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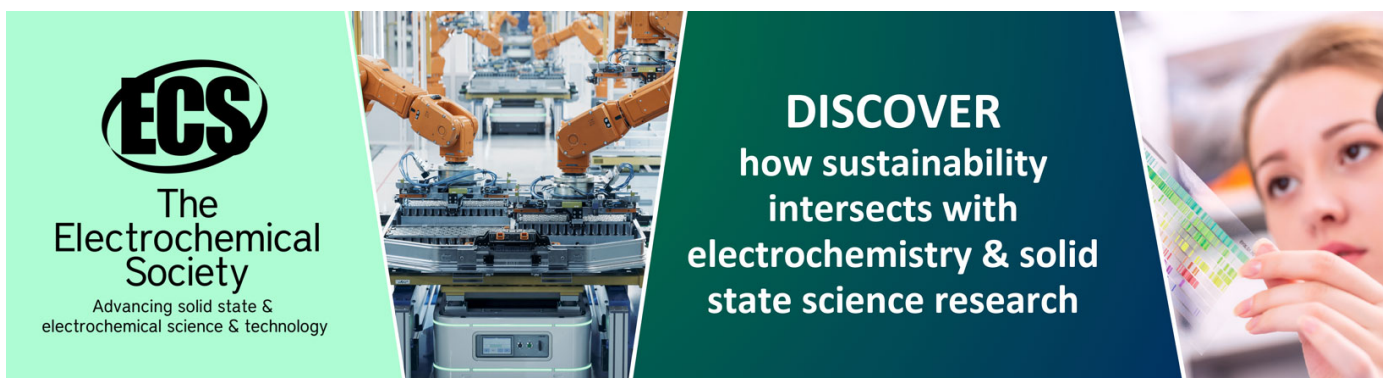
Study on Estimation and Improvement of Agricultural Carbon Emission Efficiency in China

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Study on Estimation and Improvement of Agricultural Carbon Emission Efficiency in China

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Abstract. In order to have a better understanding of agricultural carbon emission efficiency in China and in east, west and central regions, slack based measure (SBM) under the undesirable outputs is used for measuring the agricultural carbon emission efficiency, where the agricultural carbon emission in 2006 to 2015 in 30 provinces of China is estimated as undesirable output. Then the input-output looseness is used for exploring the reasons for the efficiency difference in different regions and their improvement direction. The results show that the efficiency in east is high and stable, and that in central and west is low. In terms of the whole country, the two indexes with the biggest room for improvement are agricultural capital input and land input. The redundancy rates of agricultural capital input in the three regions are relatively high, while those of land input are high in the central and west regions. This paper aims to provide some references for making rational policies on agricultural carbon emission reduction with regional differentiation and overall coordination.

1. Introduction

In recent years, climate change has been the most serious environmental problem in the world, and all countries have attached importance to low-carbon development as an important way to cope with the climate and environment change. For the external pressure on emission reduction and the urgent demand on sustainable development, China proposes reducing carbon emission of unit GDP by 60% - 65% in 2030 compared with 2005. As the significant basis of national economy of China, agriculture releases 17% of the total green gas, 50% and 92% of total methane and nitrous oxide, respectively [1]. Without efficient measures to reduce agricultural carbon emission, the agricultural carbon emission will be further increased by 30% in 2050 [2]. Therefore, actively promoting the mitigation of agricultural carbon emission and increasing agricultural carbon emission efficiency is the objective requirement of resource and ecology protection and green development realization. Meanwhile, calculating the emission efficiency and exploring the improvement direction may provide important basis for scientifically making and implementing the policies on reducing regional agricultural carbon emission.

In the field of carbon emission, the estimation of efficiency has been a hot issue. To calculate the regional efficiency, different scholars may adopt different index system and calculation method. In 1990s, Mielnik et al. put forward the carbon emission amount of a unit energy which is a standard to evaluate the developing countries in tackling the climate change patterns, based on which the empirical analysis on carbon emission situation is carried out [3]; when stressing the study on climate change, Ang



