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Recalculation of Agricultural Carbon Emissions of Chongqing in China under the Background of Rural Revitalization: Characteristic Analysis, Formation Mechanism, and Economic Correlation

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ABSTRACT

Scientific measurement of Agricultural Carbon Emissions (ACE) and its formation mechanism is of great significance for the effective formulation of high-quality agricultural development strategies. Therefore, the objectives were to study the characteristics of ACE, its formation mechanism, and its economic relevance in Chongqing by adopting the IPCC and 1997-2019 data, and with LMDI index and Decoupling index. The empirical analysis shows that the total ACE presents an M-shaped trend of "rising-steady fluctuation-falling". Energy structure, energy intensity, and population size have a negative driving effect on ACE, but economic activity is the main factor. The decoupling elasticity characteristics of ACE and economic growth are mainly weak decoupling and strong decoupling, of which the relationship is significantly coordinate. Therefore, to consolidate and enhance the goal of ACE reduction, it is necessary to strengthen the research and development of agricultural low-carbon production technology and promotion. We will continue to deepen supply-side structural reform in agriculture. We will improve the ecological environment in agriculture and rural areas.

Keywords: ACE formation mechanism, Decoupling index, High-quality development of agriculture.

INTRODUCTION

The global warming effect caused by climate change is becoming more and more serious. Ultimately, it causes negative impacts on production system (Elahi *et al*., 2021a; Elahi *et al*., 2022a; Elahi *et al*., 2022b; Elahi, 2021b). In response to global warming, the CPC Central Committee with President Xi Jinping has made the major strategic decision of "achieving carbon peak by 2030 and carbon neutral by 2060". After the "dual carbon" target was put forward, ACE also cannot be ignored. Agricultural carbon reduction plays an important role in tackling global carbon reduction. International experience shows that agriculture accounts for 25% of all CE caused by human activities. In 2017, China's agriculture accounted for 12.54% of global CE (FAOSTAT, 2019). China's agriculture, which is based on "high carbon", has gradually increased its ACE caused by production activities, accounting for about 17% of the total national CE. Moreover, it is increasing at an average annual rate of 5%. Controlling CE from agriculture and related sectors has become an

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indispensable part of China's plan to implement its emission reduction commitments under the Paris Agreement and specifically implement the "two-carbon" target. The State Council implemented the "Carbon peak 2030 Action Plan" in the agricultural field to promote emission reduction. This is the direction of China's rural revitalization and green development. In 2015, COD emissions from agricultural sources accounted for 48.06% of the total COD emissions in China. Agricultural ammonia nitrogen emissions accounted for 31.58% of the total ammonia nitrogen emissions in China. Non-point source pollution caused by agricultural production has become the main source of environmental pollution. ACE is also the main source of agricultural pollution (Shortall *et al.*, 2013; Vlontzos *et al.*, 2014).

Rural revitalization has brought about earth-shaking changes in China's rural society. Meanwhile, the sharp rise of CE in China's agricultural production and rural life has brought many challenges to the green development of rural areas. This is because there are imperfect ACE accounting and carbon trading mechanisms in rural China, and low efficiency of low-carbon economic development. Especially when many farmers are still living in rural areas of the basic national conditions of the short term. The rapid growth of China's rural society, the improvement of farmers' living standards, and the growing demand for agricultural products, CE has become an important source of rural CE. So, reducing pollution and carbon emission in the agricultural field is a two-sided whole. To peak CE and achieving carbon neutrality in rural areas is an important way to realize rural revitalization. However, the current ACE measurement system in China is not perfect. Many problems such as estimating provincial ACE and analyzing structural characteristics, has strong practical guiding significance.

At present, there are many researches on ACE in academic circles, and many achievements have been made. This can be seen in three ways: Firstly, ACE measurement and research. Study on Estimation and Improvement of ACE in China (Wu *et al*., 2020). Kuang *et al*. (2021) used IPCC CE coefficient method to calculate farmland CE in Guangxi. Tian Chengshi *et al*. (2021) include soil management, rice cultivation, and poultry breeding as carbon sources in China's agricultural carbon emission measurement system. Secondly, how to study the influencing factors of ACE? China's ACE may come from the livestock, rice planting, and agricultural energy sectors (Wen *et al*., 2022). Agricultural production is the main source of ACE (Yang *et al*., 2022). This not only includes agricultural land operation scale (Asif and Almagul, 2022), agricultural chemicals' input intensity (Koondhar *et al*., 2021). And it also includes labor factors (Zhang *et al*., 2019), Technological progress (Zaman *et al*., 2012; Liu *et al*., 2021; Cai *et al*., 2022), Marketing (Dumortier, 2021). In addition, CE reduction policy is also considered to be an essential factor affecting ACE (Wang *et al*., 2020). Thirdly, to study the relationship between ACE and economic growth. There is an inverted "U"-shaped relationship between ACE and agricultural economic growth in China (Li *et al*., 2023). Liu and Xiao (2020) noticed the U-shaped relationship between operating scale and ACE. According to Li and Wang (2023), to examine the inverted "U"-shaped effect of ACE of China and agricultural economic growth of China. However, Tian Yun *et al*. (2021) believe that there is a spatial autocorrelation between industrial agglomeration and agricultural net carbon effect in China, showing a positive "N"-shaped feature.

Totally, the existing literature has achieved fruitful results in theoretical discussion and empirical research. This has important reference value for agricultural carbon reduction strategy. However, there is room for further research on ACE. First, from the research methods calculation, whether this is based on CE from agricultural inputs such as fertilizers, or from rice planting and livestock breeding, it

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is still based on one or three types of carbon sources (Wu *et al*., 2020; Kuang *et al*., 2021; Koondhar *et al*., 2021). There is no consensus in academia. As a result, scholars estimate different results based on experience and other factors. The second is the perspective of research. Scholars explored the evolution of ACE from the national level, the Changjiang River Economic Belt or the western region. There are relatively few provincial-level regions involved, especially in western China. At the same time, few studies on ACE reduction under the background of rural revitalization. The third is the perspective of content. Many scholars mainly analyze this from one dimension or two aspects, such as timing dimension, driving factor and decoupling state. This paper rarely discusses the characteristics of ACE from three dimensions. Therefore, the systematics of the research and the prospective of the countermeasures need to be further expanded. To sum up, this paper attempts to construct a framework diagram about the impact of ACE to the high-quality development of agriculture. The contribution of this paper is that ACE in Chongqing, China are mainly studied. Based on the re-calculation of Chongqing's ACE, the correlation between Chongqing's agricultural economic growth and ACE was deeply and systematically discussed. The internal effect mechanism between ACE and economic growth was revealed. The reference was provided for the policy making of agricultural emission reduction in Chongqing. Objective of this paper is to provide reference for promoting high-quality agricultural development in the process of ecological protection and industrial revitalization in the Changjiang River Economic Belt. The results could provide reference for ACE research in similar areas. See Figure 1 for details.

