Structural Decomposition of the Spatial and Temporal Patterns and Sources of Spatial Variation in Agricultural Carbon Emissions in China

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Abstract. This paper examines the spatial distribution of agricultural carbon emissions in China from 2010-2019 and the structural decomposition of the sources of their spatial variation. Visual results are obtained using Akkis plotting, and the Thiel index is applied to quantitatively analyse the overall regional variation, intra-zone variation and inter-zone variation, as well as the contribution of intra-zone variation and inter-zone variation to the overall variation in China's agricultural carbon emissions from 2010-2019; China's agricultural carbon emissions possess a basic balance, but the eastern, western, central, and The Northeast region is characterised by uneven development within each region. In particular, the development within the western region is very uneven. It is recommended that inter-regional cooperation and exchange of emission reduction technologies be strengthened. In view of the significant differences in emission reduction effects between regions in China's agricultural carbon emissions, all regions should strengthen communication and cooperation, collaborate on scientific and technological innovation in emission reduction, focus on the promotion and application of advanced emission reduction technologies, and fully exploit the emission reduction potential to jointly achieve the goal of emission reduction and carbon reduction.

Keywords: Agricultural carbon emissions; East West gap; Industrial Distribution.

1. Introduction

Greenhouse gases are an important cause of global warming, and discussions around global warming have intensified around the world in recent years. China, as the largest developing country, is challenged by the dual pressure of greenhouse gas emission reduction and competition from low-carbon industries, and has embarked on the path of energy conservation and emission reduction under the pressure of external international public opinion and the support of national policies. As agriculture is an important support to promote the high-quality development of China's national economy, it is important to explore the spatial and temporal patterns of China's agricultural carbon emission intensity and its influencing factors in order to fully explore the potential of agricultural emission reduction, reasonably plan the direction of agricultural development, accelerate the process of building an agricultural ecological civilization and thus promote the high-quality development of China's national economy.