thought that the change in energy consumption of unit GDP which can generally represent the carbon emission situation may be regarded as a measurement index [4]. Sun held the opinion that carbon emission of unit GDP was the most effective index to evaluate the carbon emission reduction [5]. After systematically reviewing the advantages and disadvantages of the existing carbon emission efficiency calculation indexes, Zhang thought that the indexes of per capita unit GDP emission and industrialized accumulated per capita emission are more scientific and reasonable, and he compared the calculation results of the representative countries [6]. Most of the above-mentioned indexes, expressed as the ratio of total carbon emission amount to a specific element, are easy to be comprehended and handled. However, as the carbon emission efficiency is affected by many aspects including energy consumption and economic development, the index system with related aspects is more proper. In view of the characteristic, the data envelopment analysis (DEA) is widely used for measuring the efficiency by scholars. After clarifying the four indexes related to carbon emission, Ramanathan used DEA, by which the carbon emission efficiency of 17 countries in the Middle East and North Africa were acquired, to find that the global carbon emission efficiency fluctuates along with time [7]. Zofio also used DEA to evaluate the carbon emission efficiency of the countries and regions of OECD [8]. Zhou selected four related indexes based on environmental DEA, to measure the reduction performance of the top 18 carbon emission countries in the world [9]. Wang used DEA of undesirable output to build Malmquist Index to evaluate the carbon emission performance of 28 provinces of China in 1996-2007 [10]. Later, Li Tao used Ruggiero Three-stage Model to calculate the carbon emission efficiency of 29 provinces of China in 1998-2008 [11]. In the same year, Du Kerui used stochastic frontier analysis which is another efficiency calculation method, to calculate the carbon emission efficiency of each region in China in 1995-2009, by which it's found that the regional difference is obvious [12]. Zhong et al. used linear data transformation function based on BCC-DEA Model and Malmquist Index, to process the carbon emission data, and then to measure the carbon emission efficiency of 29 provinces of China in 1995-2009, by which it's found that the efficiency declines year by year and that regional characteristics are apparent [13]. Cao Ke et al. calculated the carbon emission efficiency of 30 provinces of China in 1995-2010 under the framework of total element, and thus analyzed the factors driving carbon reduction potential, carbon reduction scale, and performance change [14].

According to the existing studies, the domestic and foreign studies focus on different aspects. The foreign studies pay more attention to the selection of evaluation indexes, while the domestic studies attach more importance to the application of models. Currently, the following limits exist in the study. (1) Both the domestic and foreign scholars have measured the carbon emission efficiency from different angles mainly by means of DEA; however, the calculation results vary a lot with the different indexes selected; moreover, most studies simply focus on the overall situation or industrial angle, while few studies focus on regional efficiency or regional contrast. (2) The traditional DEA includes reciprocal transformation, undesirable output as input and linear transformation, which may usually been used for handling the undesirable output like carbon emission, neglects the looseness of output and input, which will affect the reliability of the result, so it's not applicable. In this paper, after the carbon emission efficiency of 30 provinces of China in 2006-2015 is calculated, the east, west and central regions of China are selected as the study object. Then the SBM is used for measuring the agricultural carbon emission efficiency and exploring the improvement direction. Studies related to agricultural carbon emission efficiency may be supplemented. It may provide some references for making rational policies on agricultural carbon emission reduction.

2. Study method and data source

2.1. SBM under the undesirable outputs

As agricultural carbon emission is an undesirable output, slack based measure under the undesirable outputs is proper. The model, improving the traditional DEA and involving the slack variables in the objective function, may scientifically process the undesirable output and also avoid the looseness between output and input [15-16]. In view of the processing method proposed by Wang Bing et al. [17],

this paper adopts SBM under the undesirable outputs to calculate the agricultural carbon emission efficiency.

The model assumes that the production system has n decision-making units (DMU). Each DMU contains m inputs, s_1 desirable outputs and s_2 undesirable outputs, which are expressed as $x \in \mathbf{R}_+^m$, $y^g \in \mathbf{R}_+^{s_1}$ and $y^b \in \mathbf{R}_+^{s_2}$, respectively. We can define three matrices, $X = [x_1, \dots, x_n] \in \mathbf{R}_+^{m \times n}$, $Y^g = [y_1^g, \dots, y_n^g] \in \mathbf{R}_+^{s_1 \times n}$ and $Y^b = [y_1^b, \dots, y_n^b] \in \mathbf{R}_+^{s_2 \times n}$, which fulfill $X > 0$, $Y^g > 0$ and $Y^b > 0$, correspondingly. The production possible set is:

$$P = \{(x, y^g, y^b) | x \geq X\lambda, y^g \leq Y^g\lambda, y^b \geq Y^b\lambda, \lambda \geq 0\} \quad (1)$$

