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The Impact of High-Standard Farmland Construction Policies on the Carbon Emissions from Agricultural Land Use (CEALU)

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Abstract: Agricultural activities are the second largest source of greenhouse gas emissions, and carbon emissions from agricultural land use (CEALU) have become a hot issue across the world. Although there are some studies on the impact of high-standard farmland construction policies on carbon emissions, they focus on quantitative analysis and do not give sufficient consideration to the relationship between HSFC and CEALU. Therefore, in this study, by relying on provincial panel data of China for the period 2005–2017, the effect of the high-standard basic farmland construction policy on carbon emissions from agricultural land use per unit area and its regional differences were quantitatively analyzed using the difference-in-difference (DID) model. The results showed that: (1) China's CEALU per unit area presented a fluctuating upward change, but the growth rate slowed down during the period 2005–2017, from 392.58 kg/ha to 457.72 kg/ha, with an average annual growth rate of 1.31%; (2) the high-standard farmland construction (HSFC) policy led a significant carbon emission reduction effect in agricultural land use and reduced the CEALU per unit area by 10.80% on average. With the promotion of this policy, its carbon emission reduction effect in agricultural land use presented an overall increasing change; (3) the carbon emission reduction effect of the high-standard farmland construction policy in agricultural land use was significant in central China, but non-significant in eastern China and western China.

Keywords: high-standard farmland construction (HSFC); land consolidation; carbon emissions from agricultural land use (CEALU); difference-in-difference (DID)

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1. Introduction

Climate warming, as an environmental consequence of rapid economic development, has posed a common threat to all mankind [1]. In particular, agriculture has become the second largest source of greenhouse gas emissions after industry. According to data released by the World Bank, the CO_2 generated by agricultural activities currently accounts for 20% of total global CO_2 emissions [2]. As one of the main input factors of agricultural production activities in China, agricultural land entails positive benefits, such as the production of agricultural products and the increase of the total output value of agriculture; however, it also releases a large amount of CO_2 into the atmosphere [3]. In the period 2000–2017, China's carbon emissions from agricultural land use (CEALU) increased from 52.3283 million tons to 76.1331 million tons, with an average annual growth rate of 2.25% [4]. Even so, agricultural sources still account for 24% of the country's total greenhouse gas emissions [5]. In the context of achieving the objective of carbon dioxide emissions peak and carbon neutralization [6], the exploration of the path towards carbon emission reduction in agricultural land use provides important insights on how to improve the capacity of agriculture to cope with climate change and to promote its sustainable development.

To explore the path of achieving carbon emission reduction in agricultural land use, several researchers have extensively assessed CEALU, achieving fruitful results. However, these studies mainly focused on the spatial pattern [7,8] and influencing factors of CEALU [9,10], the efficiency of carbon emissions [11,12], and the prediction of trends [13,14]. The optimization of land use patterns has not only impacted the export dynamics of crops like corn, sorghum, and wheat (which have decreased), but it has also influenced the export of barley, soybeans, and sunflowers (which have increased) [15]. These shifts in trade patterns have further implications globally, contributing to greenhouse gas emissions [16].

Some potential aspects that have not been studied in depth are the regional heterogeneity of farmland carbon emissions and the carbon reduction mechanism of high-standard farmland construction policies. High-standard farmland (HSF) is considered the concentrated contiguous cultivated land formed by rural land consolidation, supporting facilities, high and stable yield, pleasant ecological quality, strong disaster resistance, and adaptable to modern agricultural production and management modes [17,18]. The High-Standard Farmland Construction (HSFC) policy is a strategic initiative in China aimed at promoting sustainable agricultural development and ensuring food security through land consolidation [19]. It involves various measures such as land leveling projects, irrigation and drainage projects, field road projects, farmland protection, and typical field remediation methods [20,21]. Of course, in government, they prefer to call it Well-Facilitated Farmland [22]. But for now, these two concepts are basically the same, both in content and mode [23,24]. Some scholars have also paid attention to the effect of high-standard farmland construction on CEALU. Land consolidation is a typical land use activity that also affects the carbon cycle and carbon pool storage of the project area [25], producing an extremely evident carbon effect [26]. HSFC can effectively solve a series of problems, such as the fragmentation and low quality of farmland, the shortage of water conservancy facilities, and the deterioration of farmland environment [27]. It also entails a significant fertilizer reduction effect [28] and enhances the role of soil testing and formulated fertilization techniques in increasing fertilizer application efficiency [29]. In addition, Liu et al. argued that eco-friendly, high-standard farmland construction by area can effectively enhance the ecological effect of the engineering measures of “field, water, road, and forest”, standing as an effective way to achieve the simultaneous improvement and target integration of ecological service and production functions [30]. Moreover, Zhang et al. found that, after the completion of high-standard farmland construction, the area of cultivated land with ‘fully satisfied’ and ‘satisfied’ irrigation capacity increased by 7.91% and 19.64%, respectively, and that this improved irrigation capacity elevated the comprehensive grade of cultivated land quality by 0.25. In addition, they found that the area of cultivated land with ‘fully satisfied’ and ‘satisfied’ drainage capacity increased by 35.13% and 27.33%, respectively, and that this improved drainage capacity elevated the comprehensive grade of cultivated land quality by 0.31 [31].

The abovementioned studies discuss the pathways for carbon emissions reduction in agricultural land and explores the impact mechanism of HSFC on carbon emissions from land use. This enriches the research system on carbon emissions from land use and lays a solid foundation for in-depth analysis. However, in certain circumstances, HSFC may bring about some unintended negative environmental impacts, posing challenges and issues in practical implementation [32,33]. For instance, the implementation of high-standard farmland construction may require substantial financial investment [34], and the actual effects in different regions may vary due to factors such as local soil conditions, climatic characteristics, and agricultural management practices [35–37]. Additionally, high-standard farmland construction may impact local ecosystems, such as altering original biodiversity [38] and hydrological cycles [39]. Moreover, excessive agricultural water conservancy may lead to groundwater level decline [40] and soil salinization [41]. Therefore, although HSFC is widely regarded theoretically and policy-wise as an effective approach to reducing agricultural carbon emissions [42], comprehensive consideration of multiple factors is required during specific implementation, necessitating the adoption of scientifically sound planning and management measures to ensure its environmental benefits [43] and sustainability [44].

To address this gap, we conducted a comprehensive review of the policy landscape surrounding the establishment of the HSFC policies in China, examining the multifaceted reforms aimed at mitigating challenges to the CEALU. We also explored the theoretical underpinnings of the relationship between high-standard farmland construction and CEALU. Using a difference-in-difference (DID) model with provincial panel data from 2005 to 2017, we quantitatively evaluated the impact and regional disparities of HSFC policy on CEALU, providing empirical insights for future efforts to reduce CEALU through HSFC. The significance of this study lies in its potential to inform policymaking and guide practical implementation. By identifying the effects of HSFC policies on CEALU and understanding the spatial heterogeneity of these impacts, our research can contribute to the development of targeted strategies that maximize the environmental benefits of HSFC while minimizing potential negative consequences. This, in turn, can support the broader goals of sustainable agricultural development and climate change mitigation. Furthermore, the empirical findings from our DID model offer a robust analytical framework that can be applied to other regions or contexts, enhancing the global understanding of agricultural land use and its role in carbon emissions.

2. Policy Evolution and Theoretical Analysis

2.1. Policy Evolution

Since the pivotal decision by The State Council to establish a land development and construction fund in 1988, China embarked on a trajectory to explore methodologies and frameworks for the conversion of low- and medium-yield farmland into high-standard farmland [45]. However, prior to 2011, governmental departments had not delineated specific directives through formal documentation regarding the measures, standards, construction parameters, and task objectives pertinent to high-standard farmland. During this period, the primary aim of comprehensive land development was to augment the effective cultivated land area, thereby compensating for the considerable reduction in cultivated land resulting from urbanization and industrial development, thereby laying a robust groundwork for subsequent high-standard farmland initiatives. The term high-standard farmland (HSF) was initially introduced in the Central Document No. 1 in 2005 [46], followed by the issuance of a policy focused on High-Standard Farmland Construction (HSFC) in 2011. Since 2011, China has been steadfastly pursuing HSFC at an average annual rate exceeding 80 million mu. The policy directives outlined in the No. 1 Central Document from 2012 to 2016 primarily emphasized standardized construction criteria, unified supervision and evaluation mechanisms, enhancement of construction parameters, bolstering of ancillary facilities, and refinement of management and conservation mechanisms for high-standard farmland construction, while incorporating HSFC into the evaluation framework for local governments' responsibilities in safeguarding cultivated land. Up to the present moment, subsequent iterations of the No. 1 Central Document have accentuated heightened quality standards for HSFC. The National High-Standard Farmland Construction Plan (2021–2030) promulgated in 2021 further clarifies standards, contents, zoning, priorities, objectives, safeguard measures, etc. [47,48] (Tables 1 and 2). These further enriched pertinent national standards and strategic blueprints. The evolution of high-standard farmland construction policies is shown in Figure 1.

