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Decoupling of carbon emissions from agricultural land utilisation from economic growth in China

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Abstract: China, as a populous and agricultural country, is confronted with a tremendous challenge involving the balance between agricultural economic growth and carbon emissions from agricultural land utilisation (CEALU). This study calculates the total CEALU in the 31 provinces of mainland China and uses the Tapio model to analyse the decoupling of CEALU from economic growth during the period 2000–2017. The results are shown as follows: (*i*) The CEALU in China has substantially increased, and there are obvious spatial discrepancies in CEALU from the regional and provincial perspectives. (*ii*) The decoupling of CEALU from economic growth at the national level shows a progressive improvement. The decoupling trends show significant spatial disparities at the regional level due to different natural and economic conditions. (*iii*) There is an increase in the numbers of provinces, which have achieved economic growth with the reduction of CEALU. Policymakers should attach more importance to the relationship between CEALU and economic growth, and relevant policies should be adapted to local natural and economic conditions.

Keywords: agricultural sector; land use; national bureau of statistics; sustainability; Tapio model

Global warming is one of the greatest threats to human survival. The main factor causing global warming is the increase in global carbon emissions (Wu et al. 2019). According to the World Bank (2018), agricultural practices have globally produced about 20% of carbon dioxide. The agriculture in China has rapidly developed since the reform and opening-up policy in 1978. Statistics from China Rural Statistical Yearbook (CRSY) show that China's agricultural gross domestic product (GDP) had grown from EUR 13.969 billion to EUR 825.831 billion during 1978–2019, with an average annual rate of 4.373%. However, China's agricultural activities have resulted in a lot of carbon emissions, which are higher than those in any other countries (Huang et al. 2019).

Agricultural land, the uppermost material for agricultural economic development (Chen and Xie 2019), is the main factor of carbon emissions. Carbon sources, such as long-term agricultural waste, extensive use of agricultural supplies and energy, widespread planting of rice and burning of biological tissue, are directly related to agricultural land utilisation (Johnson et al. 2007; Norse 2012). Scholars have used the data of Chinese regions to calculate the carbon emissions from agricultural land utilisation (CEALU) and explore the influential factors in the changes of CEALU. The research of Lu et al. (2018) shows that the total CEALU in mainland China from 2000 to 2015 changed from 5 232.83 kilotons to 7 858.93 kilotons. Xiong et al. (2016) find that the CEALU in Hotan prefecture, China, rapidly increased from 2005 to 2009 as the rapid development of characteristic forestry, fruit industry and fruit trees in the fruiting stage all had led to an increase of agricultural material inputs. Zhao et al. (2018) use the logarithmic mean Divisia index (LMDI) model to discuss the influential factors on agricultural carbon emissions

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in China. The authors find that the major factor belongs to the economic output of water resources, which is followed by the ratio of water and land resources, population factor, land use area per capita and agricultural carbon emission intensity. The research of Chen et al. (2019) shows that agricultural carbon emissions in Fujian, China decreased during 2008–2017 and the factors on agricultural carbon emissions are geospatially nonstationary. The relationship between CEALU and agricultural economic growth also needs more attention. Studies have found that the agricultural growth of the economy will lead to a gradual increase of agricultural carbon emissions (Liu and Xin 2014; Xu and Lin 2017). Zhang et al. (2019) examine the environmental Kuznets curve (EKC) hypothesis for agricultural carbon emissions in China's main grain production areas during the period of 1996 to 2015. The agricultural carbon emissions in Sichuan, China, show a linear upward trend with the economic growth from 1997 to 2008 without the inflexion point of EKC (Li and Zheng 2011).

The above literature has provided a great contribution to this study. Paris Agreement shows that China, the largest carbon emitter in the world, may reach the carbon peak by 2030 (Zhang et al. 2019). Reducing CEALU while maintaining economic growth is one biggest challenge for China. The OECD proposed the concept of decoupling to explore the relationship between economic development and environmental pollution in 2002 (Chen et al. 2017). Tapio (2005) uses the coefficient of elasticity to establish a decoupling index, namely Tapio decoupling index. Decoupling means that the connection of economic growth and environmental pollution is blocked, or the rate of their change is not synchronised. Decoupling methods are currently used to evaluate the relationship between carbon emissions and economic growth (Ma and Cai 2019; Wu et al. 2019; Wang and Zhang 2020). Few authors have explored the decoupling of CEALU from the viewpoint of economic growth in mainland China. This populous and agricultural country successfully feeds 20% of the world's population, with less than 10% of the world's cultivated land. However, the high-speed agricultural economic growth in the country has resulted in high consumptions and high carbon emissions. China is confronted with its tremendous challenges involving the balance between agricultural economic growth and CEALU. To deal with the decoupling of CEALU from economic growth has a significant impact on the sustainable development of agriculture. Therefore, this study takes 31 provinces in mainland China as samples and uses the Tapio model to empirically analyse the decoupling characteristics of CEALU from economic growth.