In equation (1), λ is a non-negative weight vector in $\mathbf{R}_+^n$. For a certain DMU, SBM under the undesirable outputs can be expressed as the following linear programming issue:

$$\rho^* = \min \frac{1 - \frac{1}{m} \sum_{i=1}^m \frac{s_i^-}{x_{0,i}}}{1 + \frac{1}{s_1 + s_2} \left(\sum_{r=1}^{s_1} \frac{s_r^g}{y_{0,r}^g} + \sum_{r=1}^{s_2} \frac{s_r^b}{y_{0,r}^b} \right)}$$

$$\text{s. t. } \begin{cases} x_0 = X\lambda + s^- \\ y_0^g = Y^g\lambda + s^g \\ y_0^b = Y^b\lambda + s^b \\ s^- \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0 \end{cases} \quad (2)$$

In Equation (2): x_0 , y_0^g and y_0^b are the input, the desirable output and the undesirable output of this DMU, respectively. s_i^- , s_r^g and s_r^b are the corresponding slack variables. s^- , s^g and s^b are weight vectors. ρ^* is the objective function value, i.e. CLUE in this study; y_0^g and y_0^b represent the desirable and undesirable output, respectively. ρ^* decreases monotonically about s^- , s^g and s^b , and meets the condition $0 \leq \rho^* \leq 1$. When $\rho^* = 1$, i.e. $s^- = 0$, $s^g = 0$ and $s^b = 0$, the DMU is efficient; Otherwise, it is inefficient, whose inputs or outputs need to be optimized.

2.2. Index selection and data source

In view of the existing studies, this paper divides the input of agricultural production into labor, land, capital and fertilizer, and divides the output into desirable output and undesirable output. See the index system in Table 1.

Table 1. Indexes of input and output for calculating agricultural carbon emission efficiency

Input index		Output index	
Labor input	Number of agricultural employee (10 thousand people)	Desirable output	Added value of agriculture (0.1 billion CNY)
Land input	Sown area of farm crop (thousand hectares)	Undesirable output	Agricultural carbon emission (10 thousand tons)
Capital input	Input of agricultural capital (0.1 billion CNY)		
Fertilizer input	Consumption of chemical fertilizer (10 thousand tons)		

The existing calculation of agricultural carbon emission usually divides the sources of agricultural carbon emission into several parts. The first part is the carbon emission brought by farmland use,

including the carbon emission caused by the input of agricultural materials like fertilizer, pesticide and agricultural film, the loss of organic carbon caused by the destroyed surface soil which is turned over for many times, and the carbon emission caused by the indirect cost of fossil fuel due to electricity utilization during irrigation. The second part is the carbon emission brought by agricultural energy consumption. The third part is the carbon emission brought by raising ruminant animals, including the methane emission caused by enteric fermentation and manure management. The total amount of agricultural carbon emission equals to the sum of that brought by the three parts of source. See the related coefficients in the study carried out by Duan et al. [18], Min et al. [19], and IPCC [20].

In order to compare the capital input and added value of agriculture of each year, the data are deflated in this paper, for the purpose of getting rid of the influence from price and other factors. The corresponding values of each year are converted to actual values based on comparable prices of 2006, which are regarded as the desirable output variable.

The data are sourced from *China Statistical Yearbook*, *China Rural Statistical Yearbook*, *China Energy Statistical Yearbook*, and statistical data from the statistical bureau of each province. Most data of Hong Kong, Macao, Taiwan and Tibet are lost, so they are not involved herein. Finally, the panel data about 30 provinces of Chinese Mainland in 2006-2015 take shape.

3. Empirical analysis

3.1. Calculation of agricultural carbon emission efficiency

3.1.1. Agricultural carbon emission efficiency of east, central and west regions. The agricultural carbon emission efficiency of each region of China is calculated by means of SBM under the undesirable output, based on which analysis is performed from four angles, namely, mean value, standard deviation, efficiency and change rule of each province.

Table 2. Calculation result of agricultural carbon emission efficiency of east region

Year	Shanghai	Beijing	Tianjin	Shandong	Guangdong	Guangxi	Jiangsu	Hebei	Zhejiang	Hainan	Fujian	Liaoning	Standard deviation
2006	1.000	1.000	0.788	0.600	1.000	0.452	1.000	0.480	1.000	1.000	1.000	0.768	0.218
2007	1.000	1.000	0.654	0.622	1.000	0.480	1.000	0.483	1.000	1.000	1.000	0.682	0.222
2008	1.000	1.000	0.611	0.736	1.000	0.491	1.000	0.627	1.000	1.000	1.000	0.777	0.193
2009	1.000	1.000	0.474	1.000	0.723	0.417	1.000	0.688	1.000	1.000	1.000	1.000	0.224
2010	1.000	1.000	0.472	1.000	0.742	0.398	1.000	0.761	1.000	1.000	1.000	1.000	0.222
2011	1.000	1.000	0.438	1.000	0.608	0.351	1.000	0.855	1.000	1.000	1.000	0.722	0.243
2012	1.000	1.000	0.385	1.000	0.561	0.346	1.000	0.917	1.000	1.000	1.000	0.633	0.261
2013	0.539	1.000	0.382	1.000	0.582	0.350	1.000	1.000	1.000	1.000	1.000	0.677	0.268
2014	0.441	1.000	0.418	1.000	0.549	0.325	1.000	1.000	1.000	1.000	1.000	0.672	0.279
2015	0.502	1.000	0.428	1.000	0.590	0.338	1.000	1.000	1.000	1.000	1.000	0.670	0.266
Average	0.849	1.000	0.505	0.896	0.736	0.395	1.000	0.781	1.000	1.000	1.000	0.760	0.205

