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Original Research

Carbon Allowance Allocation on Chinese Industrial Sectors in 2030 under Multiple Indicators

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Abstract

Aiming at China's "2030 target," and given the key role of industrial sectors in CO_2 emission reduction, this paper selects the path of allocating carbon emission allowance among different industrial sectors. By selecting CO_2 accumulation emissions, the industry-added value and the CO_2 emission efficiency which is calculated by the super-SBM model, a carbon intensity distribution model has been established for the allocation. Considering the different preferences of policymakers, different weights are used, meanwhile, an entropy weighting method is proposed to make a contrast. The main conclusions of this paper are:

1) The tendency of decision makers to assign principles has a great impact on the distribution of responsibility for the industry's emission reduction responsibilities.
2) CO_2 emission intensity and carbon dioxide emission efficiency of various industries in China are very different, which is mainly related to the energy consumption demand, input, and output of various industries.
3) More historical accumulated emission and carbon intensity will shoulder more intensity reduction burden, and the industrial sector with the heaviest reduction burdens are those with the two high indicators, regardless of the tendency of decision makers.

Keywords: industrial sectors, super-SBM model, entropy weighting method, carbon emission allowance

Introduction

Global warming has been identified as a critical issue in all areas and has attracted worldwide attention. Carbon dioxide, a type of greenhouse gas, is often conceived as the main cause that changes the global climate and threatens human survival [1-4]. According to the Norwegian international center for climate and environmental research, the accumulated carbon emissions of China reached 146.4 billion tons in 2016 – more than the 146.2 billion tons in the United States [5]. As the world's largest energy consumer and carbon dioxide emitter, China promulgated the policy target of reducing carbon intensity during the period of 2020 by 40% to 45% based in 2005. Moreover, at the Paris Climate Conference in 2015, China once again made a commitment to reduce carbon intensity by 60% to 65% in 2030 based on the level of 2005, and vowed to put a peak on its growing CO_2 emissions by 2030 [6]. In order to reach the reduction target, the Chinese government is taking effective measures to reduce emissions. In 2013,

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seven cities and provinces began to set up regional carbon emissions to test for a national carbon deal. In 2015, China announced that it had established a carbon emissions trading market in 2017 at a bilateral meeting. In 2018, China will improve relevant legislation on the carbon market, and by 2019 the national carbon trade will finally enter the trial operation [7].

For our purposes, how to allocate the greenhouse gas emission reduction burdens has become one of the most popular and complex issues for domestic and foreign researchers [8]. It is an imperative need to evaluate the effectiveness and equity implications of using different mechanisms to reduce carbon emissions. [9] emphasized that with an increasing public desire to regulate carbon emissions, adopting renewable energy standards and green building codes is an effective measure. [10] estimated China's CO_2 emissions in 2002 and 2007 by using a production-based and a consumption-based measure at the sector industry level. [11] drew the carbon flow of China for 2008 to reveal the characteristics of carbon flow and emissions in China, including not only the energy-related carbon emissions, but also the process emission. [12] investigated the policy relevance of strategic partitioning of emission allowances in the context of actual and prospective EU climate policies, simultaneously examining the potential effects of such strategic behavior on compliance cost and emissions prices. [13] assessed the potential of CO_2 mitigation in buildings, and investigated the economic factors that determine energy-related CO_2 emissions in China's commercial and residential buildings. [14] held the view that the allowance mechanism is one of the core and most sensitive aspects in the design of a carbon emissions trading scheme.

Undoubtedly, the allocation of CO_2 emissions may be performed at different levels [15], and the type of allocating CO_2 emissions may be classified into three categories. The first category focuses on the allocation among different countries. Based on the principle of "common but differentiated" responsibility, [16] selected eleven proposals that are presently prevailing around the world, and discussed the matter of "equity and justice," which has become one of the most controversial issues in climate debates. [17] presented a carbon Lorenz curve and Gini coefficient to identify potentially unfair use of international aviation carbon emission rights in different countries. By establishing an equitable access to sustainable development model, [18] measured carbon equity after allocating from the global rather than the narrower national perspective. [19] presented an analysis on how effort-sharing approaches affect emission allowances and abatement costs of China and India; the second category concerned allocation among different provinces in China. [20] proposed regional allocation based on equity and development principles, emphasizing equity and development strategies. Given that a fixed national emission reduction target could be achieved by imposing emission quotas among different regions, [21] proposed a novel nonlinear programming approach to investigate the optimal carbon emission quota allocation for China, by developing a performance-based model to measure the opportunity cost of CO_2 emission reduction and using a variable coefficient model to simulate carbon dioxide emission abatement cost, then obtain the optimal emission quota. The third category regards allocating CO_2 emissions on some specific sectors. By making an in-depth exploration in China's electricity sector and the characteristics of a sector's inner structures, [22] reviewed the factors that related to CO_2 mitigation potential and costs. By constructing a mathematical model, [23] investigated the impacts of carbon allowance allocation policy in the transportation industry, it reflected that for the sake of maximizing profits, industry managers should consider different carbon allowance allocation constraint scenarios.

When allocating carbon emissions, considerable research has been advocated and applied by the different principles and allocation criteria. Equity principle has considerable variation in implications of distributive justice, it will be important for decision-makers to clarify concepts of equity during the course of allocating carbon emissions [24]. [25] deconstructed the general principles of equity into egalitarian, sovereign, horizontal, vertical, and polluter pay equity. In order to arrive at "fair," [36] presented a sectoral approach to burden sharing, and distributed the burden of emission reductions as a limitation of coal use for power production, minimum requirements for renewable energy, and minimum energy efficiency improvement rates in industry. [27] provided an allocation scheme by considering historical emissions and future needs for developed and developing countries simultaneously, and analyzed the peak years and associated abatement costs with different starting years.

Meanwhile, plenty of scholars are interested in allocating the carbon quotas by means of two major approaches of allocation: free allocation and auction. Within a free allocation there are two acceptable ways to allocate carbon quotas: grandfathering and benchmarking. [28] considered the free allocation of emission allowances in a dynamic context and believed that grandfathering schemes which allocate allowances proportionally to past emissions are first-best. [29] derived optimal grandfathering schemes under the condition that relocation is averted with a minimum of transfers to a firm. [30] compared the mechanisms of grandfathering and benchmarking, and held the view that benchmarking can more effectively motivate manufacturers and retailers. [31] analyzed the proposal of "South-North Dialogue," and implied that those approaches were based on the criteria of responsibility, capability, and potential. According to the emission trading policy in Korea, [32] divided the emission trading scheme into two stages in the electricity sector, and found that the auction is the most powerful policy for the initial allocation of emission allowances.

