POLICY-DRIVEN LAND USE TRANSITION AND ITS STAGE-SPECIFIC IM-PACTS ON CARBON STORAGE DYNAMICS: A COUNTY-LEVEL CASE STUDY OF QINGYUN COUNTY, CHINA

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SUMMARY

Land use policies periodically shift among cropland protection, ecological construction, and economic growth. Understanding how these policy reorientations affect carbon storage is essential for county-level low-carbon land management. This study uses Qingyun County, China, as a case study. The county is characterized by severe land fragmentation, with only 713m² of cropland per capita, and experienced major policy reversals between 2017 and 2023. We integrated the PLUS-InVEST model to reconstruct land use trajectories, quantify carbon storage evolution, and project carbon storage dynamics through 2035 under three scenarios. The results reveal a rise-and-fall trend. Driven by the Three-Year Greening Campaign, carbon storage increased from 382.16 × 10^4t in 2017 to 399.61 × 10^4t in 2020. Following the implementation of the Grain-for-Farmland Policy, it declined to 392.92 × 10^4t by 2023. This trend mirrors a three-phase policy shift: ecological priority, cropland protection priority, and land consolidation. The forest protection scenario generated economic values of carbon storage that were 1.1% and 2.2% higher than those under the cropland protection and natural development scenarios, respectively. These findings may provide a theoretical basis for similar land management strategies in Latin America and the Caribbean. Brazil's Cerrado has experienced similar carbon losses associated with agri-cultural expansion. Policy-driven land use transition exerts a measurable stage-locking effect on carbon storage. As policy priorities shift, carbon storage responds accordingly. Therefore, low-carbon land optimization requires a dynamic framework that anticipates and mitigates carbon losses during policy transitions.

Introduction

Land use change is a key regulator of terrestrial ecosystem carbon storage. It accounts for approximately one-third of total anthropogenic carbon emissions, making it the second-largest carbon source after fossil fuel combustion (Foley and J, 2005; Houghton, 2010; Lu et al., 2016). Under China's goals of peaking carbon emissions by 2030 and achieving carbon neutrality by 2060, understanding how land use policy adjustments shape carbon storage dynamics has become increasingly important (Zhu et al., 2022; Zhang et al., 2023).

The PLUS-InVEST model provides a reliable framework for assessing the effects of land use change on carbon storage dynamics (Sharp and Chaplin-Kramer et al., 2018; Liang and Guan et al., 2021). It enables highly

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accurate simulation of land use conversions under multiple policy scenarios (Shi et al., 2015). This model has been widely applied in large regions such as the Yangtze River Delta (Zhou et al., 2025) and Xinjiang, as well as in watersheds, including the Fuhe River Basin (Chen et al., 2025), Taihu Lake (Zhu et al., 2025), Lijiang (Xinran et al., 2024 NOT IN REFERENCES), and the transition zone of the southwestern mountainous region (Zhou et al., 2025).

Notably, the model has also demonstrated strong applicability in Latin America. A study conducted in Três Lagoas, Brazil, combined PLUS and InVEST to assess carbon storage in a eucalyptus production area (Jimenez-Castaneda et al., 2022; Bacani et al., 2024). That study found that total carbon stock under the forest protection scenario was 2.48Tg higher than under the business-as-usual scenario, while the economic value of carbon sequestration nearly doubled. These studies consistently show that forestland and cultivated land are the primary land use types controlling carbon storage and that their conversion to construction land is the dominant factor leading to carbon stock loss (Li et al., 2023).

Despite these advances, research has focused primarily on regional or watershed scales, whereas county-level analyses remain limited. Counties represent the fundamental administrative unit for implementing land use policies; therefore, research at this scale is essential for under-standing how policy interventions affect carbon storage. Although existing scenario-based sim-ulations have explored ecological conservation and urban growth pathways (Zhang et al.; Li et al., 2025), they remain largely limited to quantifying carbon storage. Consequently, quantitative assessments of carbon storage variation under different policy scenarios remain insufficient, constraining targeted land use management at the county level. This challenge is not unique to China. Many agricultural countries in Latin America and the Caribbean face similar issues, highlighting the need to strengthen county-level research on low-carbon land management in these regions.

This study uses Qingyun County, Shandong Province, China, as a case study. Located in the North Shandong Plain within the Yellow River Delta, the county experienced a rare cycle of policy reversals between 2017 and 2023. This cycle comprised three phases. The first was the Three-Year Greening Campaign, during which forestland expanded and carbon storage increased. The second was the non-grain cropland recultivation campaign, during which forestland was converted back to cropland and carbon storage declined. The third involved small-to-large field consolidation, during which cropland expanded, and carbon storage came under increasing pressure.

These policy reversals occurred within a short period and within a single administrative unit, providing a natural experiment for investigating the causal relationship between policy re-orientation and carbon storage responses. Owing to the county's low topographic relief, land use patterns are highly sensitive to policy and market conditions. Land conversion is frequent, and conversion pathways are well defined, making the area particularly suitable for high-precision simulations using the PLUS model. Moreover, low-carbon land management in Qingyun County remains underdeveloped, making scenario-based analyses particularly relevant.

The policy swing dilemma faced by Qingyun County is not unique to China. The county must continuously balance food security, ecological protection, and economic development. Latin America and the Caribbean also include numerous agricultural counties facing similar land use conflicts. A study on environmental efficiency in Latin American agriculture found that only a few countries can offset agricultural emissions through land-use-related carbon sequestration (van Oudenhoven and De Groot, 2013). Research conducted in Brazil's Sergipe semiarid region es-timated that, under the business-as-usual scenario, carbon emissions would reach 736,900 Mg CO_2-eq by 2030, whereas the protected forest scenario would increase carbon sequestration by 481,900 Mg CO_2-eq, equivalent to approximately US$11.6 million (Hora, 2001). A compre-hensive overview estimated soil organic carbon losses of 4.21 Pg C in forests, 1.86-7.32 Pg C in grasslands, and 0.36 Pg C in mangroves across the region (2018; Jimenez-Castaneda et al., 2022). These studies demonstrate the potential effects of policy adjustments on carbon storage and highlight the importance of county-level scenario simulations.

Of particular relevance, a 2024 Brazilian study employed the same coupled PLUS-InVEST approach used in the present research (Jimenez-Castaneda et al., 2022; Bacani et al., 2024). The authors reported that total carbon stock under the protected forest scenario was 2.48 Tg higher than under the business-as-usual scenario, while the economic value of carbon sequestration reached US$117.43 million, nearly double that of the business-as-usual scenario (Bacani et al., 2024). The study also revealed substantial variation in carbon stocks among forest, savanna, eucalyptus plantations, and pastureland, underscoring the importance of scenario analysis (Bacani et al., 2024). These findings are consistent with the results of the present study, in which forest protection scenarios provide significant advantages for maintaining carbon storage and increasing the eco-nomic value of carbon storage. Together, these results support the reliability and broader ap-plicability of the PLUS-InVEST approach for assessing the effects of land use policies on carbon storage at the county or municipal scale.

Therefore, the empirical experience of Qingyun County may provide a useful conceptual reference for comparable agricultural counties in Latin America and the Caribbean, although the transferability of specific findings should be evaluated in light of local conditions. The stage-locking effects of policy-driven land use transition on carbon storage, together with the trade-offs in the economic value of carbon storage under different policy scenarios, have direct implications for low-carbon land use planning in these regions.