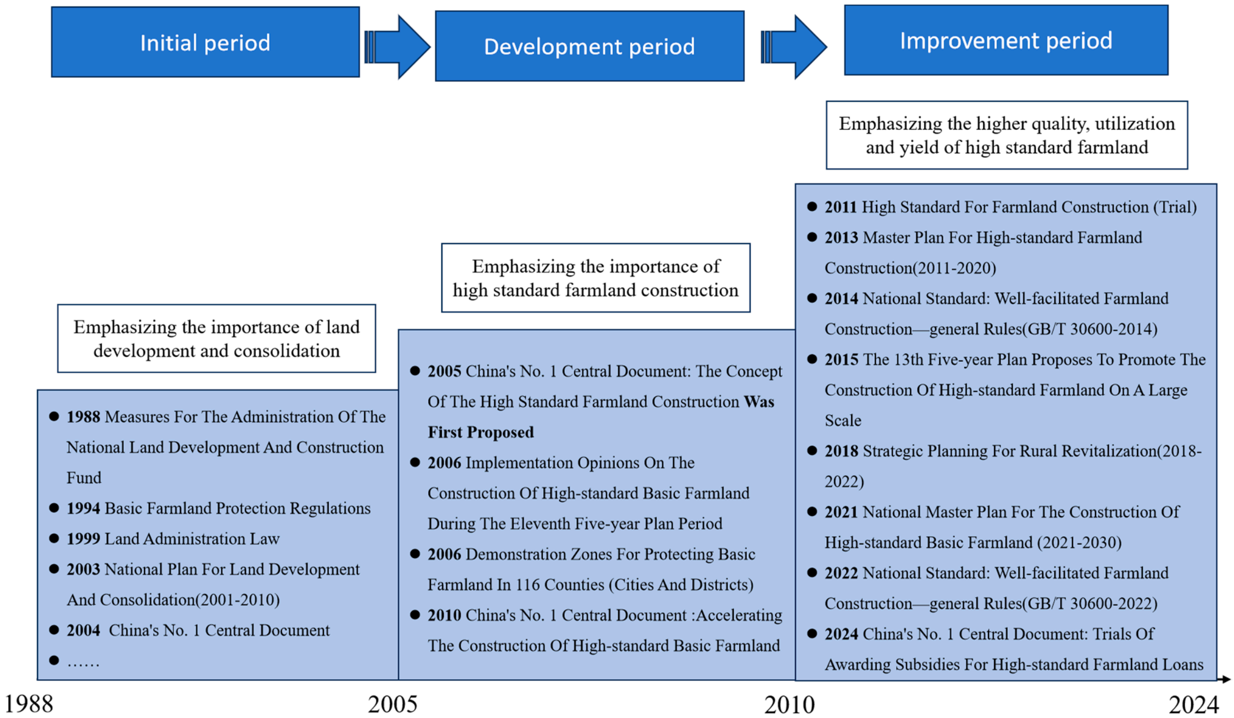


Figure 1. The evolution of high-standard farmland construction policies [49].

Table 1. The main elements of HSFC policies [47,48].

Standards	Contents	Zoning	Objectives	Safeguard Measures
GB/T 33130-2016	Farmland Consolidation	Northeast Region	1.075 billion Mu (2025)	Government Overall Planning
GB/T 33469-2016	Soil Improvement	Huang-Huai-Hai Area	1.2 billion Mu (2030)	Planning Guidance
GB/T 21010-2017	Irrigation And Drainage	The Middle and Lower Reaches of The Yangtze River		Fund Guarantee
GB 50288-2018	Field Road	Southeast Region		Scientific and Technological Support
GB 5084-2021	Agricultural Field Protection Ecological and Environmental Protection	Southwest Region		Supervision and Assessment
GB/T 30600-2022	Farmland Power Transmission and Distribution	Northwest Region		
	Science and Technology Service Management, Protection and Utilization	Qinghai-Tibet Region		

Table 2. The main measures, content and purpose of HSFC policies [47].

Measures	Content	Purpose
Agricultural measures	Farmland Consolidation Soil Improvement	Optimize the spatial distribution of high-standard farmland Improve the quality of cultivated land
Forestry measures	Protection forest of agriculture and forestry system	Improve soil and water conservation and flood control
Water conservancy measure	Irrigation project Drainage works	Improve the guarantee rate of agricultural irrigation Improve the ability to withstand storms
Infrastructure construction measures	Field road construction Farmland electricity transmission and distribution	Improve the direct access road network to farmland Improve the quality and safety of electricity use
Scientific and technological measures	Location monitoring of cultivated land quality Digital farmland construction	Tracking and monitoring the change of farmland quality Improve the level of precision and wisdom

2.2. Theoretical Analysis: The Logical Relationship between HSFC and CEALU

2.2.1. Optimization Process

The construction of high-standard farmland is a meaningful policy to promote green agriculture and low-carbon, high-quality development [50]. The optimization process of HSFC is structured around three critical paths designed to improve soil quality, optimize farmland water conservancy, and reduce energy saving and emission [51]. Principally, agricultural measures such as farmland remediation and soil improvement are geared towards augmenting soil fertility, thereby bolstering agricultural productivity while concurrently fostering carbon sequestration through heightened organic matter accumulation [52,53]. Forestry measures, encompassing farmland shelterbelt protection, serve to fortify carbon sequestration efforts by preserving and expanding vegetal cover, effectively amplifying carbon sink capacities [54]. Water conservancy measures, notably irrigation and drainage projects, not only ameliorate water management in agriculture but also facilitate carbon sequestration by optimizing soil moisture levels and averting erosive phenomena [55]. Infrastructure construction measures, such as field road development and farmland electricity distribution, streamline operational efficiency in agricultural endeavors, thereby curtailing energy expenditure and associated carbon emissions [56,57]. Finally, scientific and technological support measures, exemplified by cultivated land quality assessment [58] and digital agricultural infrastructure [59], afford precision farming capabilities, optimizing resource allocation and concomitantly diminishing the carbon footprint per unit of agricultural output. This comprehensive approach underscores the interconnectedness between agricultural practices and carbon dynamics within the environment, underscoring the imperative of embracing multifaceted strategies to concurrently enhance productivity and environmental sustainability in agriculture whilst addressing the exigencies posed by climate change [60].

2.2.2. Action Process

The mechanism underlying carbon emission reduction in agricultural land through soil quality enhancement, agricultural water resource optimization, and the promotion of energy efficiency and emission mitigation is intricate and interrelated [61]. One side, soil quality enhancement, involves augmenting soil fertility and structure, achievable via the dissemination of organic fertilizers, compost, and soil conditioners. This practice not only amplifies crop yields but also sequesters carbon within the soil matrix, thereby mitigating atmospheric carbon dioxide levels [62]. Even more, optimizing agricultural water resources is pivotal for achieving water use efficiency and fostering sustainable agricultural practices [63]. Adoption of irrigation techniques such as drip irrigation and rainwater harvesting minimizes water usage while maximizing crop water utilization efficiency. This curtails energy consumption for water extraction and conveyance, thereby reducing greenhouse gas emissions [64]. Moreover, the implementation of precision agriculture technologies, including smart irrigation systems and soil sensors, empowers farmers to make informed resource allocation decisions, thereby bolstering efficiency and emission reduction [65]. Notably, the amelioration of soil quality serves as the cornerstone, providing a fertile milieu for crop growth while sequestering carbon [66]. Concurrently, the optimization of agricultural water resources ensures judicious water utilization, thereby curtailing wastage and diminishing the carbon footprint of agricultural activities [67]. Advancing energy conservation and emission mitigation, alongside the utilization of renewable energy sources and precision agriculture technologies, further diminishes greenhouse gas emissions, thereby enhancing sustainability. These three pathways synergistically contribute to augmenting carbon sequestration capacity, optimizing resource utilization efficiency, and propelling agricultural practices towards a more sustainable and carbon-neutral paradigm. Through this conduit, the groundwork is laid for realizing carbon emission reduction in agricultural land utilization.

2.2.3. Implementation Process

Enhancing carbon sequestration, optimizing resource utilization efficiency, and transitioning agricultural production methods represent effective strategies for mitigating CAELU. Initially, practices such as the implementation of high-standard crop rotation and the integration of organic matter facilitate the cultivation of robust soil ecosystems [68]. By sequestering carbon and fostering additional carbon sinks, these methods counterbalance carbon emissions stemming from agricultural activities [69]. Subsequently, the optimization of inputs including water, fertilizers, and energy within high-standard agricultural settings minimizes resource wastage, thus bolstering resource efficiency [70]. This approach not only curtails the energy-intensive production and transportation of agricultural inputs but also mitigates carbon emissions associated with land use practices [71]. Moreover, the establishment of HSFC catalyzes the adoption of environmentally sustainable and more efficient farming techniques, thereby enhancing the resilience of agricultural ecosystems [72]. Furthermore, the application of digital agricultural technologies enables real-time monitoring and assessment of land quality [73,74], furnishing a scientific foundation for precision and sophistication in carbon emission reduction strategies within land use management [75]. Figure 2 illustrates the mechanism by which the HSFC contributes to CEALU through five major measures and three key processes.

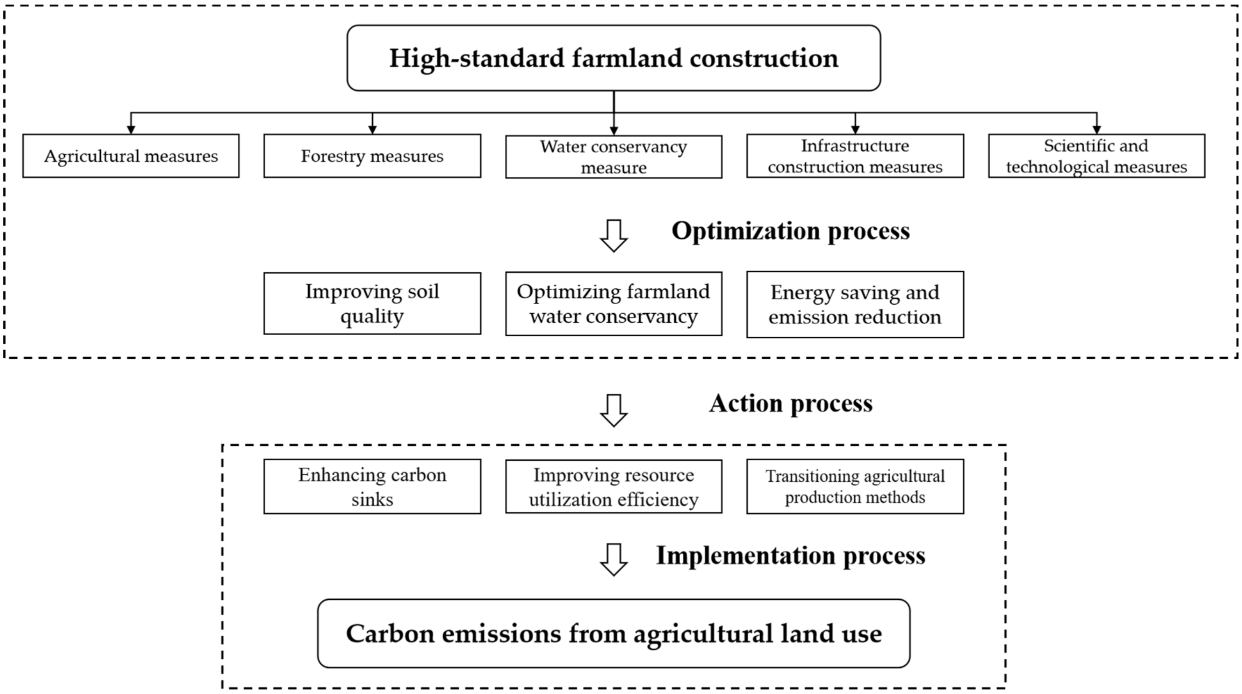


Figure 2. The Logical Relationship between HSFC and CEALU.