MATERIAL AND METHODS

Calculation of the CEALU. The CEALU refer to the carbon emissions caused by activities on agricultural land. The sources of CEALU are diverse and complex. Agricultural land mainly includes the following four categories: farmland, garden, woodland, and grassland. Woodland and grassland mainly act as natural carbon sinks, and the proportion of garden is relatively small. Accordingly, CEALU in this study mainly refers to carbon emissions resulting from chemical fertilisers, pesticides, and energy consumption during the crop production process (West and Marland 2002; Lu et al. 2018).

The CEALU can be calculated by Equation (1):

$$C = \sum C_i = \sum T_i \bullet \delta_i \tag{1}$$

where: C – CEALU; C_i – the amount of carbon emissions for various types of carbon sources; T_i – the amount of the i^{th} carbon sources; δ_i – the coefficient of the i^{th} carbon sources.

According to the previous studies (West and Marland 2002; Xiong et al. 2016; Chen et al. 2019), we calculate the carbon emissions caused directly or indirectly by agricultural material inputs, specifically chemical fertilisers, pesticides, agricultural film, agricultural machinery, soil organic carbon released from agricultural land, and carbon emissions resulting from agricultural irrigation. Table 1 shows carbon sources and coefficients of CEALU according to the research of Lu et al. (2018).

Calculation of decoupling elasticity and decoupling type. The OECD decoupling index model and the Tapio model are the two most widely adopted methods when describing decoupling (Ma and Cai 2019). The Tapio model emphasises the analysis of individual years, which overcomes the difficulties encountered by the OECD index model in selecting the base period (Wang and Su 2019). This study uses the Tapio model to explore the decoupling state. According to the specification of Tapio's model (Tapio 2005), the decoupling of CEALU from economic growth can be calculated by Equation (2):

$$D^x = \frac{\Delta C^x / C^x}{\Delta GDP^x / GDP^x} = \frac{\dfrac{C^x - C^{x-1}}{C^{x-1}}}{\dfrac{GDP^x - GDP^{x-1}}{GDP^{x-1}}} \tag{2}$$

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Table 1. Carbon sources and coefficients of CEALU

Carbon sources	Calculation method	Coefficient	Unit
Chemical fertilisers	consumption of chemical fertilisers in rural areas	0.8956	kg C/kg
Pesticides	consumption of pesticides	4.9341	kg C/kg
Agricultural film	consumption of plastic film for farm use	5.1800	kg C/kg
Agricultural machinery	total power of agricultural machinery	0.1800	kg C/kW
Tillage	sown area of farm crops	312.6000	kg C/km^2
Agriculture irrigation	effective irrigation area	25.0000	kg C/hm^2

Source: Authors' processing according to the research (Lu et al. 2018)

where: D^x – the value of decoupling elasticity in the year x; ΔC^x and ΔGDP^x – the differences of carbon emissions and GDP during the period x–1 to x, respectively; C – CEALU; GDP – measured by the gross output value of farming production.

The decoupling state of CEALU from agricultural economic growth is classified into eight types according to Tapio model (Tapio 2005) (Figure 1).