Based on land use data from Qingyun County covering the period 2017-2023, this study applies the coupled PLUS-InVEST model to achieve three objectives. First, it analyzes coun-ty-level land use change and quantifies carbon storage evolution to characterize the temporal relationship between policy shifts and carbon storage dynamics. Second, it simulates carbon storage dynamics and the economic value of carbon storage in 2035 under three scenarios: natural development, Forest Protection Priority, and cropland protection priority. Third, it identifies policy optimization pathways to enhance county-level carbon sink capacity. The findings are expected to provide empirical evidence to support spatially explicit land use planning and carbon management strategies aligned with China's dual-carbon goals.

Materials and Methods

General profile of the study area

Qingyun County is located in northwestern Shandong Province, China (Figure 1). It has flat terrain, with elevations ranging from 5.1 to 7.5m. This low relief makes land use highly sensitive to policy and market changes. The county has a temperate continental monsoon climate, and its soils are predominantly Fluvo-aquic soils and Solonchaks. Qingyun is a typical

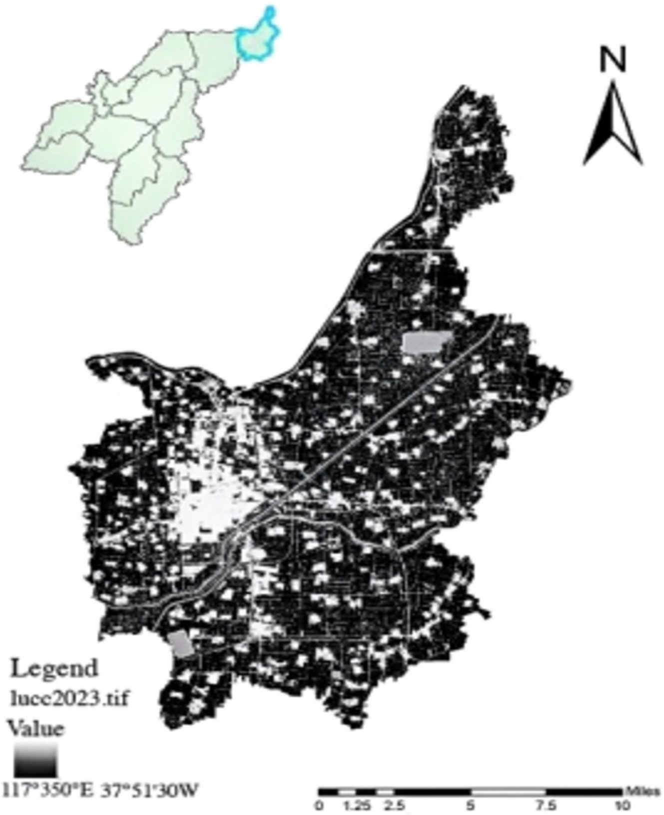

Figure 1. Location map of Qingyun County.

agricultural county characterized by severe land fragmentation and only 713m² of cropland per capita. Between 2017 and 2023, it experienced three major policy reversals: the Three-Year Greening Campaign, the non-grain cropland recultivation campaign, and small-to-large field consolidation. These policy changes induced stage-specific land use transitions, making the county a natural laboratory for investigating policy-driven responses of carbon storage.

Data sources

The data used in this study included land use, carbon density, meteorological, elevation, and slope data. Land use data were obtained from the National Land Use Change Survey of Qingyun County for 2017, 2020, and 2023. Elevation and slope data were derived from the 1:500 topo-graphic maps of Qingyun County and supplemented with data from the Geospatial Data Cloud. Carbon density values were determined according to the actual conditions of Qingyun County.

The original land use classification was consolidated into six categories: cultivated land, forest land, grassland, water bodies, construction land, and unused land. All driving-factor data were preprocessed in ArcGIS, resampled to a uniform spatial resolution of 30m × 30m, and standardized to the same projected coordinate system as the Qingyun County land use data.

Research methods

InVEST model

The InVEST model, a widely used tool for assessing ecosystem service values, is fre-quently applied to the comprehensive evaluation of multiple ecosystem services. In this study, the InVEST model categorizes terrestrial carbon storage into four components: aboveground carbon storage, belowground carbon storage, soil carbon storage, and dead organic matter carbon storage.

$$c_k = c_{above} + c_{below} + c_{soil} + c_{dead} \quad (1)$$

$$c_{total} = \sum_{k=1}^{n} A_k \times C_k,\ k = 1,2,\ n \quad (2)$$

C_k represents the total carbon density of the kth land use type (t/hm²). $C_{a\beta ove}$ denotes the aboveground carbon density (t/hm²), $C_{\beta elow}$ the belowground carbon density (t/hm²), C_{soil} the soil carbon density (t/hm²), and C_{dead} the dead organic matter carbon density (t/hm²). C_{total} rep-resents the total ecosystem carbon storage (t). A_k is the area of the kth land use type (hm²), and k indicates the land use category.

Previous studies have demonstrated that carbon density is closely correlated with mean annual precipitation and mean annual temperature. To improve the accuracy of the calculations, benchmark data from a climatically similar region (Shandong Province) were adopted to cali-brate the model parameters. During 2017-2023, the mean annual precipitation was 870.785mm in Shandong Province and 622.787mm in Qingyun County, whereas the corresponding mean annual temperatures were 14.109°C and 13.671°C, respectively. The carbon density correction coefficient was obtained by substituting these data into the correction equations. The final car-bon density values for the study area were calculated by multiplying the reference carbon densi-ty by the corresponding correction coefficient. The correction equations are as follows:

$$k_B = \frac{1}{2}\left(\frac{0.03\times p_1 + 14.4}{0.03\times p_2 + 14.4} + \frac{-0.04\times T_1 + 43.0}{-0.04\times T_2 + 43.0}\right) \quad (3)$$

$$k_S = \frac{1}{2}\left(\frac{0.07\times p_1 + 79.1}{0.07\times p_2 + 79.1} + \frac{-3.4\times T_1 + 157.7}{-3.4\times T_2 + 157.7}\right) \quad (4)$$

$$k_D = \frac{1}{2}\left(\frac{0.01\times p_1 + 0.58}{0.01\times p_2 + 0.58} + \frac{-0.03\times T_1 + 2.03}{-0.03\times T_2 + 2.03}\right) \quad (5)$$

k_B denotes the biomass correction coefficient. k_S represents the soil organic matter correction coefficient. k_D indicates the dead organic matter correction coefficient. p_1 and p_2 are the mean annual precipitation of the study area and the reference region, respectively. T_1 and T_2 are the mean annual temperature of the study area and the reference region, respectively. The carbon density values corresponding to the different land use types in Qingyun County are presented in Table I.

PLUS model

The PLUS model is used to simulate and forecast land use dynamics by identifying the driving mechanisms underlying land use transitions. The model supports the spatiotemporal characterization of land use evolutionary processes and facilitates analysis of land use expansion patterns and their associated driving factors. Accordingly, it generates the development probabilities of individual land

TABLE I
CARBON DENSITY OF DIFFERENT LAND USE TYPES IN QINGYUN COUNTY

Land use types	Aboveground carbon density (t/hm²)	Belowground carbon density (t/hm²)	Soil organic carbon density (t/hm²)	Dead organic carbon density (t/hm²)
Cultivated land	1.08	0.23	78.42	0.17
Forest land	3.71	0.77	107.49	0.57
Grassland	0.40	0.08	84.89	0.07
Water area	0.12	0.02	68.42	0.02
Construction land	0.01	0.00	64.03	0.00
Unused land	0.01	0.00	9.94	0.00

use units and the contribution weights of the driving factors.