3. Methods and Materials

3.1. Methods

The high-standard farmland construction policy was formally launched nationwide in 2011 and was gradually implemented following the principle of "focusing on major grain-producing areas, and giving due consideration to non-major grain-producing areas" [76]. Since the implementation of this policy, the scale of high-standard farmland construction in 31 provinces (cities) across the country has continuously changed. Significant differences also exist among provinces in terms of the target tasks and construction progress under this policy. This means that the implementation of the policy has the following characteristics: First, it generates a difference in the land consolidation area of a same province before and after policy implementation. Second, it generates a difference in land consolidation area between different provinces at a same time point. These characteristics allow to assess the effect of the high-standard farmland construction policy on CEALU using the DID model. Taking into account the regional heterogeneity of the study, China is divided into an eastern region, central region, and western region according to the regional classification method used in previous studies [77,78] (Figure 3). By relying on the significant advantages of the DID model in analyzing the net effect of policies [79–81], the following continuous DID model was built to test the effect of the high-standard farmland construction policy on CEALU:

$$InC_{it} = \alpha + \beta Hrate_i \times I_t^{post} + \delta X_{it} + \mu_i + \gamma_t + \varepsilon_{it} \quad (1)$$

where InC_{it} denotes the CEALU in the i-th province in period t, expressed in the form of natural logarithm; $Hrate_i$ denotes the proportion of land consolidation area; I_t^{post} denotes the dummy variable of the time point of policy implementation; X_{it} denotes the control variable; μ_i denotes the fixed effect of province; γ_i denotes the fixed effect of year; ε_{it} is a random error term; α is a constant term; and β and δ are parameters to be estimated.

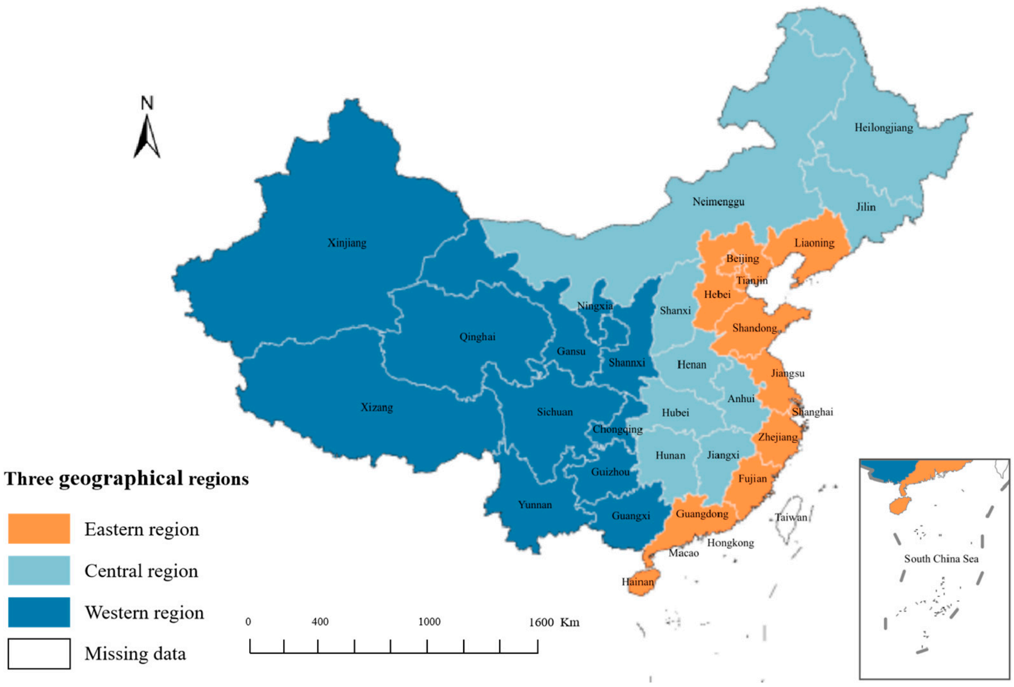


Figure 3. Study area and three geographical regions. Note: the base maps of research are made according to the Chinese standard map No. GS(2022)1873.

It should be noted that the general DID model uses dummy variables to distinguish between the experimental group and the control group. By contrast, this study used the continuous variable "proportion of land consolidation area" to distinguish between the experimental group and the control group. That is, policy implementation divides the sample into the experimental group (i.e., samples with a high proportion of land consolidation area) and the control group (i.e., samples with a low proportion of land consolidation area). This continuous DID model does not change the basic nature of the DID model; moreover, it can capture more data variability, and avoid the possible deviation caused by the artificial setting of the experimental group and the control group [82].

3.2. Data and Variable

3.2.1. Dataset Used

This study employed panel data for 31 provinces (regions/cities) in China, excluding Hong Kong, Macao, and Taiwan, covering the period 2005–2017. The basic data were derived from the China Rural Statistical Yearbook (2006–2018), the Finance Yearbook of China (2006–2018), and the China Statistical Yearbook (2006–2018). The data sources can be found at: https://kns.cnki.net/kns/advsearch?dbcode=CYFD (accessed on 20 March 2024). It should be noted that since 2012, the data on "Headcount in primary industry" were no longer published in the China Rural Statistical Yearbook. In order to ensure the consistency and integrity for the empirical study, the data on "Headcount in primary industry" are obtained through the provincial statistical yearbooks of 31 provinces (autonomous regions/cities); for example, the Beijing Municipal Statistical Yearbook, Guangdong Provincial Statistical Yearbook, and so on (Data from publicly websites of the regions). All other data variables are available through the previous three yearbooks.

3.2.2. Variable Selection

Explained variable: CEALU per unit area. CEALU denotes the carbon emissions caused by agricultural land use activities. Their sources are diverse and complex, and include the development and utilization of cultivated land, gardens, forests, and grasslands [83]. Referring to the results of existing studies [84,85], in this study, CEALU indicates the carbon emissions released by energy consumption in the production process of chemical fertilizers, pesticides, crops, etc. The calculation formula of the CEALU per unit area is as follows:

$$C = \sum C_i = \sum T_i \bullet \delta_i / S \tag{2}$$

where C denotes CEALU; C_i denotes the carbon emissions from each type of source; T_i denotes the number of each type of carbon emission sources; δ_i denotes the carbon emission coefficient of each type of source; and S denotes the sown area of a crop. Referring to existing studies, Table 3 illustrates the carbon emission coefficient of each type of source.

Table 3. Carbon sources and coefficients of CEALU.

Carbon Sources	Emission Coefficient	Unit	References
Chemical fertilizer	0.8956	kg C/kg	West and Marland [86]
Pesticide	4.9341	kg C/kg	Lu et al. [87]
Thin film	5.180	kg C/kg	Tian et al. [88]
Total power of agricultural machinery	0.18	kg C/kW	Kuang et al. [84]
Tillage over	312.6	kg C/ha	Han et al. [89]
Irrigation	25	kg C/ha	Dubey et al. [90]

Core explanatory variable: HSFC policy. The Standard for Well-facilitated Capital Farmland Construction (GB/T 30600-2022) [48] defines high-standard farmland as "centralized and contiguous basic farmland formed through rural land renovation in a certain period, with the characteristics of adequate supporting facilities, high and stable yield, sound ecology, strong disaster resistance, and high adaptability to modern agricultural production and operation mode." In this study, high-standard farmland was characterized using the interaction term ($Hrate_i \times I_t^{post}$) between the proportion of land consolidation area and the dummy variable of the time point of policy implementation. The proportion of land consolidation area ($Hrate_i$) is the percentage of the area of transformed medium and low-yield fields and high-standard farmland in the total area of cultivated land. I_t^{post} denotes the dummy variable of the time point of policy implementation. When $t \geq 2011$, I_t^{post} is set as 1; otherwise, it is set as 0.

Control variables: referring to existing research findings [4,84], in this study, the control variables include urbanization level, economic development level, industrial structure, labor input, investment level, proportion of food crops, soil quality, and farmland irrigation conditions (Table 4).

Table 4. Descriptive statistics.

Variables	Average Value	Standard Deviation	Min.	Max.
CEALU per unit area (C), kg/ha	482.2	182.0	170.1	1154.4
Proportion of land consolidation area (Hrate), %	0.1	0.1	0.0	0.9
Urbanization level (Urban), Urban population as a percentage of total population, %	0.5	0.1	0.2	0.9
Soil quality (Soil), Soil erosion control area, kha	3490.8	2847.1	0.0	13,600.2
Field irrigation condition (Irri), Effective irrigation area, kha	1991.4	1537.7	115.5	6031.1
Per unit area yield of grain (Fyield), Grain output per unit area, kg/ha	5149.2	996.1	3045.7	7885.9
Investment level (Ginves), Investment in fixed assets of the whole society, billion yuan	37.4	21.8	14.6	267.6
The proportion of food crops (Frate), Proportion of grain sown area to total sown area, %	65.4	12.4	31.3	82.6
Labor input (Labor), Headcount in primary industry, thousand people	9388.3	6948.7	370.9	31,390.3
Economic development level (GDP), PGDP, thousand yuan	28.3	17.8	5.2	107.0
Industrial structure (Grate), Proportion of agricultural output value to GDP, %	10.9	5.6	0.4	32.7

4. Results and Analysis

4.1. Spatiotemporal Characteristics of CEALU

The CEALU per unit area of 31 provinces (regions/cities) in China in 2005–2017 was calculated, and the change chart of CEALU per unit area vs. growth rate was plotted (Figure 4). At national level, during the period 2005–2017 the CEALU per unit area increased from 392.58 kg/ha. to 457.72 kg/ha, with an average annual growth rate of 1.31%. This change can be divided into three stages: rapid rise, slow rise, and rapid decline. First, during the period 2005–2007, the CEALU per unit area increased from 292.58 kg/ha to 429.10 kg/km^2, with a peak annual growth rate of 5.99% in 2006. Second, from 2008 to 2014, the CEALU per unit area increased from 433.03 kg/ha to the peak value of 473.32 kg/ha, while the annual growth rate followed a declining change. Third, from 2015 to 2017, the CEALU per unit area increased from 472.37 kg/ha to 457.72 kg/km^2, and CEALU achieved negative growth.

