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Carbon Emission Reduction Potential Dataset Balancing per Capita and Benefit in Each Province of China

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Abstract: We developed a dataset on the potentialities of carbon emission reduction and the emissions efficiency metadata extracted for 29 provinces in China. The data were obtained from the *China Statistical Yearbook*, the *China Energy Statistical Yearbook*, and the China Stock Market & Accounting Research Databases for the period of 1997–2015. Hainan, Tibet, Hong Kong, Macao, and Taiwan were not included in the dataset because of incomplete data. Firstly, we converted the fixed capital generated over the study period into uniform values with reference to the constant price in 1952 using an implicit investment deflator in each province. Secondly, referring to the set depreciation rate and the base period capital stock, we applied the perpetual inventory method to estimate annual capital stocks. Actual GDPs, with reference to the 1952 baseline value, were calculated by dividing the nominal GDP values of the provinces for the period of 1997–2015 by the 1952-based GDP deflator. Total carbon emissions for each province were calculated from fossil fuel combustion and cement consumption values along with associated carbon emission coefficients. These values were then divided by the value for the total provincial population recorded at the end of the year to calculate per capita carbon emission values. In our study, carbon dioxide emissions resulted from the growth of each unit of GDP were considered to reflect the carbon emission intensity. Accordingly, we applied the Super-SBM model to measure carbon emission efficiency levels. We measured the equity of regional carbon emissions based on per capita carbon emissions. Finally, we used the Markov model to calculate the club convergence index of carbon emission efficiency and fairness to assess their importance in relation to China's carbon reduction potential, with an emphasis on carbon emissions. The dataset contains 10 tables depicting the following categories of annual provincial-level data for the period of 1997–2015: (1) annual capital stocks; (2) annual GDP values with reference to baseline statistics for 1952; (3) annual per capita carbon emissions; (4) annual carbon emission intensity; (5) carbon emission efficiency calculated using the Super-SBM model; (6) energy consumption; (7) Markov transfer probability results for per capita carbon emissions and carbon emission efficiency in China; (8) a club convergence index model of per capita emissions and the efficiency of regional carbon emission reduction for different temporal durations; (9) difference test of regional solidification degree based on the results of re-

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gional per capita carbon emissions and carbon emission efficiency; and (10) estimation results for the carbon emission reduction potentials of provinces in China based on levels of coordination of per capita and efficiency. The dataset was archived in one data file in .xlsx format, with the data size of 134 KB. The research analysis related to the dataset was published in the *Journal of Natural Resources* (Vol. 34, No.1, 2019).

Keywords: carbon reduction potential; per capita carbon emissions; carbon emission efficiency; China; Journal of Natural Resources

1 Introduction

China's GDP has increased by about 50% since the implementation of the 12th Five-Year Plan. Excessive CO_2 emissions which are accompanied with this rapid economic growth have emerged as an increasingly urgent issue. To achieve the UN Sustainable Development Goals and to safeguard the welfare of the population, the Chinese government has announced a carbon emission intensity reduction target of 60%–65% of CO_2 emissions per unit of GDP compared with the emission level in 2005. Under existing constraints, the development of a more accurate method for measuring the carbon emission reduction potential and a more harmonious planning of carbon emission path can facilitate a more rational and scientific regional emission reduction policy. This study aimed to contributing theoretical inputs for establishing and improving the economic system with a green and low-carbon development cycle, thereby enabling the compelling vision of clear waters and lush mountains, considered as invaluable assets, to be achieved. Current research on the reduction of carbon emissions has mainly focused on three core principles: the fairness of carbon emissions[1–3], the efficiency of carbon emissions[4–8], and a dual principle with a combination of both principles[9–11]. Studies conducted from a singular perspective[1–8] do not allow for a comprehensive consideration. Some studies have adopted the principles of fairness and efficiency of carbon emissions[9–11], but they have ignored significant variations relating to carbon reduction potential. Consequently, the measurements applied may not be sufficiently scientific and rigorous, which may reduce the value and effectiveness of the policy inputs. To address this gap, we used provincial-level data to calculate the club convergence index of carbon emission fairness and efficiency in 29 provinces of China for the period of 1997–2015. We subsequently compared the importance of applying these two principles in relation to carbon emissions and assessed the extent of their coordination. The dataset can provide reference for the Chinese government when making the allocation of carbon rights and the sharing of responsibility for reducing emissions within the country.

