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*Article*

# Can High-Standard Farmland Construction Reduce Carbon Emissions from Agricultural Land Use?—Evidence from China

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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. However, few scholars explored the impact of agricultural land policies on carbon emissions, such as the High-standard farmland construction(HSFC) in China.Thus，by relying on provincial panel data for 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 trend 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 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 this policy, its carbon emission reduction effect in agricultural land use presented an overall increasing trend. 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 CO2 generated by agricultural activities currently accounts for 20% of the total global CO2 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 CO2 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, numerous scholars 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 adapt to modern agricultural production and management mode [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], produces 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 areas 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 discusses 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 have extended the existing research in various dimensions. Firstly, we conducted a comprehensive review of the policy landscape surrounding the establishment of the High-Standard Farmland Construction (HSFC) in China. This examination delineated the multifaceted reforms embedded within the policy framework, encompassing fields, soil, water, and infrastructure, aimed at mitigating challenges such as land fragmentation, deteriorating soil quality, and insufficient water resources, all of which serve as impediments to augmenting grain production capacity. Concurrently, the development of high-standard farmland expands the scope of agricultural land management, thereby fostering conducive conditions for the modernization of agricultural mechanization and the expansion of market capacity for outsourced social services. Secondly, we delved into the theoretical underpinnings concerning the nexus between the construction of high-standard farmland and Carbon Emissions from Agricultural Land Use(CEALU). Further exploration of basic farmland construction may engender practices conducive to land preservation and sustainable utilization, thereby elucidating the rationale behind curtailing carbon emissions from agricultural land, and thereby advancing initiatives for carbon emission reduction within agricultural land utilization. In this study, we employed a difference-in-difference (DID) model leveraging provincial panel data from China spanning the period 2005-2017. This model was instrumental in quantitatively evaluating the impact and regional disparities of HSFC policy on CEALU, thereby furnishing empirically-grounded and judicious policy insights for fostering future endeavors aimed at reducing CEALU through reliance on HSFC.

## 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 of The 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 the standards, contents, zoning, priorities, objectives, safeguard measures, etc. [47](Tables 1 and 2). These further enriched pertinent national standards and strategic blueprints.The evolution of High-Standard Farmland Construction policies are shown in Figure 1

**Table 1.** The main measures, content and purpose of HSFC policies.

| Standards | Contents | Zoning | Objectives | Safeguard Measures |
|---|---|---|---|---|
| GB/T 33130-2016 | Farmland Consolidation | Northeast Region | 1.075 billion Mu (2025) | Government Overall Planning |
| GB/T33469-2016 | 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 |
| | Agricultural Field Protection | | | |
| GB 5084-2021 | Ecological and Environmental Protection | Southwest Region | | Supervision and Assessment |
| GB/ T 30600-2022 | Farmland Power Transmission and Distribution | Northwest Region | | |
| ...... | Science and Technology Service | Qinghai-Tibet Region | | |
| | Management, Protection and Utilization | | | |

**Table 2.** The main measures, content and purpose of HSFC policies.

| Measures | Content | Purpose |
|---|---|---|
| Agricultural measures | Farmland Consolidation | Optimize the spatial distribution of high-standard farmland |
| | Soil Improvement | 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 | Improve the guarantee rate of agricultural irrigation |
| | Drainage works | Improve the ability to withstand storms |
| Infrastructure construction measures | Field road construction | Improve the direct access road network to farmland |
| | Farmland electricity transmission and distribution | Improve the quality and safety of electricity use |
| Scientific and technological measures | Location monitoring of cultivated land quality | Tracking and monitoring the change of farmland quality |
| | Digital farmland construction | Improve the level of precision and wisdom |