Chongqing, which is a municipality in the west of China, integrates "big city, big countryside, big mountain area and big reservoir area". As an important ecological barrier of the Changjiang River, Chongqing should achieve carbon peak and carbon neutralization. It is not only a major measure to promote green and sustainable development but also a major task to play an exemplary role

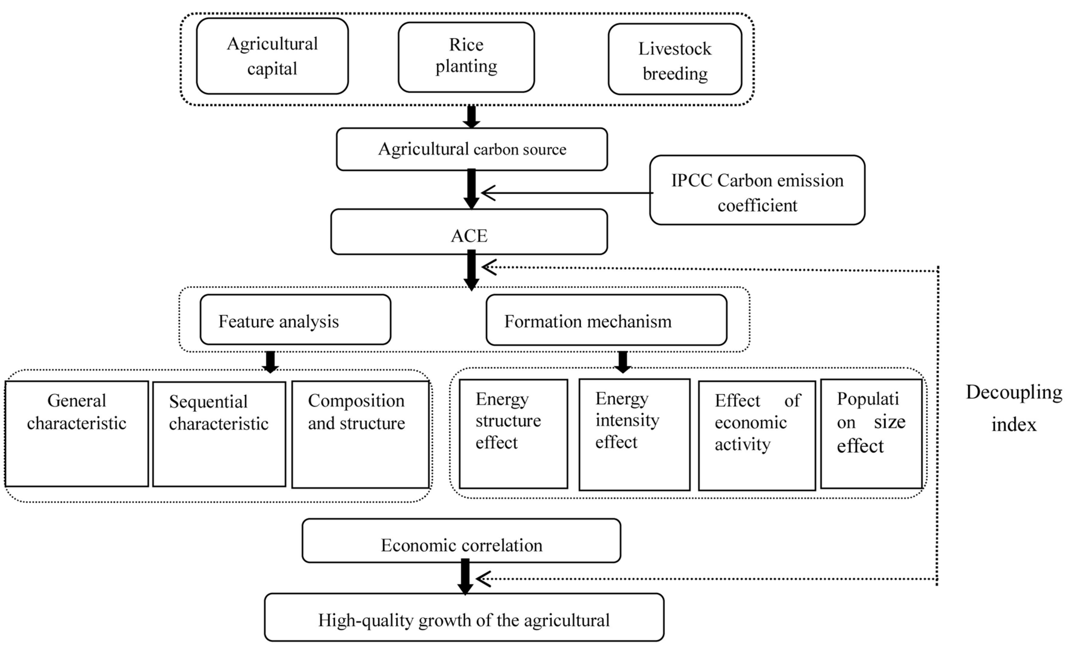

Figure 1. Temporal characteristics and economic correlation of ACE.

in promoting the green development of the Changjiang River Economic Belt. In view of this, based on the agricultural carbon source perspective. In this paper, the IPCC CE coefficient method was used to re-estimate ACE of Chongqing in China from 1997 to 2019.

This paper focuses on three issues: (i) The IPCC CE coefficient method was used to investigate the overall situation, temporal characteristics, and composition structure of ACE in Chongqing, (ii) The LMDI decomposition method was used to explore the driving factors of ACE in Chongqing, and (iii) The decoupling elasticity index model was used to analyze the relationship between ACE and economic growth in Chongqing.

MATERIALS AND METHODS

Estimation of ACE

ACE refers to the greenhouse gas emission directly or indirectly generated by the input of materials in agricultural production, rice cultivation, livestock and poultry manure, and intestinal fermentation. This paper is based on the perspective of agricultural carbon sources, and the relevant research results of Li and Zhao (2013), Tian *et al*. (2020), Hwa *et al*. (2021), Liu *et al*. (2022) and Wen *et al*. (2022) to estimate ACE from three aspects of the two major agriculture and livestock production. The first is the direct or indirect carbon emission caused by the input of agricultural production materials (chemical fertilizer, etc.). Secondly, how much is the emission of methane (CH_4) during the growing season of rice. The third is methane emission from livestock (pigs, poultry, etc.) mainly due to intestinal fermentation and methane (CH_4) emission from manure management (Mc Carl and Schneider, 2000). There are three main methods to measure ACE: IPCC carbon emission coefficient method, material balance algorithm and actual measurement method. Among them, the material balance algorithm mainly aims at the calculation of CE generated by petroleum and other fossil fuel consumption. The CE coefficient method is mainly used for ACE. Therefore, this paper uses IPCC CE coefficient method to estimate ACE and estimates the total consumption of various agricultural carbon sources by multiplying their respective CE coefficients, which are shown in Table 1. Accordingly, the ACE calculation formula are as follows:

$$C_1 = \sum C_{1i} = \sum E_{1i} \times F_{1j} \quad (1)$$

$$C_2 = \sum C_{2i} = \sum E_{2i} \times F_{2j} \quad (2)$$

$$C_3 = \sum C_{3i} = \sum E_{3i} \times F_{3j} \quad (3)$$

In Equations (1), (2), and (3), C_{1i}, C_{2i}, and C_{3i} represent the total CE from agricultural inputs, rice cultivation, and livestock breeding, respectively. C_{1i}, C_2i and C_{3i} represent the ACE caused by various carbon sources, respectively. E_{1i}, E_{2i} and E_{3i} represent the specific quantities consumed by various carbon sources. F_{1i}, F_{2i}, and F_{3i} represent the CE coefficient corresponding to various carbon sources.

Carbon Emission Factor Decomposition Model -- LMDI Decomposition Method

LMDI (Logarithmic Mean Division Index) and SDA (structure) decomposition are two methods used in the study of CE factor decomposition. This is based on the Kaya identity proposed by Yoichi (Kaya, 1990). LMDI decomposition method can not only effectively solve the problem of decomposition without residual error. Moreover, the target variable can be decomposed into the product of many factors convenient for calculation and analysis. Therefore, it is widely used by scientists.