2 Metadata of Dataset

Table 1 presents a metadata summary of the dataset[12], including the dataset full name, short name, authors, year of the dataset, data format, data size, data files, data publisher, and data sharing policy, etc.

3 Methods

Based on the data for 29 provinces from 1997 to 2015, we measured the efficiency of carbon emissions using the Super-SBM model, and the equity of regional carbon emissions on the basis of per capita carbon emissions. Finally, we applied the Markov model to calculate the club convergence index of carbon emission efficiency and fairness and subsequently assessed their importance with regard to China's carbon reduction potential, with an emphasis on carbon emissions.

Table 1 Metadata summary of "Potentialities dataset of carbon emission reduction based on per capita and efficiency in provincial level of China"

Items	Description
Dataset full name	Potentialities dataset of carbon emission reduction based on per capita and efficiency in provincial level of China
Dataset short name	C_EmissionReduction_ProvChina
Authors	Zhou, D. AAG-1775-2019, Institute of Studies for the Great Bay Area, Guangdong University of Foreign Studies, zhoudi19880101@163.com Hua, S. R. AFF-8627-2019, School of Economics and Trade, Guangdong University of Foreign Studies, hsharon09@163.com
Geographical region	29 provinces in China (excluding Hainan, Tibet, Hong Kong, Macau, and Taiwan)
Year	1997–2015
Data format	.xlsx Data size 134 KB
Data files	The following categories of annual data from 29 provinces in China are included in the dataset for the period of 1997–2015: (1) annual capital stocks; (2) annual GDP data with reference to baseline statistics for 1952; (3) annual per capita carbon emissions; (4) annual carbon emissions intensity; (5) carbon emission efficiency calculated using the Super-SBM model; (6) energy consumption; (7) per capita carbon emissions and carbon emission efficiency in China calculated using the Markov transition probability matrix; (8) a club convergence index model of per capita carbon emissions and the efficiency of regional carbon emission reduction under periods of varying duration; (9) difference test of regional solidification degree based on the results of regional per capita carbon emissions and carbon emission efficiency; and (10) estimation results for the carbon emission reduction potentials of provinces in China according to levels of coordination between per capita carbon emissions and carbon emission efficiency
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Data publisher	Global Change Research Data Publishing & Repository, http://www.geodoi.ac.cn
Address	No. 11A, Datun Road, Chaoyang District, Beijing 100101, China
Data sharing policy	***Data*** from the Global Change Research Data Publishing & Repository includes metadata, datasets (data products), and publications (in this case, in the *Journal of Global Change Data & Discovery*). ***Data*** sharing policy includes: (1) ***Data*** are openly available and can be free downloaded via the Internet; (2) End users are encouraged to use ***Data*** subject to citation; (3) Users, who are by definition also value-added service providers, are welcome to redistribute ***Data*** subject to written permission from the GCdataPR Editorial Office and the issuance of a ***Data*** redistribution license; and (4) If ***Data*** are used to compile new datasets, the 'ten percent principal' should be followed such that ***Data*** records utilized should not surpass 10% of the new dataset contents, while sources should be clearly noted in suitable places in the new dataset[13]
Communication and searchable system	DOI, DCI, CSCD, WDS/ISC, GEOSS, China GEOSS

