International Conference on Applied Energy 2020
Dec. 1 - Dec. 10, 2020, Bangkok / Virtual
Paper ID: 0683

CARBON ALLOWANCE ALLOCATION, SECTORAL COVERAGE IN THE CARBON MARKET, AND NATIONALLY DETERMINED CONTRIBUTIONS: A CASE STUDY IN CHINA

Jihong Zhang [1], Si Cheng [2*], Shaozhou Qi[2, 3]
1 Institution of Quality Development Strategy, Wuhan University, China
2 Center of Hubei Cooperative Innovation for Emissions Trading System, Hubei University of Economics, China
3 Climate Change and Energy Economics Study Center, Economics and Management School, Wuhan University, China
*Corresponding author: chengsi@hbue.edu.cn

ABSTRACT

The carbon market has become an important tool that global countries use to achieve their emission reduction commitments, or Nationally Determined Contributions (NDCs). Sectoral coverage and carbon allowance allocation are the most important considerations in the construction of a carbon market. In this study, we propose a multi-criteria allocation scheme based on the principle of equity, efficiency, and feasibility, considering carbon abatement costs and carbon leakage risks. An improved zero sum gains-data envelopment analysis model in accordance with China's NDCs is used for allowance allocation. Subsequently, the sectoral coverage choice of the carbon market is proposed. The results of this study are the following: most carbon allowances are concentrated in six sectors; sixteen sectors have major shares of the overall emission reduction; and the allocation method used in this study can help the carbon market reduce emissions at a lower cost, while preventing carbon leakage to a certain extent.

Keywords: carbon allowances; carbon market; multi-criteria allocation; Nationally Determined Contributions (NDCs); sectoral coverage; zero sum gains-data envelopment analysis (ZSG-DEA)

NONMENCLATURE

Symbols	
CE_t	carbon emission in year t
GDP_t	GDP of China in year t
$CE_{industry_t}$	industrial carbon emission in year t
I_t	carbon intensity of sectors in year t
TCA_t	overall carbon allowances in year t
IVA_t	industrial added value in year t
$ICEA_p$	initial carbon allowances of industry p
CE_p	historical carbon emissions of industry p.

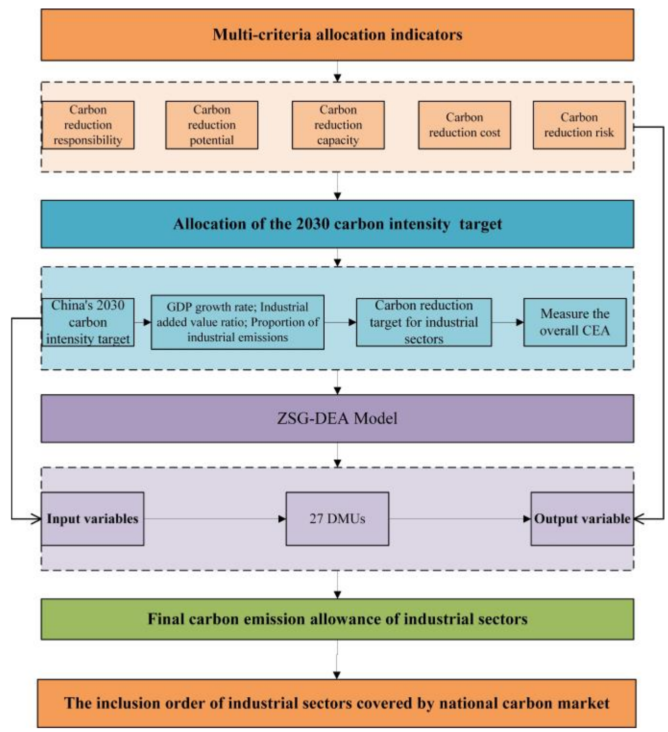

Fig. 1 Research framework

1. INTRODUCTION

The Paris Agreement on Climate Change represents a landmark in global environmental governance that leaves space for individual parties to formulate their Nationally Determined Contributions (NDCs). The carbon market has become an important tool for global countries to achieve their emission reduction commitments. China has made many efforts to meet its NDC targets, one of the most important of which has been the establishment of a national carbon market. Sectoral coverage and carbon allowance allocation is one of the most important concerns in the construction of a carbon market. Emerging economies face a social-economic context unique due to the uncertainty of their economic situation. Thus, sectoral coverage and carbon allowance allocation in these regions is an increasingly complex issue.

