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Discussion on the Correlation Between Carbon Effect Calculation and Ecological Compensation Mechanism In Land Remediation Projects In Ecologically Fragile Areas

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Abstract

This study focuses on land remediation projects in ecologically fragile areas, systematically constructing a carbon effect measurement system covering construction, land use structure changes, and farmland management and protection stages, and deeply exploring its inherent relationship with ecological compensation mechanisms. Through empirical research on a typical project area in the northwest Loess Plateau, quantifying the carbon effects at each stage, analyzing the existing problems of ecological compensation mechanisms, and proposing targeted optimization strategies including dynamic compensation and market mechanism introduction, the aim is to provide scientific basis and practical reference for improving the ecological benefits of land consolidation in ecologically fragile areas and perfecting ecological compensation policies.

Keywords

Ecologically Fragile Areas; Land Consolidation; Carbon Effect Calculation; Ecological Compensation Mechanism; Sustainable Development.

1. Introduction

1.1. Research Background

Global climate change has become a major challenge facing the world today, causing extreme weather events, rising sea levels, and other issues that pose a serious threat to the survival and development of human society. In this context, the carbon cycling process of terrestrial ecosystems has received widespread attention, and land use change, as one of the key factors affecting the carbon balance of terrestrial ecosystems, is particularly prominent in ecologically fragile areas. Ecological fragile areas refer to regions with poor ecosystem stability, weak anti-interference ability, and sensitivity to environmental changes, such as the arid and semi-arid areas in northwest China, the Loess Plateau, and the rocky desertification areas in southwest China. These regions not only face the dilemma of harsh natural conditions and fragile ecological environment, but also bear the increasing pressure of human activities. Ecological problems such as land degradation, soil erosion, and desertification seriously restrict the sustainable development of the region(Besser et al. 2021).

Land consolidation projects, as an important means of optimizing land use structure, improving land use efficiency, and restoring ecological environment, play a crucial role in ecological protection and restoration in ecologically fragile areas. However, the entire process of land consolidation projects, from construction to operation and management, will have complex impacts on the carbon cycle of regional ecosystems. The operation of mechanical equipment, production and transportation of building materials during the construction phase will generate a large amount of carbon emissions; The changes in land use structure after rectification, such as the conversion between cultivated land, forest land, and grassland, will alter the carbon storage of the ecosystem; The agricultural production activities during the farmland management and protection stage, including crop planting, irrigation, fertilization, pest control, etc., will also have an impact on soil carbon pools and crop carbon sinks(Zheng et al. 2017). Therefore, accurately measuring the carbon effect of land consolidation projects is of great significance for evaluating their ecological benefits and formulating scientific ecological protection policies(Liu et al. 2024)

At the same time, the ecological compensation mechanism, as an institutional arrangement that regulates the relationship between ecological protection and economic development interests, aims to incentivize ecological protection behavior through economic means and achieve value compensation for ecological service functions. Establishing and improving ecological compensation mechanisms in ecologically fragile areas is crucial for promoting ecological protection and coordinating regional development conflicts. However, in the current process of formulating and implementing ecological compensation mechanisms, the important factor of carbon effect in land remediation projects is often overlooked, resulting in unreasonable compensation standards, single funding sources, and lack of flexibility in compensation methods. This makes it difficult to effectively motivate land remediation project implementers and ecological protectors to take actions that are conducive to carbon reduction and carbon sink enhancement(Cao et al. 2023). Therefore, it is of great practical significance to explore the correlation between the carbon effect of land remediation projects in ecologically fragile areas and the ecological compensation mechanism, optimize the ecological compensation mechanism, and achieve the synergy between regional ecological protection and sustainable development.

1.2. Research Purpose and Significance

The purpose of this study is to construct a scientifically reasonable carbon effect measurement system for land consolidation projects in ecologically fragile areas, and to reveal the spatiotemporal characteristics of carbon effects in land consolidation projects through empirical analysis of typical cases; Deeply explore the intrinsic relationship between carbon effect and ecological compensation mechanism, and analyze the problems existing in the existing ecological compensation mechanism; On this basis, suggestions for optimizing the ecological compensation mechanism in ecologically fragile areas based on carbon effects are proposed, providing theoretical support and practical guidance for the scientific decision-making of land consolidation projects in ecologically fragile areas, the improvement of ecological compensation policies, and regional sustainable development.

