with the carbon emission coefficient method of land use, and calculates the total amount of land use carbon emission according to the area of main land use types and energy consumption by using relevant formulas. The temporal changes of total land use carbon emissions in Inner Mongolia from 2001 to 2021 were obtained. At the same time, starting from the factors that affect the security of land use carbon emissions, the pressure-response model is selected to construct the evaluation index system, and 20 indexes are selected to constitute the evaluation index system of land use carbon emissions security. The combined weight method was used to obtain the combined weight reflecting the interactive relationship between each index and carbon emissions, and the multi-index comprehensive evaluation model was applied to calculate the safety value of land use carbon emissions, and the temporal changes of the safety level of carbon emissions in Inner Mongolia were analyzed through the dynamic changes of the safety value. At the same time, by constructing a grey prediction model, GM(1,1) model was used to predict the change trend of land use carbon emission security in Inner Mongolia from 2022 to 2031 with the help of the index data of Inner Mongolia from 2001 to 2021, in order to provide a scientific basis for the work of land use carbon emission reduction in Inner Mongolia.

2. Data and methods

2.1. Index system construction

This paper starts from the factors affecting the safety of land use carbon emissions, and chooses the pressure-response model to build the index evaluation system on the premise of ensuring the scientific rationality of the evaluation index system, Reference to Nan Ling et al. 's [5]research results, determine the index system that constitutes land use carbon emission safety evaluation ,see Table 1

Table 1 Evaluation indices and weight of carbon emissiom security by land use

Target layer	Criterion layer	Index layer	Unit	Index property	Entropy weight	AHP weight	Combined weight
Safety value of land use carbon emission E	Pressure system B1	U1 Population density	people·hm-2	—	0.054	0.15	0.099
		U2 Urbanization rate	%	—	0.054	0.007	0.022
		U3 GDP per capita	yuan·people -1	—	0.023	0.124	0.058
		U4 The proportion of secondary industry	%	—	0.054	0.096	0.079
		U5Urban per capita disposable income	yuan·people -1	—	0.038	0.012	0.023
		U6 Rural per capita net income	yuan·people -1	—	0.047	0.089	0.07
		U7 Fertilizer application amount per unit of cultivated land	kg·hm-2	—	0.036	0.076	0.057
		U8 Use amount of mulch per unit of	kg·hm-2	—	0.053	0.067	0.065

	cultivated land					
	U9 Energy consumption per unit of GDP	kg·Ten thousand yuan -1	—	0.054	0.051	0.058
	U10 Energy consumption per unit of industrial added value	kg·Ten thousand yuan -1	—	0.054	0.014	0.03
	U11 Per capita construction land area	hm2·Ten thousand yuan -1	—	0.054	0.044	0.053
	U12 Carbon emissions per unit of GDP	kg·Ten thousand yuan -1	—	0.051	0.016	0.031
	U13Carbon emission per unit construction land	kg·hm-2	—	0.054	0.047	0.055
	U14 Per capita ecological land area	hm2·people -1	+	0.054	0.043	0.053
	U15 Carbon uptake per unit of agricultural land	kg·hm-2	+	0.052	0.02	0.035
	U16 Soil and water compatibility	%	+	0.054	0.02	0.036
Response system B2	U17 Per unit grain yield	kg	+	0.049	0.027	0.039
	U18 Urban per capita park green space	hm2·people -1	+	0.054	0.038	0.049
	U19 Comprehensive utilization rate of industrial solid waste	%	+	0.054	0.032	0.045
	U20 Forestry investment as a percentage of GDP	%	+	0.054	0.028	0.042

2.2. Data Sources

The land use data used in this study were derived from detailed survey data of land use change in Inner Mongolia from 2001 to 2021, Socio-economic data are from Inner Mongolia Statistical Yearbook (2001-2021). It should be noted that the agricultural land in this study includes cultivated land, forest land and grassland. Ecological land includes cultivated land, forest land, grassland and water area. The carbon emission of agricultural land was calculated by the application amount of fertilizer conversion, the total power of agricultural machinery, the sown area of cultivated land and the corresponding carbon emission coefficient. The carbon absorbed by cultivated land is the carbon fixed by photosynthesis of crops on it[5]. Carbon absorption coefficient method was adopted for forest land and grassland[6]. Carbon emissions of construction land are calculated indirectly through energy consumption per unit of GDP[5].