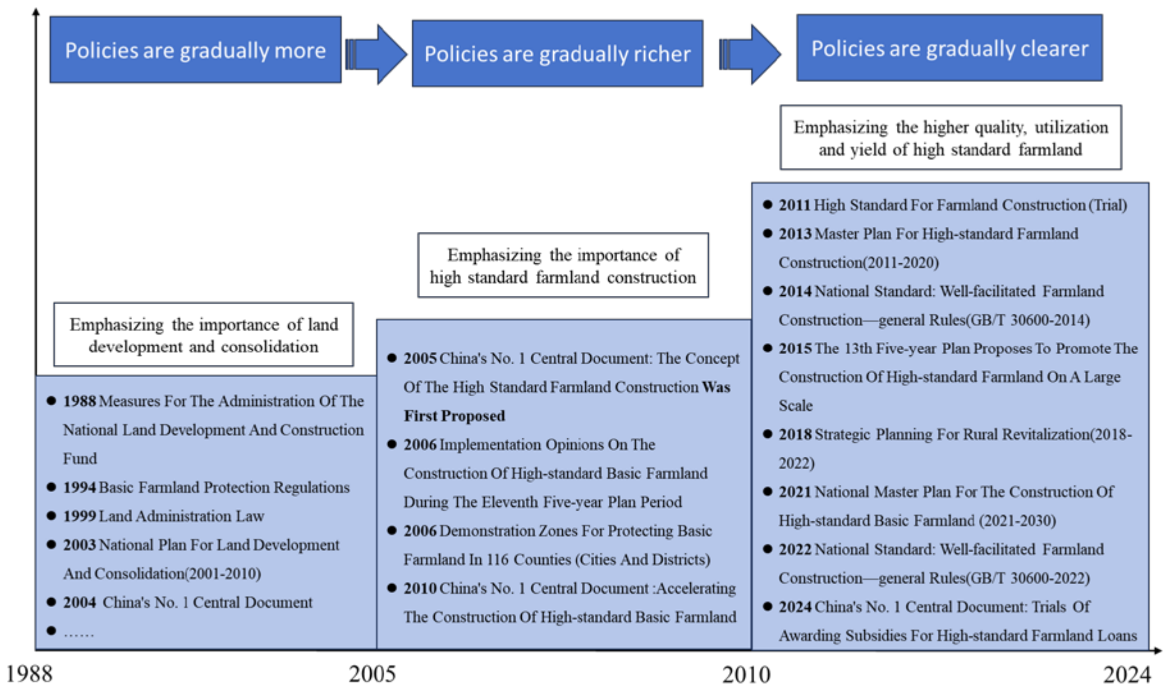

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**Figure 1.** The evolution of High-Standard Farmland Construction policies.

### *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, low-carbon and high-quality development [48].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 [49].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 [50,51]. Forestry measures, encompassing farmland shelterbelt protection, serve to fortify carbon sequestration efforts by preserving and expanding vegetal cover, effectively amplifying carbon sink capacities [52]. 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 [53]. 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 [54,55]. Finally, scientific and technological support measures, exemplified by cultivated land quality assessment [56] and digital agricultural infrastructure [57], 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 [58].

#### 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 [59]. 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. [60] Even more, optimizing agricultural water resources is pivotal for achieving water use efficiency and fostering sustainable agricultural practices [61]. 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 [62]. 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 [63]. Notably, the amelioration of soil quality serves as the cornerstone, providing a fertile milieu for crop growth while sequestering carbon [64]. Concurrently, the optimization of agricultural water resources ensures judicious water utilization, thereby curtailing wastage and diminishing the carbon footprint of agricultural activities [65]. 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 [66]. By sequestering carbon and fostering additional carbon sinks, these methods counterbalance carbon emissions stemming from agricultural activities [67]. Subsequently, the optimization of inputs including water, fertilizers, and energy within high-standard agricultural settings minimizes resource wastage, thus bolstering resource efficiency [68]. This approach not only curtails the energy-intensive production and transportation of agricultural inputs but also mitigates carbon emissions associated with land use practices [69]. Moreover, the establishment of HSFC catalyzes the adoption of environmentally sustainable and more efficient farming techniques, thereby enhancing the resilience of agricultural ecosystems [70]. Furthermore, the application of digital agricultural technologies enables real-time monitoring and assessment of land quality [71,72], furnishing a scientific foundation for precision and sophistication in carbon emission reduction strategies within land use management [73].Figure 2 illustrates the mechanism by which the HSFC contributes to CEALU through five major measures and three key processes.

