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Research Article

Efficiency of Carbon Dioxide (CO_2) Emission Control Target Allocations in China

Liyun Chen [1] **and Zhiwei Li** [2]

[1] *College of Economy and Management, Tianjin Agricultural University, Tianjin 300384, China*
[2] *Tianjin Key Laboratory for Control Theory & Applications in Complicated System, Tianjin University of Technology, Tianjin 300384, China*

Correspondence should be addressed to Liyun Chen; chenliyunjg@126.com

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Effectively allocating emission control targets is critical for China to achieve its emission reduction goals. This study researched the efficiency of total carbon dioxide (CO_2) emission control target allocations during the 13th Five-Year Plan period (2015–2020). The efficiency of carbon intensity reduction targets, allocated by the National Development and Reform Commission in 30 regions, was assessed using a Directional Distance Function (DDF) model. Then, a Zero-Sum Gains (ZSG)-DDF model was constructed to determine how to optimally allocate total CO_2 emission, under the premise of maximizing economic benefits and minimizing CO_2 emissions. The results showed that in the case of fixed total CO_2 emissions, to improve the resource allocation efficiency, the quota should be increased in the regions with high efficiencies, and the quota should be reduced in the regions with low efficiencies. The results in this paper can help guide the future allocations of total CO_2 emission in China.

1. Introduction

Climate change has attracted increasing attention worldwide, as both an environmental and economic problem. The United Nations Framework Convention on Climate Change (UNFCCC) has stated that a long-term goal is keeping the gas concentrations of the atmosphere greenhouse at a fixed level; this requires individual countries to control the emissions of greenhouse gas. In China's Work Plan for Controlling Greenhouse Gas Emission during the 13th Five-Year Plan Period (2015–2020), the National Development and Reform Commission set a target to reduce CO_2 emission per unit of gross domestic product by 18 percent from 2015 levels by 2020.

There are three ways to identify and allocate more specific CO_2 emission reduction goals. (1) The carbon intensity (that is, the CO_2 emission per unit of GDP) reduction target can converted into a total CO_2 emission reduction target using the scenario analysis method. The total CO_2 emission target can then be decomposed for each region. Finally, each region can break down its carbon targets across industries. (2) After converting the carbon intensity reduction target into the total CO_2 emission reduction target, the target can be directly allocated to different industries. (3) Carbon intensity reduction targets can be allocated directly to provinces, municipalities, and autonomous regions across the country or can be allocated directly to different industries [1]. The National Development and Reform Commission selected the third option, directly distributing the national target for reducing carbon intensity to provinces, municipalities, and autonomous regions during the 13th Five-Year Plan period.

There was currently no specific, universally accepted, worldwide scheme for allocating the total amount of CO2. Researchers around the world have put forward different allocation principles, with research mainly focusing on two core principles: equity and efficiency [2]. The equity principle means that subjects participating in the allocation of total CO2 emission should have equal rights [3]. The most widely used indicators to assess this include the population, the gross domestic product (GDP) level, and the level of historical emissions (that is, the grandfather method) [4, 5]. The efficiency principle means that the allocation should maximize the economic benefit while also allocating the total amount of CO2 emissions.

To capture the resource allocations and production efficiencies, researchers apply the Data Envelope Analysis (DEA) method to create multiple constraints and to establish a production possibility set including multiple input-output indicators. Some researchers have used the DEA derivative models to allocate the total amount of CO2 emissions [6–9]. The Zero-Sum Gains DEA (ZSG-DEA) can achieve the maximum allocation efficiency in the case of fixed total amount. This method is widely used to allocate total CO2 emissions.

During production, the target product is desirable output, and CO2 is often treated as a pollutant, known as an undesirable output. Producers generally want to simultaneously maximize the desirable output and minimize the undesirable output. However, the ZSG-DEA model cannot currently solve this problem on its own. As such, the contribution of this paper was to combine a DDF (Directional Distance Function) with a ZSG-DEA model to construct a ZSG-DDF model. The model was used to examine approaches for optimally allocating total CO2 emissions, under the premise of maximizing economic benefits and minimizing CO_2 emissions. This involved establishing different improvement directions of desirable output and undesirable output [10–12].

The rest of this paper is organized as follows. Section 2 introduces the input-output indicators and data sources and describes the construction of the ZSG-DDF model. Section 3 provides the empirical results and analysis. First, the DDF model was used to examine the regional allocation efficiency of China's current CO_2 emission control targets. Then, the ZSG-DDF model was applied to adjust the initial allocation results to optimize the allocation efficiency. Section 4 summarizes the conclusions.