In summary, LMDI was used to discuss the importance of various influencing factors in the process of ACE change in Chongqing. Based on the research of Liu Yaqing and Gao Yao (2022), Kaya identity and preliminary research of Yeying (2015), the

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Table 1. Estimated coefficients of ACE.[a]

Carbon source type	Carbon source factor	Expression	Carbon emission coefficient	Reference source
Agricultural capital investment	Fertilizer (C_1)	$E_1 \times F_1$	0.90 kg kg^{-1}	IPCC
	Pesticide (C_2)	$E_2 \times F_2$	4.93 kg kg^{-1}	IPCC
	Mulching films (C_3)	$E_3 \times F_3$	5.18 kg kg^{-1}	IPCC
	Irrigation (C_4)	$E_4 \times F_4$	266.48 kg hm^{-2}	IPCC
	Ploughing (C_5)	$E_5 \times F_5$	312.60 kg hm^{-2}	IPCC
	Use of agricultural machinery (C_6)	$(A_m \times B)+(W_m \times C)$	Am is the total sown area of crops, Wm represents the total power of agricultural machinery; B, C the coefficients are respectively 16.47 kg hm^{-2} and 0.18 kg kw^{-1}	Min *et al*.
Rice planting	Rice (C_7)	$E_7 \times F_7$	6.83 g m^{-2}	Tian *et al*.
Livestock and poultry breeding	Pig (C_8)	$E_8 \times F_8$	34.1 kg/head. years	Hong.
	Poultry (C_9)	$E_9 \times F_9$	0.14 kg/only. years	Tian *et al*.

[a] Note: The carbon source factors of livestock and poultry production in Chongqing mainly come from pigs and poultry, and they are calculated according to the data of market output. See Min Jisheng *et al*. (2012) for the specific calculation method. Greenhouse gases caused by methane (CH_4) were converted to 6.8182 tC.

driving factors of ACE mainly include energy consumption intensity, agricultural industrial structure, agricultural economic activities and agricultural employees. The formula is stated as follows:

$$C = EI \times CI \times SI \times AL \tag{4}$$

Where,

$$EI = \frac{C}{PGDP}, \quad CI = \frac{PGDP}{AGDP}, \quad SI = \frac{AGDP}{AL},$$

In Equation (4), C= Total ACE, PGDP= The total output value of farming and animal husbandry, AGDP= The total value of agricultural output; EI= Energy Intensity factor, represents the impact of energy consumption intensity change on CE; CI= Energy structure factor, indicating the impact of agricultural industrial structure change on CE; SI= Economic activity factor, which represents the impact of agricultural production activities on CE; AL= Population size factor, which represents the impact of the number of agricultural employees on CE.

According to the LMDI decomposition method, let us suppose the CE in the base period is T^0, and the CE in the t period is T^t. We use the addition decomposition of the LMDI, and decompose the decomposition expression of each effect in agricultural carbon emission. A brief account is as follows:

$$\begin{cases} \Delta EI = \sum \dfrac{C^t - C^0}{LnC_t - LnC_0} Ln \dfrac{EI^t}{EI^0}; \\ \Delta CI = \sum \dfrac{C^t - C^0}{LnC_t - LnC_0} Ln \dfrac{CI^t}{CI^0} \end{cases}$$

$$\Delta SI = \sum \frac{C^t - C^0}{LnC_t - LnC_0} Ln \frac{SI^t}{SI^0};$$

$$\Delta AL = \sum \frac{C^t - C^0}{LnC_t - LnC_0} Ln \frac{AL^t}{AL^0}$$

The total effect:

$$\Delta C_{total} = C^t - C^0 = \Delta EI + \Delta CI + \Delta SI + \Delta AI \tag{6}$$

In Equations (5) and (6) above, ΔEI, ΔC, ΔSI, and ΔAL they represent Energy Intensity effect, energy structure effect,

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economic activity effect and population size effect, respectively.

Carbon Emission Decoupling Model -- Decoupling Elasticity Index Model

The CE factor decomposition model is only used to discuss the contribution of each carbon source factor of ACE. However, it can not effectively measure the decoupling state between agricultural economic growth, ACE, and the actual effect of energy conservation. To study the correlation between ACE and agricultural economic growth, a decoupling index is constructed based on proposed by Tapio in 1970 (Tapio, 2005). [See article available literature 22]. Decoupling model is built on the basis of OECD model, adopts the concept of "elasticity" to dynamically reflect the decoupling relationship between economic and energy variables, and optimizes the defects of decoupling index (Tapio, 2005). If CE grows at a negative rate or slower than economic growth, it is considered decoupling. It can reflect the development state between them effectively and intuitively, and overcome the deficiency of OCED decoupling index method in the selection of base period. Its formula is as follows:

$$e = \frac{\Delta C}{C} / \frac{\Delta GDP}{GDP} \tag{7}$$

In the Equation (7), *e* represents the elasticity coefficient of agricultural gross product to ACE, which is used to measure the utilization efficiency of CE in various industries, C represents the total amount of ACE in the current period, △C represents the increment of ACE, and GDP is the Gross Agricultural Product. △GDP refers to the increment of agricultural production.

Data Sources and Description

The data comes from public data, such as Chongqing Statistical Yearbook (1998-2020). The input of agricultural inputs such as chemical fertilizer and the planting area of rice are calculated by the actual data of the year. The irrigation data is replaced by the effective irrigated area of the year. The tillage data is represented by the sown area of crops. The number of pigs and poultry is calculated according to the year-end market data of livestock and poultry in each year.

Table 2. Types and definitions of Decoupling Index.

Decoupling state	e	△GDP/GDP	△C/C	Paraphrase
Strong decoupling	e< 0	> 0	< 0	At best, the economy grows and CE fall
Weak decoupling	e≦ 0< 0.8	> 0	> 0	Energy efficiency is improving and the economy is growing faster than CE
Expansion connection	0.8≦ e≦ 1.2	> 0	> 0	Economic growth is less than or equal to the increase in CE
Expansion negative decoupling	e> 1.2	>0	>0	Economic growth is slower than the increase in CE
Strong negative decoupling	e< 0	< 0	> 0	At worst, CE rise and economies decline
Weak negative decoupling	0e< 0.8	< 0	< 0	Energy efficiency is falling and economies are shrinking faster than CE
Recession conjunct	0.8≦ e≦ 1.2	< 0	< 0	The rate of economic decline is greater than or equal to the decline in CE
Recession unhook	e>1.2	< 0	< 0	The economy is declining faster than CE are falling

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The growth cycle of pigs and poultry is adjusted according to 200 and 55 days, respectively. The output values of planting, animal husbandry and total value of agricultural output are taken based on 1997, and Comparable price of GDP will be selected to eliminate the interference of price factors.

RESULTS AND DISCUSSION

Analysis of ACE Characteristics

Based on Chongqing Statistical Yearbook (1998-2020). Using Equations (1), (2), and (3), this paper estimated the ACE in Chongqing from 1997 to 2019. See Figure 2.