2.3. Research Methods

2.3.1. Combination weight method based on relative entropy theory

Subjective weighting method is more subjective and may deviate from the actual situation. Although objective weighting method is objective, it may lack the support of theoretical experience. The combination weight method can not only eliminate the randomness of subjective weighting method, but also ensure the accuracy of objective weighting method sample data. Combined weight method combines the advantages of the two weighting methods to effectively reduce the impact of data volatility on the results. The formula for calculating combined weight is as follows:

$$W_i = \frac{\prod_{j=1}^{p}(u_{ji})^{\frac{1}{p}}}{\sum_{j=1}^{m}\prod_{j=1}^{p}(u_{ji})^{\frac{1}{p}}} \quad (1)$$

In the formula, W_i is the combined weight, and u_{ji} is the weight of the ith index in the jth weighting method.

2.3.2. Determination and classification of safety value

To determine the safety value of carbon emission, the safety value is calculated by multiplying the standardized data of each index with the corresponding combined weight and summing.

$$E = \sum_{i=1}^{m} w_i \cdot P_i \quad (2)$$

In the formula, E is the safety value of carbon emission, w_i is the combined weight, and P_i is the standardized data of indicators.

Based on the relevant research and the actual situation in Inner Mongolia, the safety value of carbon emission from land use was divided into 5 levels by using the non-equidistant method[7],see Table 2.

Table 2 Evaluation ranking on carbon emission security by land use

state	safety	sub-security	Critical safety	unsafe	morbid
interval	(0.85,1]	(0.65,0.85]	(0.4,0.65]	(0.25,0.45]	[0,025]

2.3.3. 2.3.3 GM (1,1) Prediction model

GM(1,1) model is a method for accurate prediction of sample data, which requires little regularity of sample data, does not require a large number of sample data, and requires little computation, so there will be no inconsistency between quantitative results and qualitative analysis results[8]. By distinguishing the degree of correlation between the sample data, we can find out the regularity characteristics between the sample data, and make fuzzy prediction for the development of things through the grey prediction model. In order to directly reflect the change trend of land use carbon emissions security in Inner Mongolia from 2022 to 2031, the GM (1,1) prediction model was introduced. Based on the simulation of index values, the prediction accuracy of the model was determined according to the posteriori error, small error probability and average relative error,see Table 3.

Table 3 Accuracy standards for model testing

Prediction accuracy class	good	qualified	reluctantly	disqualification
α	＞0.95	＞0.8	＞0.7	≤0.7
C	＜0.35	＜0.5	＜0.65	≤0.65

3. Results and analysis

Carbon emissions, carbon uptake and net carbon emissions of land use in Inner Mongolia Autonomous Region during 2001-2021 were calculated using the above methods, and the results were shown in Figure 1 (carbon emissions were positive and carbon uptake was negative).

The combined weights of each index were calculated using the above method (Table 1). The multi-index comprehensive evaluation model was used to calculate the security value of land use carbon emissions in Inner Mongolia during 2001-2021, and the security status of land use carbon emissions in Inner Mongolia during 2022-2031 was predicted.

3.1. Land use carbon emission effect

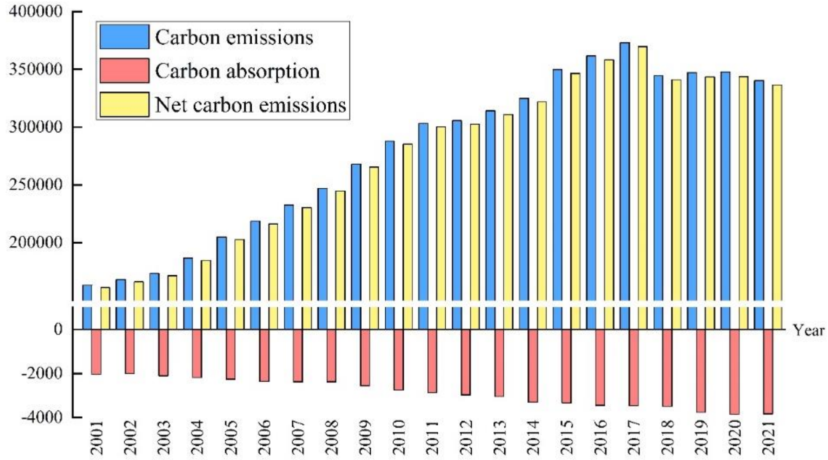

Fig 1 Map of total carbon emission/total carbon absorption/net carbon emission in Inner Mongolia during 2021-2031