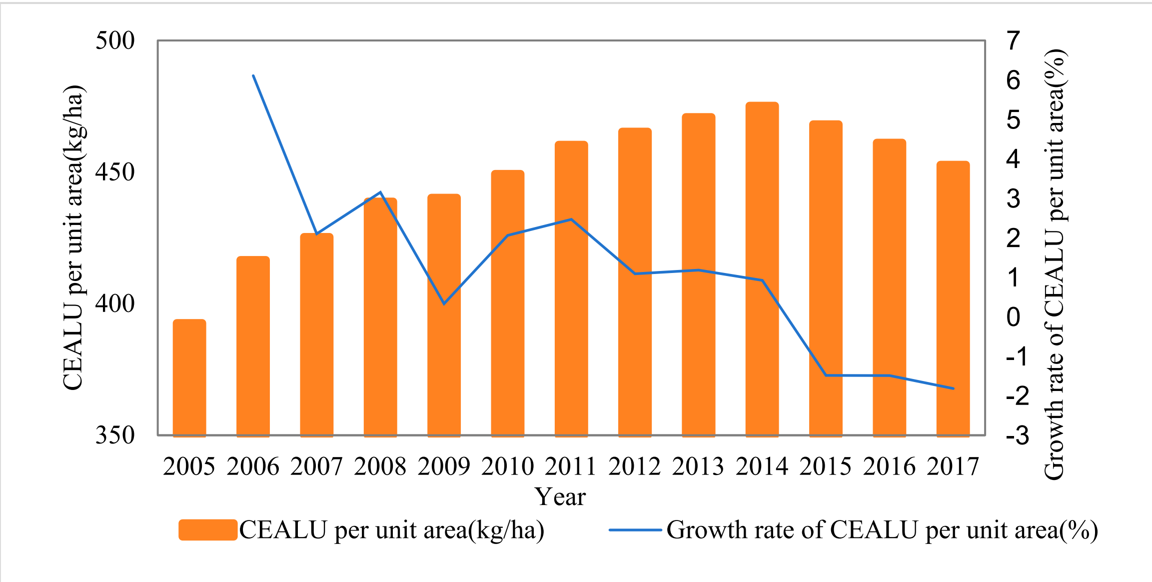


Figure 4. Changes of CEALU per unit area during 2005–2017.

In the period 2005–2017, the three provinces (regions/cities) with the lowest CEALU per unit area were Qinghai, Guizhou, and Heilongjiang, with 217.37 kg/ha, 226.15 kg/ha, and 228.78 kg/ha, respectively. The three provinces (regions/cities) with the highest CEALU per unit area were Beijing, Hainan, and Fujian, with 819.42 kg/ha, 889.25 kg/ha, and 796.57 kg/ha, respectively (Figure 5). Among the 11 provinces whose average annual growth rate of the CEALU per unit area was lower than the national average, eight provinces (i.e., Shandong, Jiangsu, Jiangxi, Hubei, Hebei, Hunan, Sichuan, and Liaoning) were major grain-producing areas in China. In 2011, the high-standard farmland construction policy was formally launched nationwide. In the period 2005–2010, only the CEALU per unit area of Shanghai achieved a negative growth, with an average annual growth rate of −3.16%. In the period 2011–2017, the CEALU per unit area of eight provinces (regions/cities) achieved a negative average annual growth rate, seven of which (i.e., Shandong, Hubei, Hunan, Liaoning, Anhui, Henan, Shanxi, and Inner Mongolia) are major grain-producing areas.

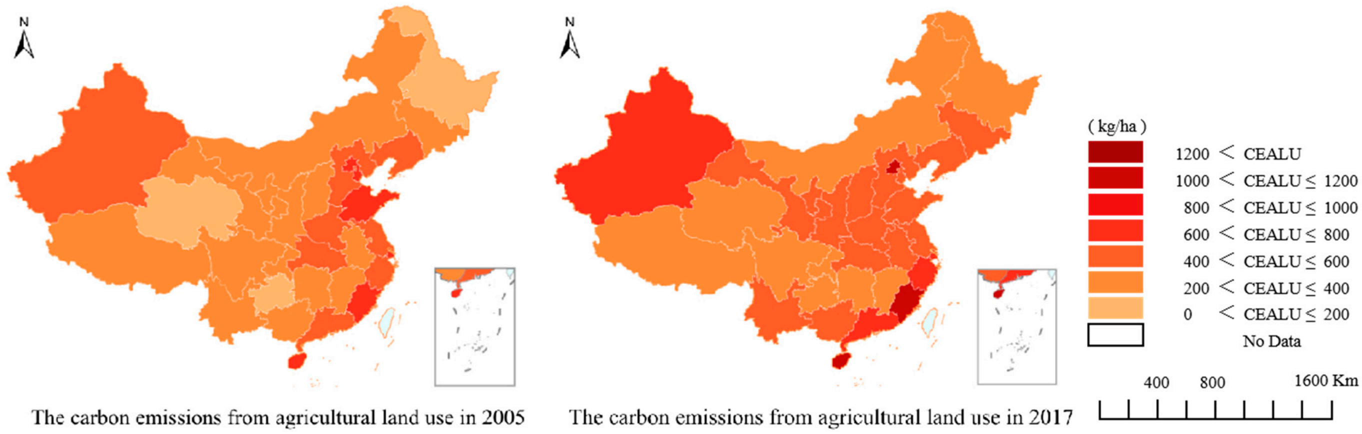


Figure 5. The CEALU of each province in China from 2005 to 2017.

4.2. Did HSFC Reduce CEALU?

4.2.1. Estimation Results of the Baseline Regression Model

Table 5 illustrates the results of the empirical regression of the effect of the high-standard farmland construction policy on CEALU. The estimation results of standard errors based on the fixed effect, random effect, and POLS showed that the effect of the high-standard farmland construction policy on the CEALU per unit area was uniformly significant at the level of 5%, and that the variable of the high-standard farmland construction policy had a negative efficient. This suggested that the high-standard farmland construction policy could significantly reduce the CEALU per unit area. On average, all other conditions being equal, the implementation of the high-standard farmland construction policy significantly reduced the CEALU per unit area by 10.80%.

Table 5. The results of regression model estimation.

Variables	Fixed Effect-Based	Random Effect-Based	Standard Error Based on POLS
$Hrate \times I_t^{post}$	−0.1080 **	−0.1080 **	−0.1080 **
	(0.0499)	(0.0520)	(0.0520)
$Urban$	−0.4620	−0.4620	−0.4620
	(0.4899)	(0.5104)	(0.5104)
$InLyield$	0.3540 **	0.3540 **	0.3540 **
	(0.1346)	(0.1402)	(0.1402)
$InFtate$	−0.5375 **	−0.5375 **	−0.5375 **
	(0.2098)	(0.2186)	(0.2186)
$InLabor$	0.2671 **	0.2671 **	0.2671 **
	(0.1142)	(0.1190)	(0.1190)

Table 5. *Cont.*

Variables	Fixed Effect-Based	Random Effect-Based	Standard Error Based on POLS
GDPsq	-6.27×10^{-12} (2.20×10^{-11})	-6.27×10^{-12} (2.30×10^{-11})	-6.27×10^{-12} (2.30×10^{-11})
InSoil	−0.1373 (0.0937)	0.0101 (0.0204)	0.0101 (0.0204)
InIrri	0.0195 (0.0267)	−0.1373 (0.0976)	−0.1373 (0.0976)
InInvest	0.0195 (0.0267)	0.0195 (0.0278)	0.0195 (0.0278)
value	0.0025 (0.0063)	0.0025 (0.0066)	0.0025 (0.0066)
Constant term	4.4349 ** (1.8696)	5.6299 *** (1.8341)	5.6299 *** (1.8341)
Sample size	390	390	390
R^2	0.6349	—	0.9701

Note: ** $p < 0.05$; *** $p < 0.01$. The value in brackets is the robust standard error of the regression coefficient. Both the individual fixed effect and the year fixed effect have been controlled.