Overall Characteristics of ACE

The results showed that the total ACE in Chongqing increased from 356.09×10^4 t in 1997 to 358.43×10^4 t in 2019, a total increase of 2.34×10^4 t. From the perspective of industry, CE from agricultural inputs increased from 101.32×10^4 t in 1997 to 136.25×10^4 t in 2019, a total increase of 34.93×10^4 t, and its proportion in total ACE also increased from 28.45% to 38.01%.CE from rice cultivation decreased from 37.16×10^4t in 1997 to 30.51×10^4 t in 2019, a total reduction of 6.65×10^4 t. CE from livestock and poultry farming decreased from 217.61×10^4 t in 1997 to 191.67×10^4 t in 2019, a total reduction of 25.94×10^4 t. In 2019, agricultural inputs, rice cultivation and livestock and poultry production accounted for 38.01, 8.51 and 53.48% of the total ACE, respectively.

Analysis of Temporal Characteristics of ACE

As can be seen in Figure 2, the total ACE since the direct administration of Chongqing has shown an "M" shaped trend of "rising-steady fluctuation-declining". ACE in Hubei Province showed an "inverted U-shaped" feature. Due to the different regional development strategies and production conditions, the turning point of ACE in Chongqing appeared at different times and showed an irregular "inverted U-shaped" feature overall. Accordingly, ACE can be divided into three stages: One is in a period of rapid rise (1997-2005). The figure increased from 356.09×10^4 t in 1997 to 409.60×10^4 t in 2005, an increase of 53.51×10^4 t. ACE shows a rapid growth trend. On the one hand, livestock and poultry breeding scale gradually expanded, coupled with the poor management of manure in rural areas and other reasons, directly led to the increase of ACE. On the

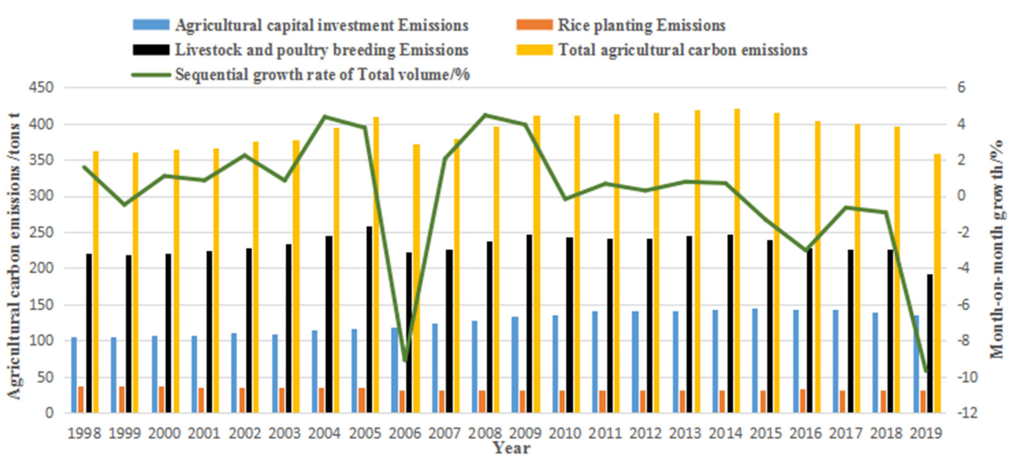

Figure 2. ACE in Chongqing from 1997 to 2019 (Units: 10^4 t).

other hand, in 2004, the central government issued a series of policies to benefit farmers. By adjusting the industrial structure and increasing farmers' employment, farmers' enthusiasm was greatly aroused and agricultural inputs increased, which indirectly caused the increase of ACE. Second, it is in a period of stable fluctuation (2006-2015). It increased from 372.29×10^4 to 415.96×10^4 t, with an annual increase of 10.79×10^4 t. The decrease and relatively low fluctuation trend from 2005 is due to the fact that Chongqing actively responds to the national response to climate change and proposes the target of "reducing carbon emission intensity by 40% (compared with 2005) by 2020". And actively adopted measures such as Interim Measures of Chongqing Municipality on the Management of CE Right Trading [(2014) No.17] related to energy saving and control of greenhouse gas emissions. At the same time, after 2007, China's overall animal husbandry industry has been established and intensive feeding technology has been promoted, resulting in a relatively stable decline in CE caused by intestinal fermentation and manure management. Third, it is on a downward trend (2016-2019). It decreased from 403.34×10^4 to 358.43×10^4 t, with an annual decrease of 3.48 percentage points. This is mainly because the number of pigs and poultry in Chongqing decreased from 17.6774 million and 24.9281 million, respectively, in 2016 to 14.8042 million and 22.4152 million, respectively, in 2019. This directly reduces methane emissions from intestinal fermentation in livestock and poultry production and from manure management.

3) Composition Structure Analysis of ACE

From Figure 2, livestock and poultry farming accounted for the largest proportion of the three carbon sources in 2019, reaching 53.48%. Agricultural inputs followed, reaching 38.01%. Rice cultivation accounts for only 8.5%. Therefore, ACE mainly come from livestock and poultry breeding and agricultural inputs. First, Livestock and poultry farming are the main carbon sources of ACE, accounting for 53.48% of the total. Therefore, it is urgent to strengthen environmental governance in livestock and poultry farming, reduce CE and improve the ecological environment. Secondly, the carbon emission caused by agricultural inputs accounts for 38.01% of the total ACE in Chongqing, which still shows a slow rising trend. In other words, it increased from 101.32×10^4 in 1997 to 136.25×10^4 t in 2019, a total increase of 34.93×10^4 t, the annual growth rate was 1.04 percentage points. The input of chemical fertilizer caused 59.87% of ACE in Chongqing. The ACE caused by agricultural film production, agricultural irrigation, and pesticides accounted for 16.20, 13.65 and 5.97% of the total, respectively. In terms of fertilizer application, the intensity of fertilizer application increased from 173.07 kg hm^{-2} in 1997 to 243.89 kg hm^{-2} in 2019, which is now far beyond the internationally recognized safety valve limit of 225.00 kg/hm^2 for fertilizer application. The reason for this is that, although Chongqing Municipal Government has introduced relevant emission reduction measures, the contradiction between more people and less land is relatively prominent. Under the dual pressure of survival and development, the pattern of "three highs" in agriculture has been formed, which leads to the annual growth trend of chemical fertilizer use and the increase of ACE. Zhou *et al*. (2014) found that although the cultivated land area in Chongqing showed an annually decreasing trend, the effective irrigated area of farmland increased annually, leading to a slow rise in CE caused by agricultural irrigation. Third, rice cultivation is one of the carbon sources that can not be ignored. Since the direct administration of Chongqing, the carbon emission caused directly or indirectly by rice production fluctuates steadily between 10.4% and 7.6% of the total ACE. In 2019, CE from rice cultivation in Chongqing accounted for 8.5 percent of the total. Therefore, to achieve national carbon dioxide emissions to peak by 2030, Chongqing, as a local government,

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needs to optimize agricultural industrial structure and apply new agricultural technologies to comprehensively improve agricultural mechanization and intelligentize.