In this context, the reasonable allocation of carbon allowances among different industrial sectors based on the NDCs target and the choice of sectoral coverage in the national carbon market are of great significance. This paper proposes a multi-criteria allocation scheme based on the principle of equity, efficiency, and feasibility, considering carbon abatement costs and carbon leakage risks, and adopts an improved ZSG-DEA model in accordance with China's NDCs, which promotes the transparency and scientific robustness of carbon allowance allocation.

2. RELATED WORKS

Several scholars have investigated the allocation of carbon allowances for China's industrial sectors based on the emission intensity reduction target in 2020 [1,2]. More specifically, some scholars further conducted studies on certain sectors [3–6]. Equity, efficiency, and feasibility are recognized as the most important principles [1,7,8]. Regarding allocation methods, many scholars have used the single-criterion approach to investigate carbon allowances allocation at the industrial level due to its simplicity [9]. However, multi-criteria allocation, which integrates different allocation principles, can produce fewer differences between the smallest and largest targets for different entities and enables more consensus-based entitlements. Sectoral coverage has been studied by many scholars [10–12], several of whom have adopted the CGE model. Another group of studies classified the sectors into different types based on the results of carbon allowance allocation.

In summary, the literature offers an important foundation for this study, but leaves room for improvement. First, from the perspective of allocation criteria and the choice of sectoral coverage of the carbon market, few studies have considered sectors' carbon abatement costs and carbon leakage risks, which are unique elements that must be analyzed in allowance allocation under the context of the carbon market. Second, when it comes to running a ZSG-DEA model, the boundary between input and output variables often seems ambiguous. Further, the existing literature primarily focuses on ways to achieve China's 2020 goals.

Therefore, based on the principle of equity, efficiency, and feasibility, in this study, we employ the indicators of carbon abatement costs and carbon leakage risks to integrate the carbon market into the criteria for carbon allowance allocation. The research method employed in this study integrates multi-criteria allocation principles and indicators into an improved ZSG-DEA model in accordance with China's NDCs proposed by Fang et al. [13].

3. METHODOLOGY AND DATA

3.1 Framework

Fig. 1 depicts the research framework for this study. First, the multi-criteria allocation scheme is used as the output variable of the ZSG-DEA model to reflect the principles of equity, efficiency, and feasibility. Second, we estimate industries' initial carbon allowance allocation based on their historical carbon emissions, and then reallocate the initial carbon allowances given their DEA efficiency obtained from the ZSG-DEA model. We then continue the process of reallocation until all industries have reached a DEA efficiency of 100%. Finally, based on abatement costs and carbon leakage risks, we propose an inclusion order for industrial sectors covered by the national carbon market.

3.2 Multi-criteria allocation scheme

The principles of equity, efficiency, and feasibility are adopted in this study for carbon allowance allocation. Thus, carbon emissions in all industrial sectors are measured from the perspectives of the responsibility, potential, capacity, cost, and risk for reducing emissions. Based on the representativeness of indicators and a comprehensive review of the literature, the suite of indicators used to capture these principles are presented in Table 1.

Table 1 The initial Multi-criteria indicators

Principle	Dimension	Indicator	Description
Equity	Responsibility	Labor input	Average number of employees
		Historical carbon emissions	Cumulative historical emissions
Efficiency	Potential	Energy intensity	$\frac{\text{Energy consumption}}{\text{industrial added value}}$
		Proportion of coal consumption	$\frac{\text{Coal end consumption}}{\text{Total energy end consumption}}$
	Capacity	R&D investment intensity	$\frac{\text{Industrial R\&D expenditures}}{\text{industrial value added values}}$
Feasibility	Cost	Abatement costs	$\frac{(\text{carbon emissions} \times \text{carbon price})}{\text{industrial added value}}$
	Risk	Carbon leakage risk	$\frac{\text{Industry export volume + industry import vo}}{\text{industry total output + industry import vol}}$

3.3 Allocation of the 2030 carbon intensity target

The relationship of carbon emission intensity between China and industrial sectors can be expressed as:

$$\frac{CE_{industry_t}}{IVA_t} = \frac{CE_t}{GDP_t} \times \frac{GDP_t}{IVA_t} \times \frac{CE_{industry_t}}{CE_t} \quad (1)$$