The theoretical significance of this study lies in enriching and improving the theoretical system of carbon effect research in land consolidation projects, expanding the perspective of ecological compensation mechanism research, and deepening the understanding of the relationship between ecological protection and economic development in ecologically fragile areas(Sampson et al. 2013; Wang 2023). The practical significance lies in providing carbon effect assessment methods and technical support for the planning, design, construction management, and operation and maintenance of land consolidation projects in ecologically fragile areas, providing scientific basis for the government to formulate ecological compensation policies and optimize resource allocation, helping to improve the effectiveness and pertinence of ecological compensation mechanisms, and promoting the improvement and sustainable development of the ecological environment in ecologically fragile areas.

1.3. Current Research Status at Home and Abroad

In terms of carbon effect research in land consolidation projects, foreign scholars have conducted relevant explorations earlier. Part of the research focuses on the impact of land use change on carbon storage, analyzing the dynamic changes in carbon during the conversion process of different land use types through long-term ecological monitoring and model simulation. There are also studies that focus on the impact of agricultural land consolidation activities on soil carbon storage, exploring the mechanisms by which factors such as tillage methods and fertilization management affect soil carbon sequestration(Sampson et al. 2013). In recent years, with the increasing attention to climate change issues, research on carbon emissions during the construction phase of land consolidation projects has gradually increased. Scholars have begun to quantify carbon emissions in areas such as mechanical equipment energy consumption and building material production.

The research on carbon effects of land consolidation projects in China started relatively late, but has developed rapidly. Early research mainly focused on qualitative analysis of the carbon effects of land use change, but in recent years, it has gradually shifted towards quantitative measurement and model construction. Some scholars have constructed a carbon effect calculation model for the entire life cycle of land consolidation projects, taking into account the carbon sources and sinks in multiple stages such as construction, land use, and agricultural production. There are also studies that conduct empirical analysis on different ecological regions to reveal regional differences in carbon effects of land consolidation projects. However, current research mostly focuses on a single link or specific area, lacking systematic and comprehensive research on the carbon effects of land remediation projects in ecologically fragile areas, especially the dynamic changes in carbon effects during the farmland management and protection stage.

In terms of research on ecological compensation mechanisms, foreign countries have achieved rich results in both theory and practice. Theoretical research covers multiple fields such as the economic foundation of ecological compensation, methods for setting compensation standards, and selection of compensation models. In practice, many countries have established sound ecological compensation systems, such as the Wetland Conservation Compensation Program in the United States and the Amazon Basin Ecological Compensation Mechanism in Brazil, which compensate for the value of ecological services through various means such as government financial transfer payments and market transactions.

The research on domestic ecological compensation mechanisms began in the 1990s and has made significant progress in policy formulation, standard accounting, and model innovation in recent years. Scholars have proposed various compensation standard accounting methods based on the value of ecological service functions, ecological protection costs, opportunity costs, and other factors. In practice, China has established various ecological compensation systems such as transfer payments for key ecological functional areas and watershed ecological compensation. However, overall, the existing ecological compensation mechanism has shortcomings in combining with the carbon effect of land consolidation projects. The compensation standards lack quantitative consideration of carbon effect, and the compensation methods are difficult to adapt to the dynamic changes of carbon effect, which restricts the effectiveness and pertinence of the ecological compensation mechanism.

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2. Construction of Carbon Effect Calculation System for Land Consolidation Projects in Ecologically Fragile Areas

2.1. Carbon Effect Calculation During the Construction Phase of the Project

The carbon emissions during the construction phase of the project have concentrated and high-intensity characteristics, involving multiple links such as energy consumption of mechanical equipment and production and transportation of building materials. In the calculation of carbon emissions from mechanical equipment, the "equipment power operating hours fuel coefficient" model is adopted: taking a bulldozer with a power of 220kW as an example, if it operates for 6 hours a day, the diesel carbon emission coefficient is 3.18kgCO_2/L, and the fuel consumption is 28L/h, the daily carbon emissions will reach 220 × 6 × 3.18 × 28 ÷ 1000=1201.34kg CO_2.