Table 2 shows that, in terms of the mean value, the overall efficiency of the east region is excellent, as the mean value of agricultural carbon emission efficiency of most provinces is larger than 0.7; in terms of the standard deviation, the difference among provinces is obvious, as the standard deviation fluctuates about 0.2. According to the performance of each province, the agricultural carbon emission efficiency of Hainan, Beijing, Jiangsu, Zhejiang and Fujian which are well developed in modern agriculture is obviously high. Even though Hainan still stayed at the developing stage of modern agriculture, it had realized some efficiency, as the relative efficiency involved scale and technology. Guangxi is the province with the lowest efficiency, with merely 0.395 of average efficiency, so its input and output should be improved. As for the change rule of carbon emission efficiency of each province, the efficiency of Shandong and Hebei rose somewhat from 2006 to 2015, among which the efficiency of Shandong increased by 0.520 that was the largest; that of Tianjin, Guangdong and Liaoning decreased

dramatically, which should be noticed; and that of Beijing, Hainan, Jiangsu, Zhejiang and Fujian remained high in the sample years, which showed a good development trend.

Table 3 shows the calculation result of agricultural carbon emission efficiency of each province in the central region in 2006-2015.

Table 3. Calculation result of agricultural carbon emission efficiency of central region

Year	Inner Mongolia	Jilin	Anhui	Shanxi	Jiangxi	Henan	Hubei	Hunan	Heilongjiang	Standard deviation
2006	0.423	0.466	0.383	0.301	0.428	0.482	0.556	0.439	0.334	0.077
2007	0.379	0.458	0.360	0.261	0.434	0.424	0.501	0.493	0.318	0.081
2008	0.417	0.473	0.400	0.256	0.484	0.425	0.535	0.593	0.349	0.100
2009	0.380	0.430	0.314	0.183	0.400	0.349	0.488	0.477	0.321	0.094
2010	0.359	0.460	0.333	0.339	0.385	0.349	0.467	0.456	0.317	0.060
2011	0.341	0.372	0.301	0.320	0.336	0.329	0.451	0.396	0.281	0.052
2012	0.339	0.360	0.286	0.253	0.324	0.287	0.453	0.384	0.297	0.061
2013	0.346	0.377	0.294	0.245	0.332	0.303	0.472	0.394	0.354	0.065
2014	0.340	0.345	0.270	0.244	0.331	0.289	0.594	0.370	0.478	0.110
2015	0.313	0.331	0.276	0.243	0.345	0.281	0.577	0.372	0.496	0.110
Average	0.364	0.407	0.322	0.265	0.380	0.352	0.509	0.437	0.355	0.070

As shown in Table 3, in terms of the mean value, the overall efficiency of agricultural carbon emission of the central region is not high, as the mean value of agricultural carbon emission efficiency of most provinces is 0.3-0.5. In terms of the standard deviation, the gap among provinces in agricultural carbon emission is small. The corresponding standard deviation of each year is lower than 0.1, and it tends to decline along with time, which means that the difference within the region is reduced. According to the efficiency performance of each province, the mean efficiency of just Jilin and Hubei is higher than 0.5, and that of Hubei is just 0.509 which is the highest mean value among the provinces in Central region. The province with the lowest efficiency is Shanxi whose agricultural carbon emission efficiency of most years was lower than 0.3, and even as low as 0.183 in 2009. As for the change rule of carbon emission efficiency of each province with regard to 2006 and 2015, the agricultural carbon emission efficiency of just Hubei and Heilongjiang increased slightly, while that of other provinces declined to different extent.

Table 4 shows the calculation result of agricultural carbon emission efficiency of each province in the west region in 2006-2015.