As for the method of carbon allowance allocation, [33] measured operational efficiency with the Malmquist Index, in which power capacity, coal consumption, and employee number are used as input variables and power generation as the output variables. [34] built a carbon dioxide emissions allocation mechanism based on the radial zero sum gains data envelopment (ZSG-DEA) allocation model, and used the ZSG-DEA model to allocate carbon dioxide emissions between different Chinese provinces. [35] applied the input-output model to explain the relationship between China's inter-regional spillover of carbon dioxide emissions and domestic supply chains for 2002 and 2007.

Traditional CO_2 emission allocation is generally focused on the distribution of different regions and the geographical location [36, 37]. This kind of allocation problem arises mainly from two angles, one is the international distribution of responsibility between different countries, the other is among the different provinces. There is little research on the distribution of emission reduction responsibilities between different industries from the perspective of a country's industry. Undoubtedly, industry is the main source of energy and resource consumption and pollutants in the country, while meanwhile it seriously impedes sustainable development. In this sense, a necessary but changeable step is to reach a consensus on the responsibility sharing of CO_2 emission reductions among different industry sectors. In different terminal sectors, related carbon dioxide reduction policies should be targeted, for the reason that the main carriers of CO_2 flow are different [38]. Therefore, it is critical to investigate the influence of factors of CO_2 emissions changes in the major industries so as to provide recommendations for policy makers.

In this paper, we propose a new perspective on the allocation of carbon dioxide emissions by decomposing the national emission reduction target into industrial sectors by illustrating the super-SBM model dealing with undesirable outputs to measure the emission efficiency of carbon dioxide. Simultaneously, it must be based on the principles of egalitarianism, equity, and efficiency in order to construct a comprehensive index and analyze the strategies of carbon dioxide emissions at industry sectors. This will provide a reference and basis for a future national allowance allocation at the sector level.

Material and Methods

Indicator Selection

We select accumulated carbon dioxide emissions, industrial added value, and carbon dioxide emissions efficiency as indicators for emission reduction responsibility, capacity, and potential, respectively, to quantify the burdens each industry might shoulder (Table 1).

The Assumptions of the Model Are as Follows

Responsibility

As we all know, the more historical cumulative emissions of carbon dioxide industry, the greater contribution to the global greenhouse, and they should bear the responsibility [39-41]. Since the climate negotiations, the international community has had a heated discussion on the issue of allocating responsibility for emission reduction and the issue of equitable distribution of carbon dioxide emission rights. In particular, the principle of fairness on the allocation of carbon dioxide emissions refers to how every industry should have equal rights of carbon dioxide emissions. In addition, the industries that have accumulated more carbon dioxide in history will contribute more to global warming, so the greater the burden of reducing emissions they should bear.

Capacity

Carbon intensity control of industrial sectors need to adjust the energy structure, improve the efficiency of energy consumption, introduce new technology, and so on, it will need a lot of money. In practice, the economy and emissions capital investment ability are varied from industries. Particularly, the capacity principle is on behalf of the ability of industry funds to undertake the costs of reducing emissions while

Table 1. Intensity reduction allocation principles and indicator selection.

Indicator	Principle	Interpretation	Dimension
Historical accumulated carbon dioxide emission	Egalitarian	The more the industry accumulates carbon dioxide emissions, the greater the contribution to the greenhouse effect, the greater the responsibility for reducing emissions	Responsibility
Industrial added value	Vertical	The greater the value added value of the industry, the stronger the economic emission reduction ability, and the greater the burden of emission reduction.	Capacity
CO_2 emission efficiency	Efficiency	The lower the efficiency of CO_2 emission in the industry, the more unfavorable the control of the national emission intensity	Potential

Table 2. Conversion coefficient and CO_2 emissions conversion coefficient of different kinds of energy.

Energy	Statistical unit	Conversion coefficient	CO_2 emissions conversion coefficient (C/(t/t))
Coal	million ton	0. 7143 kgce/kg	0. 747
Coke	million ton	0. 9714 kgce/kg	0. 855
Crude oil	million ton	1. 4286 kgce/kg	0. 585
Gasoline	million ton	1. 4714 kgce/kg	0. 553
KeroSne	million ton	1. 4714 kgce/kg	0. 571
DieSl oil	million ton	1. 4571 kgce/kg	0. 592
Fuel	million ton	1. 4286 kgce/kg	0. 618
Natural gas	billion cubic meters	1. 2721 kgce/m^3	0. 448
Power	billion kwh	0. 1229 kgce/(kwh)	1. 814

ensuring their own stable development. Different industries have different economic backgrounds and outputs, and the added value of its representing the industry to create new value in the process of production operation also represents industry's contribution to the gross domestic product (GDP). More value-added industries will be more capable of cutting emissions, and the feasibility of reducing emissions will be higher [42-44].

Potential (CO_2 Emissions Efficiency 2005)

CO_2 emissions efficiency is for the dimension of reduction potential, which means one industry with high CO_2 emissions efficiency has more room to increase the emission reduction efforts. In contrast, the lower the efficiency of CO_2 emission in the industry, the greater the responsibility for CO_2 emissions reduction. It can also be understood as carbon resource configuration optimization principle, reflecting the principle of coordinated development of economy and environment – namely the limits on emissions of CO_2 limited space, as much as possible in order to obtain the biggest economic output. With global environmental problems, the greenhouse effect has caused especially widespread concern, and different scholars have proposed different methods or indicators to evaluate the efficiency of CO_2 emissions. [45] introduced a concept of industry CO_2 emissions efficiency and relative design and industry CO_2 emissions coefficient to measure it. Based on the stochastic non-radial model, [46] evaluated energy efficiency, CO_2 emissions efficiency, energy-saving potential, and CO_2 emissions reduction potential in China. [47] applied an inseparable input-output measure model to analyze eight container ports with CO_2 emissions in China.

Estimation of Carbon Emissions

In the process of production, coal, carbon, oil, and other energy inputs inevitably lead to emissions of carbon dioxide and other pollutants. We employ the normalized approach recommended by the Intergovernmental Panel on Climate Change in the IPCC guideline to assess China's CO_2 emissions [48], which can be calculated according to the following Eq. 1:

$$CO_2 = \sum_{i=1}^{9} E_i * K_i * M_i * \frac{12}{44} \tag{1}$$

…where i indicates different fossil fuels, including coal, coke, crude oil, gasoline, kerosene, diesel oil, fuel, natural gas, and power. E_i represents total consumption of different kinds of energy; K_i and M_i represent conversion coefficient and CO_2 emissions conversion coefficient, respectively; and parameter 12/44 is the ratio between the mass of one carbon atom and the mass of one carbon dioxide molecule. As shown in Table 2.