Analysis on the Formation Mechanism of ACE

In order to explore the formation mechanism of agricultural carbon source consumption, according to the LMDI model, this paper uses Equations (4), (5), and (6) for calculation. The decomposition results of drivers of ACE in Chongqing from 1997 to 2019 were calculated. The results are shown in Figure 3.

From Figure 3, in general, since the direct administration of Chongqing, agricultural energy structure, energy intensity and population size effect have all promoted ACE reduction to varying degrees. Compared with the period before direct administration, the three effects reduced CE by 973.94×10^4 t in total during the 23 years from 1997 to 2019.Since the direct administration of Chongqing municipality, the restraining effects of ACE are Energy intensity effect> Population size effect> Energy structure effect. During the 14th Five-Year Plan period, Chongqing Municipal Party Committee and municipal government continued to consolidate and enhance the effect of ACE reduction. We should promote the scale, park and standardization of agricultural production in an orderly and reasonable manner. We will strengthen agricultural science and technology and equipment support. We will further optimize the agricultural industrial structure, orderly guide the transfer of agricultural labor force to non-agricultural sector, and will promote carbon reduction in agriculture and promote high-quality development of agriculture.

Mechanism Analysis of Energy Structure Effect on ACE

The energy structure effect of Chongqing has achieved 19.05×10^4 t carbon emission reduction since its direct administration. Its contribution to agricultural carbon reduction ratio is 131%. Its contribution ratio to ACE reduction is 131%, and the annual carbon emission reduction is 0.83×10^4 t. This shows that agricultural industrial structure negatively drives ACE, but the reduction effect is relatively small. From the energy structure effect of interannual CE, the annual change is not large, nor is the increase or decrease in CE. Furthermore, it shows that

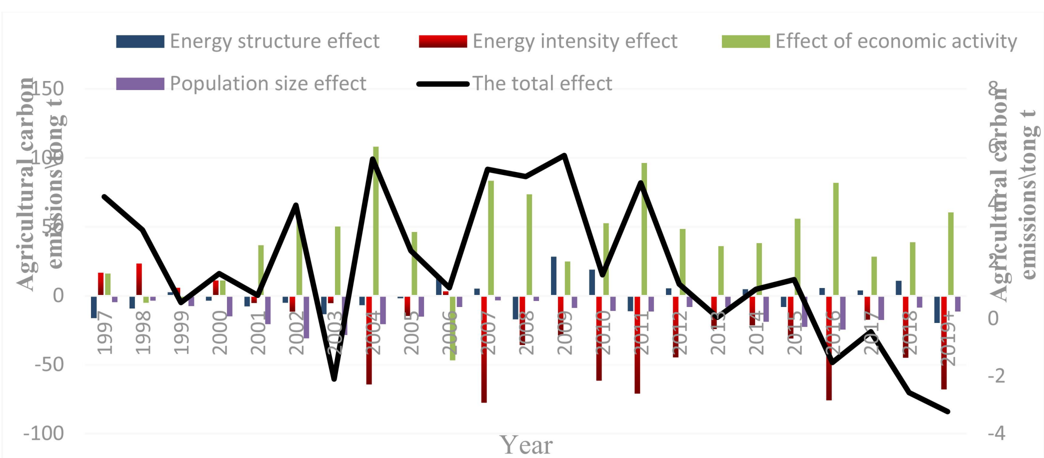

Figure 3. Decomposition results of ACE in Chongqing from 1997 to 2019 (Units: 10^4 t).

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Chongqing agricultural industrial structure is relatively stable. Because of the unique location, environment, and special market conditions, the agricultural industrial structure of Chongqing needs to be determined by agricultural production conditions. The "two groups" area in Chongqing is mainly based on planting and animal husbandry. It is relatively difficult to adjust agricultural industrial structure on a large scale. Accordingly, the adjustment of Chongqing agricultural industrial structure is given priority with local area fine-tuning. Therefore, the effect of energy structure on inhibiting ACE is weak.

Mechanism Analysis of Energy Intensity Effect on ACE

The energy intensity effect of Chongqing has achieved 643.10×10^4 t carbon emission reduction since its direct administration. Its contribution ratio to ACE reduction is 4432.12%. The annual carbon emission reduction reached 27.96×10^4 t. Assuming other factors remain unchanged, this shows that the improvement of agricultural production efficiency has a positive contribution to ACE reduction in Chongqing. Therefore, energy intensity effect significantly suppressed ACE

Mechanism Analysis of Economic Activities Effect on ACE

Since the direct administration of Chongqing, the significant enhancement of economic activity effect caused the ACE increment of 988.45×10^4 t. This shows that the rapid growth of agricultural economy will lead to an annual increase of 42.98×10^4 t of ACE in Chongqing. In 2020, the percapita disposable income of rural residents in Chongqing was 16,361 Yuan (1USD=6.5786CNY), lower than the national average of 770 Yuan (1USD=6.5786CNY) in the same period. In 2020, the benefit of agriculture in Chongqing reached 180.333 billion Yuan, accounting for 7.2% of the city's GDP. Therefore, the emission reduction model of abandoning agricultural economic activities to reduce ACE will not be implemented

Mechanism Analysis of Population Size Effect on ACE

The population size effect of Chongqing achieved 311.79×10^4 t CE reduction since its direct administration. The annual CE reduction is 13.56×10^4 t. Therefore,population size affect negatively derivedACE. This shows that the change of agricultural labor force size has made an important positive contribution to CE reduction since Chongqing Municipality of China. This is related to the continuous deepening of agricultural supply-side structural reform in Chongqing in recent years. We will build agricultural modernization demonstration areas to improve the quality of farmers. We will carry out projects to improve the quality of agricultural products, and promote the development of standard gardens for vegetables and tea, and standardized demonstration farms for livestock and poultry. It enhanced the quality consciousness of agricultural products and reduced the input of agricultural means of production. We will strengthen the promotion of agricultural science and technology extension services in order to promote agricultural carbon reduction.