There is a significant spatial dependence i.e. positive correlation in the level of carbon emissions in Chinese provinces, a serious path dependence in the spatial geographical distribution, and a significant agglomeration and relatively low mobility, which shows that it is still difficult for each province to get rid of the clusters in the region. The regional spatial distribution of carbon emissions in China has formed a spatial agglomeration of carbon emissions centred on Hebei province. Therefore, according to the findings of the spatial and temporal evolution of carbon emissions in China, the problem of carbon emission reduction in China should consider the spatial and temporal dynamics of the spatial pattern effect mechanism. Agricultural carbon emissions are an important source of greenhouse gases, and agricultural production is closely related to climate change and greenhouse gas emissions [1]. The Chinese government attaches great importance to the construction of ecological civilization and environmental protection, emphasizing the reduction of greenhouse gas emissions in agricultural production and the development of green, low-carbon and sustainable agriculture. At present, research on agricultural carbon emissions has focused on the measurement, spatial and temporal characteristics, influencing factors, and equity and efficiency of agricultural carbon emissions. On the one hand, the measurement of agricultural carbon emissions is important for understanding the sources, emissions and structural characteristics of agricultural greenhouse gas emissions. Min and Tian [2, 3] has comprehensively measured China's agricultural carbon emissions and explored the spatial and temporal evolution of agricultural carbon emissions, finding that China's agricultural carbon emissions have been on an upward trend in phases since 1993, and concluding that efficiency and structural factors have a certain suppressive effect on carbon emissions, but the effect is not significant and highly volatile. Zhang [1] studied the total, structural and efficiency changes of China's agricultural carbon emissions using the life cycle assessment method, and concluded that China's total agricultural carbon emissions are on an upward trend, the intensity of agricultural carbon emissions is on a downward trend, and the proportion of carbon emissions caused by energy and agrochemicals in the structure of agricultural carbon emissions is increasing. On the other hand, the influencing factors of agricultural carbon emissions have been widely discussed by academics. Tian et al [4] suggested that factors such as efficiency, labour and structure have an important impact on agricultural carbon emission reduction. Han et al [5] found that among the factors influencing the change of agricultural carbon emissions in China from the perspective of energy consumption and trade, the import effect has the largest contribution to the carbon emissions of agricultural energy consumption in China at the present stage, while the other influencing factors are, in order of their cumulative contribution, the terms of trade effect, the export counter-effect, the industry scale effect and the energy efficiency effect. Wang et al [6] emphasized that the overall increase of total agricultural carbon emissions in China is obvious, and agricultural production efficiency shows a bimodal convergence; agricultural production efficiency has a significant threshold effect on agricultural emission reduction, and improving agricultural production efficiency is an effective way to reduce agricultural emissions. Dong [7] found that there is a strong correlation between industrial structure and agricultural carbon emissions in general, but the correlation between the proportion of each industry and agricultural carbon emissions varies to some extent; the correlation between industrial structure and agricultural carbon emissions also varies in different provinces. Chen et al [8] suggested that agricultural carbon emissions were negatively correlated with agricultural mechanization, while positively correlated with industrial upgrading. Hu and Chuan [9] suggest that agricultural policies have a significant negative relationship with agricultural carbon emissions. In addition, the equity and efficiency of agricultural carbon emissions and other frontier issues have also received increasing attention. Tian and Yun [10] examined the equity and variability of agricultural carbon emissions in different provinces and regions of China in terms of ecological carrying capacity and economic contribution of agriculture. Gao et al [11] argued that there is spatial convergence and convergence in the agricultural carbon emission performance of various provinces and regions in China. Wu et al [12] assessed the agricultural carbon emission reduction potential of different provinces and regions in China from both equity and efficiency perspectives. Zhang et al [13] used Cite Space III software to analyse the existing literature and found that carbon emissions and carbon sinks from agricultural land, non-CO_2 greenhouse gas emissions from agricultural production, and carbon footprint of agricultural products are the frontier topics in agricultural carbon emission research. In the context of developing green and low-carbon agriculture, it is important to understand the spatial distribution and dynamic evolution of agricultural carbon emissions in China in order to reasonably formulate agricultural carbon emission reduction policies. However, relatively few studies have been conducted to investigate the spatial distribution and dynamic evolution of agricultural carbon emissions. Among them, Tian et al [14] and Liu et al [15] investigated the regional disparity and dynamic evolution of agricultural carbon emissions in China using the Kernel density estimation method and Markov chain method, respectively, but there are problems such as insufficient research on the internal dynamics of regional agricultural carbon emissions distribution, strong subjectivity and unstable results. Based on this, this paper uses the panel data of 29 provinces in mainland China from 1993 to 2017 to systematically investigate the spatial distribution and dynamic evolution of agricultural carbon emissions in China based on the measurement of agricultural carbon emissions by province, the spatial analysis based on visualization techniques and the Kernel density estimation and conditional probability density estimation methods in the non-parametric approach, which can The spatial distribution of agricultural carbon emissions in China and its dynamic evolution were systematically investigated based on the spatial analysis and non-parametric methods. Meanwhile, Zhao [16] calculated and compared the carbon intensity ratios of different and related products. Sun [17] concluded that there is a high correlation between carbon emission efficiency and carbon emission intensity. As carbon emissions become increasingly stringent [18], Cao [19] considered production disturbances as one of the key factors affecting the carbon performance of production systems to demonstrate their impact on the dynamic characteristics of carbon emissions. Ryu [20] argued that the marginal cost of carbon abatement generally increases with increasing sensitivity of temperature to carbon emission concentrations and economic growth rates, but decreases with real the marginal cost of carbon emission reduction generally increases with increasing sensitivity of temperature to carbon concentration and economic growth rate, but decreases with increasing real returns to capital.

2. Research Methodology and Data Sources

2.1 Methodology

As carbon emissions are not uniformly equal across the country, there are large variations in carbon emissions across China's provinces, both between and within their respective regions. This paper focuses on the analysis of the spatial and temporal patterns of agricultural carbon emissions in China and the differences in spatial patterns, as a way to investigate the sources of disparities and gaps. In this paper, the Thiel coefficient is chosen as a tool to study the spatial differences in agricultural carbon emissions.

The Thiel index (total variance)

This paper uses a one-stage Thiel index decomposition to calculate the differences in agricultural carbon emissions between regions. Thiel index is an indicator of data variation used to measure differences between regions, and the GE0 index is chosen in this paper to measure and analyse the differences between and within zones in agricultural carbon emissions across Chinese provinces. ge0 is a Thiel index based on generalised entropy ($\propto$=0), a Thiel index weighted by population, and the only in the paper y variable is agricultural carbon emissions.