Super-SBM Models

As an environmental pollutant, carbon dioxide is the undesired output generated by industry to obtain the desired output. There's discrepancy between industries at energy consumption demand, production technology, production process, and carbon dioxide emissions. [49] evaluated the unified efficiency of China's industrial sector by applying a non-radial DEA model. [50] proposed an improved super-SBM model dealing with undesirable outputs, and measured energy efficiencies of various industrial sectors in China. The super-SBM model has the high discriminating ability for further ranking the efficient DMUs that are particularly suitable for dealing with CO_2 emissions [51, 52] constructed the calculation model based on slack variable (slacks-based measure, SBM). The slack variable directly into the objective function formed a kind of radial, and the angle of efficiency measurement method can avoid radial deviation and the selection of angle difference. [53] held the view that slack is often not captured by the directional technology distance function; however, it is an important source of inefficiency. [54] put forward the SBM model, and solved the problem of slack variable with the expected output, and the model in the ecological efficiency and environment efficiency evaluation quickly got a large number of applications and showed good character and credibility.

Supporting a production system with n DMUs, each unit has three factors: inputs, desirable outputs, and undesirable outputs, as represented by three vectors: X, Y_g, Y_b.

Respectively, $X = [x_1, x_2, \ldots, x_n]$, $Y_g = [y_1^g, y_2^g, \ldots, y_n^g]$, and $Y_b = [y_1^b, y_2^b, \ldots, y_n^b]$, and the super-SBM model dealing with undesirable outputs for evaluating DMU is as follows:

$$\min \rho^* = \frac{1 + \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_i}}{1 - \frac{1}{s_1 + s_2}\left(\sum_{r=1}^{S_1}\frac{s_r^g}{y_r^g} + \sum_{t=1}^{S_2}\frac{s_t^b}{y_t^b}\right)}$$

$$s.t. \quad x_i \geq \sum_{j=1,\neq 0}^{n} x_{ij}\lambda - s_i^-$$

$$y_t^b \geq \sum_{j=1,\neq 0}^{n} y_{tj}^b\lambda - s_t^b$$

$$1 - \frac{1}{s_1 + s_2}\left(\sum_{r=1}^{S_1}\frac{s_r^g}{y_r^g} + \sum_{t=1}^{S_2}\frac{s_t^b}{y_t^b}\right) > 0$$

$$s^-, s^g, s^b, \lambda \geq 0 \quad i = 1,2\ldots,m \quad r = 1,2,\ldots,q \quad j = 1,2,\ldots,n \tag{2}$$

…where λ is the intensity vector; $s = (s^-, s^g, s^b)$ corresponds to the slacks in inputs, desirable outputs and undesirable outputs; m, s_1, and s_2 stand for the number of factors for inputs, desirable outputs, and undesirable outputs; and the optimization function value of ρ^* is the efficiency value of the decision-making unit (x_{ik}, y_{rk}^g, y_{rk}^b). The efficiency value of the super-SBM model will exceed 1, which can overcome the defect that cannot be compared with the efficiency of the previous effective unit, and can further accurately compare the effective value of unit efficiency.

This paper uses a panel of 42 industries in China from 2005 to 2015 to investigate the optimal carbon emission quota allocation among industries. Like many previous studies, labor, capital stock, and energy are introduced in the model as input factors, value-added of the industry is used as a sole desirable output, and CO_2 emission are used as an undesirable output. [55] evaluated the industrial CO_2 emissions efficiency, and emissions for the 30 provinces in China. This indicates that the efficiency of undesired outputs can be calculated by the ratio of the undesired output value to the pre-optimal output value; therefore, we can define CO_2 emissions efficiency (Ce) as Eq. 3:

$$C_e = \frac{y_{tj}^b\lambda - s^b}{y_{tj}^b} \tag{3}$$

Allocation Method for China's Intensity Reduction Target

Comprehensive Emission Reduction Index Construction

The comprehensive index of emission reduction R_i is constructed based on the three indicators of capacity, responsibility, and potential, which are quantified by the historically accumulated CO_2 emissions, industrial added value, and CO_2 emissions efficiency. The higher the value of R_i, the more reduction burden an industrial sector needs to shoulder. The index of θ_i is calculated by the following formula:

$$\theta_i = \omega_1 A_i + \omega_2 B_i + \omega_3 C_i \tag{4}$$

…where θ_i is the comprehensive index for i industrial sector; A_i represents the performance of responsibility allocation indicators under the principle of fairness of the industry (namely the cumulative carbon dioxide emissions of i industries), and the greater the value in the industry, the greater the burden will be borne; B_i represents the principle of industry feasibility, namely the value added value of i industries, and the greater the added value of the industry, the greater the burden of emission reduction; on behalf of the principle of responsibility allocation performance indicators, C_i represents carbon dioxide emissions efficiency, which is calculated by the super-SBM efficiency evaluation model where the smaller the value, on the contrary, the greater the burden the industry may shoulder; i represents 42 industrial sectors of China (i = 1, 2, . . . , 42); and ω_1, ω_2, ω_3 are the weights for the three indicators, representing the tendency of decision makers to assign principles in the allocation plan, and satisfying the equation $\omega_1+\omega_2+\omega_3 = 1$.

The multi-indicator weighting allocations of eight cases are shown in Table 3.

Case 1, equal weights, considers three allocation principles, and the distribution of three principles gives the same preference.

Table 3. Weights of indicators under four cases.

Weight	ω_1	ω_2	ω_3	$\omega_1+\omega_2+\omega_3$
Case1	0. 33	0. 33	0. 33	1
Case2	0. 5	0. 25	0. 25	1
Case3	0. 25	0. 5	0. 25	1
Case4	0. 25	0. 25	0. 5	1

Case 2, preference for capacity, means the dimensions of capacity in preference to responsibility and potential.

Case 3, preference for responsibility, means that cumulative carbon dioxide emissions are the most important of the three indicators.

Case 4, preference for potential, means that potential is of significance to carbon dioxide intensity reduction target.

Entropy Weighting Method

Entropy weighting method is a mathematical method to calculate a comprehensive index based on the comprehensive consideration of the information provided by each factor. As an objective comprehensive weighting method, it determines the weight according to the amount of information transmitted to the decision-maker.

The emission reduction weighting decision making matrix A of the three indicators for the industrial sectors is given as below:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \tag{5}$$

…where r_{ij} represents the value of indicator j for industry sector i (i = 1, 2, 3, . . . , n; j = 1, 2, . . . , m). Then, due to the different units, normalization is conducted as follows:

$$c_{ij} = \frac{r_{ij}}{\sum_{i=1}^{n} r_{ij}} \tag{6}$$

The standardized decision making matrix is as follows:

$$c = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1m} \\ c_{21} & c_{22} & \cdots & c_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ c_{n1} & c_{n2} & \cdots & c_{nm} \end{bmatrix} \tag{7}$$

The entropy of each indicator can be calculated after standardizing statistical data. The entropy H_i of the ith indicator can be defined as:

$$H_i = -k \sum_{j=1}^{n} c_{ij} \ln c_{ij} \tag{8}$$

…where k = 1/ln*n*, suppose $c_{ij} = 0$, then $c_{ij} \ln c_{ij} = 0$. The weighted entropy value is obtained using the following equation:

$$\omega_i = \frac{1 - H_i}{m - \sum_{i=1}^{m} H_i} \tag{9}$$

Allocating China's 2030 Intensity Reduction Target

Based on the comprehensive index in the above section, the carbon intensity reduction burden is quantified for each industry and the allocation model is constructed. The allocation target is based on 60-65% carbon dioxide emission reduction per unit of GDP from 2005 levels by 2030. In this study, we select 65% reduction as the example target.

$$I_{2030} = \beta I_{2005} \tag{10}$$

The value of β is the reduction target in 2030, and it is the residual coefficient representing national carbon intensity after achieving the 2030 reduction target, indicating that the value of China's carbon intensity is β times that of 2005; I_{2030} is the carbon intensity of China in 2030 and I_{2005} is the carbon intensity of China in 2005.