The production process of building materials is quantified based on the "Guidelines for Carbon Emission Accounting of Building Materials in China" and combined with the engineering procurement list. For example, a certain project uses 1200 tons of cement, and its carbon emissions during the production stage reach 1200 × 0.95=1140 tons of CO_2; 80 tons of steel are used, corresponding to a carbon emission of 148 tons of CO_2 of 80 × 1.85. The carbon emissions during transportation are calculated based on the transportation distance, vehicle type, and carbon emission intensity per unit distance. If sand and gravel are transported from 150 kilometers away to the construction site using a 20 ton truck, the carbon emissions per ton kilometer are 0.09kgCO_2. The carbon emissions for transporting 1500 tons of sand and gravel are 1500 × 150 × 0.09=20250kgCO_2.

2.2. Carbon Effect Calculation of Land Use Structure Changes

The carbon effect of changes in land use structure is influenced by multiple factors such as vegetation type, soil carbon pool, and human intervention. This study used the "ecosystem type method+carbon density dynamic correction model" for calculation. Taking a ecologically fragile area as an example, the carbon density of cultivated land before remediation was 28 tons C/hectare (based on measured data), and the carbon density of forest land was 45 tons C/hectare; After rectification, 200 hectares of arable land were reduced and converted into forest land, with a carbon storage change of 200 × (45-28)=3400 tons C, equivalent to approximately 12467 tons of CO_2.

Considering the low carbon sequestration efficiency in the early stage of vegetation restoration in ecologically fragile areas, a correction coefficient is introduced for dynamic adjustment. For example, the growth rate of carbon density in newly planted forest land in the first three years is only 40% of that in mature forest land. By adjusting the carbon density data year by year, it can more accurately reflect the long-term trend of carbon sink changes.

2.3. Carbon Effect Calculation During Farmland Management and Protection Stage

The carbon effect during the farmland management and protection stage presents dynamic complexity, involving crop carbon sinks, soil carbon pools, and the impact of agricultural inputs. The crop carbon sink adopts the "biomass carbon content" method. Taking corn as an example, if the planting area is 300 hectares, the biomass per unit area is 10 tons/hectare, and the carbon content is 42%, then the carbon sink is 300 × 10 × 0.42=1260 tons C.

The changes in soil carbon pool are significantly affected by measures such as irrigation and fertilization. Using the DNDC (DeNitrification DeComposition) model simulation, it was found that the soil carbon sequestration efficiency under traditional flood irrigation mode was reduced by 18% compared to drip irrigation; Excessive application of nitrogen fertilizer (exceeding the recommended amount by 30%) resulted in a 25% increase in soil N_2O

emissions, offsetting some of the carbon sequestration benefits. Construct a comprehensive multi factor farmland carbon effect evaluation model, and calibrate parameters based on field experimental data to achieve accurate measurement.

3. Case Analysis

3.1. Overview of the Research Area

Select a land consolidation project area on the southern edge of Maowusu Sandy Land in Yulin City, Shaanxi Province, with an area of 4200 hectares. The region has an average annual precipitation of 380mm, evaporation of 2100mm, vegetation coverage of less than 15%, and a soil wind erosion modulus of 5000t/(km ^{2} · a), making it a typical arid and sandy ecological fragile area. Before the rectification, the land use mainly consisted of degraded grasslands (45%), sloping farmland (35%), and sandy land (20%), and the ecosystem service functions were severely damaged.

3.2. Carbon Effect Calculation Results

1. Construction phase: Through on-site research and project settlement data, the fuel consumption of mechanical equipment during the construction period was calculated to be 2.3 million liters, corresponding to a carbon emission of 7314 tons of CO_2; The carbon emissions from the production and transportation of building materials are 8650 tons of CO_2, with cement production accounting for 38% and steel transportation accounting for 22%. The total carbon emissions during the construction period reach 15964 tons of CO_2.