Table 4. Calculation result of agricultural carbon emission efficiency of west region

Year	Yunnan	Sichuan	Ningxia	Xinjiang	Gansu	Guizhou	Chongqing	Shaanxi	Qinghai	Standard deviation
2006	0.352	0.581	0.201	0.516	0.314	0.334	0.485	0.350	0.409	0.117
2007	0.364	0.545	0.196	0.450	0.289	0.353	0.332	0.345	0.344	0.097
2008	0.364	0.631	0.215	0.500	0.320	0.407	0.403	0.419	1.000	0.228
2009	0.305	0.487	0.207	0.422	0.281	0.313	0.350	0.507	1.000	0.235
2010	0.299	0.458	0.227	0.462	0.285	0.295	0.337	0.394	1.000	0.233
2011	0.237	0.406	0.233	1.000	0.271	0.260	0.308	0.477	1.000	0.313
2012	0.268	0.424	0.220	0.416	0.252	0.238	0.312	0.549	1.000	0.247
2013	0.306	0.456	0.224	0.449	0.274	0.326	0.331	0.510	1.000	0.233
2014	0.273	0.420	0.228	0.476	0.265	0.311	0.339	0.528	1.000	0.238
2015	0.274	0.434	0.228	0.474	0.259	0.389	0.345	0.539	1.000	0.235
Average	0.304	0.484	0.218	0.517	0.281	0.323	0.354	0.462	0.875	0.197

As shown in Table 4, in terms of the mean value, the overall efficiency of agricultural carbon emission of the west region was low, as the mean value of most provinces was 0.3-0.5, while the overall

efficiency of the West was slightly higher than that of the Central in the later period. In terms of the standard deviation, it fluctuated greatly in the sample years, and the difference among each province was obvious. According to the efficiency performance of each province in the West, the mean efficiency of just Qinghai and Xinjiang is higher than 0.5, and that of Qinghai reaches 0.875 which is the highest. Moreover, since 2008, the efficiency of Qinghai remained 1.000 at the production frontier, showing a good development trend. The province with the lowest efficiency was Ningxia whose agricultural carbon emission efficiency in the sample years was lower than 0.3, and even as low as 0.2 in 2007; and the agricultural carbon emission efficiency of Gansu was also lower than 0.3, as its efficiency remained about 0.3 in early years but declined to 0.25 in recent years. As for the change rule of carbon emission efficiency, the agricultural carbon emission efficiency of Qinghai, Shaanxi, Ningxia and Guizhou increased somewhat; in particular, that of Qinghai increased by 0.591, and remained stable, which means that the input and output of agricultural carbon emission efficiency is continuously improving; in other provinces in the west region, the efficiency declined to different extent, but the falling range of most provinces was lower than 0.1.

Among the 30 provinces, the carbon emission efficiencies of 8 provinces in most years were 1.000, which means that the 8 areas had optimum input and output that effectively considered agricultural development and carbon emission control. Among the 22 inefficient provinces, the efficiencies of Shandong, Hebei and Liaoning lied between 0.5 and 1, which means that implementing more improvement on their input and output would realize effectiveness. The efficiency of Shandong had remained at the production frontier since 2008, showing a good development trend. By contrast, the agricultural carbon emission efficiencies of Yunnan, Sichuan and Jiangxi were relatively low, averaging between 0.3 and 0.6, which means that it could be improved. The last three provinces with regard to the efficiency are Ningxia, Shanxi and Gansu. The agricultural carbon emission efficiency of Ningxia in the sample years was lower than 0.3, and that of Shanxi and Gansu in more than half of sample years was lower than 0.3. It means that all of the three provinces were inefficient regions. In order to realize the optimum agricultural carbon emission efficiency, their input and output must be improved.

3.1.2. Comparative analysis on regional agricultural carbon emission efficiency. According to the arithmetic mean efficiency of each province in the sample years, the efficiencies of 12 provinces including Beijing and Hainan were higher than the national average, while those of 18 provinces including Yunnan and Guizhou were lower than the national average. Thus, the provinces with high efficiency were in the east, while most provinces with low efficiency were in the west and central part. Do obvious differences exist in the efficiency among regions? How does the efficiency of each region tend to develop? In order to answer the above questions, the average efficiency and standard deviation of agricultural carbon emission in the three regions were calculated herein. See more details in Table 5.