As for each industry, the relationship between the residual coefficient and carbon intensity also exists.

$$I_{i2030} = \beta_i I_{i2005} \tag{11}$$

…where β_i is the residual coefficient for each industrial sector, and I_{i2005} and I_{i2030} are the carbon intensities of i industrial sectors in 2005 and 2030, respectively.

The bigger the comprehensive index, the greater the carbon intensity reduction burden that the industrial sector might take. This means that carbon intensity may be reduced to a lower level if the β_i value is smaller. In addition, since the marginal abatement cost increases, the cost of cutting one more unit of emission rises, and therefore the marginal mitigation burden should diminish. This trend can be manifested by processing the comprehensive index as a natural logarithm form, with the function of β_i defined as follows:

$$\beta_i = f(\theta_i) = \partial Ln(\theta_i^{-1}) \tag{12}$$

The CO_2 emission amount of China in 2030 can be expressed by Eqs. (13) and (14):

$$CE_{2030} = \sum_{i=1}^{n} I_{i2005} \beta_i GDP_{i2030} \tag{13}$$

$$CE_{2030} = GDP_{2030} I_{2030} \tag{14}$$

…where Ə is the parameter to be estimated, CE_{2030} is the CO_2 emission amount of China in 2030, and GDP_{2030}

and GDP_{i2030} are the national and i industrial sector GDP values in 2030, respectively. From Eq. (10) to Eq. (14), we obtain the mathematical expressions of parameter a as follows:

$$\partial = \frac{GDP_{2030}\beta I_{2005}}{\sum_{i=1}^{n} Ln(\theta_i^{-1}) I_{i2005} GDP_{i2030}} \tag{15}$$

Based on the value of Ə, we can get the residual coefficient of βi , which means that the carbon intensity per unit of GDP in 2030 might be reduced to βi times that of 2005. We obtain the carbon intensity value accordingly. If each industrial sector achieves this carbon intensity value, the national carbon intensity reduction target will be met.

Data Source and Processing

According to the data and processing methods, we calculate the values of three indicators in 42 industrial sectors in China (Table A1). This paper proposes a carbon intensity reduction target allocation method at the industry level in order to provide decision makers with reference information to distribute the mitigation target. The data source and processing method are as follows:

Labor is represented by the number of annual average employees in the industrial sector as sourced from the China Statistical Yearbook and China industrial statistics yearbooks from 2005-2015.

For capital, we utilize the outstanding net value of fixed asset of the enterprises above designated scale as the proxy for capital input. The data are collected from the China Statistical Yearbook.

Energy is the total energy consumption of sub-industries as the proxy for energy input. The data are collected from the China Statistical Yearbook.

Desirable output is the industrial added value data (2005-2007) collected from the Chinese Statistical Yearbook. However, since these data are only counted to year 2007, the industrial added value data from 2008 to 2015 are calculated using the officially released annual average growth rate of added values, and the data are from National Bureau of Statistics of China and the China Statistical Yearbook (2005-2007).

Undesirable output data are collected from the National Bureau of Statistics, the China Statistical Yearbook, and the China Energy Statistics Yearbook. Most of the CO_2 emitted by the electricity sector is utilized for producing electrical power, therefore, the actual energy consumption of the electricity sector is only the energy consumption corresponding to the self-use of electricity.

Based on these data, accumulated carbon dioxide emissions of 42 industrial sectors in China from 2000 to 2005, industrial added value of 2005 and CO_2 emissions efficiency of 20005 are calculated. Because the units for the three indicators are different, the data cannot be added together directly. We therefore chose a percentage to do the calculation. The descriptive statistical characteristics of the above-mentioned 76 input/output variables are shown in Table 4. This suggests that the median of different indicators is smaller than the mean value, and a larger standard deviation shows the unbalanced production status of different industrial sectors, which is more prominent in terms of desirable outputs and undesirable outputs.

Results and Discussion

CO_2 Efficiency Performance in China's Industrial Sectors

Spearman's coefficient shows that the DMU production process has some so-called "isotonicity." In addition, the correlation between inputs and undesirable outputs is insignificant, in line with the actual production expectation (Table 5). Therefore, CO_2 efficiency measured by the super-SBM model is reliable, and the research results are completely believable.

Table 4. Descriptive statistical characteristics of input and output variables.

Variable	Inputs			Outputs	
	Labor (10 thousand people)	Capital (100 million yuan)	Energy (Standard coal)	Industrial add value (100 million yuan)	CO_2 emission (100 million tonnes CO_2)
Mean	229. 63	1035. 78	4796. 11	3515. 55	152. 59
Median	130. 44	670. 17	1356. 64	1774. 49	16. 88
Maximum	926. 60	8860. 38	39544. 25	24370. 20	2144. 19
Minimum	0. 21	4. 08	34. 98	2. 70	0. 30
Standard Deviation	213. 26	1635. 18	8037. 36	5244. 39	398. 05
Skewness	1. 33	3. 73	2. 77	2. 88	3. 87
Kurtosis	1. 74	15. 16	8. 44	8. 88	16. 32

Table 5. Spearman's rank correlation for inputs and outputs of 42 industrial sectors.

	Labor	Capital	Energy
Industrial added value	0. 827**(0. 000)	0. 848**(0. 000)	0. 776**(0. 000)
CO_2 emissions	0. 539**(0. 000)	0. 788**(0. 000)	0. 940**(0. 000)

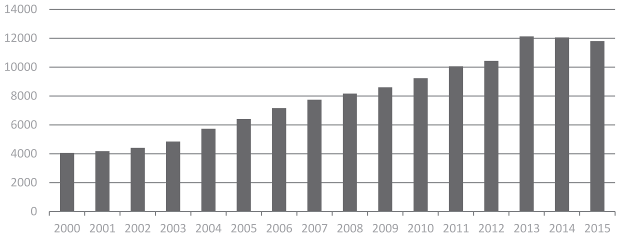

Fig. 1. Total CO_2 emissions in 42 industries from 2005 to 2015.