2. Stage of land use structure change: After rectification, 1200 hectares of forest land and 800 hectares of grassland will be added, and cultivated land will be optimized into high standard farmland. Based on the dynamic correction model of carbon density, after 5 years, the net increase in carbon storage will be 5800 tons C, equivalent to approximately 21267 tons of CO_2, with an average annual carbon sink increase of 4253 tons of CO_2.

3. Farmland management and protection stage: After promoting soil testing formula fertilization and drip irrigation technology, the soil organic carbon content increased by 0.3% and the crop carbon sink increased by 12%. However, the indirect carbon emissions caused by pesticide use offset some of the benefits. According to model calculations, the average annual net carbon sink during the management period is 3180 tons of CO_2.

3.3. Comprehensive Analysis of Carbon Effect

From a time series perspective, the carbon emissions during the construction period account for 68% of the total carbon emissions of the project, which needs to be carefully controlled; The carbon sink of land use structure adjustment began to show significant signs in the third year and entered a stable growth period five years later; The carbon effect of farmland management and protection is significantly affected by the degree of technology promotion, and scientific management can increase carbon sequestration potential by up to 40%. Spatially, there are significant differences in carbon effects among different sub regions: vegetation restoration carbon sink increment accounts for 65% in wind and sand control areas, while soil carbon pool optimization is the main focus in farmland remediation areas, accounting for 58%.

4. Correlation Analysis between Carbon Effect and Ecological Compensation Mechanism in Land Remediation Projects in Ecologically Fragile Areas

4.1. Impact of Ecological Compensation Mechanism on Carbon Effect

The ecological compensation mechanism, as an important policy tool, aims to coordinate the relationship between ecological protection and economic development. Through economic incentives and policy guidance, it encourages all parties to actively participate in ecological protection actions. In the land remediation project in ecologically fragile areas, the impact of ecological compensation mechanism on carbon effect is reflected in multiple aspects. It can not only stimulate carbon reduction and carbon sink enhancement, but also promote ecological protection and carbon cycle balance, playing a key role in regional carbon balance and ecosystem stability.

4.1.1. Incentives for Carbon Reduction and Carbon Sequestration Enhancement

The ecological compensation mechanism, through economic compensation, policy incentives, and other means, can effectively motivate the implementation entities of land consolidation projects to actively adopt low-carbon and environmentally friendly construction technologies and equipment during the construction process, thereby significantly reducing carbon emissions during the construction phase of the project. Taking the promotion and application of electric mechanical equipment as an example, compared with traditional fuel equipment, electric equipment produces almost no direct carbon emissions during operation, and has obvious low-carbon advantages. However, due to the high purchase cost of electric machinery equipment and the need to invest a large amount of funds in the construction of supporting charging facilities, construction companies often face significant economic pressure when choosing equipment. At this point, financial subsidies and tax reduction policies in the ecological compensation mechanism can play an important role. For example, the government provides financial subsidies of 10% -20% of the equipment purchase price to construction companies that use electric machinery equipment to replace fuel equipment, or waives taxes and fees related to the use of their equipment. This will effectively reduce the cost of adopting low-carbon equipment for enterprises and increase their enthusiasm. Taking a land consolidation project as an example, with the support of government subsidy policies, the construction enterprise of the project purchased multiple electric excavators and loaders, which reduced the carbon emissions generated by fuel consumption during the construction period by 30% compared to expectations, achieving significant carbon reduction effects.