Correlation Analysis between ACE and Economy

From Equation (7), the decoupling elasticity index between ACE and agricultural economic growth in Chongqing is calculated from 1997 to 2019. As can be seen from Table 3, the decoupling between ACE and agricultural economic growth in Chongqing has been mainly weak or strong, accounting for 78.26% of the total number

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of years. In general, the decoupling state is gradually improving. In most years, the growth rate of agricultural economy in Chongqing is significantly faster than the increase of ACE, and the coordination between the two is significant, which is in line with the ideal decoupling state. Accordingly, we divide it into three stages for analysis, as follows:

The first stage was from 1997 to 2000: ACE Increased while agricultural economic growth showed a downward trend.

It could be seen that decoupling state was characterized by strong negative decoupling, which was the least ideal state. On the one hand, under the premise of limited cultivated land resources in Chongqing (accounting for less than 30%), the majority of farmers tended to increase agricultural inputs such as fertilizer and agricultural film in order to improve output (Koondhar *et al*., 2021), thus increased ACE. On the other hand, the problem of "agriculture, rural areas, and farmers" are relatively prominent, and farmers have a heavy burden. As a result, the majority of farmers often choose to leave rural areas and turn to urban non-agricultural jobs due to livelihood, which leads to the relative reduction of rural agricultural production activities (Qing *et al*., 2023).

The second stage was from 2001 to 2014: The growth rate of agricultural economy

Table 3. Decoupling index and status of the relationship between ACE and agricultural economic growth in Chongqing from 1997 to 2019.[a]

Year	$\frac{\Delta C}{C}$	$\frac{\Delta GDP}{GDP}$	***e***	Characteristic	Year	$\frac{\Delta C}{C}$	$\frac{\Delta GDP}{GDP}$	***e***	Characteristic
1997	0.034	-0.013	-2.620	Strong negative decoupling	2009	0.038	0.104	0.364	Weak decoupling
1998	0.015	-0.051	-0.305	Strong negative decoupling	2010	-0.002	0.137	-0.014	Strong decoupling
1999	-0.005	-0.021	0.234	Weak negative decoupling	2011	0.007	0.163	0.040	Weak decoupling
2000	0.011	-0.020	-0.539	Strong negative decoupling	2012	0.003	0.105	0.027	Weak decoupling
2001	0.008	0.023	0.374	Weak decoupling	2013	0.008	0.063	0.120	Weak decoupling
2002	0.022	0.052	0.421	Weak decoupling	2014	0.007	0.056	0.121	Weak decoupling
2003	0.008	0.022	0.374	Weak decoupling	2015	-0.014	0.059	-0.230	Strong decoupling
2004	0.042	0.189	0.221	Weak decoupling	2016	-0.031	0.143	-0.219	Strong decoupling
2005	0.036	0.071	0.513	Weak decoupling	2017	-0.007	0.036	-0.186	Strong decoupling
2006	-0.100	-0.109	0.917	Recession connection	2018	-0.009	0.098	-0.096	Strong decoupling
2007	0.020	0.203	0.099	Weak decoupling	2019	-0.107	0.075	-1.432	Strong decoupling
2008	0.043	0.127	0.336	Weak decoupling					

[a] Note: Use Equation (7) to calculate the whole, GDP is agricultural GDP, and △GDP is the increment of agricultural GDP.

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was faster than the increase of ACE.

It could be seen that the decoupling state is mainly characterized by weak decoupling, indicating that the agricultural development mode of Chongqing has gradually changed from the traditional development mode of relying on fertilizer to the modern agricultural development mode. Chongqing has gradually stepped out of the inner development dilemma of "two high and one low" (high input, high pollution, low output) in agricultural production. This had played a positive role in ACE reduction to some extent, and the conflict between economic growth and environmental protection had gradually eased (Yang *et al*., 2022).

The third stage is from 2015 to 2019: The growth rate of agricultural economy was much faster than that of ACE.

It could be seen that all the decoupling states in this stage are characterized by strong decoupling, which was in line with the ideal decoupling state. It had shown that Chongqing achieved remarkable results in accelerating the pace of agricultural mechanization and strengthening the support of agricultural science and technology during the 13th Five-Year Plan period. The quality and efficiency of agricultural economic growth had been significantly improved. However, we should not ignore that the risk of a rebound in ACE still exists. We will continue to optimize the agricultural industrial structure and vigorously promote the scale and intensification of livestock.

CONCLUSIONS

By adopting the IPCC and 1997-2019 data, and with LMDI index and Decoupling index, this research studies the characteristics of ACE, its formation mechanism, and its economic relevance in Chongqing. The empirical analysis shows that the total ACE presents an M-shaped trend of "rising-steady and fluctuation-falling". Energy structure, energy intensity and population size effect had a negative driving effect on ACE, but economic activity was the main factor leading to the increase of ACE. The decoupling elasticity characteristics of ACE and economic growth are mainly weak decoupling and strong decoupling. Let's look at it in detail: Among the three agricultural carbon sources in Chongqing, livestock and poultry production accounted for the largest proportion of CE, accounting for 53.48%. Agricultural inputs and rice planting accounted for 38.01 and 8.50% of ACE, respectively. The input of chemical fertilizer caused 59.87% of ACE. This indicates that it is necessary to strengthen the environmental control of livestock and poultry breeding, and chemical fertilizer application and the agricultural industrial structure needs to be optimized. These three driving factors reduced CE by 973.94×10^4 t. However, agricultural economic activities will still be the leading driving factors that increase ACE, which generated 988.45×10^4 t carbon increment. In contrast, both the energy intensity effect and the energy structure effect are the primary reasons for reductions in ACE（Sun *et al*., 2022). In most years, agricultural economic growth rate was obviously faster than the increase of ACE, and the coordination between the two is significant, in line with the ideal decoupling state. However, we should not overlook to continue to consolidate and promote the low-carbon development of agriculture, since the risk of ACE increase and rebound still exist.

However, this study also has certain limitations: (i) This paper mainly focuses on the re-calculation of ACE in Chongqing, China, and lacks comparative analysis with different provinces (cities) and (ii) This paper does not study how to balance the relationship between agricultural economic development and ACE reduction in Chongqing. Future research directions are as follows:

(i) Taking western China as an example, this paper analyzes the temporal and spatial characteristics, formation mechanism, and correlation between ACE and economy, and strengthens the temporal and spatial analysis among different regions.

(ii) Accelerate the construction of agricultural power, in-depth discussion on how to balance the relationship between agricultural economic development and ACE reduction, and put forward effective policy suggestions to promote the high quality development of agriculture.

(iii) In-depth discussion on encouraging farmers to make positive contributions to agricultural emission reduction.