Based on the Thayer index, the Theil-GE0 is used to account for agricultural carbon emissions in each province, with the following formula:

$$T = \frac{1}{n} \sum_i \sum_j log \frac{\mu}{y_{ij}} \tag{1}$$

Where: *i* denotes region; *j* denotes province; y_{ij} denotes the carbon emissions of each province within each region and n denotes the number of provinces in the country.

T_i (differences between bodies in the region)

$$T_i = \frac{1}{n_i} \sum_j log \frac{\mu_i}{y_{ij}} \tag{2}$$

Where n_i represents the number of provinces and municipalities included in region *i*, μ_i represents the average amount of agricultural carbon emissions in region *i*, and y_{ij} represents the agricultural carbon emissions in province j of region *i*.

T_{WR} (national intra-regional variation)

$$T_{WR} = \sum_i \frac{n_i}{n} \frac{1}{n_i} \sum_j log \frac{\mu_i}{y_{ij}} \tag{3}$$

Where n represents the number of provinces in the country and n_i represents the number of provinces in the ith region.

T_{BR} (inter-regional variation)

$$T_{BR} = \frac{1}{n}\sum_i n_i \, log \frac{\mu_i}{\mu} \tag{4}$$

Where n represents the number of provinces in the country, n_i represents the number of provinces in the ith region, u represents the average value of agricultural carbon emissions for the 31 provinces, cities and autonomous regions in the country, and μ_i represents the average value of agricultural carbon emissions for the provinces, cities and autonomous regions in the ith region.

$$\mathrm{T} = T_{WR} + T_{BR} \tag{5}$$

Regional differences in China's agricultural carbon emissions can be broken down into intra-zone and inter-zone variation.

2.2 Data sources

The article measured the agricultural carbon emissions of 30 provinces in China from 2010-2019. Hong Kong, Macao and Taiwan could not be generalised in this study due to difficulties in obtaining data. The relevant data were obtained from the China Carbon Accounting Database 2010-2019, and individual missing data were linearly interpolated using proximate year fractional values.

3. Empirical Analysis

3.1 Spatial differences

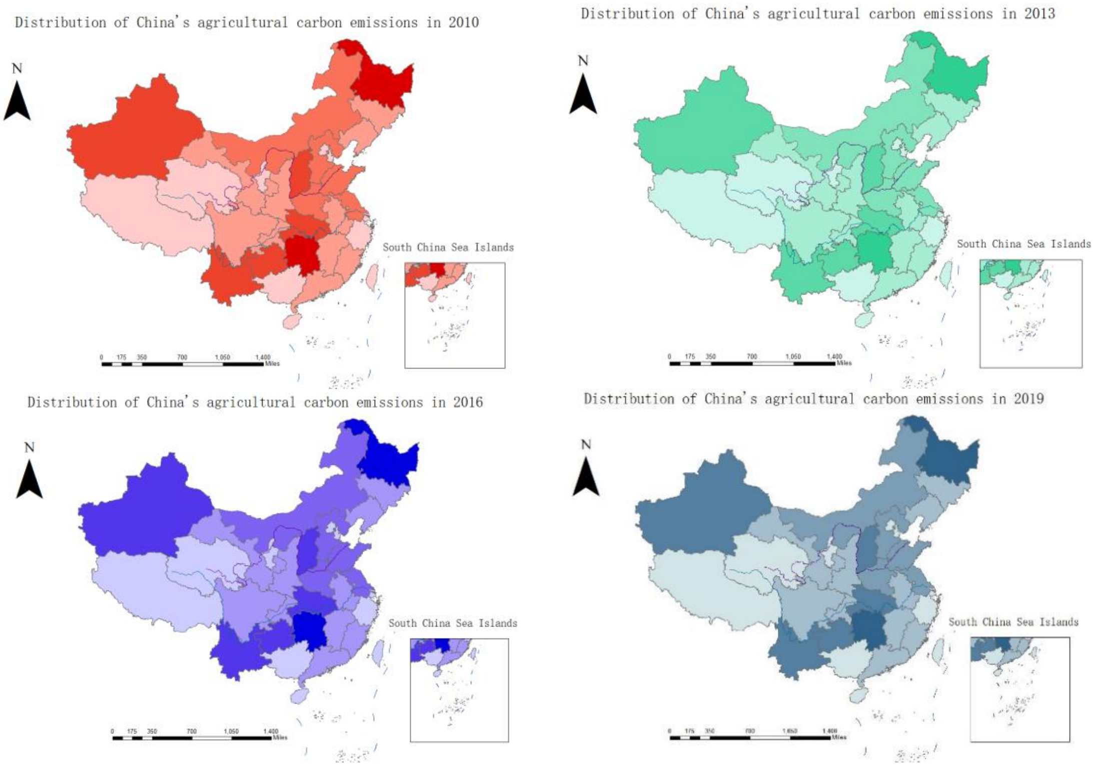

Fig. 1 Changes in China's total agricultural carbon emissions (million t) in 2010, 2013, 2016 and 2019