Data source and processing. The research sample consists of 31 provinces or municipalities in mainland

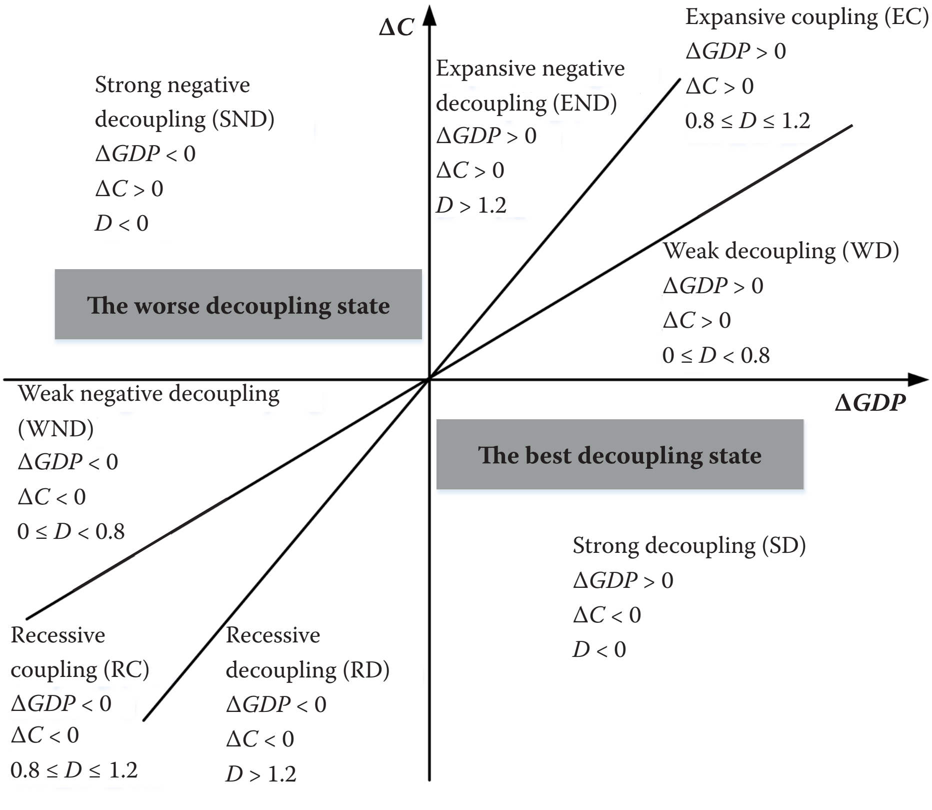

Figure 1. The schematic diagram of decoupling states of CEALU from economic growth

ΔC – differences of carbon emissions during two periods; ΔGDP – differences of GDP during two periods; D – the value of decoupling elasticity; expansive coupling (EC) – the increase in the pace of CEALU is approximately equal to economic growth; expansive negative decoupling (END) – the increase in the pace of CEALU is significantly larger than that of economic growth; recessive coupling (RC) – the decreasing pace of CEALU is approximately equal to economic growth; recessive decoupling (RD) – the decreasing pace of CEALU is significantly larger than that of economic growth; strong decoupling (SD) – economic growth increases when CEALU decrease; strong negative decoupling (SND) – economic growth decreases when CEALU increase; weak decoupling (WD) – the increase in the pace of CEALU is clearly smaller than that of economic growth; weak negative decoupling (WND) – the decrease in the pace of CEALU is considerably smaller than that of economic growth

Source: Authors' processing according to the research (Tapio 2005)

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China. The research period is from 2000 to 2017 due to data availability and integrity. Data for the study are mainly from CRSY (2001–2018). Since agricultural economic growth calculated with respect to actual price cannot longitudinally be compared, the study converts the gross output value of farming production into constant prices on the basis of the year 2000.

RESULTS AND ANALYSIS

Descriptive analysis of CEALU. Figure 2 illustrates the change tendency of the CEALU in mainland China. The CEALU of mainland China shows an overall upward trend, from 5 232.83 kilotons in 2000 to 7 613.31 kilotons in 2017, with an average annual growth rate of 2.25%. The changes in CEALU can be divided into three periods: the rapid growth period of 2000 to 2007, the slow growth period of 2008 to 2015, and the declining period of 2016 to 2017. The average annual growth rates of CEALU during the rapid growth, the slow growth, and the declining periods are 3.34%, 2.24% and –1.57%, respectively. The annual growth rate of CEALU shows a significant downward trend. China has achieved initial success in promoting low-carbon agricultural production, due to the advancement of its agricultural technology and management and its investment in the construction of high standard agricultural land.