Structurally, the PLUS model integrates two core components: the LEAS module and the CARS module. The LEAS module quantifies the relationships between land use categories and ecosystem functions, thereby evaluating changes in ecosystem services under different land use scenarios. The CARS module reproduces the patch-level characteristics of different land use types based on the analysis of dynamic change areas extracted from bi-temporal land use data.

Carbon density correction

Carbon density correlates closely with precipitation and temperature. We used benchmark data from climatically similar Shandong Province to calibrate parameters. Mean annual precipitation was 870.79mm for Shandong and 622.79mm for Qingyun County. Mean annual temperatures were 14.11°C and 13.67°C, respectively. A correction coefficient derived from these data was applied to obtain final carbon densities.

Accuracy validation

In this study, the Kappa coefficient was used to assess the simulation accuracy of the model. Before the formal analysis, the simulated land use pattern for 2023 was compared with the observed land use distribution. The resulting Kappa coefficient of 0.89 exceeded the threshold value of 0.75, indicating high simulation accuracy and confirming that the model was suitable for predicting land use patterns for 2035 (Figure 2).

Economic valuation of carbon storage

The economic value of carbon storage represents the monetary benefit derived from ecosystem carbon sequestration and storage. This value plays an important role in offsetting regional carbon emissions, enhancing the value of ecosystem services, and supporting biodiversity conservation. The economic value of carbon storage was calculated using the following equation:

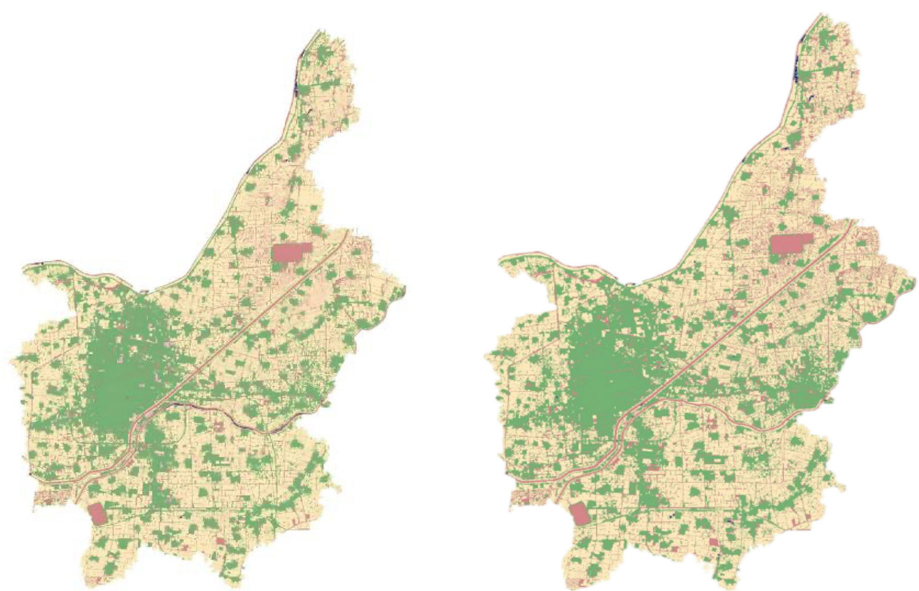

Figure 2. Temporal evolution: articles, journals and authors. Source: Authors' own elaboration.

$$p_C=\sum_{n=1}^{n} c_n \times p_n \quad (6)$$

$$p_n=F\times\ (PIF,\ e,\ n,) \quad (7)$$

p_C represents the economic value of carbon storage. c_n denotes the carbon market price in the n-th period. (*PIF*, *e*, *n*,) is the compound interest present value or future value factor, with e indicating the discount rate.

The average carbon trading price in 2023 of 64yuan/t was obtained from the Shanghai Environment and Energy Exchange. Based on this value, the carbon trading prices for 2017, 2020, and 2035 were estimated using the compound-interest present-value and future-value methods, respectively (Table II).

Contribution rate of carbon storage and driving factors

Variations in carbon storage are directly influenced by changes in land use policies. The contribution rate was calculated using the following formula, which provides a direct and systematic assessment of the effects of land use change on carbon storage dynamics. The

TABLE II
CARBON TRADING PRICES IN QINGYUN COUNTY FROM 2017 TO 2035

Year	2017	2020	2023	2035
Price of carbon trading (yuan/t)	48	55	64	115

Geodetector is a statistical method used to analyze spatially stratified heterogeneity, and its calculation formula is as follows:

$$CR= \frac{(C_1-C_0)}{C_t}\times\frac{LA}{TA} \quad (8)$$

CR represents the contribution rate of land use change to carbon storage variation. C_0 is the initial carbon storage of the land use type. C_1 denotes the carbon storage after land use conversion. C_t is the total absolute value of carbon storage changes across the study area. LA refers to the area of land undergoing type conversion. *TA* represents the total area of the study area.

$$Q=1-\frac{\sum_{h=1}^{L} N_h\sigma^2{}_h}{N\sigma^2}=1-\frac{SSW}{SST} \quad (9)$$

$$SSW=\sum_{h=1}^{L} N_h\sigma^2{}_h \quad (10)$$

$$SST=N\sigma^2 \quad (11)$$

Q represents the explanatory power of the driving factor, ranging from 0 to 1, with a higher value indicating stronger explanatory power. *L* denotes the number of classes (strata) for the driving factor. *h* refers to a specific class (h=1, 2,…). *N* and N_h are the total number of units and the number of units in class *h*, respectively. σ^2 and $\sigma^2{}_h$ represent the variance of the entire area and the variance within class *h*, respectively. SSW and SST are the sum of within-stratum variances and the total variance of the entire study area, respectively.

Scenario setting

To project future land use dynamics and their carbon consequences, three simulation scenarios for 2035 were developed based on different policy priorities. The baseline year for all simulations was 2023, representing the most recent observed land use pattern under the current policy framework (cropland protection priority). The scenarios were defined as follows.

Natural development

Land use change is assumed to continue along the historical trend observed from 2017 to 2023 without additional policy interventions. The transition probabilities for each land use type were extrapolated from the historical period. This scenario serves as a reference for assessing the consequences of maintaining current land use practices without policy adjustments. The main assumptions are: (i) continued urban expansion at the current rate; (ii) ongoing conversion of forestland and grassland to cropland driven by agricultural demand; and (iii) no additional restrictions on land use conversion beyond existing regulations.

Cropland protection priority

This scenario prioritizes food security and cropland preservation, reflecting the current policy direction in Qingyun County following the implementation of the non-grain cropland recultivation policy. The main assumptions are: (i) strict protection of cropland, with restrictions on its conversion to other land uses; (ii) limited expansion of built-up land into high-quality cropland; and (iii) maintenance of cropland area at or above the 2023 level through the recultivation of other land use types. This scenario represents a continuation of the policy direction observed between 2020 and 2023.

Forestland Protection Priority

This scenario prioritizes ecological protection and carbon sequestration through forestland conservation and expansion, representing an alternative policy pathway that emphasizes ecosystem services and enhanced carbon sink capacity. The main assumptions are: (i) strict protection of existing forestland; (ii) moderate reforestation of marginal cropland and grassland; (iii) restriction of built-up land expansion to non-forest areas; and (iv) maintenance or expansion of forestland relative to the 2023 level.