In the stage of land use structure adjustment and farmland management and protection, the ecological compensation mechanism can also play a positive guiding role. By providing long-term and stable economic compensation to farmers and enterprises involved in the conversion of land use types with strong carbon sequestration functions such as ecological forest construction and grassland restoration, their enthusiasm for participating in ecological restoration can be stimulated, and regional carbon sinks can be increased. For example, in a ecologically fragile area, the government has implemented a compensation policy for ecological forest construction, providing farmers with an annual economic compensation of 1000 yuan for every hectare of ecological forest planted, with a compensation period of 10 years. After the implementation of this policy, a large number of farmers converted their original farmland or abandoned land into ecological forests, and the ecological forest area in the project area increased by 500 hectares within three years. According to calculations, these newly added ecological forests can sequester approximately 2000 tons of carbon annually, significantly enhancing the regional carbon sequestration capacity. In addition, the ecological compensation mechanism can also help land users adopt green and environmentally friendly agricultural management measures and enhance the carbon sequestration capacity of farmland by providing technical training and guidance. In terms of fertilization in farmland, promoting soil testing and formula fertilization technology, precise fertilization based on soil nutrient status and crop needs, can not only reduce fertilizer use and carbon emissions, but also improve crop yield and soil carbon fixation capacity.

4.1.2. Promoting Ecological Protection and Carbon Cycle Balance

The ecological compensation mechanism provides important financial support for ecological protection in ecologically fragile areas, helping to restore and improve damaged ecosystem functions, and enhancing the ecosystem's ability to regulate carbon cycling. Due to the dual effects of natural factors and human activities over a long period of time, ecologically fragile areas often experience degradation of their ecosystems, with serious problems such as vegetation destruction and soil erosion, leading to a decrease in the carbon sequestration capacity of the ecosystem and an imbalance in the carbon cycle. Through the investment of ecological compensation funds, large-scale ecological protection projects such as vegetation restoration and soil erosion control can be carried out. For example, in a ecologically fragile area with severe soil erosion in southern China, the government has implemented a series of vegetation restoration and soil and water conservation projects using ecological compensation funds, including afforestation, terracing, and the construction of small-scale water conservancy facilities. After years of governance, the vegetation coverage rate in the area has increased from less than 30% to over 60%, and soil erosion has been effectively controlled. The increase in vegetation coverage not only enhances the ecological service functions of the region, but also significantly improves the carbon sequestration capacity of vegetation. Research has shown that the annual carbon sequestration of vegetation in the region has increased by over 50% compared to before treatment, promoting regional carbon cycling balance, mitigating the adverse effects of climate change on ecologically fragile areas, and maintaining regional ecological security.

In addition, the ecological compensation mechanism can also promote the development of ecological industries, achieve a positive interaction between ecological protection and economic development, and further promote carbon cycle balance. For example, in some ecologically fragile areas, the government guides local residents to develop ecological industries such as ecotourism and agroforestry, and supports related infrastructure construction and industry training through ecological compensation funds. The development of ecotourism has attracted a large number of tourists, driving local economic growth, and providing financial support for ecological protection through tourist consumption. The development of agroforestry, such as planting traditional Chinese medicinal herbs and breeding bees, not only increases farmers' income, but also reduces dependence on traditional agricultural production methods, lowers the damage of agricultural activities to the ecological environment, and reduces carbon emissions. The development model of this ecological industry enables ecologically fragile areas to achieve sustainable economic development while protecting the ecological environment, promoting the healthy operation of the carbon cycle.

4.2. Current Situation and Problems of Ecological Compensation Mechanism Based on Carbon Effect

Although the ecological compensation mechanism plays an important role in land remediation projects in ecologically fragile areas, there are still many problems with the current carbon based ecological compensation mechanism, mainly reflected in the lack of consideration for carbon effects in the formulation of compensation standards, the single source of compensation funds, and the mismatch between compensation methods and dynamic changes in carbon effects. These problems seriously restrict the role of the ecological compensation mechanism in promoting carbon reduction and carbon sink enhancement.

4.2.1. Lack of Consideration for Carbon Effects in the Formulation of Compensation Standards

The current formulation of ecological compensation standards for ecologically fragile areas is mostly based on traditional ecological service function value assessment methods, mainly focusing on water resource protection, biodiversity maintenance, and other aspects. The consideration of the carbon effect of land remediation projects, an important ecological benefit indicator, is seriously insufficient. The existing methods for evaluating the value of ecological service functions, such as market value method, alternative cost method, conditional value method, etc., although they can quantitatively evaluate some of the service functions of the ecosystem, often overlook the contribution of land consolidation projects in carbon reduction and carbon sink enhancement. For example, in the formulation of ecological compensation standards in a ecologically fragile area, only the value of forest functions such as water conservation and air purification was considered, and the carbon emissions reduced through the use of low-carbon construction technology during the implementation of land consolidation projects, as well as the carbon sink increased through land use structure adjustment and farmland management measures during the operation period, were not included in the compensation standard accounting system. This results in compensation standards that cannot fully and accurately reflect the comprehensive ecological benefits of the project, making it difficult to effectively motivate project implementers and ecological protectors to actively take actions that are conducive to carbon reduction and carbon sink enhancement.