Table 5. Average efficiency and standard deviation of agricultural carbon emission of east, central and west regions

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
East	0.793	0.780	0.803	0.810	0.815	0.786	0.777	0.754	0.745	0.753
Central	0.389	0.371	0.403	0.344	0.353	0.318	0.304	0.318	0.337	0.334
West	0.366	0.332	0.449	0.411	0.399	0.451	0.393	0.411	0.408	0.418
Standard deviation	0.240	0.248	0.219	0.252	0.255	0.241	0.251	0.229	0.218	0.222

According to the standard deviation of the three regions shown in Table 5, the overall gap tends to be enlarged with fluctuations, as the standard deviation corresponding to 2006 was 0.240, while it decreased to 0.222 in 2015. It's reckoned that the continuously enlarged gap is derived from the different development modes in different regions. As the east region owns the latest agricultural technology and a large amount of capital which helps to realize emission reduction in agricultural production and attaches more importance to resources and environment protection, its development mode is relatively

sustainable. However, due to the restriction of geography and agricultural technology level, the agricultural development mode of the central and west regions is relatively extensive, which results in low efficiency in agricultural carbon emission, great consumption of resources, and severe pollution of environment. In particular, in view of the recent development trend of the central region, its efficiency will further decline without any measures to be taken.

3.2. Analysis on input-output efficiency

In SBM, the input-output looseness may reflect the reasons for low efficiency of agricultural carbon emission, which will provide the basis for improving the efficiency. In view of the hypothesis that the latest sample might reflect the current situation best, the sample in the year of 2015 which is the latest data is studied. The redundancy rate of input is obtained by dividing the input looseness of each region by the corresponding input index value; the redundancy rate of agricultural carbon emission is obtained by dividing the looseness of agricultural carbon emission by the corresponding agricultural carbon emission amount; and the output inefficiency rate of added value of agriculture is obtained by dividing the looseness of added value of agriculture by the corresponding input.

3.2.1. Analysis on input-output efficiency of agricultural carbon emission of each province. Table 6 presents the input-output efficiency of agricultural carbon emission of each province in 2015.

According to Table 6, the redundancy rates of agricultural added output value of all provinces are zero, while redundancy exists in both the input element and agricultural carbon emission. It means that the inefficiency in agricultural carbon emission of China is not brought by insufficient agricultural output, but by resource input and undesirable output, namely, excessive resource consumption and agricultural carbon emission.

In the east region, the efficiencies of Guangxi and Tianjin rank last, with severe waste of input. The redundancy rates of agricultural labor input, agricultural capital input and agricultural acreage of Guangxi are above 50%; though the input of other indexes of Tianjin is controlled well, the redundancy rate of agricultural capital input is as high as 94.6%, which is quite noticeable. The input and output of other provinces perform relatively well, and they may reach production frontier with certain improvements.

In the central region, the last three provinces with the lowest efficiency are Shanxi, Anhui and Henan. The redundancy rate of agricultural capital input of Shanxi reaches 95.3%, the highest among the 30 provinces, and that of agricultural acreage is larger than 70%; and the redundancy rates of agricultural capital input and agricultural acreage of Anhui and Henan fluctuate between 70% and 80%. The redundancy rates of agricultural capital input of all provinces in the central region are above 60%, and those of agricultural acreage of other provinces than Hubei and Heilong are also very high. To realize the optimum agricultural carbon emission efficiency, the Central region should carry out further improvements.

In the west region, Ningxia, Gansu and Yunnan are the provinces with the lowest efficiency. The redundancy rates of agricultural capital input and agricultural acreage of Ningxia are higher than 80%, along with 55.5% of undesirable output redundancy; the redundancy rates of agricultural capital input and agricultural acreage of Gansu are as high as 87.6% and 76.9%, respectively, and that of the agricultural labor input is higher than 60%; the redundancy rates of agricultural capital input and agricultural acreage of Yunnan are higher than 70%. The similar redundancy of the three provinces indicates that improving the use efficiency of agricultural capital and agricultural acreage is quite necessary to improve the agricultural carbon emission efficiency in the West.

Table 6. Input-output efficiency of agricultural carbon emission of each province