2. Data Sources and Research Method

2.1. Indicator Selection and Data Sources. This study examined 30 provinces, municipalities, and autonomous regions in China. Tibet, Hong Kong, Macao, and Taiwan were not included because part or all of the data were not available. Input-output data for 2015 were used as a baseline to calculate the relevant data for 2020. During production, capital, labor, and energy are usually used for input, producing economic benefit and CO_2 emissions. Therefore, the input-output indicators set consisted of capital stocks, labor, energy consumption, regional GDP, and CO_2 emissions.

Data on capital, the labor force, and regional GDP were obtained from the China Statistical Yearbook; data on the amount of different energy were obtained from the China Energy Statistical Yearbook. The amount of CO_2 was measured using the relevant data and method from Guidelines for Provincial Greenhouse Gas Inventories, published by the National Development and Reform Commission of China. The specific indicators and growth rate were calculated as follows.

(1) *Capital Stocks*. This indicator was denoted by the total capital formation data. In this study, the annual development speed of capital during the "13th Five-Year Plan" period was measured as the average development speed of total capital formation during the "12th Five-Year Plan" period.

(2) *Labor*. This indicator was measured as the number of employed persons per urban unit. In this study, the annual development speed of labor during the "13th Five-Year Plan" period was measured as the average growth rate of the number of employed persons during the "12th Five-Year Plan" period.

(3) *Energy Consumption*. The amount of different energy consumption was converted into the amount of standard coal consumption, respectively. The values were then added according to the standard coal coefficient of energy conversion. Four kinds of fossil energy with high carbon levels were selected to represent the regional energy consumption: raw coal, coke, petroleum energy, and natural gas. The amount of energy consumption in 2020 was measured using the unit GDP energy consumption reduction target during the "13th Five-Year Plan" period. Where data were not available for specific regions, the national reduction target was used.

(4) *Regional GDP*. The economic development levels differed across different regions in China, and the caliber of regional accounting differed from the caliber of national GDP accounting. Further, the Chinese economy has recently slowed. Therefore, the lower limits in the GDP growth target during the 13th Five-Year Plan period were selected to compute the regional GDP in 2020.

(5) *CO_2 Emissions*. The reduction target of CO_2 emissions intensity in each region was established during the 13th Five-Year Plan period. As such, the target growth rate of CO_2 emissions at the end of 13th Five-Year Plan was computed by the growth rate of regional GDP.

2.2. Methods. For this study, 30 regions in China were selected as Decision-Making Units (DMUs), represented by $i = 1, 2, \ldots, 30$. The input indicators included capital (x^k), labor (x^l), and energy (x^e). The output indicators included regional GDP (i.e., desirable output y) and CO_2 emissions (i.e., undesirable output b). The meaning of DDF value is as follows. At the current output level, the maximum possible proportion of desirable output increases and undesirable output decreases. The direction vector of undesirable output is generally negative. Therefore, the direction vector was defined as $g = (y, -b)$; that is, the output vector of the evaluated DMU was set as the direction vector. When the direction vector took the output value of the evaluated DMU, the efficiency value of the evaluated DMU was $\theta = 1/(1+\beta)$. In this study, the output-oriented ZSG-DEA model was selected, and the proportional reduction strategy was used to reallocate the total CO_2 emissions. When the efficiency of DMU_k was lower, the amounts of CO_2 emissions for DMU_k need to reduce, and the amounts of CO_2 emissions for other DMUs could increase because of a fixed total amount. Then, the increased amounts of CO_2 emissions for DMU_j (j ≠ k) were calculated as

$$b_{j\Delta} = \frac{b_j}{\sum_{j\neq k} b_j} \times b_k \left(1 - \frac{1}{1+\beta}\right). \quad (1)$$

Therefore, the ZSG-DDF model was expressed as

$$\begin{aligned}
&\vec{D}_0\left(x, y, b; g_y, g_b\right) = \text{Max}\beta, \\
&\text{s.t.} \sum_{i=1}^{n} \lambda_i x_i \leq x_k, \\
&\sum_{i=1}^{n} \lambda_i y_i \geq y_k + \beta g_y, \\
&\sum_{i=1}^{n} \lambda_i b_i \left[1 + \frac{b_k}{\sum_{j\neq k} b_j} \times \left(1 - \frac{1}{1+\beta}\right)\right] \leq b_k + \beta g_b, \\
&\beta \geq 0, \lambda_i \geq 0, \\
&\sum_{i=1}^{n} \lambda_i \leq 1.
\end{aligned} \quad (2)$$