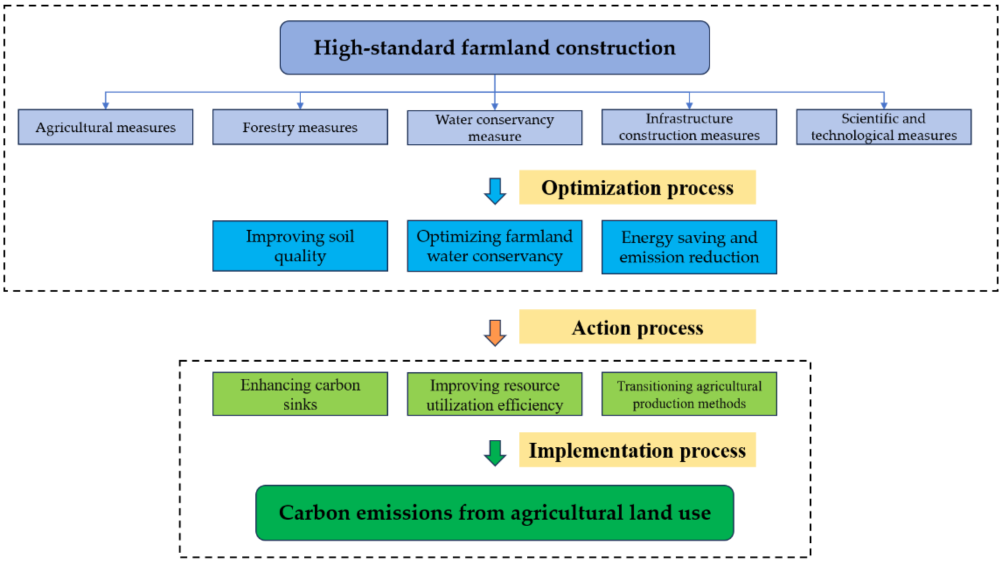


**Figure 2.** Theoretical framework of the effect of HSFC on CEALU.

## 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" [74]. 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 eastern region, central region, and western region according to the regional classification method used in previous

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studies [75,76] (Figure 3). By relying on the significant advantages of the DID model in analyzing the net effect of policies [77–79], 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; $\mu_i$ denotes the fixed effect of province; $\gamma_i$ denotes the fixed effect of year; $\varepsilon_{it}$ is a random error term; $\alpha$ is a constant term; and $\beta$ and $\delta$ are parameters to be estimated.

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 [80].

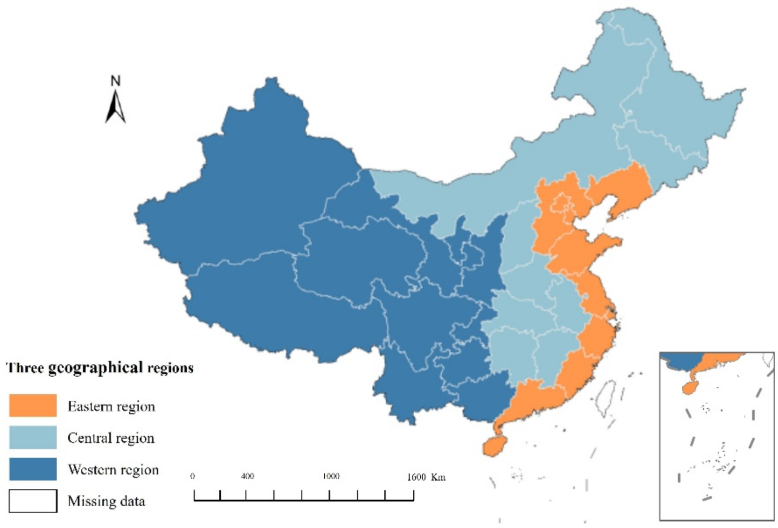


**Figure 3.** Study area and Three geographical regions. Note: ①Eastern region: Beijing, Tianjin, Hebei,Lioaning, Shandong, Jiangsu, Zhejiang, Shanghai, Fujian, Guangdong, Hainan. ②Central region: Heilongjiang, Jilin, Neimenggu, Shanxi, Henan, Anhui, Hubei, Hunan, Jiangxi. ③Western region: Xinjiang, Xizang, Qinghai, Gansu, Ningxia, Shannxi, Sichuan, Chongqing, Guizhou, Yunnan, Guangxi. ④The base maps of research are made according to the Chinese standard map No. GS(2022)1873

## *3.2. Data and Variable*

### 3.2.1. Data Sources

Based on the availability and completeness of data.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). From 2012 onwards, the data on "people employed in the primary industry" were no longer published in the

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China Rural Statistical Yearbook. For the sake of data consistency and integrity, these data were derived from the statistical yearbooks of 31 provinces (regions/cities) in China in 2017.