4.2.2. Parallel Test and Dynamic Policy Effect

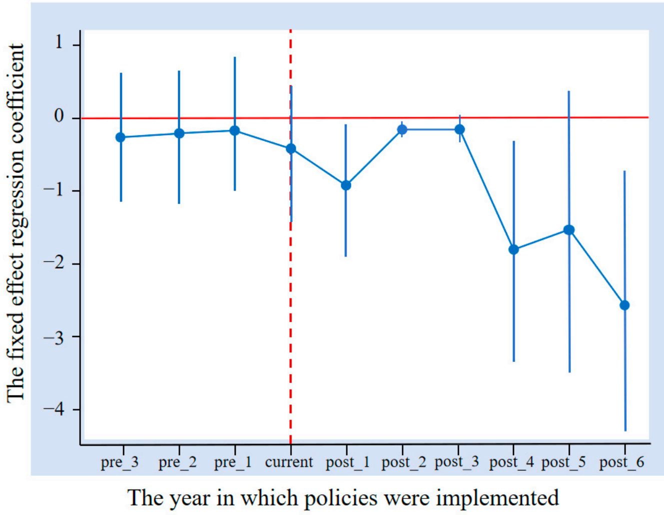
The validity of DID model estimation depends on the establishment of the parallel change hypothesis; that is, the temporal change of CEALU in the experimental group and the control group are consistent before the time point of policy intervention. Referring to existing studies [91], the following model was built to test the parallel hypothesis:

$$InC_{it} = \alpha + \sum_{t=2005}^{2017} \beta_t Hrate_t \times D_t + \delta X_{it} + \mu_i + \gamma_i + \varepsilon_{it} \quad (3)$$

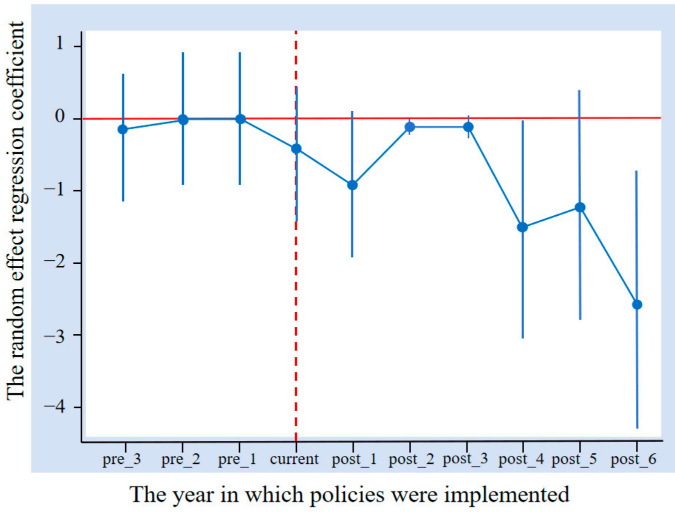
In Equation (3), D_t denotes the year dummy variable, and other variables and coefficients are the same as Equation (1). The implementation of HSFC policy can significantly reduce the CEALU, then before the implementation of the HSFC policy, the change of the interaction term between the proportion of land remediation area and the year dummy variable on the coefficient of the impact of CEALU should tend to be stable; after the point of implementation of the HSFC policy, β_t will decrease significantly.

Based on the coefficient β_t of the interaction term of the area share of land rehabilitation with the year dummy variable, the coefficient β_t of the pre-policy implementation period (2005–2010) is subjected to a joint hypothesis test to analyze the parallel. It can be found that there is a general upward change before policy implementation and the confidence interval of the impact coefficients essentially contains zero (Figure 6). Therefore, there was no significant positive correlation between years before the policy was implemented, and the parallel change hypothesis was tested to a large extent.

Table 6 shows the dynamic effect of the high-standard farmland construction policy on CEALU. The effect coefficient β_t before policy implementation was non-significant, suggesting that this policy had no expected effect on the CEALU per unit area. The effect coefficient β_t in the first year after policy implementation (i.e., 2012) was significantly negative (−0.9722). The effect coefficient β_t in the fourth year after policy implementation (i.e., 2015) was significantly reduced compared to that in the first year (−1.5235), while in the fifth year after policy implementation (i.e., 2017) reached the lowest value (−2.5768). This indicated that, with the promotion of the high-standard farmland construction policy, the carbon emission reduction effect of this policy presented an overall increasing change.



(**a**)



(**b**)

Figure 6. Parallel change test of differential model. (**a**) Fixed effect. (**b**) Random effect. Note: The vertical line passing through the origin is the 95% confidence interval of the corresponding estimated parameter. The abscissa axis represents the year of policy implementation. For example, pre_1 indicates the first year before policy implementation, post_1 indicates the first year after policy implementation, and current indicates the starting year of policy implementation (i.e., 2011).

Table 6. The estimation of the dynamic impact of HSFC policies on CEALU.

Variable	**Parallel Change FE**	**Parallel Change RE**	**Parallel Change RE**	**Parallel Change FE**	**Parallel Change RE**
Hrate × 2008	−0.2367 (0.4503)	−0.1323 (0.4654)	*Hrate* × 2015	−1.5235 ** (0.6830)	−1.4123 ** (0.7018)
Hrate × 2009	−0.2207 (0.4516)	0.0391 (0.4639)	*Hrate* × 2016	−1.2614 (0.8493)	−1.1504 (0.8668)
Hrate × 2010	−0.1524 (0.4578)	0.0219 (0.4711)	*Hrate* × 2017	−2.5768 *** (0.9405)	−2.4910 *** (0.9524)
Hrate × 2011	−0.4758 (0.4689)	−0.3641 (0.4834)	Constant term	2.2557 *** (0.6967)	2.7613 *** (0.6618)
Hrate × 2012	−0.9722 ** (0.4578)	−0.8870 * (0.4721)	Control variable	Controls	Controls
Hrate × 2013	−0.0857 (0.0535)	−0.0766 (0.0552)	Observed value	390	390
Hrate × 2014	−0.0872 (0.0673)	−0.0716 (0.0692)	F R^2	28.2418 0.5567	— —

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Standard error in parentheses; Both the individual fixed effect and the year fixed effect have been controlled.

4.2.3. Robustness Test

For the purpose of further validating the robustness of estimation results, the sample data before policy implementation (2005–2010) were selected, and 2007 and 2008 were taken as the time points of policy implementation for the placebo test. The test results are presented in Table 7, where Columns (1) and (4) illustrate the estimation results of standard errors based on the fixed effect; Columns (2) and (5) illustrate the estimation results of standard errors based on the random effect; and Columns (3) and (6) illustrate the estimation results of standard errors based on the mixed effect. As indicated by the regression results in Columns (1)–(6), neither $Hrate \times I_t^{post2008}$ nor $Hrate \times I_t^{post2009}$ exerted any significant effect on the CEALU per unit area. This means that there was no policy effect before the implementation of the high-standard farmland construction policy, and that the previous estimation results could be deemed as robust.

Table 7. The robustness test of changing the time of policy intervention.

Variable	Take 2008 as the Policy Implementation Point			Take 2009 as the Policy Implementation Point		
	(1) Fixed Effect	(2) Random Effect	(3) Mixed Effect	(4) Fixed Effect	(5) Random Effect	(6) Mixed Effect
$Hrate \times I_t^{post2008}$	−0.7225 (0.5729)	−0.5015 (0.5891)	−0.7225 (0.6315)			
$Hrate \times I_t^{post2009}$				−0.5749 (0.4945)	−0.4214 (0.5042)	−0.5749 (0.5450)
Constant term	3.5272 ** (1.4690)	3.9660 *** (0.8695)	4.5418 *** (1.5904)	3.4980 ** (1.5129)	4.0173 *** (0.8893)	4.5250 *** (1.6316)
Control variable	Controls	Controls	Controls	Controls	Controls	Controls
Sample size	180	180	180	180	180	180
R^2	0.7062	—	0.9901			

Note: ** $p < 0.05$; *** $p < 0.01$. Figures in parentheses are robust standard errors of clustering at the provincial level; province fixed effects and year fixed effects have been controlled for, and the estimates are omitted; control variables are the same as in Figure 5, and the estimates are omitted; (1) to (6) are the estimation results for the sample data from 2005 to 2010.

4.3. Is the Regional Heterogeneity Effect of HSFC on CEALU?

The samples from three regions (i.e., eastern China, central China, and western China) were estimated using Formula (1); the results are presented in Table 8. As for the samples from eastern China and western China, the effect of the high-standard farmland construction policy on the CEALU per unit area was uniformly non-significant. By contrast, in relation to the samples from central China, the effect coefficient of the high-standard farmland construction policy on the CEALU per unit area was −0.3667, and uniformly passed the significance level of 5%. This demonstrates that the carbon emission reduction effect of this policy on agricultural land use was significant in central China, but non-significant in eastern China and western China. One possible explanation is that eastern China has more favorable agricultural production conditions than central China and might have started to pay attention to the issue of agricultural greenhouse gas emissions, taking corresponding countermeasures before policy implementation. Therefore, the effect of policy implementation on agricultural carbon emission reduction was non-significant in eastern China [92]. The level of agricultural technology and equipment in central China is relatively low, and seven provinces in central China are major grain-producing areas (out of 13 at national level). The National Planning for Construction of High-standard Farmland in Agricultural Comprehensive Development (2011–2020) has put forward the principle of "focusing on major grain-producing areas, and giving due consideration to non-major grain-producing areas". As a result, the high-standard farmland construction in major grain-producing areas may have received more policy support, making a greater marginal contribution to carbon emission reduction in agricultural land use.

Table 8. The results of heterogeneity analysis.

Variable	Eastern Region	Central Region	Western Region
$Hrate \times I_t^{post}$	−0.0262 (0.0727)	−0.3667 ** (0.1806)	0.0364 (0.1527)
Constant term	14.0595 *** (1.8904)	0.1450 (1.7205)	3.0510 *** (0.9514)
Control variable	Controls	Controls	Controls
Sample size	130	104	156
R^2	0.6430	0.7796	0.8121

Note: ** $p < 0.05$; *** $p < 0.01$. The numbers in brackets are cluster robust standard errors at the provincial level. Province fixed effect and year fixed effect have been controlled, and the estimated results are omitted. The control variables were consistent with those in Table 5, and the estimated results were omitted.

5. Discussion

This study analyzes provincial-level panel data from 2005 to 2017 in China using the DID model to assess the impact of the high-standard farmland construction (HSFC) policy on carbon emissions per unit area of agricultural land (CEALU). The results of the study show that the HSFC policy has a significant positive effect on reducing CEALU, a finding that is not only important for the sustainable development of agriculture in China, but also provides a valuable reference for the development of agricultural emission reduction strategies on a global scale.