Spatially, China's agricultural carbon emission intensity shows a "center-periphery" pattern distribution, and shows a trend of spreading from the "centre" to the "periphery" (Figure 1). From 2010 to 2019, the regions with high agricultural carbon emissions in China are mainly concentrated in the Sichuan Basin, the middle and lower reaches of the Yangtze River, the middle and lower reaches of the Yellow River and the Pearl River Basin, including the traditional agricultural provinces such as Sichuan, Henan, Hunan, Jiangxi, Anhui, Hubei and Shandong. At the same time, agricultural carbon emissions increased significantly in Heilongjiang in the northeast and in Inner Mongolia and Xinjiang in the northwest, which means that the distribution of agricultural carbon emissions is spreading from the "central" provinces to the "peripheral" provinces. The reasons for this are, on the one hand, the increasing level of mechanization and scale of agriculture in the northwest, the increasing input of fertilizers, pesticides, agricultural films, diesel fuel, tillage and irrigation, and the expanding scale of livestock breeding such as cattle and sheep, which have led to a significant increase in agricultural carbon emissions in Inner Mongolia and Xinjiang provinces (cities and districts). On the other hand, with global warming, crop species are gradually shifting northward, and the area of rice cultivation in Northeast China, especially in Heilongjiang, is expanding significantly, and agricultural carbon emissions from rice cultivation are increasing significantly.

In terms of time, the overall trend of regional differences in agricultural carbon emissions is slowly increasing. It declined significantly in 2011, which was related to national policies, and then peaked in 2017, and is now on a steady upward trend due to good policy implementation.

3.2 Analysis of the characteristics of regional differences in agricultural carbon emissions in China

From Figure 2, 3 and Table 1, it can be seen that during the period 2010-2019, the overall Thiel coefficient of China's agricultural carbon emissions first declined from 0.378763 in 2010 to 0.28877 in 2011, and then generally rose to 0.388663 in 2019, indicating that the overall difference in China's agricultural carbon emissions showed a trend of narrowing and then widening. In terms of the interannual variation characteristics of the overall difference in China's agricultural carbon emissions, the change process of the difference in China's agricultural carbon emissions can be roughly divided into two stages, taking 2011 as the boundary, and divided into 2010-2011 and 2011-2019, in which the overall difference in China's agricultural carbon emissions showed a significant decreasing trend between 2010-2011, and the overall difference in this period decreased significantly by The overall difference in China's agricultural carbon emissions showed an overall upward trend between 2011 and 2019, with a slight decline in 2017-2018, and the decline in the overall difference in China's agricultural carbon emissions in 2017 was probably due to the accelerated agricultural structure optimisation and upgrading policies that have affected agricultural production in various provinces to varying degrees.

Between 2012 and 2017, the inter-zone and intra-zone Terre coefficients of China's agricultural carbon emissions showed an upward trend, rising from 0.301124067 and 0.034983936 in 2012 to 0.352620519 and 0.06967809 in 2017, respectively, decreasing by 0.051496452 and 0.034694154, indicating that, like the overall difference in China's agricultural carbon emissions, the trend of inter-zone and intra-zone differences in China's agricultural carbon emissions has widened, and the intra-zone differences have widened more than the inter-zone differences, indicating that provinces with relatively active agricultural activities within each zone have continued to expand their advantages suitable for developing agricultural production through development.