From 2001 to 2021, the net carbon emission of land use in Inner Mongolia was in a state of growth in Fig 1, with a large increase, from 1659.91 million tons in 2001 to 371.632 million tons in 2021, with a net increase of 2056.41 million tons and an overall growth rate of 123.89%. The carbon emissions of land use are far greater than the amount absorbed, and the carbon emissions of land use mainly come from agricultural land, and the carbon emissions of construction land account for a small proportion compared with that of construction land. From 2001 to 2021, the carbon uptake of land use has been increasing. Although the carbon uptake of grassland and forest land is relatively small, and the mitigation effect of grassland and forest land on the carbon emission of agricultural land and construction land is very weak, the effect of grassland and forest land on the ecological environment cannot be ignored.

3.2. Analysis of time series changes of land use carbon emission security

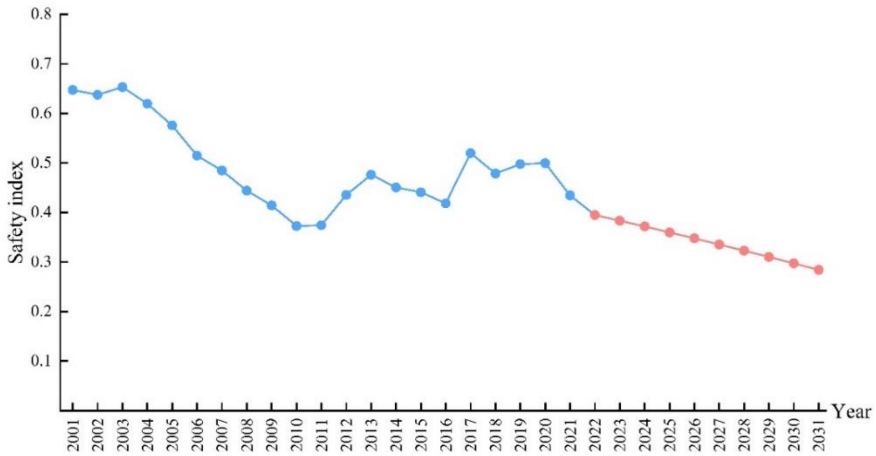

Fig 2 Carbon emission security indices on land uses in Inner Mongolia during 2021-2031

Based on the evaluation and research on the security status of land use carbon emission in Inner Mongolia from the time scale, we can know the change of land use carbon emission security level in Inner Mongolia from 2001 to 2021. As can be seen from Fig 2, from 2001 to 2021, the security index of land use carbon emissions in Inner Mongolia showed a general trend of fluctuation and decline, from 0.647 in 2001 to 0.435 in 2021, and the security level exceeded sub-security and insecurity. The highest safety value appeared in 2003, which was 0.63, and the safety state was sub-safety.The lowest safety value appeared in 2010, which was 0.373, and the safety state was unsafe.

3.3. Security prediction of land use carbon emissions

According to the index data of Inner Mongolia from 2001 to 2021, the grey prediction model was used to forecast the evaluation indexes from 2022 to 2031, and the prediction value was calculated. Then, C, small error probability α and average relative error Q were checked. The simulation accuracy of each index predicted value is qualified or above and Q is in the acceptable error range, so this model can be used for prediction. The security value of land use carbon emissions during 2001-2021 is obtained by calculation. Figure 2 shows the security prediction result of land use carbon emissions in Inner Mongolia during 2022-2031. As shown in Figure 2, from 2022 to 2031, the safety index of land use carbon emissions in Inner Mongolia approximately plummeted, with the safety value ranging from 0.395-0.284, the safety level decreased from critical safety to unsafe, and the safety state continued to weaken.

4. Conclusion

This study draws on the theory of land ecological security to study land use carbon emission security. The results show that the fluctuation of land use carbon emission safety index in Inner Mongolia decreased from 2001 to 2021, and reached the safest state in 2003, with a safety value of 0.63. From 2021 to 2031, the security index of land use carbon emission in Inner Mongolia approximately plummeted, and the security status continued to weaken. The future land use carbon emission security in Inner Mongolia is not safe, and the security situation is not optimistic.

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