All scenarios were implemented using the CARS module of the PLUS model. Transition probabilities for each scenario were derived from the LEAS module based on historical data (2017-2023) and adjusted according to the policy assumptions described above. The same set of driving factors—elevation, slope, distance to roads, distance to water bodies, population density, GDP, and land use policies—was used in all scenarios to ensure comparability. Carbon storage for each scenario was then calculated using the InVEST model with the projected land use maps as input.

For comparison purposes, the observed 2023 land use map and its corresponding carbon storage value (392.92×10^4t) were used as the baseline. All 2035 simulation results were compared with this baseline to quantify the relative changes in carbon storage under different policy priorities. Comparisons with the 2020 carbon storage value (399.61×10^4t) are also presented to illustrate the complete historical trajectory.

Results and Analysis

Impact of land use policies on land use types

Land use changes in Qingyun County are driven by market forces and policy interventions. Cultivated land, forestland, and built-up land are the dominant land use types. Rising costs of seeds, fertilizers, pesticides, diesel, and labor have increased grain cultivation expenses, while farmers' incomes remain low. Driven by cost-benefit considerations, farmers have converted land to cash crops, facility agriculture, or agri-tourism, leading to non-grain conversion in some areas.

From 2017 to 2020, cultivated land decreased from 334.20km² to 241.94km², a net loss of 92.26km². During the same period, farmers converted land to landscaping and nursery bases. Forestland expanded from 17.64km² to 76.30km², a net gain of 58.66km². Built-up land increased from 104.23km² to 110.60km². Grassland decreased from 5.22km² to 2.73km², while water bodies increased from 33.86km² to 68.41km².

From 2020 to 2023, the conversion trend reversed following the implementation of the non-grain cropland recultivation policy and the Grain-for-Farmland policy. Forestland contracted from 76.30km² to 57.08km², a loss of

19.22km², whereas cultivated land rebounded to 257.60km², a gain of 15.66km². Built-up land expanded to 113.03km², a net gain of 2.43km². Grassland further decreased to 2.39km², while water bodies remained stable at 66.09km².

The 2035 Natural Development scenario shows the continuation of these trends. Cultivated land is projected to reach 287.66km², whereas forestland is projected to decrease to 23.59km². Built-up land is projected to expand to 116.85km². The policy shift from ecological construction to cropland protection reversed the previous trend of forestland expansion, transforming the dom-inant land conversion pathway from cropland-to-forestland to forest-land-to-cropland (Figure 3).

Staged changes in land use type area and composition

Cultivated land, forest-land, and built-up land dominate Qingyun County, together ac-counting for more than 90% of the total area (Table III). From 2017 to 2020, the Three-Year Greening Campaign drove forestland expansion from 17.64km² to 76.30km² (3.52% to 15.24%), while cultivated land decreased from 334.20km² to 241.94km² (66.76% to 48.33%). This cropland-to-forestland conversion reflected the ecological construction policy.

From 2020 to 2023, the non-grain cropland recultivation policy reversed this trend. For-estland contracted to 57.08km² (11.48%), whereas cultivated land rebounded to 257.60km² (51.82%). Built-up land increased to 113.03km² (22.74%), while both grassland and water bodies declined.

The 2035 simulations show contrasting land use structures under different policy priorities. Under the Natural Development Scenario, cultivated land expands to 287.66km² (57.87%), whereas forestland shrinks to 23.59km² (4.75%). Under the Economic-Priority Development Scenario, built-up land expands the most to 122.75km² (24.69%), and cultivated land decreases to 254.74km². Under the Forestland Protection Priority Scenario, forestland reaches 31.94km², higher than under the Natural Development Scenario but lower than under the Economic-Priority

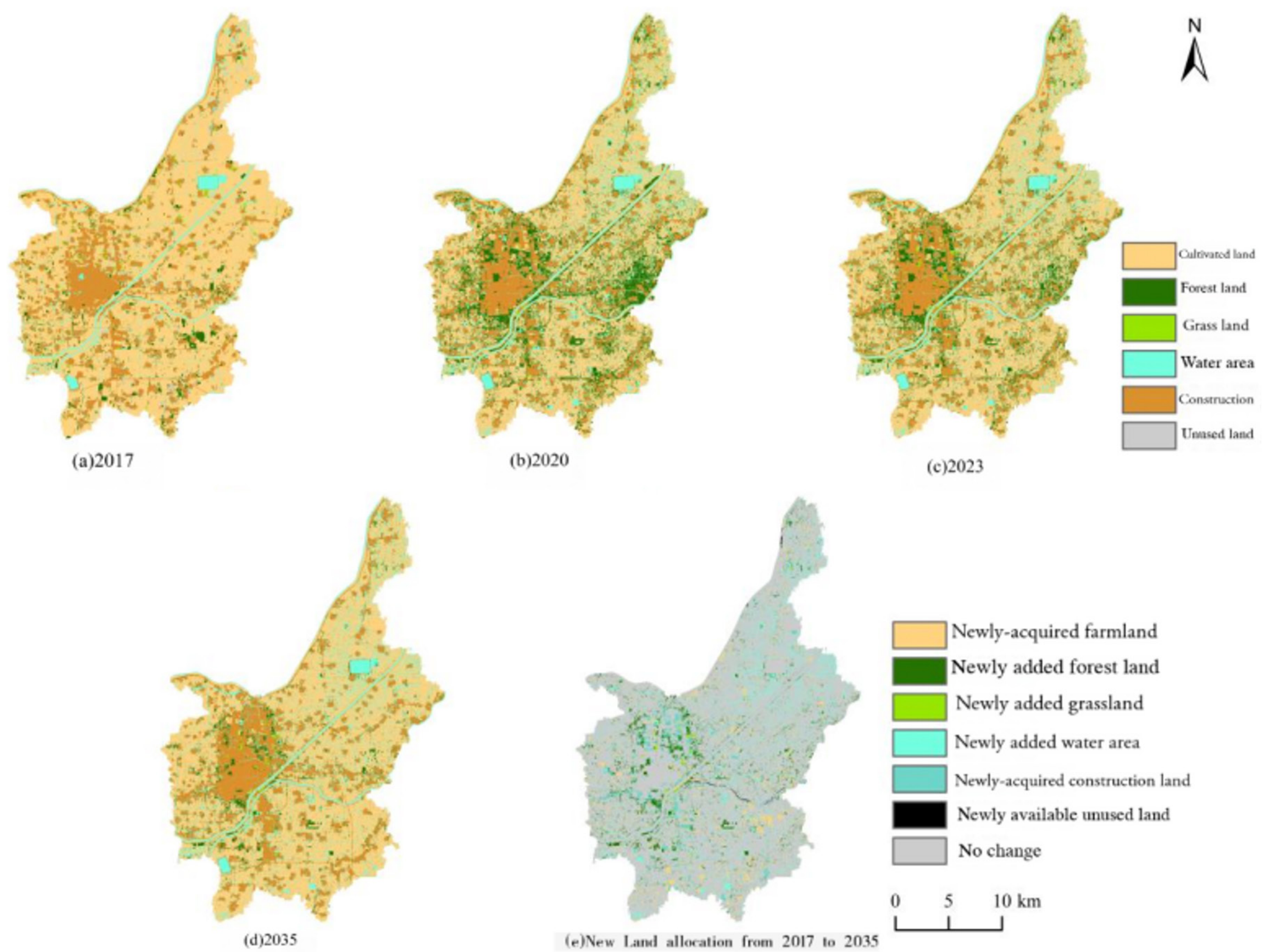

Figure 3. Spatiotemporal patterns of land use in Qingyun County from 2017 to 2035. Panels (a), (b), and (c) show the observed land use distributions in 2017, 2020, and 2023, respectively, reflecting three policy phases: ecological construction priority (2017–2020), cropland protection priority (2020–2023). Panel (d) shows the simulated land use distribution for 2035 under the natural development scenario. Panel (e) illustrates the newly allocated land by type accumulated from 2017 to 2035, highlighting the dominant conversion pathways.