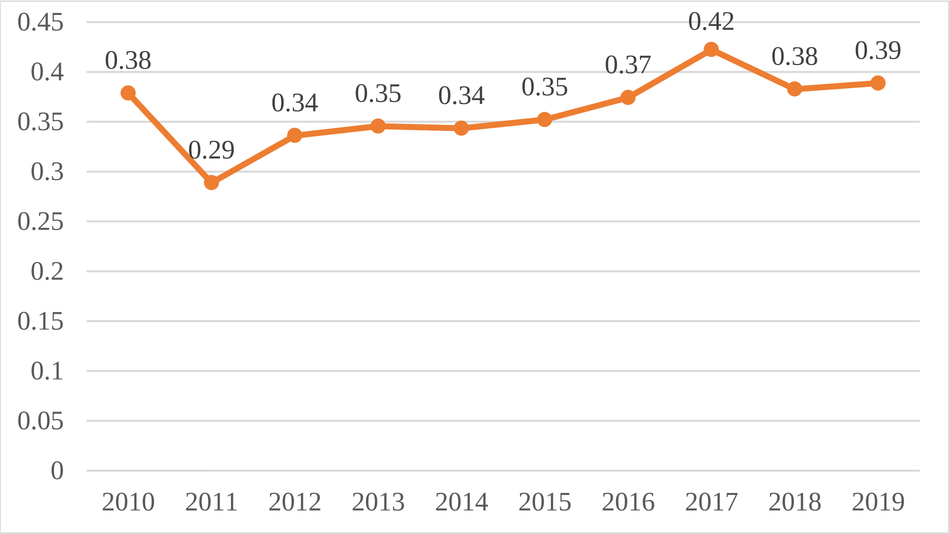

Fig. 2 2010-2019 Change in Thiel's coefficient for China's total agricultural carbon emissions (million tonnes)

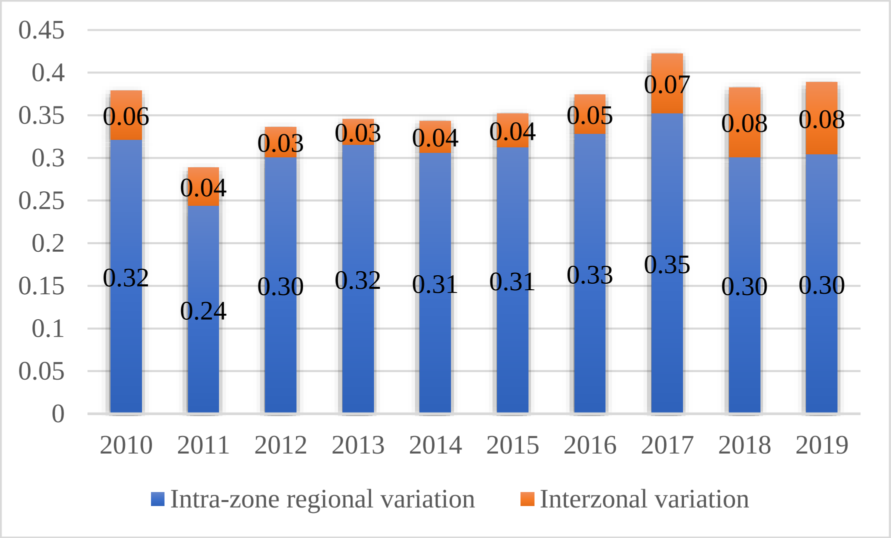

Fig. 3 Zone Variation and Inter-Zone Variation

Table 1. Thiel coefficient of China's agricultural carbon emissions

Year	Thiel's coefficient	Intra-zone regional variation	Interzonal variation
2010	0.378763	0.321536	0.057226
2011	0.28877	0.243869	0.044901
2012	0.336108	0.301124	0.034984
2013	0.345529	0.315768	0.029761
2014	0.343447	0.306179	0.037268
2015	0.352128	0.312465	0.039663
2016	0.374274	0.328369	0.045905
2017	0.422299	0.352621	0.069678
2018	0.382667	0.301267	0.0814
2019	0.388663	0.304301	0.084363

3.3 Analysis of the contribution of intra-zone and inter-zone variation in China's agricultural carbon emissions to the overall variation

From Figure 4, 5 and Table 2, the contribution of intra-zone and inter-zone variation to the overall variation in China's agricultural carbon emissions from 2010 to 2019 is 85% and 14% respectively.

It is clear that intra-zone variation contributes more to the overall variation, and even in 2019, the lowest year for intra-zone variation, the contribution is 78.2%. The contribution of intra-zone variation to overall variation in China's agricultural carbon emissions shows a weak upward and then downward trend, with an n-shaped pattern, with a maximum in 2013 and a contribution of 91.4%. It is easy to see from this that the overall variation in agricultural carbon emissions across the country is mainly due to differences in agricultural carbon emissions between provinces and cities within regions rather than between regions.