China has been committed to emissions reduction since 2005 and has achieved its reduction goals earlier than expected. The CO2 emissions intensity in 2017 had already dropped 46% from the 2005 level. Hence, China's carbon intensity target can be transformed into an intensity reduction target for industrial sectors:

$$I_{2030} - I_{2017} = \frac{CE_{industry}}{CE} / \frac{IVA}{GDP} (I'_{2030} - I'_{2017}) \quad (2)$$

To realize the allocation of carbon allowances, the overall allowances must be measurable. Assuming that there will be a linear decline in carbon emission intensity, the annual GDP is assumed to grow at a constant rate. The overall carbon allowances can be expressed as:

$$TCA_t = IVA_t \times I_{2017} \times (1-q)^{t-2017} \quad (3)$$

$$q = 1 - \sqrt[14]{\frac{I_{2030}}{I_{2017}}} \quad (4)$$

The initial carbon allowances by industry can be determined in accordance with the weights of historical carbon emissions for different industries, with the aim of causing as little derivation as possible.

$$ICEA_p = TCA \times \frac{CE_p}{\sum CE_p} \quad (5)$$

3.4 ZSG-DEA model

To maximize DEA efficiency while keeping constant the overall carbon allowances by 2030 as inputs, this study adopts an input-oriented ZSG-DEA model. One prominent merit of this model is that it allows for the optimization of all the DMUs to reach the DEA frontier without altering overall carbon allowances.

3.5 Data sources and processing

We utilized MATLAB to predict the aforementioned indicators for the period 2017-2030 with the GM (1,1) model. SPSS 16.0 was applied to investigate the correlation as well as the standardization process. In this study, 27 two-digital industries in China's industrial sector were selected as the study sample (Table 2).

4. RESULTS

4.1 Final Multi-criteria allocation scheme

To enhance the objectivity and rationality of the multi-criteria allocation scheme, we conduct a correlation analysis between the annual carbon emissions by industry and indicators. The final multi-criteria indicators for carbon allowance allocation are shown in Fig. 2.

Fig. 2 Final multi-criteria indicators for carbon allowance allocation

Table 2 Industrial sectors included in the calculation

Sector	Name
S1	Coal Mining and Dressing
S2	Petroleum and Natural Gas Extraction
S3	Ferrous Metals Mining and Dressing
S4	Nonferrous Metals Mining and Dressing
S5	Nonmetal Minerals Mining and Dressing
S6	Food Processing
S7	Food Production
S8	Beverage Production
S9	Tobacco Processing
S10	Textile Industry
S11	Garments and Other Fiber Products
S12	Papermaking and Paper Products
S13	Petroleum Processing and Coking
S14	Raw Chemical Materials and Chemical Products
S15	Medical and Pharmaceutical Products
S16	Chemical Fiber
S17	Nonmetal Mineral Products
S18	Smelting and Pressing of Ferrous Metals
S19	Smelting and Pressing of Nonferrous Metals
S20	Metal Products
S21	Ordinary Machinery
S22	Equipment for Special Purposes
S23	Transportation Equipment
S24	Electric Equipment and Machinery
S25	Electronic and Telecommunications Equipment
S26	Instruments, Meters, Cultural and Office Machinery
S27	Production and Supply of Electric Power, Steam and Hot Water

4.2 Ranking of industrial sectors based on multi-criteria indicators

As shown in Fig 3, the responsibility and cost indicators have gained prominence in three main sectors. Such sectors have large emissions and high emission reduction costs, and the implementation of the carbon market has a greater impact on these sectors. Therefore, when allocating allowances, it is important to pay attention to the cost pressures of carbon price fluctuations in these sectors.

The potential indicator gained prominence in six sectors. The energy intensities of these sectors are relatively large, indicating that at the current technological level, their emission reduction potential is relatively huge. We can therefore prioritize reducing carbon emissions in these sectors.

Twenty-one sectors have advantages in reflecting the indictors of capacity through carbon allowances reallocation, except for the six sectors. The capacity indicator is dominated by R&D investment intensity, which corresponds to an enhanced ability to control carbon emissions and, therefore, to less carbon allowances.

The risk indicator that reflects the carbon leakage risk of industrial sectors in the context of the carbon market had gained prominence in seven sectors. These sectors have larger trade intensity and greater international competition, and thus face higher carbon leakage risks in the implementation of the national carbon market. Therefore, such sectors should be placed under less pressure to reduce carbon emissions at the beginning of the carbon market.