TABLE III
AREA OF VARIOUS TYPES IN QINGYUN COUNTY FROM 2017 TO 2035

Year	Project [Area (km²) Proportion (%)]	Cultivated Land	Forest-land	Grass-land	Water Area	Construction Land	Unused Land
2017	Area	334.20	17.64	5.23	33.86	104.23	5.42
	Proportion	66.76	3.52	1.04	6.76	20.82	1.08
2020	Area	241.94	76.30	2.73	68.41	110.60	0.60
	Proportion	48.33	15.24	0.54	13.67	22.09	0.12
2023	Area	257.60	57.08	2.39	66.09	113.03	0.94
	Proportion	51.82	11.48	0.48	13.29	22.74	0.19
Natural Development Scenario in 2035	Area	287.66	23.59	2.09	66.09	116.85	0.84
	Proportion	57.87	4.75	0.42	13.29	23.51	0.17
Economic-Priority Development Scenario in 2035	Area	254.74	51.11	2.06	66.09	122.75	0.38
	Proportion	51.24	10.28	0.42	13.29	24.69	0.08
Forestland Protection Priority in 2035	Area	288.73	31.94	2.12	66.09	107.41	0.83
	Proportion	58.08	6.43	0.43	13.29	21.61	0.17

Development Scenario. Built-up land is lowest at 107.41km², whereas cultivated land reaches its highest value at 288.73km² (58.08%).

This seemingly count-er-intuitive result can be attributed to the interaction between policy con-straints and the PLUS model's econom-ic-driven transition rules. The Forestland Protection Priority Scenario simultane-ously imposes restrictions on built-up expansion and maintains cropland area, limiting forest expansion. In contrast, the Economic-Priority Scenario allows forestry activities to remain profitable, leading to larger forestland retention (51.11 km²). This indicates that carbon storage outcomes depend not only on policy labels, but also on how different constraints and incentives interact within the model.

These differences reflect policy priorities on land allocation. Cultivated land is largest under the Forestland Protection Priority Scenario due to the inertia of the Grain-for-Farmland policy and con-straints on built-up land expansion. Forestland is higher under the economic-priority scenario, pos-sibly reflecting the value of forest carbon sinks; however, this interpretation requires further assessment.

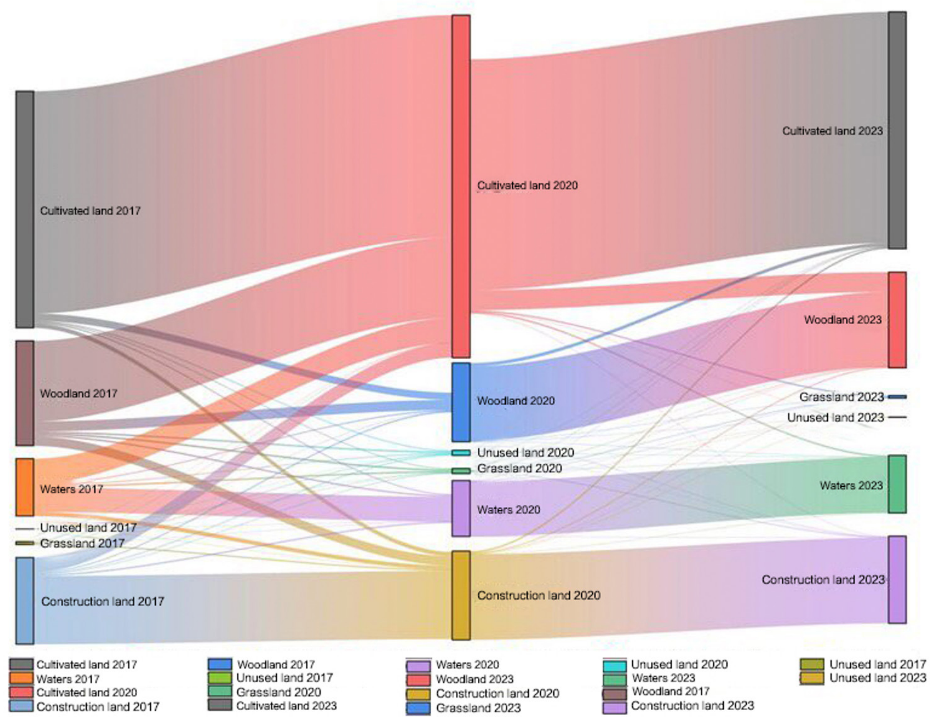

Figure 4. Carbon storage flow chart 2017-2023.

Spatiotemporal evolution of carbon storage and contributions by land use type

Carbon storage in Qingyun County is concentrated toward urban peripheries and exhibits a rise-and-fall pattern (Figure 4). This pattern is driven by land use policies and market conditions. Forestland and cultivated land are the dominant contributors. Affected by the non-grain cropland recultivation poli-cy, the contribution rate of cultivated land was 52.9% in 2017, decreased to 48.43% in 2020, and rebounded to 52.9% in 2023. Forestland showed the opposite trend, in-creasing from 5.2% in 2017 to 21.49% in 2020 before declining to 16.42% in 2023. The con-tribution of water bodies increased by 5.61%.

From a spatial perspec-tive, built-up land expansion initially in-creased and then slowed within the urban boundary because of fluctuations in the real estate market. Outside the urban boundary, large areas were converted to cultivated land after 2020 under policy protection. For-estland became more concentrated around urban areas, where industrial park shelterbelts were planned to absorb industrial CO_2 emissions. Carbon flows were closely associated with land use types. Forestland expansion drove the increase in carbon storage from 2017 to 2020, whereas the conversion of forestland to cultivated land contributed to the decline in carbon storage from 2020 to 2023. This trajectory directly reflects changes in land use policies.

Evolution of the economic value of carbon storage

The economic value of carbon storage in Qingyun County increased from 183.44 million yuan in 2017 to 251.47 million yuan in 2023, representing a cumulative increase of 68.03 million yuan (Table IV). Although total carbon storage declined after 2020, its economic value continued to increase. This trend primarily reflects changes in carbon prices over time.

The 2035 simulations show substantially higher economic values than those observed during the historical period. The economic-priority scenario yields the highest value (448.27 million yuan), followed by the Forestland Protection Priority Scenario (443.51 million yuan) and the natural development scenario (438.64 million yuan). The maximum difference among the scenarios is only 9.63 million yuan.

This ranking suggests that neither pure ecological protection nor unconstrained natural development maximizes the economic value of carbon storage. Instead, a balanced pathway in-tegrating development and environmental protection may provide greater economic benefits.

Compared with the historical period, the economic value of carbon storage under all three 2035 scenarios is approximately 2.4 times that of 2017, 2.0 times that of 2020, and 1.7 times that of 2023. This substantial increase is mainly attributable to cumulative increases in carbon prices rather than to actual growth in carbon storage.

Discussion

Policy swings drive staged changes in carbon storage

This study reveals a clear rise-and-fall trajectory of carbon storage in Qingyun County from 2017 to 2023. Total carbon storage increased from 382.16×10^4t to a peak of 399.61×10^4t before declining to 392.92×10^4t. This fluctuation closely reflects changes in land use policies. The Three-Year Greening period (2017-2020) promoted an increase in carbon storage, whereas the non-grain cropland recultivation and Grain-for-Farmland policies (2020-2023) contributed to its subsequent decline.