First, the theoretical analysis shows that the HSFC policies enhance the carbon sink function of farmland by improving agricultural infrastructure conditions and upgrading the content of soil organic matter, thus improving the ability of agricultural land carbon sequestration [31,35,42,51], realizing the transformation of farmland from carbon source to carbon sink [93], which in turn reduce the CEALU. Empirical analysis verified this result, after the implementation of the policy, although the CEALU per unit area was in an increasing change from 2005 to 2014, and began to decrease after 2014, the growth rate slowed down, and the number of provinces with a growth rate of less than zero increased from one province to eight provinces. The HSFC policies demonstrate the possibility that CEALU reduction can be effectively promoted through land remediation and improved agricultural management practices, which provides valuable lessons for other countries. Secondly, this study found that HSFC policies have a carbon reduction effect, which on average can reduce carbon emissions per unit area of agricultural land use by 10.80%. It also reveals the heterogeneity of the carbon emission reduction effect of HSFC policies in different regions, and the findings are important for the development of regional and differentiated agricultural policies. The significant effect in the central region may be related to the region's status as China's main food production base and its relatively low level of agricultural technology and equipment [84]. This suggests that policymakers should consider region-specific agricultural production conditions and socioeconomic conditions when implementing similar policies to ensure their effectiveness and adaptability. Finally, as global climate change and environmental problems become increasingly serious, how to realize a win–win situation between agricultural production and environmental protection through agricultural policies is an important issue in front of governments and researchers [9,11,86]. In recent years, the government has invested nearly 100 billion yuan per year in farmland construction, and during 2011–2020, the country has accumulated nearly 800 million mu or more of high-standard farmland, with 1.075 billion mu planned for 2025 [47]. Its implementation effect and experience can provide lessons and references for other countries.

We believe that the contribution of our study to low-carbon research on agricultural land use is significant because previous studies have focused more on a single geographic area [8,12,14] or the impact of carbon emitting elements such as fertilizers [19], neglecting the sorting out of HSFC policies and downplaying their relationship with CEALU. In addition, the findings of this study echo the reports of other international researchers on the environmental impacts of agricultural land policies. For example, some studies have emphasized the dual role of agricultural land improvement in increasing agricultural productivity and reducing environmental stress [51,53]. By comparison, we can see that despite the differences in agricultural practices and policy environments in different countries and regions [58], a common pathway to achieving environmental goals in the agricultural sector is through improved agricultural land management and the promotion of sustainable agricultural practices. Through these efforts, we can make greater contributions to the sustainable development of global agriculture and climate change mitigation. Undeniably, existing scholarly studies have also overlooked the fact that in some cases, HSFC may pose some unexpected challenges and problems [32,33].

However, this study also has certain limitations. It failed to adequately consider other factors such as climate change, technological advances, and market changes that may affect CEALU. Moreover, due to the availability problem of panel data acquisition, this study only observed 12-year changes, and future research can construct a more comprehensive analytical framework by using continuous data for a longer period of time (e.g., more than 30 years), as well as citing more control variables to improve the accuracy and reliability. In addition, this study failed to explore in depth the differences in the response of different agricultural operators to the HSFC policy. Future research can analyze different sizes and types of agricultural business entities in more detail to identify and explain the heterogeneity of HSFC policy effects. This will help to better understand the effects of policy implementation and provide a basis for policy optimization.

6. Conclusions

By relying on provincial panel data for China for the period 2005–2017, the effect of the high-standard basic farmland construction policy on the CEALU per unit area was quantitatively analyzed using a DID model. This study can be summarized as follows. First, China's CEALU per unit area presented a fluctuating upward change in the period 2005–2017, from 392.58 kg/ha to 457.72 kg/ha, with an average annual growth rate of 1.31%. After the implementation of the high-standard farmland construction policy, the number of provinces with a negative average annual growth rate of CEALU per unit area increased from one to eight. Among them, seven are major grain-producing areas in China. Second, the results of the baseline regression showed that the high-standard farmland construction policy produced a significant carbon emission reduction effect in agricultural land use, and reduced the CEALU per unit area by 10.80% on average. With the promotion of the high-standard farmland construction policy, its carbon emission reduction effect in agricultural land use presented an overall increasing change. Third, the results of the heterogeneity analysis indicated that the carbon emission reduction effect of the high-standard farmland construction policy in agricultural land use was significant in central China, but non-significant in eastern China and western China. On average, the policy reduced the CEALU per unit area by 36.67%.

Based on the results of the study, the following policy recommendations are proposed: (1) Continue to promote and optimize agricultural policies to improve the quality and level of agricultural infrastructure development. At the same time, consider regional differences and formulate differentiated HSFC policies to adapt to the characteristics of agricultural production and socio-economic conditions in different regions. Strengthen the implementation of HSFC policies, especially in major food-producing regions such as the central part of the country. (2) Promote scientific and technological innovation in agriculture and enhance the capacity and willingness of farmers to adopt sustainable agricultural technologies through education, training and technology diffusion. It is also developing precision agriculture and utilizing modern information technology to improve the efficiency of agricultural production in order to reduce carbon emissions. (3) For possible negative environmental impacts, such as biodiversity reduction and over-exploitation of water resources, reasonable planning and management measures should be taken to ensure the long-term sustainability of the HSFC policy. The HSFC policy will be further optimized in the future to improve its effectiveness in promoting sustainable agricultural development and reducing carbon emissions.

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References

1. Haoyue, W.U.; Hanjiao, H.; Yu, H.; Wenkuan, C. Measurement, spatial spillover and influencing factors of agricultural carbon emissions efficiency in China. *Chin. J. Eco-Agric.* **2021**, *29*, 1762–1773. [CrossRef]
2. World Bank. World Development Indicators: Agricultural Methane Emissions. Available online: http://data.worldbank.org/indicator/En.Atm.Meth.Kt.Ce (accessed on 25 January 2018).
3. Huang, S.; Ghazali, S.; Azadi, H.; Movahhed Moghaddam, S.; Viira, A.H.; Janeckova, K.; Sklenicka, P.; Lopez-Carr, D.; Kohl, M.; Kurban, A. Contribution of agricultural land conversion to global GHG emissions: A meta-analysis. *Sci. Total Environ.* **2023**, *876*, 162269. [CrossRef] [PubMed]
4. Zhou, M.; Hu, B. Decoupling of carbon emissions from agricultural land utilisation from economic growth in China. *Agric. Econ.* **2020**, *66*, 510–518. [CrossRef]
5. Ruhan, A.; Mu, D.; Sudesuriguge, A. Analysis on land use carbon emissions and influencing factors in Duolun county, Inner Mongolia. *J. Arid. Land Resour. Environ.* **2019**, *33*, 17–22.
6. Huang, W.; Wu, F.; Han, W.; Li, Q.; Han, Y.; Wang, G.; Feng, L.; Li, X.; Yang, B.; Lei, Y.; et al. Carbon footprint of cotton production in China: Composition, spatiotemporal changes and driving factors. *Sci. Total Environ.* **2022**, *821*, 153407. [CrossRef]
7. Liu, M.; Yang, L. Spatial pattern of China's agricultural carbon emission performance. *Ecol. Indic.* **2021**, *133*, 108345. [CrossRef]
8. Su, K.; Wei, D.-Z.; Lin, W.-X. Influencing factors and spatial patterns of energy-related carbon emissions at the city-scale in Fujian province, Southeastern China. *J. Clean. Prod.* **2020**, *244*, 118840. [CrossRef]
9. Xia, Q.; Liao, M.; Xie, X.; Guo, B.; Lu, X.; Qiu, H. Agricultural carbon emissions in Zhejiang Province, China (2001–2020): Changing trends, influencing factors, and has it achieved synergy with food security and economic development? *Environ. Monit. Assess.* **2023**, *195*, 1391. [CrossRef] [PubMed]
10. Reeve, A.; Aisbett, E. National accounting systems as a foundation for embedded emissions accounting in trade-related climate policies. *J. Clean. Prod.* **2022**, *371*, 133678. [CrossRef]
11. Chen, Y.; Li, S.; Cheng, L. Evaluation of Cultivated Land Use Efficiency with Environmental Constraints in the Dongting Lake Eco-Economic Zone of Hunan Province, China. *Land* **2020**, *9*, 440. [CrossRef]
12. Yang, H.; Wang, X.; Bin, P. Agriculture carbon-emission reduction and changing factors behind agricultural eco-efficiency growth in China. *J. Clean. Prod.* **2022**, *334*, 130193. [CrossRef]
13. Panchasara, H.; Samrat, N.H.; Islam, N. Greenhouse Gas Emissions Trends and Mitigation Measures in Australian Agriculture Sector—A Review. *Agriculture* **2021**, *11*, 85. [CrossRef]
14. Qichen, Z.; Dun, Y.; Jianping, W. Spatial and temporal evolution, influencing factors and trend prediction of carbon emissions from agricultural land use in JiuJiang city. *Res. Soil Water Conserv.* **2023**, *30*, 441–451. [CrossRef]
15. Dumortier, J.; Elobeid, A. Effects of a carbon tax in the United States on agricultural markets and carbon emissions from land-use change. *Land Use Policy* **2021**, *103*, 105320. [CrossRef]
16. Bai, Y.; Wang, Y.; Xuan, X.; Weng, C.; Huang, X.; Deng, X. Tele-connections, driving forces and scenario simulation of agricultural land, water use and carbon emissions in China's trade. *Resour. Conserv. Recycl.* **2024**, *203*, 107433. [CrossRef]
17. Liu, X.; Li, J.; Zhao, C. On building 4 hundred million mu of high-standard basic farmland in the twelfth five-year plan. *China Popul. Resour. Environ.* **2012**, *22*, 1–5.
18. Ma, X.Y.; Shao, J.A.; Cao, F. Comprehensive Performance Evaluation of High Standard Farmland Construction in Mountainous Counties—A Case Study in Dianjiang, Chongqing. *J. Nat. Resour.* **2018**, *33*, 2183–2199. [CrossRef]
19. Liu, Y.; Liao, W.; Zhang, X.; Qiu, H. Impact of high standard farmland construction policy on chemical fertilizer reduction: A case study of China. *Front. Environ. Sci.* **2023**, *11*, 1256028. [CrossRef]
20. Ye, F.; Wang, L.; Razzaq, A.; Tong, T.; Zhang, Q.; Abbas, A. Policy Impacts of High-Standard Farmland Construction on Agricultural Sustainability: Total Factor Productivity-Based Analysis. *Land* **2023**, *12*, 283. [CrossRef]
21. Li, X.; He, Y.; Fu, Y.; Wang, Y. Analysis of the carbon effect of high-standard basic farmland based on the whole life cycle. *Sci Rep.* **2024**, *14*, 3361. [CrossRef]
22. Ministry of Agriculture and Rural Affairs of the People's Republic of China. Well-Facilitated Farmland Construction—General Rules. Available online: http://www.moa.gov.cn/ztzl/gdzlbhyjs/mtbd_28775/mtbd/202204/t20220418_6396631.htm (accessed on 9 March 2018).
23. Wang, X.; Shi, W.; Sun, X.; Wang, M. Comprehensive benefits evaluation and its spatial simulation for well-facilitated farmland projects in the Huang-Huai-Hai Region of China. *Land Degrad. Dev.* **2020**, *31*, 1837–1850. [CrossRef]
24. Hu, Y.; Lu, X.; Zhao, G. Construction scale and spatial distribution of well-facilitated primary farmland of daxian county in sichuan province. *China Land Sci.* **2014**, *28*, 30–38. [CrossRef]
25. Shan, W.; Jin, X.; Yang, X.; Gu, Z.; Han, B.; Li, H.; Zhou, Y. A framework for assessing carbon effect of land consolidation with life cycle assessment: A case study in China. *J. Environ. Manag.* **2020**, *266*, 110557. [CrossRef] [PubMed]
26. Yang, Y.; Cao, T. Measurement of carbon effect in land consolidation projects and evaluation of low-carbon promotion paths: A case study of Wudi County, Shandong Province, China. *Environ. Sci. Pollut. Res. Int.* **2023**, *30*, 113068–113087. [CrossRef] [PubMed]
27. Xin, G.; Yang, C.; Yang, Q.; Li, C.; Wei, C. Post-evaluation of well-facilitied capital farmland construction based on entropy weight method and improved TOPSIS model. *Trans. Chin. Soc. Agric. Eng.* **2017**, *33*, 238–249.