Outlook

Strengthening Research and Development of Agricultural Low-Carbon Production Technologies

The government should increase investment in relevant research funds, encourage and strengthen joint research with universities, research institutes and agriculture-related enterprises. We will work to tackle key problems in agricultural science and technology and transformation of scientific research achievements. Research and development and promotion of mountain agricultural machinery, reducing agricultural irrigation causes agricultural carbon emissions.

2. Continue to Eepen Supply-Side Structural Reform in Agriculture

We will vigorously develop efficient agriculture with mountainous features, focus on ecological animal husbandry, and deepen structural adjustment of the agricultural industry. We will build green industrial clusters regional characteristic grain and oil products citrus and lemons, mustard, ecological animal husbandry, ecological fisheries, traditional Chinese medicine, featured fruits, and economic forests. Intensification and standardization of livestock and poultry farming should be promoted in a reasonable and orderly manner, and environmental governance of livestock and poultry farming should be strengthened to reduce CE.

3. Strengthen Agricultural and Rural Ecological Environment Governance Firstly, the efficiency of fertilizer should be enhanced further. We should reduce fertilizer input, integrate and promote compost use. We should also support facilities and equipment to promote the quality and efficiency of fruits, vegetables and tea, and the resource recycling as well. Secondly, we should further enhance the utilization of livestock and poultry waste resources. Government could purchase services and technology subsidies to implement the responsibility of local governments for managing the utilization of livestock and poultry manure, and the primary responsibility of livestock farmers. Encourage farmers and new agricultural operators to actively use organic fertilizer. We will promote the formation of a mechanism for sustainable utilization of livestock and poultry waste. Thirdly, continue to improve the rural living environment. We should encourage the reduction of agricultural inputs, fertilizers and pesticides, and turn waste from livestock and poultry into resources. We will focus on strengthening the treatment of rural garbage, domestic sewage, toilet waste, and accelerate the building of beautiful and ecological homes that are livable.

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REFERENCES

1. Asif, R. and Almagul, T. 2022. Dynamic Impacts of Economic Growth, Energy Use, Urbanization, Agricultural Productivity, and Forested Area on CE: New Insights from Kazakhstan. *World Dev. Sustain.,* **1:**100019.

2. Cai, A., Zheng, S., Cai, L., Yang, H. and Comite, U. 2022. How Does Green Technology Innovation Affect CE? A Spatial Econometric Analysis of China's Provincial Panel Data. *Front. Environ. Sci.,* **9:** 813811.
3. Chengshi, T. and Chen Y., 2021. Estimation of Agricultural Carbon Emissions and Evaluation of Low Carbon Level in China: Based on Derived Index and Topsis Method. *J. Natural Res.*, **36(2)**, 16. (In Chinese).
4. Chongqing Bureau of Statistics. 2021. Chongqing Statistical Yearbook. 2021. China Statistics Press, 241-251. (in Chinese).
5. Dumortier, J. and Elobeid, A. 2021. Effects of a Carbon Tax in the United States on Agricultural Markets and CE from Land-Use Change. *Land Use Policy,* **29(2):** 99-122.
6. Elahi, E., Khalid, Z. and Yan, J. 2022a. Estimating Smart Energy Inputs Packages Using Hybrid Optimisation Technique to Mitigate Environmental Emissions of Commercial Fish Farms. *Appl. Energy,* **326:**119602.
7. Elahi, E., Khalid, Z., Tauni, M. Z., Zhang, H. and Xing, L. 2021a. Extreme Weather Events Risk to Crop-Production and the Adaptation of Innovative Management Strategies to Mitigate the Risk: A Retrospective Survey of Rural Punjab, Pakistan. *Technovation,* **4:** 102255.
8. Elahi, E., Khalid, Z. and Zhang, Z. 2022b. Understanding Farmers'Intention and Willingness to Install Renewable Energy Technology: A Solution to Reduce the Environmental Emissions of Agriculture. *Appl. Energy,* **309:** 118459.
9. Elahi, Z. 2021b. Understanding Cognitive and Socio-Psychological Factors Determining Farmers' Intentions to Use Improved Grassland: Implications of Land Use Policy for Sustainable Pasture Production. *Land Use Policy,* **102(1):** 1-12.
10. Food and Fao, A. O. U. N., 2015. Food and Agriculture Organization of the United Nations.FAOSTAT[EB/OL].http://www.fao.org/faostat/zh/data/GT,2019-11-23.
11. Kaya, Y., 1990. Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios IPCC Energy and Industry Subgroup, Response Strategies Working Group.
12. Wu, H., Sipilainen, T., He, Y., Huang, H., Luo, L., Chen, W. and Meng, Y. 2021. Performance of Cropland Low-Carbon Use in China: Measurement, Spatiotemporal Characteristics, and Driving Factors. *Sci. Total Environ.,* **800:** 1-15.
13. Koondhar, M. A., Udemba, E. N., Cheng, Y., Khan, Z. A., Koondhar, M. A., Batool, M. and Kong R. 2021. Asymmetric Causality among Carbon Emission from Agriculture, Energy Consumption, Fertilizer, and Cereal Food Production- A Nonlinear Analysis for Pakistan. *Sustain. Energy Technol. Assess.,* **45:** 101099.
14. Kuang A. P. and Hu, C. 2021. Temporal and Spatial Characteristics and Economic Correlation of Agricultural Carbon Emissions in Guangxi: Based on Input Perspective. *Res. Develop. Market.*, **6**:663-669. (In Chinese).
15. Li, J., Gao, M., Luo, E., Wang, J. and Zhang, X. 2023. Does Rural Energy Poverty Alleviation Really Reduce ACE? The Case of China. *Energy Econ.,* 119.
16. Li, S. and Wang, Z. 2023. Time, Spatial and Component Characteristics of Agricultural Carbon Emissions of China. *Agriculture*, **13(1):** 1-16.
17. Li, P., and Zhao, J. 2013. An Empirical Study on China's Regional CE of Agriculture. *International Journal of Asian Business and Information Management* (IJABIM), **4**:67-77.
18. Liu, Y. and Gao, Y. 2022. Measurement and Impactor Analysis of Agricultural Carbon Emission Performance in Changjiang Economic Corridor. *Alex. Eng. J.,* **61(1):** 873-881.
19. Liu, D., Zhu, X. and Wang, Y. 2021a. China's Agricultural Green Total Factor Productivity Based on Carbon Emission: An Analysis of Evolution Trend and Influencing Factors. *J. Clean. Prod.,* **278:** 123692.
20. Liu, Y., Ying, O. and Cai, H. 2021b. Evaluation of China's Agricultural Green TFP and Its Spatiotemporal Evolution Characteristics. J. Quant. Tech. Econ., **38(5):** 39-56. (in Chinese).
21. McCarl, B. A. and Schneider, U. A. U. S. 2000. Agriculture's Role in a Greenhouse Gas Emission Mitigation World: An Economic Perspective. *Rev. Agric. Econ.,* **22(1):** 134-159.