Cultivated land and forestland were the dominant contributors, exhibiting a clear seesaw effect in their contribution rates. From 2017 to 2020, farmers converted cultivated land to for-estland. Consequently, the contribution rate of cultivated land declined from 52.9% to 48.43%, whereas that of forestland increased from 5.2% to 21.49%. These findings are consistent with those reported for the Northeast Wetlands, where non-grain conversion temporarily enhanced carbon sink capacity (Li and Yuan et al., 2025). However, such practices may compromise food security.

After 2020, following the implementation of the relevant policies, cultivated land recovered from 241.94km² to 257.60km², and its contribution rate rebounded to 52.9%. Forestland con-tracted to 57.08km², while its contribution rate declined to 16.42%. These findings demonstrate that the intensity of policy implementation influences land use patterns and carbon sink func-tionality at the county level (Zhang and Zhou et al., 2025).

This policy-driven pattern of carbon storage has also been reported in Latin America and the Caribbean (Machado and Aguiar et al., 2024). In Brazil's Cerrado, agricultural expansion has removed more than 55% of the native vegetation over the past half century. Similar to Qingyun County, the Brazilian government has used policy instruments to influence land use. The Low Carbon Agriculture Plan and the Amazon Fund constitute two of the country's principal policy instruments (Moraes and De Azevedo et al., 2025).

The carbon density difference between forestland and cropland is key. In Qingyun, for-estland carbon density is higher than cropland. This explains why carbon storage rose during forest expansion and fell during forest-to-cropland conversion. Similar patterns exist in Latin America. A study in the Brazilian Cerrado found forest soil organic carbon stocks reached 147.34 Mg C ha^{-1}, while cropland stocks were significantly lower (Nwaogu et al., 2024). Research in Brazil's dry region showed cropland stocks (60.3 Mg Cha^{-1}) are lower than native vegetation (86.6 Mg C ha^{-1}) and agroforestry systems (87.6 Mg Cha^{-1}) (Greschuk and Villela et al., 2025). Land use con-version from forest to cropland inevitably reduces carbon storage.

Policy priority trade-offs revealed by multi-scenario simulations

Multi-scenario simulations show that carbon storage declines under all three 2035 sce-narios relative to historical baselines. Using 2020 as the baseline (399.61×10^4t), the natural development scenario decreases by 17.47×10^4t, the economic-priority scenario by 0.46×10^4t, and the Forestland Protection Priority Scenario by 7.26×10^4t. This counter-intuitive finding is corroborated by Latin American studies (Bacani et al., 2024). A study in Três Lagoas, Brazil, used the same coupled PLUS-InVEST approach and found that total carbon stock under forest protection was 2.48Tg higher than under the business-as-usual scenario. The economic value reached US$117.43 million, nearly double that of the business-as-usual scenario. Significant variability was observed across land use types. Scenario analysis is therefore critically important for assessing carbon mitigation potential, both in Brazil and China.

A deeper analysis explains why the Forestland Protection

TABLE IV
ECONOMIC VALUE OF CARBON STORAGE IN QINGYUN COUNTY FROM 2017 TO 2035 UNDER

Year	2017	2020	2023	Natural Development Scenario in 2035	Economic-Priority Development Scenario in 2035	Forestland Protection Priority in 2035
Economic value of carbon storage (10,000 yuan)	18343.87	21978.68	25146.80	43864.20	44827.33	44350.82

Priority Scenario did not produce the highest carbon storage. Under this scenario, forestland reached 31.94km², exceeding the Natural Development Scenario (23.59km²) but remaining below the Economic-Priority Scenario (51.11 km²). This result reflects the interaction between policy constraints and the economic-driven transition rules embedded in the PLUS model. While the Forestland Protection Priority Scenario restricts built-up expansion and simultaneously maintains cropland area, these combined constraints also limit forest expansion. By contrast, the Economic-Priority Scenario allows greater forestland retention while maintaining economically viable forestry activities. Because forestland has the highest carbon density in Qingyun County (107.49t/hm² of soil organic carbon, compared with 78.42t/hm² for cultivated land), the larger forest area under the Economic-Priority Scenario ultimately results in higher total carbon storage. Similar trade-offs have been reported in Brazil's Cerrado, where conservation outcomes depend not only on protection policies but also on land-use configuration and carbon efficiency (Soares-Filho et al., 2012). These findings indicate that carbon storage is determined not only by policy objectives, but also by the spatial allocation of high-carbon-density land uses and the interactions among policy constraints within the simulation model. Therefore, ecological policies should consider both the quantity and spatial configuration of forestland to maximize long-term carbon storage.

The natural development scenario assumes continued expansion of built-up land and the conversion of forestland and grassland to cropland without policy interventions to protect forest resources. This results in the largest loss of forestland (from 57.08km² in 2023 to 23.59km² in 2035) and, consequently, the greatest reduction in carbon storage because forestland has the highest carbon density among all land use types in Qingyun County. In contrast, the Forestland Protection Priority Scenario maintains more forestland (31.94km²), whereas the economic-priority scenario retains the largest forestland area (51.11km²), which is consistent with the higher carbon storage projected under that scenario.

Policy implications from the perspective of carbon economic value

Carbon economic value further underscores the importance of forestland protection. The economic-priority scenario yields the highest value at 448.27 million yuan, followed by the Forestland Protection Priority Scenario at 443.51 million yuan and the natural development scenario at 438.64 million yuan. However, the economic-priority scenario comes at the cost of substantial cropland loss. In contrast, the Forestland Protection Priority Scenario achieves 392.92×10^4t of carbon storage while allowing cropland to expand to 288.73km². Its carbon economic value is only 1.06% lower.

This trade-off is widely discussed in Latin America and the Caribbean (Jimenez-Castaneda and Lal et al., 2022). A comprehensive overview estimated soil organic carbon losses of 4.21Pg C in forests, 1.86-7.32Pg C in grasslands, and 0.36Pg C in mangroves. Farmers are key actors and therefore require incentives or fair compensation. National and con-tinental policies are critical for land restoration. Jamaica's experience shows that land use poli-cies can reduce emissions (Füllberg-Stolberg, 2010). In 2020, Jamaica included land use in its nationally determined contributions. More than 25% of its land is currently under protection, with a target of 30% by 2025. Forest cover has increased, and secondary forests are recovering. These experiences provide useful policy lessons for Qingyun County.

Policy implications for Latin America and the Caribbean

Qingyun's experience provides useful references for comparable agricultural counties in Latin America and the Caribbean (Machado et al., 2024). This region faces similar land use conflicts, including the need to balance food security, ecological protection, and economic de-velopment. Brazil's agricultural expansion, Argentina's Pampas conflicts, and Central American forest challenges all demonstrate the influence of land use policies on carbon storage. Regional efforts, such as those of Guevara et al. (2008), have highlighted the challenges of digital soil mapping and carbon estimation across Latin America, further emphasizing the need for localized validation.

Three policy implications emerge. First, policy-driven land use transitions exert a stage-locking effect on carbon storage. Policymakers must anticipate the risks of carbon loss during these transitions. Second, forestland protection achieves a better balance between carbon economic value and food security. For forest-rich Latin American countries such as Brazil, Co-lombia, and Costa Rica, this finding may provide valuable policy guidance. Third, optimizing low-carbon land use requires a dynamic framework that anticipates and mitigates carbon losses.