3.1 Data Collection

We developed a dataset on the potentialities of carbon emission reduction in China. The data of 29 provinces for the period of 1997–2015 were sourced from the *China Statistical Yearbook*, the *China Energy Statistical Yearbook*, and China Stock Market & Accounting Research Databases. Hainan, Tibet, Hong Kong, Macao, and Taiwan were not included in the dataset because of incomplete data. Drawing on Shan's[14] methodology, we converted the fixed capital generated over the study period into uniform values with reference to the constant price in 1952 using an implicit investment deflator in each province. Then we applied the perpetual inventory method to estimate annual capital stocks based on the set depreciation rate and the base period capital stock. Actual GDPs in relation to the base year (1952) were obtained by dividing the nominal provincial GDPs for the period of 1997–2015 by the 1952-based GDP deflator. Total carbon emissions in each province were calculated from fossil fuel combustion and cement consumption values along with the associated carbon emission coefficient, which were then divided by the value for the total population recorded at the end of the year to calculate per capita carbon emissions. In our study, carbon dioxide emissions from the growth of each unit of GDP was used to reflect the intensity of carbon emissions.

3.2 Algorithm

We expanded the emission reduction potential index developed by Wei *et al.*[13] and calculated carbon emission reduction potential by balancing per capita carbon emissions and carbon emission efficiency. Calculation was performed using the following equation:

$$AAC_i = CCL_e \times E_i + CCL_f \times F_i \tag{1}$$

where AAC_i is the index for the carbon emission reduction potential of province i; CCL_e and CCL_f denote the weight of carbon emission efficiency and fairness, respectively, measured by the solidification degree, that is, the club convergence index in this study; E_i and F_i denote standardized carbon emission efficiency and fairness values for province I, respectively. The variables in Equation 1 have no unit.

3.3 Research Steps

3.3.1 Carbon Emission Efficiency Measurement: Super-SBM Model Incorporating Undesirable Outputs

Referring to the research of Tone[15], we applied the Super-SBM model to measure the efficiency of carbon reduction. Using the data compiled for the 29 provinces in the period of 1997–2015, we included the following inputs indicators with reference to 1952 (the base year): capital investments measured by capital stocks, labor inputs measured by the total number of employees at the end of year, and energy inputs measured by the total energy consumption. We included GDP data as a desirable output indicator with reference to statistics for 1952. Finally, we considered total carbon emissions as the undesirable output.

3.3.2 Coordination Levels between Fairness and Efficiency of Carbon Emissions and the Solidification Degree Measurement: Construction of a Markov Chain Model and the Club Convergence Index

(1) The Markov chain Model. We applied the concepts and methods proposed by Zhou *et al.*[16] to discretize fairness (efficiency) of carbon emissions within four categories: low, low-medium, high-medium, and high. Next, we calculated the transition probability of fairness (efficiency) between categories. In traditional distributed dynamic models, Markov Chain model usually only entails a consideration of cases in which the duration of a step is 1 a[17]. We constructed a transition probability matrix covering a period of several years to examine the transition process of regional carbon emission fairness (efficiency) over time and to develop a comprehensive knowledge base. The following method was applied to construct the matrix.

The probability value of Markov's transition probability matrix for d years was expressed as $P_{ij}^{t,t+d} = \{X_{t+d} = j \mid X_t = i\}$. $P_{ij}^{t,t+d} = \{X_{t+d} = j \mid X_t = i\}$ indicates that after d years, provinces categorized as type i will transition to type j in the t-th year. The following Equation was used to estimate the transition probability:

$$P_{ij}^{d} = \sum_{t=t_0}^{t_n-d} n_{ij}^{t,t+d} \Big/ \sum_{t=t_0}^{t_n-d} n_i^t \tag{2}$$

where t_n denotes the last period of the investigation, $n_{ij}^{t,t+d}$ denotes the sum of the number of regions that belonged to type i in year t and subsequently transitioned to type j in year $t+d$ over the period of the investigation, and n_i^t denotes the total number of regions where carbon emission fairness (efficiency) is categorized as type i in the t-th year. We constructed the Markov transition probability matrix of d-year duration based on an estimation of different types of transition probabilities as expressed in Equation 3 below:

$$\begin{bmatrix} \frac{n_{11}^d}{n_1^d} & \cdots & \frac{n_{ij}^d}{n_1^d} & \cdots & \frac{n_{1k}^d}{n_1^d} \\ \frac{n_{21}^d}{n_2^d} & \cdots & \frac{n_{2j}^d}{n_2^d} & \cdots & \frac{n_{2k}^d}{n_2^d} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ \frac{n_{k1}^d}{n_k^d} & \cdots & \frac{n_{kj}^d}{n_k^d} & \cdots & \frac{n_{kk}^d}{n_k^d} \end{bmatrix} = \begin{bmatrix} p_{11}^d & \cdots & p_{1j}^d & \cdots & p_{1k}^d \\ p_{21}^d & \cdots & p_{2j}^d & \cdots & p_{2k}^d \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ p_{k1}^d & \cdots & p_{k2}^d & \cdots & p_{kk}^d \end{bmatrix} \tag{3}$$

where the scale of the horizontal area of type *i* is n_i^d, which is $\sum_{t=t_0}^{t_n-d} n_i^t$ in Equation 2. In this Equation, p_{ii}^d denotes the transition probability of *i*-type regions remaining as *i*-types after *d* years. A larger p_{ii}^d value indicates a higher solidification degree of regional discrepancies in carbon fairness (efficiency) and also indicate the existence of club convergence. To compare the solidification degree of different indexes, we performed a chi-square test[18].

(2) A club convergence index considering scale effect. To measure the solidification degree of carbon emission fairness and efficiency accurately, we constructed a club convergence index on the basis of Equation 3. This index accounted for both the sizes of different types of regions (clubs) and the degree of convergence within each club, thereby obtaining the overall degree of club convergence. The following equation was used for the calculation:

$$CCL^d = p_{11}^d \times \frac{n_1^d}{\sum n_i^d} + p_{22}^d \times \frac{n_2^d}{\sum n_i^d} + \cdots + p_{kk}^d \times \frac{n_k^d}{\sum n_i^d} \tag{4}$$

where p_{kk}^d denotes the diagonal element in Equation 3, which indicates the convergence degree of *k*-type clubs for a duration of *d* years while $n_k^d / \sum n_i^d$ denotes the proportion of the size of the *k*-type club.

4 Results and Validation

4.1 Data Products

The dataset comprised 10 tables that covered the data compiled for 29 provinces in China for the period of 1997–2015. The details are shown in Table 1.

4.2 Data Results

4.2.1 Coordination of Carbon Emission Fairness and Efficiency: A Dynamic Perspective

We used a Markov Chain model with variable durations to examine the transfer of regional carbon emission fairness and efficiency between different types. Table 2 shows the transition probabilities for durations of one, three, and five years.

In general, the positions of various types of regions were relatively fixed within the overall distribution. The phenomenon was especially apparent in high-level and low-level regions. Horizontal comparison showed that low and high levels of carbon emission efficiency were associated with higher solidification degrees. To better compare the solidification degrees of carbon fairness and efficiency, it was necessary to calculate the overall solidification degrees. We integrated the solidification data for different level types of regions at a regional scale and calculated club convergence index for durations of one to five years using Equation 4. Table 3 shows that club convergence index of carbon emission efficiency was always larger than the solidification degree of carbon emission fairness at different durations. We tested the significance of differences in transfer probabilities to ensure the robustness of the results and calculated the results in each case. Table 4 shows the transfer probability for durations of one, three, and five years.

Table 2 The Markov transfer probability of carbon emission fairness and efficiency in China