[DOI: 10.22034/JAST.26.3.537]

22. Liu, Q. and Xiao, H. F. 2020. "What Is the Logic of the Scale of Farmland Management Affecting ACE?—The Mediating Role of Factor Input and the Regulating Role of Cultural Quality". *Rur. Econ.,* **5:** 10-17.
23. Yun, Q., Bingjia, Z. and Chuanhao, W. 2023. The Coupling and Coordination of ACE Efficiency and Economic Growth in the Yellow River Basin, China. *Sustainability,* **15(2):**971-971.
24. Shortall, O. K. and Barnes, A. P. 2013. Greenhouse Gas Emissions and the Technical Efficiency of Dairy Farmers. *Ecol. Indic.,* **29(7):** 478-488.
25. Sun, D., Cai, S., Yuan, X., Zhao, C., Gu, J., Chen, Z. and Sun, H. 2022. Decomposition and Decoupling Analysis of CE from Agricultural Economic Growth in China's Yangtze River Economic Belt. *Environ. Geochem. Health,* **44(9):** 2987-3006.
26. Tapio, P. 2005. Towards a Theory of Decoupling: Degrees of Decouplingin the EU and the Case of Road Traffic in Finland between 1970 and 2001. *Transp. Policy,* **12(2):** 137-151.
27. Yun, T. and Haitao, W. 2020. Equity of ACE in Major Grain-Producing Areas in China from the Perspective of Industrial Structure. *J. Agrotech. Econ.,* **1:** 47-57. (in Chinese)
28. Yun, T. and Hao, Y. M. 2021. Study on the Effect of Industrial Agglomeration on Net Agricultural Carbon in China. *J. Huazhong Agric. Univ. (Soc. Sci. Ed.),* **3:** 107-117. (in Chinese)
29. Yang, T., Li, F., Du, M., Wang, Y. and Sun, Z. 2021. Measuring Pollutant Emissions of Cattle Breeding and Its Spatial-Temporal Variation in China. *J. Environ. Manag.,* **299:** 113615.
30. Vlontzos, G., Niavis, S. and Manos, B. 2014. A DEA Approach for Estimating the Agricultural Energy and Environmental Efficiency of EU Countries. *Renew. Sustain. Energy Rev.,* **40(1):** 91-96.
31. Wang, G., Liao, M. and Jiang, J. 2020. Research on ACE and Regional CE Reduction Strategies in China. *Sustainability,* **12:** 2627.
32. Wen, S., Hu, Y. and Liu, H. 2022. Measurement and Spatial–Temporal Characteristics of Agricultural Carbon Emission in China: An Internal Structural Perspective. *Agriculture,* **12(11):** 1749-1749.
33. Wu, H., Luo, L. and Chen, W. 2020. Study on Estimation and Improvement of Agricultural Carbon Emission Efficiency in China. *IOP Conf. Ser.: Earth Environ. Sci.,* **450:** 012097.
34. Xuetao, S., Zhao Y. and Wang Z. 2023. Promotion Path of Agricultural Eco-Efficiency under the Background of Low Carbon Pilot Policy. Pol. J. Environ. Stud., **32(1):** 755-771.
35. Yang, N., Sun, X. and Qi, Q. 2022. Impact of Factor Quality Improvement on ACE: Evidence from China's High-Standard Farmland. *Front. Environ. Sci.,* **10:** 989684.
36. Yang, H., Wang, X. and Peng, B. 2022. Agriculture Carbon-Emission Reduction and Changing Factors behind Agricultural Eco-Efficiency Growth in China. J. Clean. Prod., **334:** 130193.
37. Yeying, H. 2015. An Empirical Study on ACE in Tibet: Measured Spatio-Temporal Analysis and Factor Decomposition. Practice and Understanding of Mathematics, **45(19):** 65-73. (in Chinese)
38. Zaman, K., Khan, M. M., Ahmad, M. and Khilji, B. A. 2021. Retracted: The Relationship between Agricultural Technologies and CE in Pakistan: Peril and Promise. *Econ. Model.,* **29(5):**1632-1639.
39. Zhang, L., Pang, J., Chen, X. and Lu, Z. 2019. CE, Energy Consumption and Economic Growth: Evidence from the Agricultural Sector of China's Main Grain-Producing Areas. *Sci. Total Environ.,* **665:** 1017-1025.
40. Zhou, T., Gao, M., Xie, D. -T. and Wei, Z. F. 2014. Carbon Source/sink Characteristics and Carbon Footprint Analysis of Chongqing Farmland System. *J. Southwest Univ.: Nat. Sci. Ed.*, **36(1):** 96-103. (in Chinese).

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محاسبه مجدد انتشار کربن کشاورزی در استان چونگ کینگ چین با پس زمینه احیای مناطق روستایی: تجزیه و تحلیل ویژگی‌ها، سازوکار تشکیل، و همبستگی اقتصادی

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چکیده

اندازه‌گیری علمی انتشار کربن کشاورزی (ACE) و سازوکار تشکیل آن برای تدوین مؤثر استراتژی‌های توسعه کشاورزی با کیفیت بالا از اهمیت زیادی برخوردار است. بنابراین، هدف‌های این بررسی ویژگی‌های ACE، سازوکار تشکیل آن، و ارتباط اقتصادی آن در استان چونگ کینگ با استفاده از IPCC و داده‌های ۲۰۱۹-۱۹۹۷و با شاخص LMDI و شاخص جداسازی (Decoupling index) بود. تجزیه و تحلیل تجربی نشان می دهد که کل ACE یک روند M شکل "افزایش - نوسانات - سقوط" را ارائه می دهد. ساختار انرژی، شدت انرژی و اندازه جمعیت اثر محرکه منفی بر ACE دارند، اما فعالیت اقتصادی عامل اصلی است. ویژگی‌های کشش جداشدگی(decoupling elasticity)برای ACE و رشد اقتصادی عمدتاً جداسازی ضعیف (weak decoupling) و جداسازی قوی است که رابطه به طور قابل‌توجهی هماهنگ است. بنابراین، برای تحکیم و ارتقای هدف که کاهشACE بود، تقویت پژوهش و توسعه فناوری مربوط به "تولید کم" کربن کشاورزی و ارتقاء آن ضروری است. ما به تعمیق اصلاحات ساختاری بخش عرضه در کشاورزی ادامه خواهیم داد. ما محیط زیست را در کشاورزی و مناطق روستایی بهبود خواهیم داد.

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