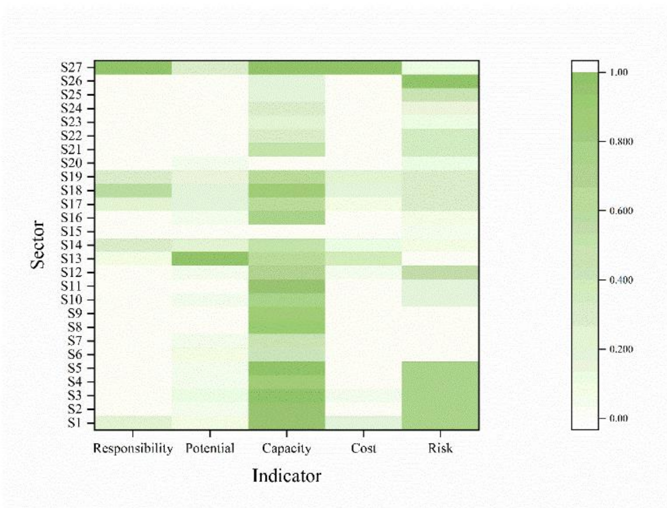

Fig. 3 Ranking of all sectors based on the five indicators

4.3 Final carbon allowances allocation and carbon emission reduction responsibility of industrial sectors

4.3.1 Carbon allowances allocation

Fig. 4 depicts the carbon allowances of the 27 sectors in descending order and the estimated cumulative carbon emissions' share in 2017-2030.

Most of the carbon allowances are concentrated in six sectors. These sectors are the cornerstone of the country, providing energy and raw materials, and it is difficult for the economy to survive and develop without them. Meanwhile, these sectors are characterized by high emissions, high energy intensity, and large abatement costs, which means that they have great potential and should take more responsibility for emission reductions. Thus, the carbon market plays an important role in promoting low-cost emissions reduction in such sectors.

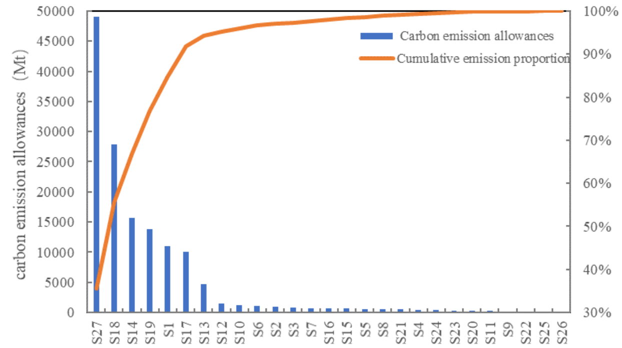

Fig. 4 Carbon allowances of 27 industrial sectors in descending order

4.3.2 Carbon emission reduction responsibility

Fig. 5 illustrates different levels of ratios, from the highest to the lowest, representing SCE in carbon emissions of various industrial sectors. Negative SCE can be found in 16 sectors, indicating that these sectors have major shares of the overall emission reduction. Positive SCE can be found in 11 sectors, which means that these sectors are under relatively low levels of carbon emission reduction.

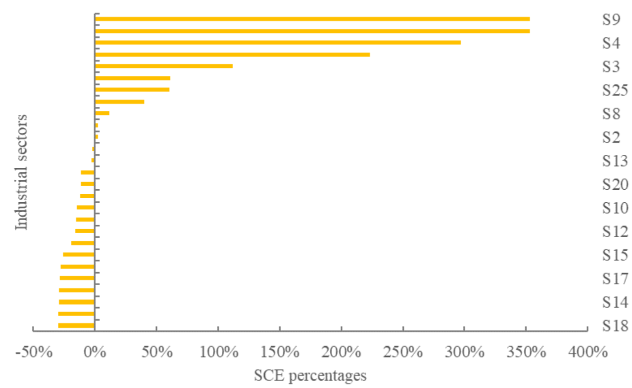

Fig. 5 SCE percentages of 27 industrial sectors

4.4 Abatement cost, carbon leakage, and carbon emission reduction responsibility of industrial sectors

Fig. 6 depicts the abatement cost–carbon leakage risk–SCE relationship for sectors with negative SCE. The abatement costs of sectors with negative SCE vary widely after standardization. At the same time, the carbon leakage risks of these sectors are relatively low. This result shows that the allocation method in this study can better promote the carbon market to reduce emissions at a lower cost while preventing carbon leakage to a certain extent.