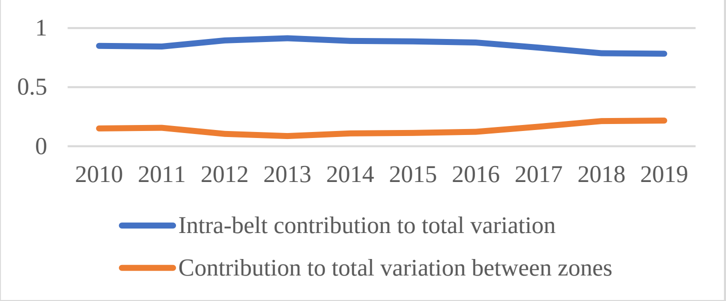

Fig. 4 Line graph of the contribution of intra-zone and inter-zone variation to the overall variation in agricultural carbon emissions in China, 2010-2019

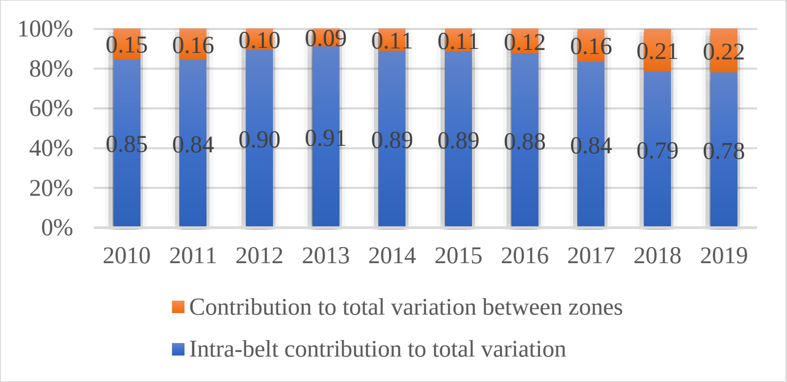

Fig. 5 Histogram of the contribution of intra-zone and inter-zone variation to overall variation in agricultural carbon emissions in China, 2010-2019

Table 2. The contribution of intra-zone and inter-zone variation

Year	Intra-belt contribution to total variation	Contribution to total variation between zones
2010	0.848913	0.151087
2011	0.844509	0.155491
2012	0.895915	0.104085
2013	0.913868	0.086132
2014	0.891489	0.108511
2015	0.887363	0.112637
2016	0.87735	0.12265
2017	0.835003	0.164997
2018	0.787282	0.212718
2019	0.782942	0.217058

3.4 Analysis of the dynamics of intra-regional variation in agricultural carbon emissions in four regions and its contribution to the overall variation

In terms of intra-regional variation in agricultural carbon emissions in the four major regions, during 2010-2019, China's agricultural carbon emissions showed the greatest intra-regional variation in the western region, followed by the three regional regions, showing a spatial pattern of spreading from the west to the periphery. The main reason for the greatest intra-belt variation in the west is that the western region includes Chongqing, Sichuan, Guizhou, Yunnan, Tibet Autonomous Region, Shaanxi, Gansu, Qinghai, Ningxia Hui, Xinjiang Uygur, Inner Mongolia and Guangxi Zhuang Autonomous Regions, some of which are mountainous and hilly, with rugged terrain unsuitable for agriculture and therefore have low agricultural carbon emissions, while others Some of these provinces and autonomous regions are mountainous and hilly, with rugged terrain unsuitable for agriculture and therefore have low agricultural carbon emissions. The topography of the western region is the most complex compared to other regions, which is the main reason for the greatest intra-zone variation.

From Figure 6 and Table 3, it can be seen that between 2010 and 2019, the intra-regional variation in agricultural carbon emissions in the northeastern, central, western and eastern regions increased from 0.047934, 0.194624, 0.290867 and 0.516568 in 2010 to 0.343029, 0.341813, 0.307166 and 0.266166 in 2019 respectively. It is easy to see that the intra-regional variation in the eastern belt declined significantly between 2010 and 2011, presumably due to the rapid development of the more backward provinces and cities in the eastern region in 2010, which reduced the regional variation and thus the intra-regional variation in agricultural carbon emissions. In addition, the more obvious dramatic change is the significant decrease in intra-regional differences in agricultural carbon emissions in the western region from 2017 to 2019, which is presumed to be due to the effect of national policies to support production in poor areas and encourage their agricultural development, promoting agricultural production activities in technologically poor areas and reducing intra-regional differences in agricultural carbon emissions in the western region.