	Decision-making unit	Agricultural carbon emission efficiency	Input redundancy				Undesirable output redundancy	Desirable output inefficiency
			Agricultural labor	Agricultural capital input	Consumption of chemical fertilizers	Agricultural acreage	Agricultural carbon emission	Added value of agriculture
East	Shanghai	0.502	20.3%	38.3%	24.7%	32.8%	48.9%	0.0%
	Beijing	1.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Tianjin	0.428	17.7%	94.6%	48.6%	56.6%	9.4%	0.0%
	Shandong	1.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Guangdong	0.590	34.9%	49.7%	22.8%	29.5%	20.0%	0.0%
	Guangxi	0.338	52.7%	77.7%	43.2%	57.0%	44.5%	0.0%
	Jiangsu	1.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Hebei	0.745	8.3%	49.9%	13.5%	27.0%	0.0%	0.0%
	Zhejiang	1.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Hainan	1.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Fujian	1.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
	Liaoning	0.670	3.0%	79.3%	5.8%	40.4%	0.3%	0.0%
Central	Inner Mongolia	0.313	21.3%	91.7%	56.0%	76.8%	40.5%	0.0%
	Jilin	0.331	21.3%	85.3%	58.9%	71.1%	41.1%	0.0%
	Anhui	0.276	51.3%	78.8%	56.8%	71.4%	49.0%	0.0%
	Shanxi	0.243	64.4%	95.3%	58.9%	77.4%	7.4%	0.0%
	Jiangxi	0.345	39.9%	75.0%	27.9%	67.8%	68.6%	0.0%
	Henan	0.281	55.4%	82.0%	64.1%	69.4%	23.5%	0.0%
	Hubei	0.577	0.0%	63.8%	32.4%	38.5%	26.6%	0.0%
	Hunan	0.372	45.1%	77.1%	21.7%	61.5%	56.2%	0.0%
	Heilongjiang	0.496	0.0%	74.5%	14.3%	59.1%	50.4%	0.0%
West	Yunnan	0.274	64.4%	77.5%	46.9%	70.9%	48.7%	0.0%
	Sichuan	0.434	47.7%	66.4%	14.7%	61.6%	37.1%	0.0%
	Ningxia	0.228	43.0%	89.9%	65.6%	81.1%	55.5%	0.0%
	Xinjiang	0.474	0.0%	65.5%	55.8%	62.7%	23.9%	0.0%
	Gansu	0.259	61.8%	87.6%	42.8%	76.9%	45.5%	0.0%
	Guizhou	0.389	66.0%	45.0%	23.1%	75.5%	39.7%	0.0%
	Chongqing	0.345	46.2%	85.2%	34.2%	68.6%	35.0%	0.0%
	Shaanxi	0.539	27.4%	58.0%	50.8%	44.8%	0.0%	0.0%
	Qinghai	1.000	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

3.2.2. *Analysis on input-output efficiency of China and its east, central and west regions.* Table 7 shows the input and output of agricultural carbon emission of China and its east, central and west regions in 2015, so as to acquire the reasons for efficiency loss of China and each region.

According to the national average input-output redundancy rate shown in Table 7, the indexes to be improved are agricultural capital input, agricultural acreage and consumption of chemical fertilizers in descending order. The redundancy of agricultural capital input has the largest influence on the inefficiency of agricultural carbon emission of China, with 56.3% of average redundancy rate, which indicates the problems of low efficiency of agricultural investment and blindness in investment existing in China. The land input has the second largest influence on the loss of agricultural carbon emission efficiency, with 46.9% of average redundancy rate, which means that the agricultural acreage of China may not be made efficient use, possibly due to the small-scale land management and extensive business mode of most regions in China. Meanwhile, a number of chemical fertilizers are wasted due to the unscientific fertilization pattern practiced by the farmers in some regions, and thus the consumption of chemical fertilizers becomes the third largest factor influencing the loss of agricultural carbon emission efficiency, with 29.5% of average redundancy rate.

Table 7. Input and output of agricultural carbon emission efficiency of China and its east, central and west regions

Decision-making unit	Agricultural carbon emission efficiency	Input redundancy				Undesirable output redundancy	Desirable output inefficiency
		Agricultural labor	Agricultural capital input	Consumption of chemical fertilizers	Agricultural acreage	Agricultural carbon emission	Added value of agriculture
East	0.773	11.4%	32.5%	13.2%	22.8%	10.3%	0.0%
Central	0.367	33.2%	80.4%	43.4%	65.9%	40.4%	0.0%
West	0.438	39.6%	63.9%	37.1%	60.2%	31.7%	0.0%
China	0.548	26.4%	56.3%	29.5%	46.9%	25.7%	0.0%

In different regions, differences exist in the main improvement direction of element input.

In the east region, the input redundancy rate is below 40%. The first element to be improved is agricultural capital input with 32.5% of average input redundancy rate, followed by agricultural acreage with 22.8% of average input redundancy rate, and then agricultural labor input and consumption of chemical fertilizers with 11.4% and 13.2% of average input redundancy rate, respectively. The undesirable output redundancy rate is just 10.3%, which means that the undesirable output is controlled well and desirable output inefficiency doesn't exist. In the central region, the input redundancy rate is the highest among the three regions, with 80.4% of agricultural capital input redundancy rate, over 60% of agricultural acreage redundancy rate, and some waste in agricultural labor input and chemical fertilizer consumption. The undesirable output redundancy rate is 40.4%, the highest among the three regions. In the west region, the input redundancy rate is relatively high, with two indexes above 60% of redundancy rate, and redundancy also exists in other inputs, along with excessive undesirable output. The first element to be improved is agricultural capital input with 63.9% of redundancy rate, followed by agricultural acreage with 60.2% of redundancy rate, and then agricultural labor input and consumption of chemical fertilizers with 39.6% and 37.1% of redundancy rate, respectively. Along with the output of every unit, 31.7% of redundancy is generated in agricultural carbon emission.