#### 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 [81]. Referring to the results of existing studies [82,83] , 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; $\delta_i$ 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 [84] |
| Pesticide | 4.9341 | Kg C /kg | Lu et al [85] |
| Thin film | 5.180 | Kg C /kg | Tian et al [86] |
| Total power of agricultural machinery | 0.18 | kg C/kW | Kuang et al [82] |
| Tillage over | 312.6 | kg C/ha | Han et al [87] |
| Irrigation | 25 | kg C/ha | Dubey et al [88] |

Core explanatory variable: HSFC policy. The Standard for Well-facilitated Capital Farmland Construction (GB/T 30600-2022) 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: 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.

| Variable names, symbols, and meanings | Average value | Standard deviation | Min. | Max. |
|---|---|---|---|---|
| CEALU per unit area (C) , kg/ha | 482.22 | 182.04 | 170.16 | 1154.36 |

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| | | | | |
|---|---|---|---|---|
| Proportion of land consolidation area (Hrate) , % | 0.05 | 0.09 | 0.00 | 0.97 |
| Urbanization leve l(Urban) , Urban population as a percentage of total population , % | 0.52 | 0.14 | 0.20 | 0.89 |
| Soil quality (Soil) , Soil erosion control area , kha | 3490.75 | 2847.04 | 0.00 | 13600 |
| Field irrigation condition (Irri) , Effective irrigation area , kha | 1991.36 | 1537.66 | 115.50 | 6031.00 |
| Per unit area yield of grain (Fyield) , Grain output per unit area , kg/ha | 5149.15 | 996.90 | 3045.73 | 7885.95 |
| Investment level (Ginves) , Investment in fixed assets of the whole society , 100 million yuan | 374.11 | 418.17 | 3045.73 | 2675.94 |
| The proportion of food crops (Frate) , Proportion of grain sown area to total sown area , % | 65.36 | 12.46 | 3045.73 | 2675.94 |
| Labor input (Labor) , Headcount in primary industry , 10 thousand people | 938.83 | 694.87 | 37.09 | 3139.00 |
| Economic development level (GDP) , PGDP , yuan | 28300 | 17800 | 5200.80 | 107000 |
| industrial structure (Grate) , Proportion of agricultural output value to GDP , % | 10.99 | 5.63 | 0.36 | 32.73 |

## 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 trend 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 trend can be divided into three stages, i.e., 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 trend. 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.

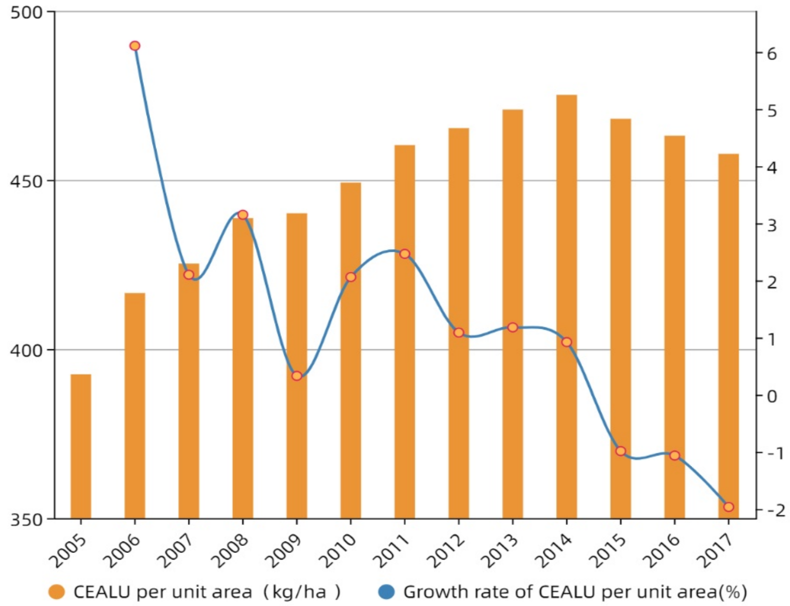



**Figure 4.** Changes of CEALU per unit area during 2005–2017.

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 (Table 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.