The CEALU of 3 regions and 31 provinces during the study period are illustrated in Figure 3 and Table 2, respectively. The CEALU of 3 regions are characterised by an overall upward trend. However, the average annual growth rates are significantly different, 0.87 in the eastern region, 2.44 in the central region, and 3.74 in the western region. One reason for this phenomenon may involve the regional differences of agricultural eco-efficiency in China (Liu et al. 2020). The efficiency in the eastern region is higher than those in both central and western regions. Furthermore, the eastern region attaches more importance to the protection of resources and the environment. The agricultural technology and modernisation are relatively lower in the western region, resulting in the inefficient use of agricultural material inputs and extensive agricultural economic growth.

Table 2 shows that the CEALU in Beijing, Shanghai, and Jiangsu decrease during the study period, while all other provinces are characterised by an increase of CEALU with different growth rates. The average annual growth rate of Inner Mongolia (6.67%) ranks the first, followed by the rates of Xinjiang and Hainan, which are 6.61% and 5.81%, respectively. One reason may be that three above provinces are in the earlier stages of agricultural economic growth, where the inefficient ways of using agricultural inputs and the low agricultural production efficiency cause the relatively higher CEALU. The main grain production provinces in China, such as Henan, Shandong, Jiangsu, Hebei, Hubei, and Anhui, have higher CEALU and higher growth rates than others provinces, as consumptions and carbon emissions in those provinces are higher because of pressures from agricultural products and national food security (Lu et al. 2018).

National and regional analysis of the decoupling elasticity. Table 3 shows that the decoupling of CEALU from economic growth in mainland China and 3 regions has progressively improved during the study period. The decoupling state can be divided into three

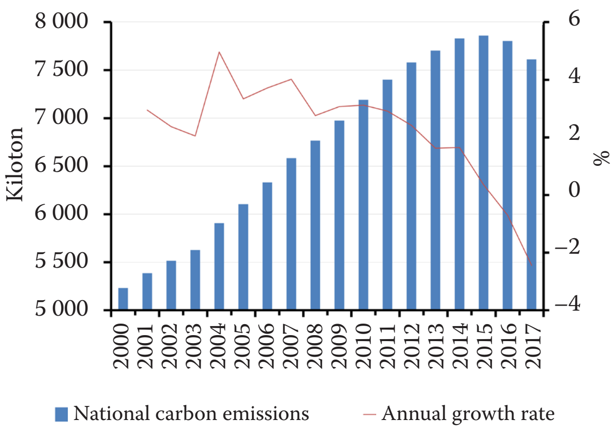

Figure 2. Changes of China's CEALU during 2000–2017

Source: Authors' calculation according to the data from CRSY [National Bureau of Statistics (2001–2018)]

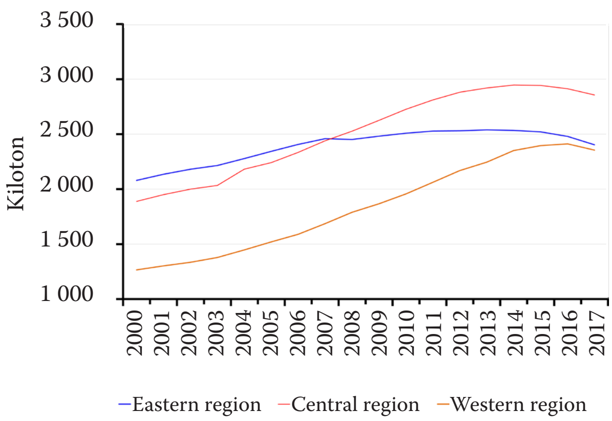

Figure 3. Evolution of CEALU in China's 3 regions during 2000–2017

Source: Authors' calculation according to the data from CRSY [National Bureau of Statistics (2001–2018)]

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Table 2. The CEALU of each province in China in main years