The Central American experience also offers valuable lessons for Qingyun County (Lal et al., 2006). CATIE has led blue carbon science and policy initiatives in Central America, ex-panding from projects in Costa Rica to broader initiatives in Panama, El Salvador, and Hondu-ras. The region has incorporated mangroves into national forest inventories and REDD+ pro-grams. This progression from local initiatives to national implementation is consistent with the dynamic policy framework proposed in this study. However, although the land use patterns and policy dilemmas in Qingyun County share similarities with those of Latin American and Carib-bean countries, their biophysical conditions, institutional frameworks, and socioeconomic con-texts vary considerably. Therefore, the policy implications presented in this study should be regarded as conceptual references rather than universally applicable conclusions. Future research should conduct comparative case studies to examine the generalizability of the stage-locking effect across different regions.

Limitations and future directions

This study has several limitations. The carbon density data used are static parameters calibrated solely using climatic factors. Future studies should integrate field sampling data to develop more refined dynamic carbon density databases. The scenario simulations are based on linear extrapolations of current policy trends. Future work could incorporate system dynamics models to simulate the complex feedback mechanisms between policies and stakeholders. This study focuses only on the quantity and economic value of carbon storage. Future research should integrate carbon storage with other ecosystem services into a unified assessment frame-work.

Conclusions

This study reveals a stage-locking effect of policy swings on county-level carbon storage. From 2017 to 2023, carbon storage in Qingyun County rose from 382.16×10^4t to 399.61×10^4t and then declined to 392.92×10^4t. This trajectory mirrored the policy shift from ecological restoration to cropland protection. Forestland and cultivated land exhibited a seesaw effect in their contribution rates. Multi-scenario simulations for 2035 show that carbon storage declines under all three scenarios. The forestland protection scenario achieves a better balance between carbon economic value and food security, with a carbon economic value only 1.06% lower than that of the eco-nomic-priority scenario. These findings indicate that policy-driven land use transitions exert a stage-locking effect on carbon storage and that low-carbon land use optimization requires a dy-namic policy framework capable of balancing carbon value and food security.

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REFERENCES

Bacani VM, Silva BHM, Sato AASA, Sampaio BDS, Cunha ER, Vick EP, Oliveira VFR, Decco HF (2024) Carbon storage and sequestration in a eucalyptus productive zone in the Bra-zilian Cerrado, using the Ca-Markov/ Random Forest and InVEST models. *Journal of Cleaner Production 444*: 141291. https://doi.org/10.1016/j.jclepro.2024.141291

Chen Z, Wei K, Hu L, Yi C, Liu S (2025) Spatiotemporal variation and driving forces of carbon storage in the Fuhe river basin, China. *Scientific Reports 15*: 30224. https://doi.org/10.1038/s41598-025-14518-7

Foley JA, DeFries R, Asner GP, Barford C, Bonan G, Carpenter SR, Chapin FS, Coe MT, Daily GC, Gibbs HK, Helkowski JH, Holloway T, Howard EA, Kucharik CJ, Monfreda C, Patz JA, Prentice IC, Ramankutty N, Snyder PK (2005) Global consequences of land use. *Science 309*: 570-574. https://doi.org/10.1126/science.1111772

Füllberg-Stolberg C (2010) Land policies in Jamaica, 1830-1940. In: van der Linden M (Ed.) *Humanitarian Intervention and Changing Labor Relations: The Long-term Conse-quences of the Abolition of the Slave Trade*. Brill. Leiden, The Netherlands. pp. 319-350.

Greschuk LT, Villela JM, Maia SMF, Pinheiro Junior CR, Tonucci RG, Signor D, Frazão LA, Lima AYV, Canisares LP, Queiroz HM, Cerri CEP, Cherubin MR (2025) Soil carbon storage in Brazilian drylands: A review. *CATENA 257*: 109144. https://doi.org/10.1016/j.catena.2025.10914

Guevara M, Olmedo GF, Stell E, Yigini Y, Aguilar Duarte Y, Arellano Hernández C, Arévalo GE, Arroyo-Cruz CE, Bolivar A, Bunning S, Bustamante Cañas N, Cruz-Gaistardo CO, Davila F, Dell Acqua M, Encina A, Figueredo Tacona H, Fontes F, Hernández Herrera JA, Ibelles Navarro AR, Loayza V, Manueles AM, Mendoza Jara F, Olivera C, Osorio Hermosilla R, Pereira G, Prieto P, Ramos IA, Rey Brina JC, Rivera R, Rodrí-guez-Rodríguez J, Roopnarine R, Rosales Ibarra A, Rosales Riveiro KA, Schulz GA, Spence A, Vasques GM, Vargas RR, Vargas R (2018) No silver bullet for digital soil mapping: Country-specific soil organic carbon estimates across Latin America. *SOIL 4*: 173-193. https://doi.org/10.5194/soil-4-173-2018

Hora R (2001) *The Landowners of the Argentine Pampas: A Social and Political History, 1860–1945*. Clarendon Press. Oxford, UK. 264 pp.

Houghton RA (2010) Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850–2000. *Tellus B: Chemical and Physical Meteorology 55*: 378-390. https://doi.org/10.1034/j.1600-0889.2003.01450.x

Jimenez-Castaneda ME, Lal R, Jones Z, Cotrufo MF, Mikhailova EA, Lorenz K, Post WM, Izaurralde RC (2022) An overview of carbon sequestration in agricultural soils of Latin America and the Caribbean. *Critical Reviews in Plant Sciences 41*: 391-405. https://doi.org/10.1080/07352689.2022.2143966

Lal R (2006) Soil carbon sequestration in Latin America. In: Lal R, Cerri CC, Bernoux M, Etchevers J, Cerri CE (Eds.) *Carbon Sequestration in Soils of Latin America*. Food Products Press. New York, NY, USA. pp. 53-72.

Li J, Yuan J, Dong Y, Liu D, Zheng H, Ding W (2025) Impact of wetland conversion to cropland on ecosystem carbon budget and greenhouse gas emissions in Northeast China. *Agricultural and Forest Meteorology 360*: 110311. https://doi.org/10.1016/j.agrformet.2024.110311

Li L, Ji G, Li Q, Zhang J, Gao H, Jia M, Li M, Li G (2023) Spatiotemporal evolution and prediction of ecosystem carbon storage in the Yiluo River Basin based on the PLUS-InVEST model. *Forests 14*: 2442. https://doi.org/10.3390/f14122442

Liang X, Guan Q, Clarke KC, Liu S, Wang B, Yao Y (2021) Understanding the drivers of sustainable land expansion using a patch-generating land use simulation (PLUS) model: A case study in Wuhan, China. *Computers, Environment and Urban Systems 85*: 101569. https://doi.org/10.1016/j.compenvurbsys.2020.101569

Lu X, Jiang H, Zhang X, Jin J (2016) Relationship between nitrogen deposition and LUCC and its impact on terrestrial ecosystem carbon budgets in China. *Science China Earth Sciences 59*: 2285-2294. https://doi.org/10.1007/s11430-015-5277-0

Machado RB, Aguiar LMS, Bustamante MMC (2024) Why is it so easy to undergo devegetation in the Brazilian Cerrado? *Perspectives in Ecology and Conservation 22*: 209-212. https://doi.org/10.1016/j.pecon.2024.08.003