**Table 5.** The CEALU of each province in China in main years (kg/ha).

| **Area** | **2005** | **2008** | **2011** | **2014** | **2017** | **Mean** | **Area** | **2005** | **2008** | **2011** | **2014** | **2017** | **Mean** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Beijing** | 692.91 | 689.35 | 721.74 | 931.61 | 1154.36 | 819.42 | **Hubei** | 476.93 | 549.49 | 536.44 | 518.28 | 481.99 | 520.93 |
| **Tianjin** | 613.26 | 717.79 | 669.49 | 627.22 | 544.22 | 660.25 | **Hunan** | 356.47 | 399.14 | 387.07 | 385.34 | 399.75 | 390.27 |
| **Hebei** | 438.18 | 456.72 | 471.19 | 493.86 | 487.03 | 471.80 | **Guangdong** | 518.95 | 629.81 | 660.01 | 652.18 | 749.90 | 648.97 |
| **Shanxi** | 313.68 | 343.16 | 377.01 | 403.82 | 406.91 | 374.96 | **Guangxi** | 346.64 | 441.30 | 459.70 | 500.09 | 508.27 | 459.05 |
| **Neimenggu** | 228.03 | 266.28 | 298.74 | 369.06 | 319.80 | 300.91 | **Hainan** | 619.51 | 836.73 | 916.64 | 925.86 | 1097.88 | 889.25 |
| **Liaoning** | 481.58 | 547.38 | 572.56 | 592.53 | 548.95 | 555.46 | **Chongqing** | 282.97 | 336.16 | 348.73 | 344.49 | 361.51 | 338.94 |
| **Ji Lin.** | 333.86 | 397.49 | 447.04 | 478.55 | 449.14 | 427.71 | **Sichuan** | 297.99 | 329.08 | 343.88 | 342.65 | 337.41 | 334.26 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Heilongjiang** | 195.77 | 197.50 | 243.45 | 270.30 | 222.17 | 228.78 | **Guizhou** | 193.13 | 237.16 | 233.98 | 230.81 | 218.67 | 226.15 |
| **Shanghai** | 753.55 | 735.05 | 626.80 | 616.84 | 646.23 | 661.50 | **Yunnan** | 303.82 | 357.00 | 385.79 | 411.49 | 450.27 | 383.14 |
| **Jiangsu** | 531.30 | 543.64 | 538.28 | 526.27 | 504.84 | 532.59 | **Xizang.** | 214.26 | 240.32 | 251.63 | 276.11 | 285.40 | 257.25 |
| **Zhejiang** | 510.28 | 594.30 | 605.45 | 650.67 | 689.49 | 620.92 | **Shaanxi** | 366.24 | 415.65 | 517.35 | 560.34 | 595.61 | 501.90 |
| **Anhui** | 387.17 | 423.06 | 455.02 | 476.86 | 458.54 | 444.99 | **Gansu** | 330.68 | 368.44 | 467.26 | 529.08 | 520.77 | 450.96 |
| **Fujian** | 640.41 | 765.42 | 745.20 | 750.24 | 1068.85 | 796.57 | **Qinghai** | 179.90 | 187.43 | 220.85 | 252.42 | 249.41 | 217.37 |
| **Jiangxi** | 348.29 | 366.13 | 377.39 | 375.88 | 353.27 | 367.57 | **Ningxia** | 293.47 | 320.92 | 358.32 | 371.31 | 418.07 | 355.78 |
| **Shandong** | 637.42 | 646.54 | 633.58 | 609.28 | 567.59 | 627.25 | **Xinjiang** | 464.76 | 536.15 | 562.74 | 684.53 | 651.85 | 571.09 |
| **Henan** | 423.73 | 483.46 | 536.28 | 556.52 | 538.64 | 513.04 | **Tatal** | 392.58 | 433.03 | 456.09 | 473.32 | 457.72 | 447.45 |