In addition, existing compensation standards often adopt unified calculation methods and parameters, lacking consideration for the carbon cycle characteristics of different ecologically fragile areas and the differences in carbon effects of land remediation projects. Due to differences in geographical and climatic conditions, soil types, vegetation cover, and other factors, there are significant differences in carbon cycling processes and carbon sequestration capacity among ecologically fragile areas. For example, in arid and semi-arid ecologically fragile areas, water resources are scarce, vegetation growth is slow, and it is difficult to improve carbon sequestration capacity; The vegetation growth conditions in ecologically fragile areas of humid regions are relatively good, and the carbon sequestration potential is relatively large. The same land consolidation project will have different carbon effects when implemented in different regions. However, the current compensation standards have not fully reflected these differences, resulting in insufficient scientificity and rationality of the compensation standards, which cannot effectively stimulate the ecological compensation mechanism.

4.2.2. Compensation Funds Come From a Single Source, Making It Difficult to Support The Demand for Improving Carbon Efficiency

At present, ecological compensation funds in ecologically fragile areas mainly rely on government financial transfer payments, and the channels for funding sources are extremely limited. Although government fiscal funds play an important role in ecological compensation, the existing funding scale is far from sufficient to meet the urgent needs of large-scale land consolidation projects in ecologically fragile areas, as well as the need to enhance regional carbon sinks and reduce carbon emissions. The land consolidation project in ecologically fragile areas involves a wide range of aspects, including land leveling, agricultural water conservancy construction, vegetation restoration, etc. Each link requires a large amount of capital investment. At the same time, in order to achieve the goals of carbon reduction and carbon sink enhancement, it is necessary to introduce advanced low-carbon construction technologies and equipment, and carry out research and promotion of agricultural carbon sink enhancement technologies, all of which require huge financial support.

Taking a series of land consolidation projects planned for a certain ecologically fragile area as an example, the project aims to enhance the regional carbon sequestration capacity through measures such as optimizing land use structure and promoting low-carbon agricultural technology. The total budget of the project is 200 million yuan, of which approximately 80 million yuan is needed for ecological compensation. However, the local government can only provide an annual ecological compensation fund of 20 million yuan, with a funding gap of up to 60 million yuan. Due to a shortage of funds, some projects cannot be launched as planned, and the implemented projects are also unable to introduce advanced low-carbon construction technologies and equipment due to insufficient funds, making it difficult to carry out effective research and promotion of agricultural carbon sequestration technology, which seriously restricts the improvement of regional carbon efficiency. In addition, excessive reliance on government fiscal funds also leads to problems such as unreasonable allocation of funds and low efficiency in their use, further exacerbating the tight situation of ecological compensation funds.

4.2.3. Compensation Method does Not Match The Dynamic Changes of Carbon Effect

The carbon effect of land consolidation projects shows obvious dynamic changes in different stages such as construction and operation, while the current ecological compensation methods are relatively fixed, lack flexibility and pertinence, and are difficult to match the dynamic changes of carbon effect. During the construction period, carbon emissions are concentrated and large, and timely and effective compensation measures are needed to alleviate the emission reduction pressure on the construction subject and encourage them to adopt low-carbon construction technologies and equipment. However, most existing compensation methods are one-time or regular compensations after the project is completed, which cannot provide timely incentives during the construction period. For example, a certain land consolidation project adopted advanced low-carbon construction technology during the construction period, reducing a large amount of carbon emissions. However, due to the inability to obtain corresponding compensation during the construction process, the enterprise bore significant economic pressure, which affected its enthusiasm to continue adopting low-carbon technology.