Moraes LM, de Azevedo JC, Lage Filho NM, de Oliveira JVC, Abreu NL, Amaral Junior FP, da Silva TC, Ruggieri AC, Faturi C, do Rêgo AC (2025) Impact of land use change and climate on the Brazilian Amazon: A review on carbon stocks and greenhouse gas emissions. *Scientia Agropecuaria 16*: 671-688. https://doi.org/10.17268/sci.agropecu.2025.051

Nwaogu C, Diagi BE, Ekwegu CV, Ajeyomi AS, Ejiogu CC, Emereibeole EI, Eneche PSU, Okeke OJ, Edokpa DO, Chike E, Ozabor F, Adekunle O, Wekpe VO, Dollah OC, Ogaga E, Nwankwoala HO, Wallace E, Onugu C, Fajembola T, Cherubin MR (2024) Soil organic carbon stocks as driven by land use in Mato Grosso State: the Brazilian Cerrado agri-cultural frontier. *Discover Sustainability 5*: 382. https://doi.org/10.1007/s43621-024-00592-w

Sharp R, Tallis HT, Ricketts T, Guerry AD, Wood SA, Chaplin-Kramer R, Nelson E, Ennaanay D, Wolny S, Olwero N, Vigerstol K, Pennington D, Mendoza G, Aukema J, Foster J, Forrest J, Cameron D, Arkema K, Lonsdorf E, Kennedy C, Verutes G, Kim CK, Guannel G, Papenfus M, Toft J, Marsik M, Bernhardt J, Griffin R, Glowinski K, Chaumont N, Perelman A, Lacayo M, Mandle L, Hamel P, Vogl AL, Rogers L, Bierbower W (2018) *InVEST User's Guide*. The Natural Capital Project, Stanford University, University of Minnesota, The Nature Conservancy and World Wildlife Fund. Stanford, CA, USA.

Shi SW, Han PF, Zhang P, Ding F, Ma CL (2015) The impact of afforestation on soil organic carbon sequestration on the Qinghai Plateau, China. *PLoS ONE 10*: e0116591. https://doi.org/10.1371/journal.pone.0116591

Soares-Filho B, Lima L, Bowman M, Viana L (2012) *Challenges for Low-Carbon Agriculture and Forest Conservation in Brazil*. Inter-American Development Bank, Environmental Safeguards Unit. Technical Notes No. IDB-TN-385. Washington, DC, USA. 40 pp. https://doi.org/10.18235/0008990

van Oudenhoven APE, de Groot RS (2013) Trade-offs and synergies between biodiversity conservation, land use change and ecosystem services. *International Journal of Biodi-versity Science, Ecosystem Services & Management 9*: 87-89. https://doi.org/10.1080/21513732.2013.796150

TRANSICIÓN DEL USO DEL SUELO IMPULSADA POR POLÍTICAS Y SUS IM-PACTOS ESPECÍFICOS POR ETAPA EN LA DINÁMICA DEL ALMACENA-MIENTO DE CARBONO: ESTUDIO DE CASO A NIVEL DE CONDADO EN QINGYUN, CHINA

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RESUMEN

Las políticas de uso del suelo cambian periódicamente entre la protección de las tierras agrícolas, la construcción ecológica y el crecimiento económico. Comprender cómo estas reorientaciones de las políticas afectan el almacenamiento de carbono es fundamental para la gestión del territorio con bajas emisiones de carbono a nivel de condado. Este estudio utiliza el condado de Qingyun, China, como estudio de caso. El condado se caracteriza por una intensa fragmentación del suelo, con apenas 713m² de tierras agrícolas por habitante, y experimentó importantes cambios en las políticas entre 2017 y 2023. Se integró el modelo PLUS-InVEST para reconstruir las trayectorias de uso del suelo, cuantificar la evolución del almacenamiento de carbono y proyectar su dinámica hasta 2035 bajo tres escenarios. Los resultados revelan una tendencia de aumento seguida de disminución. Impulsado por la Campaña de Reverdecimiento de Tres Años (Three-Year Greening Campaign), el almacenamiento de carbono aumentó de 382,16 × 10^4t en 2017 a 399,61 × 10^4t en 2020. Tras la implementación de la Política Grain-for-Farmland, disminuyó hasta 392,92 × 10^4t en 2023. Esta tendencia refleja un cambio de política en tres etapas: prioridad ecológica, prioridad de protección de las tierras agrícolas y consolidación territorial. El escenario de protección forestal generó valores económicos del almacenamiento de carbono 1,1% y 2,2% superiores a los obtenidos bajo los escenarios de protección de las tierras agrícolas y de desarrollo natural, respectivamente. Estos hallazgos pueden proporcionar una base teórica para estrategias similares de gestión territorial en América Latina y el Caribe. El Cerrado brasileño ha experimentado pérdidas de carbono asociadas con la expansión agrícola similares a las observadas en este estudio. La transición del uso del suelo impulsada por políticas ejerce un efecto mensurable de bloqueo por etapas sobre el almacenamiento de carbono. A medida que cambian las prioridades de las políticas, el almacenamiento de carbono responde en consecuencia. Por lo tanto, la optimización del uso del suelo con bajas emisiones de carbono requiere un marco dinámico que anticipe y mitigue las pérdidas de carbono durante las transiciones de política.

TRANSIÇÃO DO USO DA TERRA ORIENTADA POR POLÍTICAS PÚBLICAS E SEUS IMPACTOS ESPECÍFICOS POR ETAPA NA DINÂMICA DO AR-MAZENAMENTO DE CARBONO: UM ESTUDO DE CASO EM NÍVEL DE CON-DADO EM QINGYUN, CHINA

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RESUMO

As políticas de uso da terra alternam-se periodicamente entre a proteção das terras agrícolas, a construção ecológica e o crescimento econômico. Compreender como essas reorientações das políticas afetam o armazenamento de carbono é essencial para a gestão territorial de baixo carbono em nível de condado. Este estudo utiliza o Condado de Qingyun, China, como estudo de caso. O condado caracteriza-se por elevada fragmentação da terra, com apenas 713m² de terras agrícolas por habitante, e passou por importantes mudanças nas políticas entre 2017 e 2023. O modelo PLUS-InVEST foi integrado para reconstruir as trajetórias de uso da terra, quantificar a evolução do armazenamento de carbono e projetar sua dinâmica até 2035 sob três cenários. Os resultados revelam uma tendência de aumento seguida de redução. Impulsionado pela Campanha de Reflo-restamento de Três Anos (Three-Year Greening Campaign), o armazenamento de carbono au-mentou de 382,16 × 10^4t em 2017 para 399,61 × 10^4t em 2020. Após a implementação da Política Grain-for-Farmland, reduziu-se para 392,92 × 10^4t em 2023. Essa tendência reflete uma mudança de política em três etapas: prioridade ecológica, prioridade para a proteção das terras agrícolas e consolidação territorial. O cenário de proteção florestal gerou valores econômicos do ar-mazenamento de carbono 1,1% e 2,2% superiores aos obtidos nos cenários de proteção das terras agrícolas e de desenvolvimento natural, respectivamente. Esses resultados podem fornecer uma base teórica para estratégias semelhantes de gestão territorial na América Latina e no Caribe. O Cerrado brasileiro tem apresentado perdas de carbono associadas à expansão agrícola semelhantes às observadas neste estudo. A transição do uso da terra orientada por políticas públicas exerce um efeito mensurável de bloqueio por etapas sobre o armazenamento de carbono. À medida que as prioridades das políticas mudam, o armazenamento de carbono responde de forma correspondente. Portanto, a otimização do uso da terra de baixo carbono requer uma estrutura dinâmica capaz de antecipar e mitigar as perdas de carbono durante as transições de políticas.