Region	Province	The amount of CEALU (unit: kilotons)				
		2000	2006	2012	2017	Average
Eastern region	Beijing	24.82	22.03	21.20	13.96	20.92
	Tianjin	22.32	31.28	31.22	23.92	28.94
	Hebei	325.84	386.44	417.59	408.21	390.66
	Liaoning	162.69	188.27	240.84	229.04	208.45
	Shanghai	34.67	29.25	23.36	18.41	26.91
	Jiangsu	392.08	406.36	408.44	381.48	401.43
	Zhejiang	133.90	146.20	150.51	136.59	144.03
	Fujian	150.31	164.51	170.96	165.60	164.25
	Shandong	581.67	718.27	688.51	630.46	667.94
	Guangdong	219.59	259.24	305.31	317.02	277.71
	Hainan	30.98	55.05	72.53	77.88	61.61
Central region	Shanxi	105.56	121.98	149.45	145.58	130.74
	Jilin	133.85	177.89	245.52	273.36	207.91
	Heilongjiang	159.13	215.68	316.08	328.10	251.56
	Anhui	305.52	362.02	418.04	400.15	378.38
	Jiangxi	147.58	184.02	209.71	199.19	187.72
	Henan	487.40	618.55	775.35	793.56	676.71
	Hubei	313.42	364.29	430.80	383.47	379.86
	Hunan	235.96	289.77	336.25	332.67	299.25
Western region	Inner Mongolia	97.32	153.50	230.05	288.27	189.97
	Guangxi	178.19	234.54	283.45	303.43	251.88
	Chongqing	86.55	99.04	119.74	120.73	107.34
	Sichuan	267.40	292.61	332.32	323.07	304.15
	Guizhou	81.52	96.42	122.16	123.76	106.43
	Yunnan	143.28	192.46	274.73	305.77	226.76
	Tibet	3.12	5.26	6.19	7.25	5.64
	Shaanxi	140.61	156.75	246.12	242.05	191.18
	Gansu	100.87	124.72	201.67	195.39	159.53
	Qinghai	8.57	8.80	12.69	13.85	10.80
	Ningxia	25.79	34.46	46.33	47.35	38.59
	Xinjiang	132.33	191.28	293.48	383.75	248.09
Total		5 232.83	6 330.94	7 580.61	7 613.31	6 745.35

Source: Authors' calculation according to the data from CRSY [National Bureau of Statistics (2001–2018)]

periods: the period of 2000–2009 characterised by expansive coupling (EC) and weak decoupling (WD), the period of 2009–2015 characterised by WD, and the period of 2015–2017 that is stable at strong decoupling (SD). There is no significant gap between the growth rate of economic growth and CEALU during the period of 2000–2009. The decoupling elasticity fluctuates between 0.8 and 1.2, and the states of EC and WD alternately appear. Agriculture value-added decreases carbon emissions (Wang et al. 2020), and provides financial support for environmental protection of agricultural production. A series of programs have been created to promote the transformation of agricultural production in China, such as zero growth of fertiliser consumption.

Accordingly, resource consumption and pollutant emissions are lower than economic growth in China. Table 3 shows that the periods of 2009–2015 and 2015–2017 are featured by the decoupling state of WD and SD.

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Table 3. Decoupling of CEALU from economic growth in regions

Periods	Eastern region		Centre region		Western region		The whole China	
	D	state	*D*	state	*D*	state	*D*	state
2000–2001	0.60	WD	0.88	EC	1.47	END	0.82	EC
2001–2002	0.96	EC	0.51	WD	0.49	WD	0.61	WD
2002–2003	0.63	WD	–0.40	SND	1.41	END	4.10	END
2003–2004	0.40	WD	0.58	WD	0.79	WD	0.58	WD
2004–2005	0.87	EC	0.64	WD	0.92	EC	0.81	EC
2005–2006	0.55	WD	0.58	WD	1.18	END	0.69	WD
2006–2007	0.60	WD	1.54	EC	1.02	EC	1.09	EC
2007–2008	–0.09	SD	0.65	WD	1.01	EC	0.60	WD
2008–2009	0.41	WD	1.23	END	1.01	EC	0.90	EC
2009–2010	0.34	WD	0.88	EC	0.95	EC	0.73	WD
2010–2011	0.15	WD	0.54	WD	0.87	EC	0.52	WD
2011–2012	0.03	WD	0.61	WD	0.85	EC	0.56	WD
2012–2013	0.00	WD	0.02	WD	0.04	WD	0.02	WD
2013–2014	0.01	WND	–0.02	SND	–0.11	SND	–0.04	SND
2014–2015	–0.12	SD	–0.02	SD	0.35	WD	0.07	WD
2015–2016	–0.80	SD	–0.21	SD	0.11	WD	–0.17	SD
2016–2017	–0.75	SD	–0.42	SD	–0.45	SD	–0.52	SD

D – the value of decoupling elasticity; expansive coupling (EC) – the increase in the pace of CEALU is approximately equal to economic growth; expansive negative decoupling (END) – the increase in the pace of CEALU is significantly larger than that of economic growth; state – the decoupling state of CEALU from economic growth; strong decoupling (SD) – economic growth increases when CEALU decrease; strong negative decoupling (SND) – economic growth decreases when CEALU increase; weak decoupling (WD) – the increase in the pace of CEALU is clearly smaller than that of economic growth; weak negative decoupling (WND) – the decrease in the pace of CEALU is considerably smaller than that of economic growth