Duration (a)	Type	Carbon emission fairness					Carbon emission efficiency				
		n	L	ML	MH	H	*n*	L	ML	MH	H
1	L	117	**0.880,3**	0.119,7	0.000,0	0.000,0	144	**0.951,4**	0.048,6	0.000,0	0.000,0
	ML	135	0.088,9	**0.844,4**	0.066,7	0.000,0	108	0.111,1	**0.777,8**	0.111,1	0.000,0
	MH	101	0.000,0	0.089,1	**0.811,9**	0.099,0	125	0.000,0	0.096,0	**0.872,0**	0.032,0
	H	169	0.000,0	0.000,0	0.071,0	**0.929,0**	145	0.000,0	0.000,0	0.020,7	**0.979,3**
3	L	104	**0.778,8**	0.201,9	0.019,2	0.000,0	126	**0.928,6**	0.071,4	0.000,0	0.000,0
	ML	120	0.150,0	**0.716,7**	0.116,7	0.016,7	98	0.234,7	**0.571,4**	0.193,9	0.000,0
	MH	92	0.010,9	0.173,9	**0.641,3**	0.173,9	113	0.000,0	0.168,1	**0.734,5**	0.097,3
	H	148	0.000,0	0.006,8	0.135,1	**0.858,1**	127	0.000,0	0.000,0	0.063,0	**0.937,0**
5	L	92	**0.695,7**	0.282,6	0.021,7	0.000,0	108	**0.907,4**	0.092,6	0.000,0	0.000,0
	ML	104	0.182,7	**0.653,8**	0.144,2	0.019,2	88	0.284,1	**0.443,2**	0.261,4	0.011,4
	MH	79	0.025,3	0.177,2	**0.531,6**	0.265,8	101	0.019,8	0.217,8	**0.613,9**	0.148,5
	H	131	0.007,6	0.015,3	0.190,8	**0.786,3**	109	0.000,0	0.000,0	0.082,6	**0.917,4**

Note: L, ML, MH, and H are the four levels of low, medium low, medium high, and high; *n* is number of samples.

Table 3 Club convergence index model of fairness and efficiency of regional carbon emission reduction under different durations

Time	Duration (a)	Fairness of carbon emission reduction	Efficiency of carbon emission reduction
1997–2015	K=1	0.873,6	0.904,2
	K=3	0.760,8	0.808,2
	K=5	0.682,3	0.736,5

Table 4 Solidification degree difference test of fairness and efficiency of regional carbon emission

Duration (a)	Type	*Q*	df	c^2	*P*
1	F-E	39.566,7	12	21.026,1	8.50E–05
	E-F	37.631,8	11	19.675,1	9.00E–05
3	F-E	81.231,0	12	21.026,1	2.40E–12
	E-F	74.203,6	12	21.026,1	5.20E–11
5	F-E	108.449,1	12	21.026,1	0.00E+00
	E-F	96.747,6	12	21.026,1	2.40E–15

As shown in Table 4, the differences were significant because the test results under different durations all invalidated the null hypothesis and these differences continued to increase over time; this finding was consistent with the results shown in Table 2.

4.2.2 Carbon Emission Reduction Potentials of Provinces in China According to the Coordination Levels of Fairness and Efficiency

We constructed a club convergence index to evaluate the importance of fairness and efficiency principles in investigation of regional carbon emission reduction potential in China. The average values of club convergence index for carbon emission fairness and efficiency over durations of one to five years were 0.768,7 and 0.816,7 (in proportions of 0.484,9 and 0.515,1), respectively. Substituting proportions as weights into Equation 1, the results are shown in Table 5.

The results presented in Table 5 indicate that the carbon emission reduction potential of most provinces has improved, as indicated by the coordination level of carbon emission fairness and efficiency. These results reveal that, the use of equal weights in previous studies led to underestimation of the carbon emission reduction potentials for most provinces. The differences were relatively large for Jiangxi, Sichuan, and Guizhou in 1997, and for Jiangxi, Henan, Guangdong, Guangxi, Sichuan, and Gansu in 2015. It reveals that weight adjustment for coordination levels of fairness and efficiency had a greater impact in these provinces. The carbon emission reduction potential of provinces evidencing increased potential (positive differences) was mainly driven by carbon emission efficiency. Most of the differences shown in Table 5 are positive, confirming that the solidification problem relating to the efficiency of carbon emissions in China is of more concern.