3. Empirical Results and Analysis

3.1. Statistical Description of Input-Output Data of 30 Regions in China in 2015. The calculations of energy consumption and CO_2 emissions in 2020 depend on the associated data in 2015 (i.e., the end of 12th Five-Year Plan). As such, the specific data for 2015 are listed in Table 1. In a DDF model, the DMU will have a higher efficiency when the inputs yield more desired output and less undesired output. Comparing with other regions, Shandong Province had the largest amount of capital input, showing there were more capital-intensive industries. Qinghai Province had invested the lowest labor and energy; however, it also had the lowest accompanying outputs. This led to a production efficiency that was lower. Guangdong Province had invested the most labor and the amount of GDP was highest, indicating that it had more labor-intensive industries. Shanxi Province consumed abundant energy and produced the highest amount of CO_2 emissions, showing that Shanxi Province had more opportunities to conserve energy conservation and reduce CO_2 emission.

3.2. Initial Allocation Efficiency of Chinese Total CO_2 Emission in 2020. Previous studies have mostly used DEA-derived models to research the direct allocation of total carbon emission among regions or industries. Few studies, however, have examined the allocation efficiency of carbon intensity emission reduction targets among regions allocated by the National Development and Reform Commission. Using the given carbon intensity reduction targets for different region in the Work Plan for Controlling Greenhouse Gas Emission (2015–2020), the specific values of CO_2 emission were calculated. Based on the specific data for 2015 and the accompanying growth rate, the DDF model was applied to obtain the initial allocation efficiency of total CO_2 emissions in 30 regions of China (specific results could be seen in Table 2).

The efficiency value of 9 regions was 1, that is, these regions were situated at the production frontier (the production frontier is the boundary in the optimal state, and the efficiency is highest when the combination of input and output is on the production frontier); the efficiency values of 4 regions were 0.9–1, which meant that the 4 regions nearly reached the production frontier, and 6 regions could not reach the production frontier, with efficiency values of less than 0.7. This indicated that the allocation plan based on China's total carbon emission control of the National Development and Reform Commission (2015–2020) had not yet optimally allocated resources.

Among the 13 regions with higher efficiency values, most were located in the east and central regions [13] and had relatively developed economies, abundant levels of capital investment, and high energy utilization efficiencies [8] (Inner Mongolia also had a high efficiency but is located in a different geographic area). In contrast, the regions with low efficiency were mostly western regions with relatively underdeveloped economic levels and production capacities [14–17]. The technological innovation level should be improved to improve the levels of energy utilization efficiency and to reduce CO_2 emissions.

3.3. Adjustment Results of Total CO_2 Emission Allocation Based on the ZSG-DDF Model. Total CO_2 emissions are fixed at a country level. Allocating the carbon intensity levels across regions based on established reduction targets may result in unreasonable resource allocations in many regions, highlighting the need to further improve allocation efficiencies. To obtain the optimal allocation of resources at the end of the 13th Five-Year Plan period and to optimize the relative efficiency of each region in the total CO_2 emission allocation scheme, this study used the ZSG-DDF model to reallocate the total CO_2 emissions in 2020.

After three iterations, the CO_2 emission quotas were adjusted: the amount of CO_2 emissions for the regions with lower efficiency values was reduced. The amount of CO_2 emissions was increased for the regions on the production frontier because of their higher input-output efficiency. This was consistent with the idea of zero-sum benefits based on a fixed total amount of CO_2 emissions, whereby efficient regions receive increasingly higher quotas and inefficient regions receive increasingly lower quotas. The average efficiency value of all regions increased to 0.91, improving the efficiency of resource allocations across all regions.

Table 3 shows that after the first iteration, the mean value of input-output efficiency increased from 0.85 to 0.87. There were still only 9 regions with an allocation efficiency of 1;

Table 1: The descriptive analysis of input-output data of 2015.

	Mean value	Standard deviation	Maximum value	Minimum value
Capital stock (100 million yuan)	13444.08	8106.99	35587.40	2317.10
Labor (10^4 persons)	600.97	419.29	1948	62.7
Energy consumption (10^4 tons of standard coal equivalent)	18012.36	13600.96	60987.46	2367.15
GDP (100 million yuan)	24162.10	17737.61	72812.60	2417.10
CO_2 emission (10^4 tons)	44909.45	35261.21	161297.8	5501.25

Table 2: The efficiency of CO_2 emission allocations.