Source: Authors' calculation according to the data from CRSY [National Bureau of Statistics (2001–2018)]

Table 3 shows that the decoupling of CEALU from economic growth also has significant spatial disparities at a regional level. The decoupling states in the eastern region converge to the stable WD before 2014 and have been approaching SD since 2015, which implies that the economic growth in the eastern region does not depend on the increase of CEALU. The decoupling states in the central region are rather chaotic, which cannot meet the evolution law. There are seven main grain production areas in the central region (China has 13 main grain production areas in total), in which the factors of decoupling states are relatively complex. On the contrary, the levels of agricultural export rate and agricultural land scale management are higher in minor grain production areas. The western region has gone through three main decoupling states: the expansive negative decoupling (END) period of 2000–2006, the EC period of 2006–2012, and the WD period of 2012–2017. The gap of the growth rates between economic growth and CEALU shows a significant downward trend. One reason may be the lower agricultural technology in the western region, which results in high consumption and carbon emissions in the process of agricultural land utilisation. The lower level of economic growth during the period of 2000–2006 makes the decoupling state remaining on END. The progress of the agricultural economy and technology has eventually turned the decoupling state into WD.

Provincial analysis of the decoupling elasticity. This section divides the study period into three sub-periods: 2000–2006, 2006–2012, and 2012–2017. Figure 4 shows that significant spatial-temporal disparities characterise the decoupling states of CEALU from economic growth in 31 provinces during the three sub-periods at the province level. The number of provinces that have achieved economic growth with the decrease of carbon emissions shows an upward trend. The decoupling state SD can respectively be seen in 1 province, 3 provinces, and 16 provinces during the sub-periods of 2000–2006, 2006–2012, and 2012–2017.

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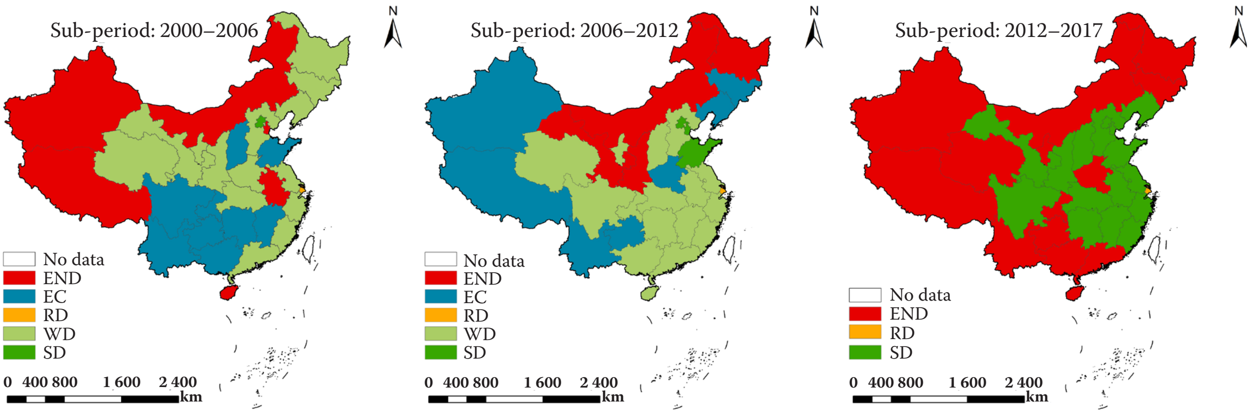

Figure 4. Decoupling of CEALU from economic growth of each province

No data – the data in Taiwan, Hong Kong, Macao are not available and integrated
Expansive coupling (EC) – the increase in the pace of CEALU is approximately equal to economic growth; expansive negative decoupling (END) – the increase in the pace of CEALU is significantly larger than that of economic growth; recessive decoupling (RD) – the decreasing pace of CEALU is significantly larger than that of economic growth; strong decoupling (SD) – economic growth increases when CEALU decrease; weak decoupling (WD) – the increase in the pace of CEALU is clearly smaller than that of economic growth
Source: Authors' calculation according to the data from CRSY [National Bureau of Statistics (2001–2018)]

Such provinces as Jiangsu, Zhejiang, and Fujian belong to the main developed economic or agricultural areas. The inverse U-shaped Kuznets curve between agricultural economic growth and the environmental quality shows that environmental degradation can be worsened because of the economic increase in the early stages of development, while environmental quality will be improved with economic growth after reaching a threshold level (Azad et al. 2020). The relationship between agricultural economic growth and environmental pollution in provinces (the decoupling state is SD) has jumped over the inverted U-shaped inflection point. The provinces have reached the stage where the agricultural carbon intensity decreases with agricultural economic growth.