28. Liang, Z.H.; Zhang, L.; Zhang, J.B. Land consolidation and fertilizer reduction: Quasi-natural experimental evidence from china's well-facilitated capital farmland construction. *Chin. Rural. Econ.* **2021**, *04*, 123–144.
29. Zhang, L.; Liang, Z.H.; Pu, Y.X. Effect and improvement of soil testing and formulated fertilization technology in the Yangtze River Economic Belt. *J. Huazhong Agric. Univ.* **2021**, *40*, 30–42. [CrossRef]
30. Liu, C.; Wu, Y.; Wang, C. Zoning method for well-facilitated farmland construction based on improvement of ecological services. *Trans. Chin. Soc. Agric. Eng.* **2018**, *34*, 264–272. [CrossRef]
31. Tian'en, Z.; Li, Z.; Kun, F.; Xuejie, Z.; Huning, G.; Zhang, M.; Ma, Y. Effects of high-standard farmland construction on farmland quality and contribution of irrigation and drainage index. *J. Agric. Resour. Environ.* **2022**, *39*, 978–989. [CrossRef]
32. Jibin, Z.; Jingan, S.; Deti, X. Dynamic changes of soil organic carbon for basic farmland and non-basic farmland of Dianjiang county in recent 30 years. *Trans. Chin. Soc. Agric. Eng.* **2016**, *32*, 254–262.
33. Soulé, E.; Charbonnier, R.; Schlosser, L.; Michonneau, P.; Michel, N.; Bockstaller, C. A new method to assess sustainability of agricultural systems by integrating ecosystem services and environmental impacts. *J. Clean. Prod.* **2023**, *415*, 137784. [CrossRef]
34. Jiansheng, L.; Wenju, Y.; Xiaomin, Z.; Xinwen, L. Theory and Application of Well-facilitied Capital Farmland Construction: An Analysis Based on the Gap Degree and Investment Intensity. *China Popul. Resour. Environ.* **2014**, *24*, 47–53.
35. Song, W.; Wu, K.; Zhao, H.; Zhao, R.; Li, T. Arrangement of High-standard Basic Farmland Construction Based on Village-region Cultivated Land Quality Uniformity. *Chin. Geogr. Sci.* **2019**, *29*, 325–340. [CrossRef]
36. Středová, H.; Středa, T.; Rožnovský, J. Long-term comparison of climatological variables used for agricultural land appraisement. *Contrib. Geophys. Geod.* **2013**, *43*, 179–195. [CrossRef]
37. Li, J.; Wang, W.; Li, M.; Li, Q.; Liu, Z.; Chen, W.; Wang, Y. Impact of Land Management Scale on the Carbon Emissions of the Planting Industry in China. *Land* **2022**, *2022*, 816. [CrossRef]
38. Carvalheiro, L.G.; Veldtman, R.; Shenkute, A.G.; Tesfay, G.B.; Pirk, C.W.W.; Donaldson, J.S.; Nicolson, S.W. Natural and within-farmland biodiversity enhances crop productivity. *Ecol. Lett.* **2011**, *14*, 251–259. [CrossRef]
39. Wu, Q.; Xiong, K.; Li, R.; Xiao, J. Farmland hydrology cycle and agronomic measures in agroforestry for the efficient utilization of water resources under karst desertification environments. *Forests* **2023**, *14*, 453. [CrossRef]
40. Xiao, M.; Li, Y.; Zheng, S. Effect of Rural Sewage Irrigation Regime on Water-Nitrogen Utilization and Crop Growth of Paddy Rice in Southern China. *Phyton-Int. J. Exp. Bot.* **2023**, *92*, 1215–1233. [CrossRef]
41. Ke, Z.; Liu, X.; Ma, L.; Dong, Q.G.; Jiao, F.; Wang, Z. Excavated farmland treated with plastic mulching as a strategy for groundwater conservation and the control of soil salinization. *Land Degrad. Dev.* **2022**, *33*, 3036–3048. [CrossRef]
42. Yang, N.; Sun, X.; Qi, Q. Impact of factor quality improvement on agricultural carbon emissions: Evidence from China's high-standard farmland. *Front. Environ. Sci.* **2022**, *10*, 989684. [CrossRef]
43. Cao, X.; Sun, B.; Chen, H.; Zhou, J.; Song, X.; Liu, X.; Deng, X.; Li, X.; Zhao, Y.; Zhang, J.; et al. Approaches and Research Progresses of Marginal Land Productivity Expansion and Ecological Benefit Improvement in China. *Bull. Chin. Acad. Sci.* **2021**, *36*, 336–348. [CrossRef]
44. Ustaoglu, E.; Collier, M.J. Farmland abandonment in Europe: An overview of drivers, consequences, and assessment of the sustainability implications. *Environ. Rev.* **2018**, *26*, 396–416. [CrossRef]
45. The State Council. Trial Measures for the Administration of Recovery of National Land Development and Construction Funds. Available online: https://xueshu.baidu.com/usercenter/paper/show?paperid=a5583c0a75fcd7235c0f4719edbd893b&tn=SE_baiduxueshu_c1gjeupa&ie=utf-8&site=baike (accessed on 27 August 2018).
46. Central Government of the People's Republic of China. China's No. 1 Central Document: Opinions on Several Policies to Further Strengthen Rural Work and Improve the Overall Agricultural Production Capacity. Available online: https://www.gov.cn/test/2006-02/22/content_207406.htm (accessed on 30 January 2015).
47. National Development and Reform Commission. The National High-Standard Farmland Construction Plan (2021–2030). Available online: https://www.ndrc.gov.cn/fggz/fzzlgh/gjjzxgh/202111/t20211102_1302810.html (accessed on 2 November 2015).
48. National Public Service Platform for Standards Information. National Standards Search. Available online: https://std.samr.gov.cn/gb (accessed on 20 March 2024).
49. Central People's Government of the People's Republic of China. The State Council Policy Document Library. Available online: https://www.gov.cn/zhengce/zhengcewenjianku/index.htm?t=zhengcelibrary (accessed on 20 March 2024).
50. Haitao, L. Ocus on the green development of Agriculture and Help achieve the Goal of "Double carbon"—A review of China's Agricultural Carbon Emission Reduction Path Study. *Issues Agric. Econ.* **2022**, *09*, 144. [CrossRef]
51. Yu, S.; Weiping, L.; Zhen, X. Model evaluation of the impact of high-standard farmland construction policy on planting structure. *Trans. Chin. Soc. Agric. Eng.* **2023**, *39*, 227–235. [CrossRef]
52. Zhao, R.; Wu, K. Soil Health Evaluation of Farmland Based on Functional Soil Management—A Case Study of Yixing City, Jiangsu Province, China. *Agriculture* **2021**, *11*, 583. [CrossRef]
53. Qiao, L.; Wang, X.; Smith, P.; Fan, J.; Lu, Y.; Emmett, B.; Li, R.; Dorling, S.; Chen, H.; Liu, S.; et al. Soil quality both increases crop production and improves resilience to climate change. *Nat. Clim. Chang.* **2022**, *12*, 574–580. [CrossRef]
54. Tianjiao, F.; Dong, W.; Ruoshui, W.; Yixin, W.; Zhiming, X.; Fengmin, L.; Yuan, M.; Xing, L.; Huijie, X.; Caballero-Calvo, A.; et al. Spatial-temporal heterogeneity of environmental factors and ecosystem functions in farmland shelterbelt systems in desert oasis ecotones. *Agric. Water Manag.* **2022**, *271*, 107790. [CrossRef]