	Carbon intensity reduction targets for the 13th Five-Year Plan period (%)	The initial values of DDF	Initial efficiency of allocation	Iterative adjustment efficiency	The degree of decline in carbon intensity	Allocation efficiency by historical emission
Beijing	20.5	0.00	1.00	1.00	-11.5%	1.00
Tianjin	20.5	0.05	0.95	0.99	-1.2%	0.94
Hebei	20.5	0.14	0.88	0.88	23.0%	0.88
Shanxi	18.0	0.65	0.60	0.66	71.8%	0.60
Inner Mongolia	17.0	0.00	1.00	1.00	-16.4%	1.00
Liaoning	18.0	0.00	1.00	1.00	-15.0%	1.00
Jilin	18.0	0.10	0.91	0.91	10.4%	0.91
Heilongjiang	17.0	0.33	0.75	0.87	41.5%	0.75
Shanghai	20.5	0.00	1.00	1.00	-11.5%	1.00
Jiangsu	20.5	0.00	1.00	1.00	-11.5%	1.00
Zhejiang	20.5	0.00	1.00	1.00	-11.5%	1.00
Anhui	18.0	0.20	0.84	0.88	26.4%	0.84
Fujian	19.5	0.07	0.93	0.97	2.5%	0.93
Jiangxi	19.5	0.25	0.80	0.89	31.1%	0.81
Shandong	20.5	0.00	1.00	1.00	-11.5%	1.00
Henan	19.5	0.27	0.79	0.90	34.3%	0.80
Hubei	19.5	0.03	0.97	0.99	-6.4%	0.98
Hunan	18.0	0.00	1.00	1.00	-15.0%	1.00
Guangdong	20.5	0.00	1.00	1.00	-11.5%	1.00
Guangxi	17.0	0.15	0.87	0.95	11.8%	0.87
Hainan	12.0	0.38	0.73	0.88	36.3%	0.73
Chongqing	19.5	0.14	0.88	0.95	13.2%	0.91
Sichuan	19.5	0.13	0.88	0.95	12.9%	0.88
Guizhou	18.0	0.53	0.65	0.82	54.2%	0.66
Yunnan	18.0	0.31	0.76	0.89	34.3%	0.77
Shaanxi	18.0	0.47	0.68	0.81	54.8%	0.68
Gansu	17.0	0.60	0.63	0.77	59.2%	0.63
Qinghai	17.0	0.40	0.71	0.87	38.3%	0.72
Ningxia	12.0	0.47	0.68	0.71	56.7%	0.68
Xinjiang	12.0	0.71	0.58	0.74	64.4%	0.59

Table 3: The iterative change process of the ZSG-DDF model.

	一	二	三
The mean value of input-output efficiency	0.87	0.89	0.91
Number of regions reaching the production frontier	9	9	9
Number of regions nearly reaching the production frontier	7	7	8
Number of regions far from the production frontier	9	6	4

however, the number of regions nearly reaching the production frontier increased from 4 to 7. After the second iteration, the mean value of input-output efficiency increased to 0.89; the number of regions with efficiency values above 0.9 remained unchanged. After the third iteration, the mean value of input-output efficiency increased to 0.91; the number of regions with an efficiency value of 1 remained unchanged, and the number of regions nearly reaching the production frontier increased to 8. The efficiency values for other regions improved significantly; however, the efficiency values for Shanxi, Ningxia, Gansu, and Xinjiang remained low.

To improve the input-output efficiency of the 30 regions, 9 regions with high allocation efficiency should be allocated a higher CO_2 emission quota, while the CO_2 emission quota should be reduced in regions with low efficiency (such as Shanxi, Guizhou, Shaanxi, Gansu, Ningxia, and Xinjiang). These changes could lead to a significant increase in the ability to reach a higher carbon intensity reduction target. The regions with high efficiency levels were mostly those with high levels of economic development. These regions placed relatively high importance on the environment and were able to effectively control environmental pollution. Therefore, higher input-output efficiency should be associated with a higher CO_2 emission quota allocation.