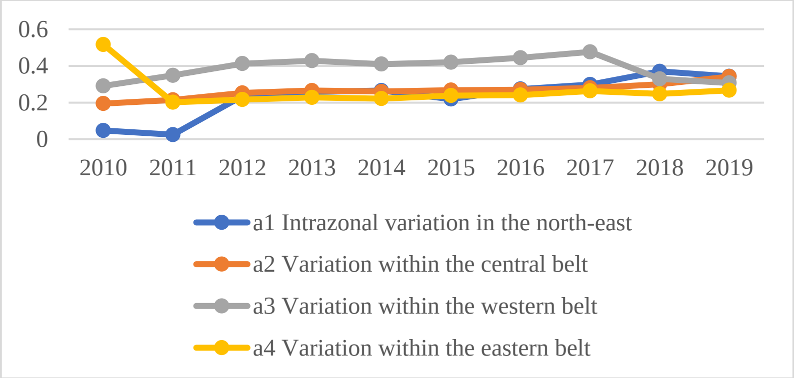

Fig. 6 Trends in the evolution of intra-belt variation in agricultural carbon emissions in eastern, central, western and northeastern China, 2010-2019

Table 3. Intra-regional variation in agricultural carbon emissions

Year	a1 Intrazonal variation in the north-east	a2 Variation within the central zone	a3 Variation within the western zone	a4 Variation within the eastern zone
2010	0.047934	0.194624	0.290867	0.516568
2011	0.025253	0.214637	0.348238	0.201748
2012	0.236309	0.252616	0.412323	0.216234
2013	0.258207	0.26572	0.42824	0.228099
2014	0.265534	0.260236	0.40965	0.221773
2015	0.219234	0.267686	0.41997	0.238297
2016	0.273787	0.270322	0.444153	0.24063
2017	0.298506	0.280192	0.476489	0.26367
2018	0.370166	0.300223	0.329426	0.247432
2019	0.343029	0.341813	0.307166	0.266737

4. Conclusions and recommendations

(1) Between 2010 and 2019, the overall difference in China's agricultural carbon emissions tends to increase, in the opposite direction of the change in China's regional economic differences, indicating that China's agricultural carbon emissions play a role in reducing economic regional differences to a certain extent.

(2) The intra-belt variation in China's agricultural carbon emissions shows a downward trend, contrary to the upward trend in the inter-belt variation. In terms of the contribution of intra-zone and inter-zone differences to the overall difference in China's agricultural carbon emissions, the contribution of intra-zone differences to the overall difference is much larger than that of inter-zone differences, indicating that intra-zone differences have become the main component of the overall difference in China's agricultural carbon emissions. The difference between the contribution of intra-belt variation to the overall variation in China's agricultural carbon emissions and the contribution of inter-belt variation to the overall variation shows a trend of narrowing.

(3) In terms of the contribution of intra-regional variation in agricultural carbon emissions to the overall variation, the western region has the largest contribution to the overall variation in agricultural carbon emissions, followed by the remaining three regions. In terms of the increase in the contribution of agricultural carbon emissions to the overall variation in the four major regions, the East, Central, West and Northeast regions all show a general trend of expansion.

(4) Promote agricultural carbon emission reduction according to local conditions Each Chinese province (municipality, region) should take into account local resource endowment conditions, give full play to its comparative advantages, actively adjust its agricultural industrial structure and explore the key factors affecting agricultural carbon emissions, so as to promote agricultural carbon emission reduction to the maximum extent while achieving stable development of agriculture. Create a good policy environment To achieve low-carbon development and ecological civilization in the agricultural sector, the government should play a more important role by guiding policies, strengthening agricultural funding support policies, promoting the full use of agricultural production by-products such as straw, and striving to create a fair and reasonable policy environment for agricultural carbon emission reduction. Strengthen inter-regional exchanges and cooperation on emission reduction technologies In response to the significant differences in emission reduction effects between regions in China's agricultural carbon emissions, regions should strengthen exchanges and cooperation, collaborate on scientific and technological innovation in emission reduction, focus on the promotion and application of advanced emission reduction technologies, fully explore the potential for emission reduction, and jointly achieve the goal of emission reduction.

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