The decoupling states converge to the stable END in 4 provinces: Hainan, Inner Mongolia, Tibet, and Xinjiang. These provinces are characterised by the weak agricultural foundation and the relatively backward of agricultural technology and management. They have stuck in the stage where agricultural economic growth depends on resource consumption and pollutant emissions, while the rate of economic growth lags behind CEALU. The decoupling state of CEALU from economic growth in 10 provinces (Guangdong, Jilin, Heilongjiang, Henan, Guangxi, Chongqing, Guizhou, Yunnan, Qinghai, and Ningxia) has turned from WD or EC to END during the study period. This means that the gap between the growth rates of CEALU and economic growth has further been widened. One reason may be that these provinces greatly rely on inputs of fertilisers and pesticides in the process of agricultural growth, which can aggravate CEALU.

CONCLUSION AND POLICY IMPLICATIONS

The CEALU in China has substantially increased, and the spatial discrepancies are obvious at the regional level during the study period. The CEALU in the eastern region decreased while those in central and western regions gradually increased over time. CEALU in Beijing, Shanghai, and Jiangsu decreased during the study period, while other provinces all showed an increase with different growth rates. Inner Mongolia had the largest average annual growth rate of CEALU, followed by Xinjiang and Hainan.

The decoupling of CEALU from economic growth in the whole China shows a progressive improvement during the study period. The decoupling state was stable at SD after 2015, while the average annual growth rate of CEALU has been negative since 2015. One main reason is that China ceased refunding fertiliser production and imposed a 13% value-added tax on some fertilisers in 2015. This led to the close of certain small and medium enterprises which had used antiquated fertiliser processes, which thus reduced the supply of fertiliser but increased its price. There is a significant spatial disparity at decoupling trends among the three regions due to the differences in natural and eco-

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nomic conditions. The decoupling of CEALU from economic growth shows significant spatial-temporal disparities at province level during the study period. From 2000 to 2017, the number of provinces that had achieved economic growth with the CEALU reduction showed an upward trend.

To reduce CEALU should be a priority of China's agricultural environmental policy. In the developed coastal areas in eastern China, the proportion of agriculture is smaller to its entire industry, and the level of agricultural development is relatively higher. The reduction potential of CEALU is relatively weaker in the eastern region due to the law of diminishing margin. Eastern region should further reduce the proportion of traditional agriculture but develop the sort of modern agriculture and ecological agriculture in the direction of fewer carbon emissions. The central region in mainland China is considered the greatest potential area in reducing CEALU, as the majority grain production areas are in central China. The main grain production regions play a pivotal role in the process of ensuring national food security. The government of the People's Republic of China should increase the investment of agricultural infrastructure construction and low-carbon technology innovation in central China, which will gradually help achieve an ideal decoupling state of CEALU and economic growth. The western region in China has great potential for both agricultural economic growth and CEALU reduction. The conditions of agricultural infrastructure, agricultural economic development, agricultural technology, and production efficiency in the western region are significantly worse than those in central and eastern regions. To continually improve the agricultural economy, agricultural infrastructure, and agricultural technology is the most important way to coordinate the relationship between economic growth and CEALU in the western region.

To improve the relationship between the decoupling state of CEALU and economic growth is a gradual, long-term process in a populous and agricultural country or region. Macro-economic control and adjustment should be reinforced in order to achieve an ideal decoupling state of CEALU and economic growth. For example, to put a higher value-added tax on conventional fertilisers but waive the value-added tax on organic fertilisers can decrease conventional fertiliser consumption from the perspective of supply. In terms of demand, to levy consumer taxes on conventional fertiliser but subsidise users of organic fertilisers will encourage farmers to use more organic fertilisers than conventional fertilisers.

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