According to Eq. 1., we calculated the total of CO_2 emissions from 2000 to 2015 (as presented in Fig. 1). Meanwhile, based on the super-SBM models analysis mentioned above, we can obtain the CO_2 emission efficiency of 42 industrial sectors. Obviously, there exist distinct differences in terms of CO_2 emissions efficiency among various industrial sectors. As can be seen from Fig. 2, other mining industry and manufacturing of waste resources and materials recycling and processing have the highest CO_2 emissions efficiencies, which ranged from 1 to 1.8 from 2005 to 2015. Additionally, almost all of agriculture, forestry, the fishery industry, tobacco manufacturing, wholesale, retail, accommodation and catering, manufacturing of metal products, and the construction industry are more than 1, except for a few years. Thus, in comparison with others, these industrial sectors have reached the frontier of production, relatively more advanced technology, and less pollution.

Some studies suggest that in the process of efficiency evaluation, by adjusting input and output variables, the efficiency of carbon dioxide emissions will increase to 1, which will be optimized. It can be seen that the carbon dioxide emission efficiency has a close relationship with the output. However, it is not accurate to assign the responsibility only through the efficiency of carbon dioxide emissions during the distribution of emissions. Inefficient industries should certainly undertake larger emission tasks. However, in the process of carbon allowance allocation, the description of efficiency indicator is not comprehensive, which means that in order to make the allowance more equitable and reasonable, we should take into consideration multiple indicators.

Comparative Analysis of Multiple Indicators

Characterization of Equal Weighting

Under the equal weighting case, we assign the reduction burden according to the indicator values for capacity, responsibility, and potential equally (see Fig. 3.). According to the allocation results, the 42 industrial sectors can be divided into four categories of high, medium high, medium, and low reduction burdens. The first category contains four industrial sectors, whose intensity reduction burdens are more than 65%. The second and third categories contain 10 industrial sectors with intensity reduction burdens from 65% to 50% and 18 industrial sectors with intensity reduction burdens from 50% to 35%, respectively. The fourth category contains three industrial sectors, whose intensity reduction burdens are less than 35%.

We make a comparison of the four categories and analysis the characteristics by integrating the indicators. Manufacturing of oil processing, coking, nuclear fuels processing, smelting and the rolling process of ferrous metal, manufacturing of non-metal products, ferrous

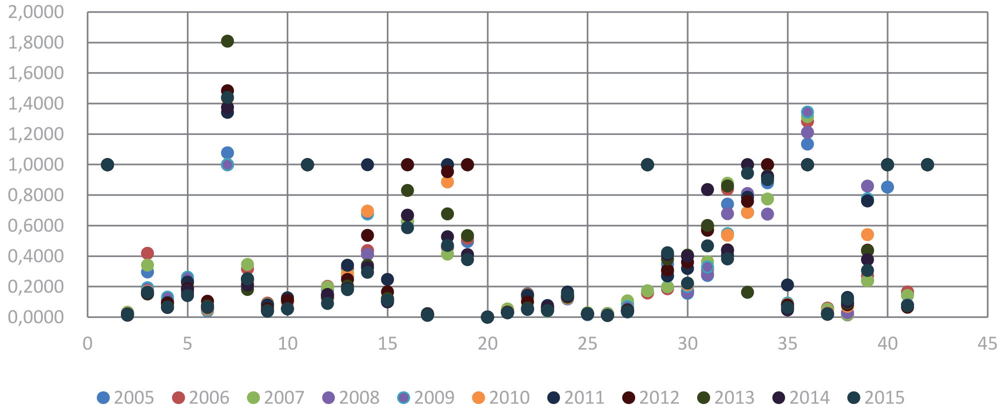

Fig. 2. CO_2 efficiencies of 42 industrial sectors in 2005-2015 in China.

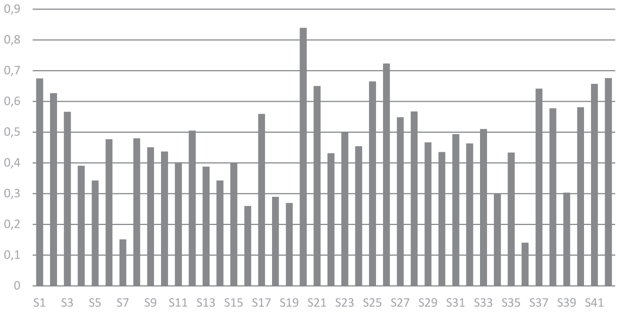

Fig. 3. Carbon intensity reduction burdens in 2030 under the equal weighting case.

metal, manufacturing of raw chemical materials and chemical products, transportation, storage, and postal service are with higher accumulated CO_2 emissions and industrial value added. However, lower values of CO_2 emissions efficiency, in particular wholesale, retail, accommodation, and catering have highest industrial value added, but the value of CO_2 emissions efficiency is 1 from 2005-2015. In the second category, production and supply of electricity, heat, gas and water, coal mining and washing, construction industry, manufacturing metal products, oil and natural gas mining, smelting and rolling process of non-ferrous metal, and the manufacutre of communication devices, computers, and other electronic devices and textile manufacturing have high accumulated CO_2 emissions and industrial value added, whereas the production and distribution of gas, paper making, and paper products manufacturing, and the manufacture of chemical fibers all have low values for industrial value added. Specifically, manufacturing metal products and the construction industry with the value of CO_2 emissions efficiency is 1, while all of the industrial sectors in the third category have low accumulated CO_2 emissions, industrial value added, and high CO_2 emissions efficiency. In contrast with the first three categories, the accumulated CO_2 emissions and industrial value added are the lowest of the fourth category, and other mining industry, furniture manufacturing, manufacturing of instruments, cultural and official mechanics, and handicrafts and other manufacturing have higher CO_2 emissions efficiency, though the value of non-ferrous metal mining, leather, fur, feather, and related products manufacturing, printing, and record medium reproduction manufacturing, cultural, educational, and sports goods manufacturing and production and distribution of water range from 0. 14 to 1. In contrast, this is higher than most of the industrial sector in the first three categories.

According to the results above, it is can be concluded that an industrial sector with high indicators of historical accumulated emissions and carbon intensity will shoulder more intensity reduction burden. Thus, the industrial sector with the heaviest reduction burdens are those with two high indicators for the equal weighting case.

Characterization of Preferred Responsibility Case

Fig. 4 shows that manufacturing of oil processing, coking, and nuclear fuels processing, wholesale, retail, accommodation and catering, agriculture, forestry, the fishery industry, smelting, and rolling process of ferrous metal, transportation, storage and postal service, manufacturing of non-metal products ferrous metal, manufacturing of raw chemical materials and chemical products, and production and supply of electricity, heat, gas and water assumed greater responsibility for emission reduction. The main characteristics of these industries are: high energy consumption, low CO_2 emission efficiency, and high historical accumulated emission. In the process of China's economic development, various industries have to coordinate the relationship between their own development and environmental protection, rationally utilize resources, reduce energy consumption, and improve energy efficiency targets. Hence, industrial structure adjustment is an important strategy. On the one hand, the adjustment and establishment of a reasonable industrial structure can promote economic and social development, and on the other hand, it can adapt the industry to the change of market demand. To adjust industrial structure unreasonable industry, make the coordinated development of various industry departments, and provide products, services, and employment opportunities for social needs. At the same time, applying advanced industrial technology can obtain the best economic benefits.