### *4.2. Did HSFC Reduce CEALU?*

#### 4.2.1. Estimation Results of The Baseline Regression Model

Table 6 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 6.** 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** (0.0499) | -0.1080** (0.0520) | -0.1080** (0.0520) |
| *Urban* | -0.4620 (0.4899) | -0.4620 (0.5104) | -0.4620 (0.5104) |
| *InLyield* | 0.3540** (0.1346) | 0.3540** (0.1402) | 0.3540** (0.1402) |
| *InFtate* | -0.5375** (0.2098) | -0.5375** (0.2186) | -0.5375** (0.2186) |
| *InLabor* | 0.2671** (0.1142) | 0.2671** (0.1190) | 0.2671** (0.1190) |
| *GDPsq* | -6.27E-12 (2.20 E-11) | -6.27 E-12 (2.30 E-11) | -6.27 E-12 (2.30 E-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 | 0.0025 | 0.0025 |

| | | | |
|---|---|---|---|
| | (0.0063) | (0.0066) | (0.0066) |
| Constant term | 4.4349** | 5.6299*** | 5.6299*** |
| | (1.8696) | (1.8341) | (1.8341) |
| Sample size | 390 | 390 | 390 |
| $R^2$ | 0.6349 | — | 0.9701 |

Note: ①* $\rho < 0.1$; ** $\rho < 0.05$; ** $\rho < 0.01$. ②The value in brackets is the robust standard error of the regression coefficient. ③Both the individual fixed effect and the year fixed effect have been controlled.

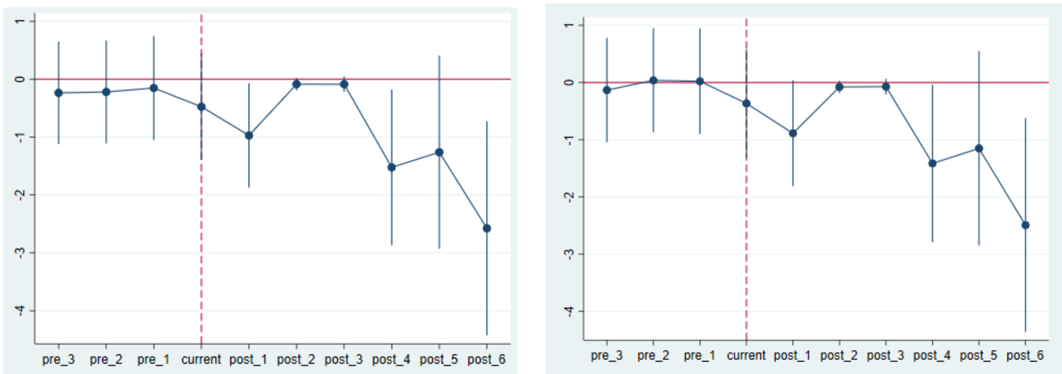
4.2.2. Parallel Trend Test and Dynamic Policy Effect

The validity of DID model estimation depends on the establishment of the parallel trend hypothesis, that is, the temporal change trends of CEALU in the experimental group and the control group are consistent before the time point of policy intervention. Referring to existing studies [89], the following model was built to test the parallel trend hypothesis:

$$InC_{it} = \alpha + \sum_{t=2005}^{2017} \beta_t Hrate_t \times D_t + \delta X_{it} + \mu_i + \gamma_i + \varepsilon_{it} \quad (2)$$

where denotes the dummy variable of year, and the other variables and coefficients are the same as those in Formula (1). The implementation of the high-standard farmland construction policy can significantly reduce CEALU. Then, before the implementation of this policy, the effect coefficient of the interaction term between the proportion of land consolidation area and the dummy variable of year on CEALU should present a steady change trend. After policy implementation, will decline significantly.

On the basis of the coefficient of the interaction term between the proportion of land consolidation area and the dummy variable of year, the coefficient before policy implementation should be subjected to a joint hypothesis test, so that the parallel trend test can be performed. Overall, presented an upward trend before policy implementation, and its confidence interval basically contained 0 (Figure 5). Therefore, before policy implementation, did not show any significant positive correlation across different years, and the parallel trend hypothesis was largely validated




(a) Fixed effect (b) Random effect

**Figure 5.** Parallel trend test of differential model. Note: ① The vertical line passing through the origin is the 95% confidence interval of the corresponding estimated parameter. ② The abscissa axis represents the year of policy implementation. For example, -1 indicates the first year before policy implementation, 1 indicates the first year after policy implementation, and 0 indicates the starting year of policy implementation (i.e., 2011).