From the regional 13th Five-Year Plan, the average GDP growth rate of Shanxi Province was the lowest, and the reduction targets of energy consumption intensity and CO_2 emission intensity were not high. However, Shanxi Province consumed largest energy and produced highest amount of CO_2 emissions in 2015. This indicates that there were significant opportunities for conserving energy conservation and reducing CO_2 emission. Guizhou, Shaanxi, Gansu, Ningxia, and Xinjiang had a low proportion of GDP compared to the country overall; they also have underdeveloped economies, heavy industrial structures, high energy consumption levels, and relatively poor environmental governance. To improve the input-output efficiency, there should be a reduction in these regions' CO_2 emission quotas.

Each region's proportion of historical CO_2 emissions, as a percentage of the entire country's emissions, was used to recalculate new allocations of CO_2 emission quotas for each region in 2020. The allocated efficiencies were essentially consistent with the efficiencies allocated in light of the carbon intensity reduction targets in the 13th Five-Year Plan. This is because the original allocation of China's CO_2 emission intensity reduction target primarily considered the CO_2 emissions of different region in the past; it was those levels that determined the required region-specific emission reductions.

During the 13th Five-Year Plan period, the CO_2 emission allocation plan of the National Development and Reform Commission, which was under the total emissions control, did not give higher quotas to efficient regions but rather gave them to inefficient regions [18–20]. In other words, the economically developed regions had higher resource allocation efficiency, and the CO_2 emission reduction targets were correspondingly higher. However, the CO_2 emissions in a region have a close relationship to its speed of economic growth. China's economic growth in CO_2 emissions cannot be completely decoupled in short time. The allocation of CO_2 emissions should therefore consider a region's economic development level. A more developed economy should be associated with a greater demand for CO_2 emissions.

4. Conclusion

Allocating CO_2 emissions plays an important role in developing carbon trading markets and in the ability of countries to realize national CO_2 emission reduction targets. This paper makes the following main contributions to the field. First, the efficiencies of carbon intensity reduction targets allocated by the National Development and Reform Commission in 30 regions were assessed using a DDF model. Second, a ZSG-DDF model was constructed to study approaches for optimizing the allocation efficiency of total CO_2 emissions, under the premise of maximizing economic benefits and minimizing CO_2 emissions.

The results showed the following. (1) The initial allocation efficiency of China's total CO_2 emissions in 2020 was not optimal. In the case of fixed total CO_2 emissions, to improve the allocations, regions with a high efficiency level should receive higher quotas, and regions with a low efficiency level should receive lower quotas. (2) The CO_2 emission intensity reduction targets of the National Work Plan for Controlling Greenhouse Gas Emission in the 13th Five-Year Plan primarily used CO_2 emissions in the past for each region as the reference basis. Some regions were assigned CO_2 emission quotas that were inconsistent with their resource allocation efficiency, resulting in lower efficiency levels. Economically developed regions had a higher level of resource allocation efficiency and higher carbon intensity reduction targets. The allocation scheme prioritized equity with respect to historical emissions and regional equity. That scheme did not give priority to the optimal efficiency of regional resource allocation or the maximum emission reduction effect achieved with the minimum level of input.

This study highlighted implications for future regional allocations of CO_2 emissions. (1) The principle of prioritizing efficiency should be considered when allocating CO_2 emissions among different regions in the future planning. On the premise of sustaining economic growth, the principle could encourage regions with significant levels of energy consumption and environmental pollution to change the mode of economic growth, strengthen energy conservation and emission reductions, and adjust the industrial structure. It would also encourage regions to prioritize the development of the green economy and to promote an ecological civilization, further improving the production efficiency. (2) In the long run, the allocation plan developed to allocate national total CO_2 emission control targets among different regions needs to be executable, considering both regional equity and allocation efficiency. It is particularly important to determine which indicators best represent regional equity. This is needed to guarantee the smooth achievement of the national CO_2 emission reduction targets; encourage the smooth operation of the CO_2 emission trading market; and achieve the carbon peak and carbon neutrality at an early date.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References

[1] W. J. Yi, L. L. Zou, J. Guo, K. Wang, and Y.-M. Wei, "How Can China Reach its CO2 Intensity Reduction Targets by 2020: A Regional Allocation Based on Equity and Development," *Energy Policy*, vol. 39, p. 2407, 2011.

[2] Q. W. Yu and F. P. Wu, "Bi-level programming model of provincial carbon emission allocation from the coupling perspective of fairness and efficiency," *Soft Science*, vol. 32, no. 4, p. 72, 2018, in Chinese.