Characterization of Preferring Capacity Case

Compared with equal case, the responsibility for reducing emissions of Other Mining industries comes into the first category. The main reason is that the industrial added value of other mining industry rank high in the 42 industrial sectors. This confirms the assumption that industries with more added value must be more capable of reducing emissions, and the feasibility of reducing emissions will be higher. At the same time, our country has set up a carbon trading market under which companies will be assigned an emissions quota and will be able to profit from selling excess permits to other firms if they are below their

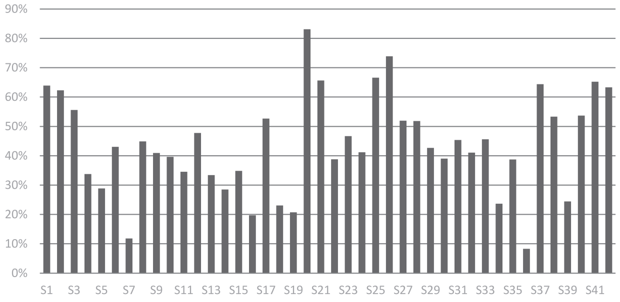

Fig. 4. Carbon intensity reduction burdens in 2030 under the preferring responsibility case.

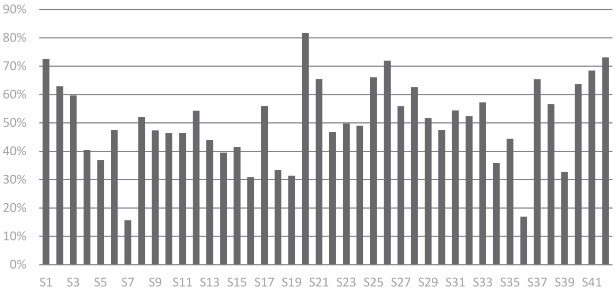

Fig. 5. Carbon intensity reduction burdens in 2030 under the preferred capacity case.

quota. In the process of pilot exploration, we should gradually establish a sound methodology system, and foster more third-party certification bodies, and establish a nationwide registration system. We should explore the formation of an emission rights distribution system, price formation system, and emission reduction incentive system (Fig. 5).

Characterization of Preferring Potential Case

The results in Fig. 6 show that the responsibility of leather, fur, feather, and related products manufacturing, production and distribution of water, printing and record medium reproduction manufacturing, manufacturing instruments, cultural and official mechanics, cultural, educational and sports goods manufacturing, furniture manufacturing, other mining industry and manufacturing of waste resources and materials recycling and processing emissions responsibility is low. The main reason is that these industries in aspects such as human resources and energy input is less, and the phenomenon is mainly related to the social demand. But it does not mean that the industry contribution rate of carbon dioxide is very low, and does not need to control and develop policies. China is in industrialization accelerate process, the manufacturing industry is the main power of economic growth, most of these industries belong to the second industry, the overall sustainable development of the economy is at a low profit, under powered industry chain at the bottom. Based on this, we should further promote the marketization of energy prices on the basis of fully considering economic affordability while taking into account the role of structural adjustment and technological progress.

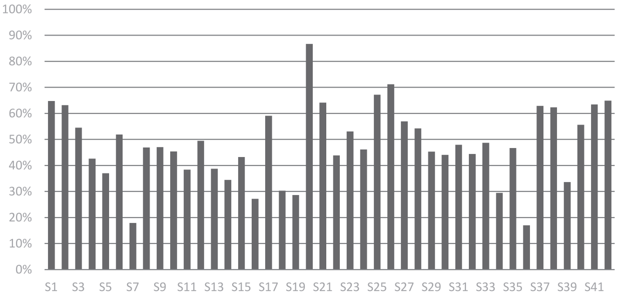

Fig. 6. Carbon intensity reduction burdens in 2030 under the preferred potential case.

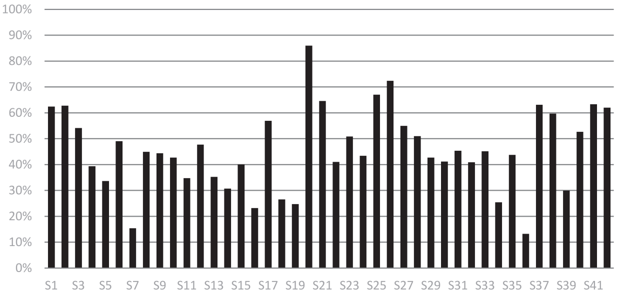

Fig. 7. Carbon intensity reduction burdens in 2030 under entropy weighting.

Characterization of Entropy Method Case

In summary, in the process of contrasting allocation system, it is of vital importance to incorporate equity and fairness as well as select appropriate indicator selection, considering the industrial sector's actual situation and development status. Hence, in order to eliminate the influence of different preferences on the distribution results, this paper uses the allocation model based on entropy method to make a comparison. The entropy method is a kind of objective weighting method. It makes use of the inhomogeneity of data itself to reflect the importance of indicators, and gives an objective weight to allocate the carbon quotas more accurately. Compared to the allocation method based on equal weights, the allocation results based on entropy method seems more reasonable. The result in Fig. 7 further proves the conclusion that the industrial sector with high indicators of CO_2 accumulated emission will shoulder more reduction burden.

Conclusions

By building a carbon intensity distribution model, this paper allocated China's national responsibility distribution among the various industries. Based on the results, the main conclusions and policy suggestions are as follows:

1) Research has shown that the CO_2 emissions efficiency of manufacturing of oil processing, coking and nuclear fuels processing, manufacturing of non-metal products ferrous metal and smelting and rolling process of ferrous metal is lower from 2005 to 2015. The reason is that the cumulative carbon dioxide emissions of these industries are higher, while the added value of the industry is lower, resulting in lower CO_2 emission efficiency, and has not shown a convergence trend. Furthermore, they are typical energy-intensive and highly polluting industries, and therefore the input and output is unreasonable.

In summary, it is required to pay more attention to adjusting industrial structure, controlling production, and developing such industry.

2) Under multiple indicators, whatever the inclination of policy makers, manufacturing of oil processing, coking, and nuclear fuels processing and smelting and rolling process of ferrous metal are assigned more carbon dioxide intensity reduction burden, at more than 70%. The comment of those industries is that they have at least two higher indicators. In addition, the tendency of decision makers on different allocation principles has a great impact on the distribution of emission reduction responsibility in some industries, particularly in leather, fur, feather and related products manufacturing, and the manufacture of instruments, cultural, and official mechanics. They all exhibit a common characteristic in that the gap between preferring potential case and preferring capacity case is over 10%. This study demonstrates that these industries require less input but have stronger economic capacity. Therefore, their responsibilities are reduced when the decision maker is biased toward the capacity case.