Table 5 Estimation of carbon emission reduction potential in provinces of China based on the perspective of fairness and efficiency coordination

	1997			2015		
Province	Coordination	Equality	Difference	Coordination	Equality	Difference
Beijing	0.651,9	0.649,7	+0.002,2	0.127,8	0.124,1	+0.003,7
Tianjin	0.479,3	0.481,1	**–0.001,8**	0.432,3	0.426,1	+0.006,2
Heibe	0.532,5	0.526,5	+0.006,0	0.605,3	0.596,7	+0.008,6
Shanxi	0.955,2	0.956,5	**–0.001,3**	0.814,9	0.810,5	+0.004,4
Inner Mongolia	0.646,3	0.640,4	+0.005,9	0.980,5	0.981,1	**–0.000,6**
Liaoning	0.224,2	0.231,2	**–0.007,0**	0.153,1	0.157,9	**–0.004,8**
Jilin	0.559,1	0.551,9	+0.007,2	0.547,9	0.537,6	+0.010,3
Heilongjiang	0.579,4	0.571,0	+0.008,4	0.534,2	0.523,7	+0.010,5
Shanghai	0.399,9	0.411,7	**–0.011,8**	0.133,9	0.134,9	**–0.001,0**
Jiangsu	0.411,9	0.405,2	+0.006,7	0.529,9	0.521,5	+0.008,4
Zhejiang	0.362,7	0.357,4	+0.005,3	0.483,3	0.473,6	+0.009,7
Anhui	0.486,5	0.474,9	+0.011,6	0.524,7	0.513,6	+0.011,1
Fujian	0.071,7	0.070,6	+0.001,1	0.388,2	0.380,4	+0.007,8
Jiangxi	0.449,6	0.437,1	+0.012,5	0.540,4	0.527,1	+0.013,3
Shandong	0.448,8	0.440,9	+0.007,9	0.596,2	0.587,6	+0.008,6
Henan	0.478,6	0.466,9	+0.011,7	0.572,2	0.559,7	+0.012,5
Hubei	0.487,3	0.477,5	+0.009,8	0.490,2	0.479,4	+0.010,8
Hunan	0.455,4	0.443,8	+0.011,6	0.483,6	0.471,7	+0.011,9
Guangdong	0.441,6	0.432,8	+0.008,8	0.489,4	0.476,9	+0.012,5
Guangxi	0.391,5	0.380,0	+0.011,5	0.503,5	0.490,8	+0.012,7
Chongqing	0.427,7	0.417,5	+0.010,2	0.423,2	0.414,0	+0.009,2
Sichuan	0.508,2	0.494,8	+0.013,4	0.509,3	0.496,1	+0.013,2
Guizhou	0.608,0	0.595,7	+0.012,3	0.624,4	0.612,7	+0.011,7
Yunnan	0.122,6	0.121,5	+0.001,1	0.193,9	0.190,7	+0.003,2
Shaanxi	0.495,5	0.484,9	+0.010,6	0.636,7	0.627,1	+0.009,6
Gansu	0.494,7	0.483,6	+0.011,1	0.553,4	0.541,4	+0.012,0
Qinghai	0.529,6	0.517,9	+0.011,7	0.601,6	0.589,9	+0.011,7
Ningxia	0.562,2	0.556,1	+0.006,1	0.943,5	0.943,4	+0.000,1
Xingjiang	0.575,3	0.566,5	+0.008,8	0.747,4	0.740,0	+0.007,4

5 Discussion and Conclusion

We calculated the efficiency of carbon reduction for 29 Chinese provinces in the period of 1997–2015. To achieve this, we applied the Super-SBM model incorporating undesirable outputs, and measured the fairness of regional per capita carbon emissions. We subsequently applied the Markov Chain model to calculate the carbon club convergence index of efficiency and fairness, with the aim of assessing their importance for China’s carbon reduction potential.

We recalculated the carbon emission potential of each province based on the coordination levels of the principles of fairness and efficiency, thereby providing scientific basis for the government to reduce carbon emissions. The results indicated that the degree of carbon club convergence relating to the efficiency of China's regional carbon emissions was higher and that the solidification problem of long-term low efficiency of carbon emissions is more severe than the long-term problem of inequity. A second important finding relates to the underestimation of China's potential carbon emissions, which will impact the allocation of carbon rights and the sharing of responsibility for reducing emissions within the country.

Author Contributions

Zhou, D. designed the algorithm and was responsible for the overall design of the dataset. Hua, S. R. collected the data and wrote the data paper.

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