55. Sang, Z.; Zhang, G.; Wang, H.; Zhang, W.; Chen, Y.; Han, M.; Yang, K. Effective Solutions to Ecological and Water Environment Problems in the Sanjiang Plain: Utilization of Farmland Drainage Resources. *Sustainability* **2023**, *15*, 16329. [CrossRef]
56. Penghui, J.; Dengshuai, C.; Manchun, L. Farmland landscape fragmentation evolution and its driving mechanism from rural to urban: A case study of Changzhou City. *J. Rural. Stud.* **2021**, *82*, 1–18. [CrossRef]
57. Sardaro, R.; Bozzo, F.; Fucilli, V. High-voltage overhead transmission lines and farmland value: Evidences from the real estate market in Apulia, southern Italy. *Energy Policy* **2018**, *119*, 449–457. [CrossRef]
58. Li, L.; Han, J.; Zhu, Y. Does environmental regulation in the form of resource agglomeration decrease agricultural carbon emissions? Quasi-natural experimental on high-standard farmland construction policy. *J. Clean. Prod.* **2023**, *420*, 138342. [CrossRef]
59. Shen, Z.; Wang, S.; Boussemart, J.-P.; Hao, Y. Digital transition and green growth in Chinese agriculture. *Technol. Forecast. Soc. Chang.* **2022**, *181*, 121742. [CrossRef]
60. Coomes, O.T.; Barham, B.L.; MacDonald, G.K.; Ramankutty, N.; Chavas, J.P. Leveraging total factor productivity growth for sustainable and resilient farming. *Nat. Sustain.* **2019**, *2*, 22–28. [CrossRef]
61. Frank, S.; Havlík, P.; Stehfest, E.; van Meijl, H.; Witzke, P.; Pérez-Domínguez, I.; van Dijk, M.; Doelman, J.C.; Fellmann, T.; Koopman, J.F.L.; et al. Agricultural non-CO_2 emission reduction potential in the context of the 1.5 °C target. *Nat. Clim. Chang.* **2019**, *9*, 66–72. [CrossRef]
62. Shang, Q.; Ling, N.; Feng, X.; Yang, X.; Wu, P.; Zou, J.; Shen, Q.; Guo, S. Soil fertility and its significance to crop productivity and sustainability in typical agroecosystem: A summary of long-term fertilizer experiments in China. *Plant Soil* **2014**, *381*, 13–23. [CrossRef]
63. Chen, B.; Han, M.Y.; Peng, K.; Zhou, S.L.; Shao, L.; Wu, X.F.; Wei, W.D.; Liu, S.Y.; Li, Z.; Li, J.S.; et al. Global land-water nexus: Agricultural land and freshwater use embodied in worldwide supply chains. *Sci. Total Environ.* **2018**, *613–614*, 931–943. [CrossRef]
64. Zhao, R.; Liu, Y.; Tian, M.; Ding, M.; Cao, L.; Zhang, Z.; Chuai, X.; Xiao, L.; Yao, L. Impacts of water and land resources exploitation on agricultural carbon emissions: The water-land-energy-carbon nexus. *Land Use Policy* **2018**, *72*, 480–492. [CrossRef]
65. Yang, Y.; Jin, Z.; Mueller, N.D.; Driscoll, A.W.; Hernandez, R.R.; Grodsky, S.M.; Sloat, L.L.; Chester, M.V.; Zhu, Y.-G.; Lobell, D.B. Sustainable irrigation and climate feedbacks. *Nat. Food* **2023**, *4*, 654–663. [CrossRef]
66. Zomer, R.J.; Bossio, D.A.; Sommer, R.; Verchot, L.V. Global sequestration potential of increased organic carbon in cropland soils. *Sci. Rep.* **2017**, *7*, 15554. [CrossRef]
67. Auerswald, K.; Fischer, F.K.; Kistler, M.; Treisch, M.; Maier, H.; Brandhuber, R. Behavior of farmers in regard to erosion by water as reflected by their farming practices. *Sci. Total Environ.* **2018**, *613–614*, 1–9. [CrossRef]
68. Shah, K.K.; Modi, B.; Pandey, H.P.; Subedi, A.; Aryal, G.; Pandey, M.; Shrestha, J.; Fahad, S. Diversified Crop Rotation: An Approach for Sustainable Agriculture Production. *Adv. Agric.* **2021**, *2021*, 8924087. [CrossRef]
69. Barbieri, P.; Pellerin, S.; Nesme, T. Comparing crop rotations between organic and conventional farming. *Sci. Rep.* **2017**, *7*, 13761. [CrossRef] [PubMed]
70. Vejan, P.; Khadiran, T.; Abdullah, R.; Ahmad, N. Controlled release fertilizer: A review on developments, applications and potential in agriculture. *J. Control. Release* **2021**, *339*, 321–334. [CrossRef] [PubMed]
71. Zhu, W.; Huang, B.; Zhao, J.; Chen, X.; Sun, C. Impacts on the embodied carbon emissions in China's building sector and its related energy-intensive industries from energy-saving technologies perspective: A dynamic CGE analysis. *Energy Build.* **2023**, *287*, 112926. [CrossRef]
72. Johansson, E.L.; Brogaard, S.; Brodin, L. Envisioning sustainable carbon sequestration in Swedish farmland. *Environ. Sci. Policy* **2022**, *135*, 16–25. [CrossRef]
73. Weersink, A.; Fraser, E.; Pannell, D.; Duncan, E.; Rotz, S. Opportunities and Challenges for Big Data in Agricultural and Environmental Analysis. *Annu. Rev. Resour. Econ.* **2018**, *10*, 19–37. [CrossRef]
74. Bi, X.; Wen, B.; Zou, W. The Role of Internet Development in China's Grain Production: Specific Path and Dialectical Perspective. *Agriculture* **2022**, *12*, 377. [CrossRef]
75. Patrício, D.I.; Rieder, R. Computer vision and artificial intelligence in precision agriculture for grain crops: A systematic review. *Comput. Electron. Agric.* **2018**, *153*, 69–81. [CrossRef]
76. Ministry of Finance of the People's Republic of China. Doing a Good Job in the Implementation of the National High-Standard Farmland Construction Plan for Comprehensive Agricultural Development and Vigorously Promoting High-Standard Farmland Construction. Available online: http://nfb.mof.gov.cn/zhengwuxinxi/gongzuotongzhi/201304/t20130410_816024.html (accessed on 16 March 2013).
77. Kuang, B.; Lu, X.H.; Zhou, M. Dynamic Evolution of Urban Land Economic Density Distributionin China. *China Land Sci.* **2016**, *30*, 47–54. [CrossRef]
78. Nie, Y.; Li, Q.; Wang, E.; Zhang, T. Study of the nonlinear relations between economic growth and carbon dioxide emissions in the Eastern, Central and Western regions of China. *J. Clean. Prod.* **2019**, *219*, 713–722. [CrossRef]
79. Delgado, M.S.; Florax, R.J.G.M. Difference-in-differences techniques for spatial data: Local autocorrelation and spatial interaction. *Econ. Lett.* **2015**, *137*, 123–126. [CrossRef]
80. Zheng, W.; Shen, G.Q.; Wang, H.; Hong, J.; Li, Z. Decision support for sustainable urban renewal: A multi-scale model. *Land Use Policy* **2017**, *69*, 361–371. [CrossRef]

81. Stuart, E.A.; Huskamp, H.A.; Duckworth, K.; Simmons, J.; Song, Z.; Chernew, M.; Barry, C.L. Using propensity scores in difference-in-differences models to estimate the effects of a policy change. *Health Serv. Outcomes Res. Methodol.* **2014**, *14*, 166–182. [CrossRef] [PubMed]
82. Yu, Y.; Zhang, J.; Zhang, K.; Xu, D.; Qi, Y.; Deng, X. The impacts of farmer ageing on farmland ecological restoration technology adoption: Empirical evidence from rural China. *J. Clean. Prod.* **2023**, *430*, 139648. [CrossRef]
83. Cao, J.; Li, C.; Gao, X.; Cai, Y.; Song, X.; Siddique, K.H.M.; Zhao, X. Agricultural soil plastic as a hidden carbon source stimulates microbial activity and increases carbon dioxide emissions. *Resour. Conserv. Recycl.* **2023**, *198*, 107151. [CrossRef]
84. Kuang, B.; Lu, X.; Han, J.; Zhang, Z. Regional differences and dynamic evolution of cultivated land use efficiency in major grain producing areas in low carbon perspective. *Trans. Chin. Soc. Agric. Eng.* **2018**, *34*, 1–8. [CrossRef]
85. Johnson, J.M.F.; Franzluebbers, A.J.; Weyers, S.L.; Reicosky, D.C. Agricultural opportunities to mitigate greenhouse gas emissions. *Environ. Pollut.* **2007**, *150*, 107–124. [CrossRef] [PubMed]
86. West, T.O.; Marland, G. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: Comparing tillage practices in the United States. *Agric. Ecosyst. Environ.* **2002**, *91*, 217–232. [CrossRef]
87. Lu, X.; Kuang, B.; Li, J.; Han, J.; Zhang, Z. Dynamic Evolution of Regional Discrepancies in Carbon Emissions from Agricultural Land Utilization: Evidence from Chinese Provincial Data. *Sustainability* **2018**, *10*, 552. [CrossRef]
88. Tian, Y.; Zhang, J.-B.; He, Y.-Y. Research on Spatial-Temporal Characteristics and Driving Factor of Agricultural Carbon Emissions in China. *J. Integr. Agric.* **2014**, *13*, 1393–1403. [CrossRef]
89. Han, H.; Zhong, Z.; Guo, Y.; Xi, F.; Liu, S. Coupling and decoupling effects of agricultural carbon emissions in China and their driving factors. *Environ. Sci. Pollut. Res.* **2018**, *25*, 25280–25293. [CrossRef] [PubMed]
90. Dubey, A.; Lal, R. Carbon Footprint and Sustainability of Agricultural Production Systems in Punjab, India, and Ohio, USA. *J. Crop Improv.* **2009**, *23*, 332–350. [CrossRef]
91. He, Y.Q.; Chen, R.; Wu, H.Y.; Xu, J.; Song, Y. Spatial dynamics of agricultural carbon emissions in China and the related driving factors. *Chin. J. Eco-Agric.* **2018**, *26*, 1269–1282. [CrossRef]
92. Chen, Y.B.; Wang, S. Evaluation of Agricultural Carbon Emission Reduction Effect of Agricultural Comprehensive Development Investment: Event Analysis Based on High-standard Farmland Construction. *J. Agrotech. Econ.* **2023**, *06*, 67–80. [CrossRef]
93. Tao, L.; Jixia, L.I.; Jingjuan, H. Spatial-temporal pattern and influencing factors of high-quality agricultural development in China. *J. Arid. Land Resour. Environ.* **2020**, *34*, 1–8. [CrossRef]