In the future, the state mandatory reduction internal responsibility can be conducted at a regional perspective, and the allocation of the regional can also start from the industry perspective. When assigning responsibility for carbon dioxide emission reduction in various industries, it is not only necessary to consider the efficiency of energy consumption or carbon dioxide emission, but also the fairness and feasibility principle of the distribution scheme.

Appendix A. Industry code and names of 42 sub-industries.

Industry structure	Industry code	Industry name
Primary industry	S1	Agriculture, forestry, fishery and fishery industry
Secondary industry	S2	Coal mining and washing
	S3	Oil and natural gas mining
	S4	Ferrous metal mining
	S5	Non-ferrous metal mining
	S6	Non-metal mining
	S7	Other Mining industry
	S8	Agricultural products processing
	S9	Food manufacturing
	S10	Wine, beverage, and refined tea manufacturing
	S11	Tobacco manufacturing
	S12	Textile manufacturing
	S13	Textile clothing and leather products manufacturing
	S14	Leather, fur, feather, and related products manufacturing
	S15	Wood processing and wood, bamboo, cane, palm, and straw manufacturing
	S16	Furniture manufacturing
	S17	Paper making and paper products manufacturing
	S18	Printing and record medium reproduction manufacturing
	S19	Cultural, educational, and sports goods manufacturing
	S20	Manufacturing of oil processing, coking, and nuclear fuels processing
	S21	Manufacturing of raw chemical materials and chemical products
	S22	Manufacturing of medicine
	S23	Manufacturing of chemical fibers
	S24	Manufacturing of rubber and plastic
	S25	Manufacturing of non-metal products ferrous metal
	S26	Smelting and rolling process of ferrous metal

Appendix A. Continued.

	S27	Smelting and rolling process of non-ferrous metal
	S28	Manufacturing of metal products
	S29	Manufacturing of ordinary machinery
	S30	Manufacturing of special equipment
	S31	Manufacture of transport equipment
	S32	Manufacturing of electrical machinery and equipment
	S33	Manufacturing of communication device, computers, and other electronics
	S34	Manufacturing of instruments, cultural, and official mechanics
	S35	Handicrafts and other manufacturing
	S36	Manufacturing of waste resources and materials recycling and processing
	S37	Production and supply of electricity, heat, gas, and water
	S38	Production and distribution of gas
	S39	Production and distribution of water
	S40	Construction industry
Tertiary industry	S41	Transportation, storage, and postal service
	S42	Wholesale, retail, accommodation and catering

Appendix B. Indicator values of 42 industrial sectors in China.

	Accumulated CO_2 emissions 2000-2005 (100 million tons CO_2)	Industrial added value 2005 (100 million yuan)	CO_2 emission efficiency 2005
S1	495. 5069615	22420	1. 0000
S2	1259. 532786	2888. 25	0. 0279
S3	687. 7858025	4813. 96	0. 2970
S4	32. 74280622	426. 5	0. 1034
S5	24. 9014186	427. 6	0. 1906
S6	83. 26692956	280. 51	0. 0418
S7	17. 37618636	2. 7	1. 0779
S8	193. 2188871	2745. 96	0. 2398
S9	100. 669119	1168. 32	0. 0872
S10	92. 5933201	1164. 73	0. 1080
S11	23. 76823136	2059. 99	1. 0000
S12	261. 0902628	3240. 19	0. 1809
S13	29. 31000493	1419. 86	0. 3182
S14	17. 01643681	944. 38	0. 4347
S15	40. 30841332	510. 86	0. 1013
S16	7. 648840279	384. 87	0. 6260
S17	300. 2265295	1146. 4	0. 0250
S18	12. 6969378	463. 06	0. 4573
S19	8. 092975757	379. 71	0. 4966
S20	5220. 298386	1981. 64	0. 0022
S21	1892. 572891	4391. 92	0. 0426

Appendix B. Continued.

S22	79. 32774534	1529. 8	0. 1545
S23	208. 5913414	485. 31	0. 0427
S24	95. 85621336	1867. 41	0. 1257
S25	1866. 004715	2807. 92	0. 0187
S26	4054. 736927	5776. 9	0. 0243
S27	327. 7799565	1929. 65	0. 0352
S28	84. 58119696	9399. 93	1. 0000
S29	117. 0269451	2966. 96	0. 3467
S30	75. 32512582	1681. 56	0. 1574
S31	136. 5902495	3830. 52	0. 2743
S32	43. 91364417	3574. 13	0. 7418
S33	38. 2120619	5722. 11	1. 0000
S34	8. 58559633	733. 19	0. 8814
S35	67. 92108905	570. 83	0. 0742
S36	6. 440059813	59. 93	1. 1355
S37	1624. 831648	5719. 79	0. 0592
S38	149. 2793822	134. 52	0. 0157
S39	13. 59950593	261. 64	0. 2413
S40	159. 5570365	10133. 8	0. 8532
S41	1535. 179009	10835. 7	0. 1651
S42	245. 4708954	24370. 2	1. 0000

(Dates are from the China Statistical Yearbook from 2000 to 2005)

Appendix C. Intensity reduction burdens for 42 industrial sectors under the eight cases.

	Case1	Case2	Case3	Case4
S1	67%	64%	73%	65%
S2	63%	62%	63%	63%
S3	57%	56%	60%	55%
S4	39%	34%	41%	43%
S5	34%	29%	37%	37%
S6	48%	43%	47%	52%
S7	15%	12%	16%	18%
S8	48%	45%	52%	47%
S9	45%	41%	47%	47%
S10	44%	40%	46%	45%
S11	40%	35%	46%	38%
S12	51%	48%	54%	49%
S13	39%	33%	44%	39%
S14	34%	28%	40%	34%
S15	40%	35%	42%	43%
S16	26%	20%	31%	27%
S17	56%	53%	56%	59%
S18	29%	23%	33%	30%
S19	27%	21%	31%	29%
S20	84%	83%	82%	87%
S21	65%	66%	65%	64%
S22	43%	39%	47%	44%
S23	50%	47%	50%	53%
S24	45%	41%	49%	46%
S25	67%	67%	66%	67%
S26	72%	74%	72%	71%
S27	55%	52%	56%	57%
S28	57%	52%	63%	54%
S29	47%	43%	52%	45%
S30	44%	39%	47%	44%
S31	49%	45%	54%	48%

Appendix C. Continued.