Table 7 shows the dynamic effect of the high-standard farmland construction policy on CEALU. The effect coefficient $\beta_t$ before policy implementation was non-significant, suggesting that this policy had no expected effect on the CEALU per unit area. The effect coefficient $\beta_t$ in the first year after policy implementation (i.e., 2012) was significantly negative (-0.9722). The effect coefficient $\beta_t$ 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 trend.

**Table 7.** The estimation of the dynamic impact of HSFC policies on CEALU.

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

Note: ①* $\rho < 0.1$; ** $\rho < 0.05$; ** $\rho < 0.01$. ②Standard error in parentheses; ③Both 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 8, 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 8.** 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) | (2) | (3) | (1) | (2) | (3) |
| | Fixed effect | Random effect | Mixed effect | Fixed effect | Random effect | Mixed effect |

| | | | | | | |
|---|---|---|---|---|---|---|
| $Hrate \times I_t^{post2008}$ | -0.7225<br>(0.5729) | -0.5015<br>(0.5891) | -0.7225<br>(0.6315) | | | |
| $Hrate \times I_t^{post2009}$ | | | | -0.5749<br>(0.4945) | -0.4214<br>(0.5042) | -0.5749<br>(0.5450) |
| Constant term | 3.5272**<br>(1.4690) | 3.9660***<br>(0.8695) | 4.5418***<br>(1.5904) | 3.4980**<br>(1.5129) | 4.0173***<br>(0.8893) | 4.5250***<br>(1.6316) |
| Control variable | Controls | Controls | Controls | Controls | Controls | Controls |
| Sample size | 180 | 180 | 180 | 180 | 180 | 180 |
| $R^2$ | 0.7062 | — | 0.9901 | | | |

*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 9. 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 [90]. The level of agricultural technology and equipment in central China is relatively low, and 7 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 9.** The results of heterogeneity analysis.

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

Note: ①* $\rho < 0.1$; ** $\rho < 0.05$; ** $\rho < 0.01$. ②The numbers in brackets are cluster robust standard errors at the provincial level. ③Province fixed effect and year fixed effect have been controlled, and the estimated results are omitted. ④.The control variables were consistent with those in Table 6, and the estimated results were omitted.

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## 5. Discussion

"Properly achieving the carbon dioxide peak and carbon neutralization" is a key task put forward at the 2020 Central Economic Working Conference. China's long-term pursuit of quantitative growth in agricultural production has consumed a high amount of land, energy, and other resources, causing a series of agricultural environmental problems [91]. As an important part and a basic industry of the national economy, agriculture faces problems such as high total carbon emissions, unbalanced regional development, and wide influence. As such, it needs to be integrated into the construction of the pattern towards carbon dioxide peak and carbon neutralization, so as to improve its ability to cope with climate change and promote the sustainable development of agriculture. High-standard farm construction is an important measure taken by China to improve agricultural production conditions in a planned and organized way. In recent years, the central government has invested nearly 100 billion yuan per year in farmland construction. From 2011 to 2020, the country has built a cumulative total of about 800 million mu of high-standard farmland. By improving infrastructure conditions and the organic matter of farmland and grassland, high-standard farmland can increase the ability of farmland to absorb greenhouse gases and fix carbon dioxide, thereby transforming farmland from carbon source to carbon sink [92]. High-standard farmland construction has a great potential to promote carbon emission reduction in agricultural land use. In this context, in this study the CEALU per unit area of 31 provinces (regions/cities) in China in 2005-2017 was calculated. Moreover, a quantitative analysis was performed using the DID method to identify the "net effect" of the high-standard farmland construction policy on CEALU, and eliminate the confusing effect of unobservable factors that do not change with time. This approach not only improved the accuracy of research conclusions, but also further expanded and extended existing studies.

## 6. Conclusions

By relying on provincial panel data for China for the period 2005-2017 and based on the concept of quasi-natural experiment, the effect of the high-standard basic farmland construction policy on the CEALU per unit area was quantitatively analyzed using a DID model. The findings of this study can be summarized as follows. First, China's CEALU per unit area presented a fluctuating upward trend 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 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 trend. 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%.

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