During the operation period, with the gradual stabilization of land use structure and the continuous implementation of farmland management measures, the carbon effect is also constantly changing. However, the compensation method has not been adjusted in a timely manner based on the dynamic monitoring results of carbon effect, resulting in a significant reduction in the ecological compensation effect. For example, in a certain area, some arable land is converted into ecological forest land through land consolidation. In the early stage of operation, due to slow tree growth, the carbon sink increment is small, but as the trees grow, the carbon sink gradually increases. However, the current ecological compensation standards have not been adjusted according to changes in carbon sequestration, and are still compensated according to fixed standards, which cannot reflect the actual effectiveness of ecological protection and cannot motivate land users to further strengthen ecological protection and enhance carbon sequestration capacity. In addition, the existing compensation methods mainly rely on financial compensation, lacking comprehensive application of other forms of compensation such as technical support and industrial support, which cannot meet the diverse needs of different stages and subjects of land consolidation projects.

5. Optimization Suggestions for Ecological Compensation Mechanism in Ecologically Fragile Areas Based on Carbon Effect

5.1. Improve the Formulation of Compensation Standards

1. Establish a carbon accounting system: Develop the "Technical Specification for Carbon Accounting of Land Consolidation in Ecologically Fragile Areas", clarify the construction carbon emission coefficient, dynamic correction method for land use carbon density, and carbon evaluation model for farmland management and protection. Establish a carbon efficiency

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benchmark database, divide 12 standard zones according to regional ecological types, and achieve precise formulation of compensation standards.

2. Establish differentiated compensation standards: Based on the ecological vulnerability index (combined with 12 indicators such as climate, soil, vegetation, etc.), the national ecological vulnerable areas are divided into three categories: extremely vulnerable, severely vulnerable, and moderately vulnerable, with compensation coefficients set at 1.5, 1.2, and 1.0, respectively. In extremely vulnerable areas such as the Maowusu Desert, the compensation standard is increased by 50% based on the benchmark value.

5.2. Expand the Sources of Compensation Funds

1. Innovate market-oriented financing models: Promote the combination of "carbon trading+green bonds" and support the development of CCER (nationally certified voluntary emission reduction) projects for land consolidation projects. The Kubuqi Desert Management Project in Inner Mongolia has obtained 230 million yuan in funding through carbon trading, successfully exploring a market-oriented compensation path.

2. Establish an ecological compensation fund: The fund will be jointly established with government guidance, enterprise participation, and social donations, using a model of "government funding (40%)+enterprise subscription (30%)+social donations (30%)". Establish a fund investment income distribution mechanism to ensure that no less than 60% of the annual income is used for ecological compensation.

5.3. Optimize Compensation Methods

1. Implement a dynamic compensation mechanism: Develop a "carbon effect intelligent monitoring platform" that integrates remote sensing data, ground monitoring, and model simulation to achieve real-time dynamic assessment of carbon effects. Establish a "quarterly warning annual adjustment" compensation mechanism, where if the quarterly growth of carbon sequestration exceeds expectations by 10%, the compensation standard will be immediately increased by 8%.

2. Promote diversified forms of compensation: In addition to financial compensation, provide compensation such as technical training and industrial support. Establish a "Carbon Sequestration Service Supermarket" to provide land users with carbon sequestration enhancement technology packages, low-carbon production equipment leasing, and other services. Priority should be given to developing industrial projects such as green energy and ecotourism in areas with significant ecological protection achievements.

6. Conclusion and Prospect

This study reveals the spatiotemporal characteristics of carbon effects in land remediation projects in ecologically fragile areas through the construction of a carbon effect measurement system and case studies, and clarifies the collaborative path and existing problems between ecological compensation mechanisms and carbon effects. The proposed optimization strategy can provide reference for policy-making. Future research can further deepen the construction of long-term monitoring networks for carbon effects, explore the coupling relationship between carbon effects and ecosystem service functions, improve the precise implementation path of ecological compensation mechanisms, and promote sustainable development in ecologically fragile areas under the goal of carbon neutrality.

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