[3] D. Zhou, W. J. Wang, and Z. J. Chen, "Research on the redistribution of carbon emission quotas in China based on the importance of indicators to carbon emission," *China Environmental Science*, vol. 40, no. 12, p. 5552, 2020, in Chinese.

[4] Y. Tian and C. B. Chen, "Reward and punishment scheme of China's provincial carbon emission reduction based on the allocation of carbon emission rights," *China Population,Resources and Environment*, vol. 30, no. 11, p. 56, 2020, in Chinese.

[5] K. Fang, Q. F. Zhang, and L. M. Du, "Analyzing the impacts of allocation schemes for initial emission allowance on provincial emission trading strategies and their abatement costs," *Acta Scientiae Circumstantiae*, vol. 41, no. 2, p. 697, 2021.

[6] Y. H. Sun, A. P. He, and S. Y. Peng, "Study on provincial distribution efficiency of carbon emissions right under the constraint of carbon intensity target," *Statistics & Information Forum*, vol. 34, no. 6, p. 76, 2019, in Chinese.

[7] H. Y. Liu and Y. Wang, "Research on initial allocation of energy-consuming right and CO_2-emission right based on historical method and ZSG-DEA method," *Chinese Journal of Management Science*, vol. 28, no. 9, p. 210, 2020, in Chinese.

[8] J. Q. Wu, S. J. Hou, and Z. C. Guan, "Energy environment efficiency evaluation and the carbon reduction responsibility allocation across chiese provinces," *Journal of Systems Science and Mathematical Sciences*, vol. 38, no. 4, p. 406, 2018, in Chinese.

[9] L. Y. Chen, Y. He, G. Li, C. Li, and J. Ren, "Initial allocation model of CO_2 emission allowances based on the equity-efficiency tradeoff," *Asia Pacific Journal of Operational Research*, vol. 38, no. 2, Article ID 2050048, 2021.

[10] Z. Li, J. Wang, and S. Che, "Synergistic effect of carbon trading scheme on carbon dioxide and atmospheric pollutants," *Sustainability*, vol. 13, no. 10, p. 5403, 2021.

[11] X. Wu, Z. Liu, L. Yin et al., "A haze prediction model in chengdu based on LSTM," *Atmosphere*, vol. 12, no. 11, p. 1479, 2021.

[12] L. Yin, L. Wang, W. Huang, S. Liu, B. Yang, and W. Zheng, "Spatiotemporal analysis of haze in beijing based on the multi-convolution model," *Atmosphere*, vol. 12, no. 11, p. 1408, 2021.

[13] L. Y. Chen and Q. Duan, "Decomposition analysis of CO_2 emission driving factors in Chinese provinces based on production-theoretical decomposition analysis," *Natural Hazards*, vol. 84, no. 1, p. S273, 2016.

[14] Y. Liu, J. Tian, W. Zheng, and L. Yin, "Spatial and temporal distribution characteristics of haze and pollution particles in China based on spatial statistics," *Urban Climate*, vol. 41, Article ID 101031, 2022.

[15] Y. Liu, B. Li, X. Lei et al., "Novel method for high-performance simultaneous removal of NOx and SO2 by coupling yellow phosphorus emulsion with red mud," *Chemical Engineering Journal*, vol. 428, Article ID 131991, 2022.

[16] X. Chen, C. Huang, H. Wang, W. Wang, X. Ni, and Y. Li, "Negative emotion arousal and altruism promoting of online public stigmatization on COVID-19 pandemic," *Frontiers in Psychology*, vol. 12, Article ID 652140, 2021.

[17] H. Gao, P.-H. Hsu, K. Li, and J. Zhang, "The real effect of smoking bans: evidence from corporate innovation," *Journal of Financial and Quantitative Analysis*, vol. 55, no. 2, pp. 387–427, 2020.

[18] R. Guo, S. Lv, and X. J. Cao, "Research on distribution efficiency of carbon emission reduction of six major industries in China based on ZSG-DEA model," *Ecological Economy*, vol. 36, no. 1, p. 14, 2020, in Chinese.

[19] W. Pan and W. L. Pan, "Research on quota allocation of provincial CO_2 emission rights in China based on energy efficiency," *Soft Science*, vol. 32, no. 6, p. 45, 2018, in Chinese.

[20] J. Dong, R. Deng, Z. Quanying, J. Cai, Y. Ding, and M. Li, "Research on recognition of gas saturation in sandstone reservoir based on capture mode," *Applied Radiation and Isotopes*, vol. 178, Article ID 109939, 2021.