S32	46%	41%	52%	44%
S33	51%	46%	57%	49%
S34	30%	24%	36%	29%
S35	43%	39%	44%	47%
S36	14%	8%	17%	17%
S37	64%	64%	65%	63%
S38	58%	53%	57%	62%
S39	30%	24%	33%	34%
S40	58%	54%	64%	56%
S41	66%	65%	68%	63%
S42	68%	63%	73%	65%

Appendix D. The industrial CO$_2$ emissions efficiencies in China's 42 industrial sectors.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
S1	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000
S2	0. 0279	0. 0325	0. 0324	0. 0223	0. 0209	0. 0201	0. 0211	0. 0189	0. 0145	0. 0138	0. 0165
S3	0. 2970	0. 4194	0. 3421	0. 1856	0. 1940	0. 1701	0. 1627	0. 1529	0. 1550	0. 1592	0. 1642
S4	0. 1034	0. 1100	0. 1102	0. 1056	0. 1322	0. 0960	0. 0966	0. 0898	0. 0655	0. 0645	0. 0678
S5	0. 1906	0. 2356	0. 2301	0. 2433	0. 2628	0. 2192	0. 2306	0. 1886	0. 1595	0. 1801	0. 1424
S6	0. 0418	0. 0521	0. 0488	0. 0551	0. 0589	0. 0595	0. 0764	0. 1050	0. 0737	0. 0646	0. 0665
S7	1. 0779	1. 0000	1. 0014	1. 0000	1. 0000	1. 4350	1. 3432	1. 4848	1. 8098	1. 3758	1. 4408
S8	0. 2398	0. 3180	0. 3465	0. 1985	0. 2247	0. 2322	0. 2497	0. 2522	0. 1823	0. 2119	0. 2523
S9	0. 0872	0. 0928	0. 0852	0. 0720	0. 0725	0. 0605	0. 0813	0. 0548	0. 0443	0. 0411	0. 0401
S10	0. 1080	0. 1151	0. 1096	0. 0956	0. 1005	0. 0976	0. 1275	0. 1115	0. 0556	0. 0567	0. 0554
S11	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000
S12	0. 1809	0. 2027	0. 1979	0. 1253	0. 1347	0. 1253	0. 1404	0. 1493	0. 1304	0. 1473	0. 0907
S13	0. 3182	0. 3229	0. 2904	0. 2686	0. 2638	0. 2784	0. 3412	0. 2480	0. 2047	0. 1874	0. 1812
S14	0. 4347	0. 4373	0. 4109	0. 4130	0. 6767	0. 6958	1. 0000	0. 5368	0. 3410	0. 3249	0. 2948
S15	0. 1013	0. 1179	0. 1224	0. 1150	0. 1228	0. 1183	0. 2480	0. 1667	0. 1226	0. 1010	0. 1105
S16	0. 6260	0. 6662	0. 6342	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	0. 8313	0. 6693	0. 5873
S17	0. 0250	0. 0237	0. 0224	0. 0206	0. 0198	0. 0177	0. 0218	0. 0158	0. 0141	0. 0142	0. 0128
S18	0. 4573	0. 4609	0. 4139	1. 0000	1. 0000	0. 8870	1. 0000	0. 9543	0. 6776	0. 5278	0. 4712
S19	0. 4966	0. 5174	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	0. 5354	0. 4106	0. 3780
S20	0. 0022	0. 0019	0. 0023	0. 0016	0. 0014	0. 0011	0. 0013	0. 0008	0. 0007	0. 0006	0. 0005
S21	0. 0426	0. 0495	0. 0546	0. 0293	0. 0338	0. 0360	0. 0337	0. 0327	0. 0303	0. 0304	0. 0305
S22	0. 1545	0. 1519	0. 1470	0. 1270	0. 1271	0. 1163	0. 1445	0. 1004	0. 0609	0. 0520	0. 0523
S23	0. 0427	0. 0458	0. 0422	0. 0519	0. 0611	0. 0680	0. 0770	0. 0644	0. 0487	0. 0660	0. 0442
S24	0. 1257	0. 1326	0. 1589	0. 1200	0. 1243	0. 1273	0. 1652	0. 1434	0. 1320	0. 1382	0. 1483
S25	0. 0187	0. 0259	0. 0297	0. 0166	0. 0185	0. 0214	0. 0227	0. 0226	0. 0217	0. 0210	0. 0243
S26	0. 0243	0. 0247	0. 0245	0. 0144	0. 0145	0. 0137	0. 0124	0. 0122	0. 0126	0. 0127	0. 0138
S27	0. 0352	0. 0904	0. 1074	0. 0642	0. 0705	0. 0482	0. 0489	0. 0451	0. 0419	0. 0389	0. 0358
S28	1. 0000	0. 1589	0. 1739	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000
S29	0. 3467	0. 1869	0. 1999	0. 2952	0. 2688	0. 3033	0. 2720	0. 3094	0. 3811	0. 4110	0. 4230
S30	0. 1574	0. 1725	0. 1764	0. 1684	0. 2025	0. 2146	0. 3202	0. 3614	0. 4072	0. 4006	0. 2236
S31	0. 2743	0. 3117	0. 3642	0. 2834	0. 3297	0. 5769	0. 5941	0. 5705	0. 6018	0. 8371	0. 4683

Appendix D. Continued

S32	0. 7418	0. 8407	0. 8788	0. 6789	0. 5481	0. 5377	0. 4058	0. 4414	0. 8608	0. 4375	0. 3828
S33	1. 0000	1. 0000	1. 0000	0. 8113	0. 6881	0. 6871	0. 7868	0. 7603	0. 1639	1. 0000	0. 9441
S34	0. 8814	0. 9101	0. 7754	0. 6762	1. 0000	1. 0000	1. 0000	1. 0000	0. 9265	0. 9215	0. 9023
S35	0. 0742	0. 0829	0. 0852	0. 0854	0. 0927	0. 0841	0. 2120	0. 0805	0. 0634	0. 0483	0. 0637
S36	1. 1355	1. 2842	1. 3154	1. 2120	1. 3450	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000
S37	0. 0592	0. 0599	0. 0534	0. 0291	0. 0277	0. 0274	0. 0234	0. 0200	0. 0210	0. 0202	0. 0202
S38	0. 0157	0. 0183	0. 0188	0. 0308	0. 0814	0. 0716	0. 1300	0. 0823	0. 0926	0. 1015	0. 1183
S39	0. 2413	0. 2726	0. 2384	0. 8598	0. 7771	0. 5417	0. 7626	0. 4398	0. 4359	0. 3777	0. 3071
S40	0. 8532	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000
S41	0. 1651	0. 1661	0. 1430	0. 0813	0. 0794	0. 0749	0. 0731	0. 0660	0. 0742	0. 0771	0. 0769
S42	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000	1. 0000

This table is calculated by the model of Super-SBM. Labor capital stock, and energy are input factors, value-added of the industry is used as a sole desirable output and CO_2 emission is used as an undesirable output. It indicates that the efficiency of undesired outputs can be calculated by the ratio of the undesired output value to the pre-optimal output value. Therefore, CO_2 emissions efficiency is calculated by Eq. 3.

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Conflict of Interest

The authors declare no conflict of interest.

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