To sum up, in terms of the national and regional level, agricultural capital input is the index that should draw most attention. Redundancy of agricultural capital input exists in all the inefficient decision-making units somewhat, even in the east region which stays at the production frontier. The redundancy rate of Tianjin even reaches 90%, which means that the efficiency of agricultural investment in China is quite low. In recent years, China has provided more and more financial and political support for agricultural investment, so the investors become more and more enthusiastic. However, most investors have little knowledge about agriculture, and their blindness in investment leads to redundancy of agricultural capital input. Besides, the redundancy of agricultural acreage input should also be improved. Excessive land input and inefficient use exist in the central and west regions including Yunnan, Ningxia, Shaanxi, Guizhou, Inner Mongolia and Gansu, which results in severe land resource waste. It's supposed that the small scale of land management, low degree of land intensification and extensive production result in low efficiency of land use, and thus redundancy in land input comes into being. Reducing the blind investment in agricultural capital and increasing the land use rate are the key steps to improve the agricultural carbon emission efficiency in the three regions.

4. Conclusion and suggestion

Obvious difference exists in the agricultural carbon emission efficiency among the regions, and the overall difference remains stable. The agricultural carbon emission efficiencies of China and east region fluctuate about 0.6 and 0.8, respectively, and those of the central and west region fluctuate between 0.3 and 0.5. Among the three regions, the efficiency of east region is far ahead; that of west region is being improved even though it was the worst at the beginning; and that of central region lies between that of the east and west regions, but declining to the last place in recent years. It's found that redundancy exists

in the agricultural carbon emission of every inefficient unit. The redundancy rates of agricultural capital input of almost the three regions are very high. The provinces with relatively high redundancy rate of farmland input are basically located in the central and west regions. Therefore, the following suggestions are proposed herein.

(1) The total amount of agricultural carbon emission should be controlled based on different local conditions. Based on the differences in agricultural development condition and resource endowment as well as the characteristics of spatial distribution of agricultural carbon emission, the measures and policies on low-carbon agriculture development should be established and implemented according to circumstances, and the different correlation features of agricultural carbon emission and influencing factors of each region should be considered as a whole. The common but differentiated principles on emission reduction should be insisted, and the agricultural emission reduction objectives should be worked out. In particular, in the region where agricultural carbon emission is excessive, strict emission reduction tasks should be planned, and technologies on agricultural carbon emission reduction should be introduced actively, so as to realize the overall emission reduction of China.

(2) Differentiated production mode should be adopted according to the agricultural carbon emission efficiency. As the efficiency of east region is relatively high, the allocation of production materials should be further optimized based on maintaining the high efficiency, and it should do all efforts to catch up with the production frontier. As the central and west regions cover many big agricultural provinces, the agricultural carbon emission is inevitable, and the excessive undesirable output results in low efficiency. However, in Shandong which is also a big agricultural province, the agricultural carbon emission efficiency is 1.000, which means that the allocation of production materials is quite efficient and that no redundancy exists. It may set an example for other big agricultural provinces to improve their efficiency.

(3) The redundancy of input and undesirable output should be highlighted. The redundancy of agricultural capital input is severe, which alerts that the blind investment in agriculture should be brought down. The related departments should establish and cultivate complete and practical agricultural business and skill training platform, for the purpose of providing intellectual capital to agricultural investment. The redundancy of land input indicates that the use efficiency of farmland is relatively low, which requires changing the traditional and small-scale agriculture and promoting the large-scale use of farmland and industrialization of agriculture. For the redundancy of undesirable output, the key lies in source control, and animal husbandry and crop farming are the main sources of agricultural carbon emission. The calculation result shows that the carbon emission brought by enteric fermentation and manure management due to raising ruminant animals in some provinces equals to a half of the total amount of agricultural carbon emission. Thus, the manure management should be enhanced, and the technology of emission reduction and the development mode of husbandry-farming combination should be further explored. The husbandry-farming circulation technology, large-scale husbandry management technology, livestock and poultry feed R&D technology, and fecal treatment technology should be further innovated, in order to increase the feed use rate, reduce the husbandry waste pollution and enhance the husbandry waste reuse.

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