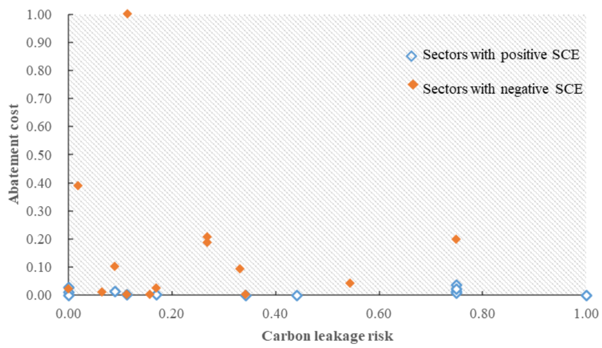

Fig. 6 Abatement costs-carbon leakage risk–SCE relationship plot for different industrial sectors

4.5 Inclusion order of industrial sectors covered by the national carbon market

In order to monitor the emission reductions of different industrial sectors more effectively, and provide a reference for the choice of sectors covered by the national carbon market in the meantime, in this study, we further classify the sectors with negative SCE based on the abatement costs and carbon leakage risks.

In Fig. 7, 16 industrial sectors with negative SCE by carbon leakage risks are plotted on the horizontal axis and abatement costs are plotted on the vertical axis. The average value of carbon leakage risks of these sectors is set as the boundary of high risk and low risk, as represented by a dotted horizontal line. Similarly, the average value of abatement costs is set as the boundary of high cost and low cost, as represented by a dotted vertical line. Divided by these two reference lines, sixteen sectors are clustered into four zones.

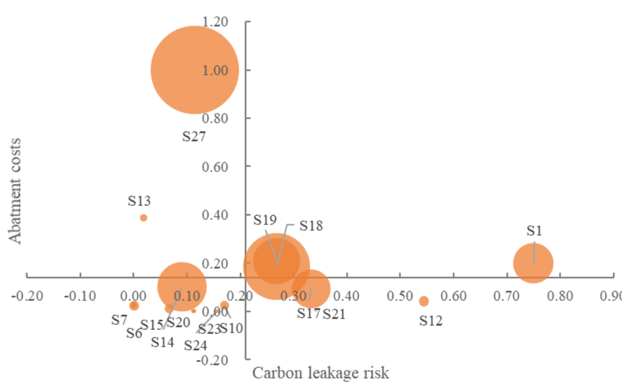

Fig 7 Classification of industrial sectors based on abatement costs and carbon leakage risks

(1) Sectors that are prioritized and compulsorily included in the national carbon market: S1, S14, S17, S19, S27. These five sectors have major shares of overall emission reduction. In order to give full play to the role of the carbon market in reducing emissions and promoting the achievement of the 2030 target, these sectors should be the first to be considered in the system.

(2) Sectors that are selected and encouraged to be included in the national carbon market: S6, S7, S10, S15, S23 and S24. These sectors are located in the third zone, which have relatively lower abatement costs and low carbon leakage risks, and in the meantime have fewer shares of overall emission reduction, thus having fewer effects on the target of carbon emission reduction.

(3) Sectors voluntarily included in the national carbon market: S12, S13, S21. These sectors are in the second and fourth zones. Although these sectors also have fewer shares of the overall emission reduction, their abatement costs or carbon leakage risks are relatively high; thus, these sectors can voluntarily join the carbon market.

5. DISCUSSION

5.1 Carbon allowances allocation under different schemes

To further explore how changes in indicators affect carbon allowances, we compared two allocation schemes: (1) the allocation of carbon allowances under the multi-criteria scheme proposed in this study, and (2) ignoring the abatement costs and carbon leakage risks.

Fig. 8. shows that although the results of the two allocation schemes are quite similar, differences are present. Scheme 1 allocates more allowances than Scheme 2 for some sectors, especially in S1 with higher carbon leakage risk, and S27 with higher abatement costs. While, Scheme 1 allocates less allowances than Scheme 2 for some sectors with lower carbon leakage risks or lower abatement costs, such as S13 and S17.

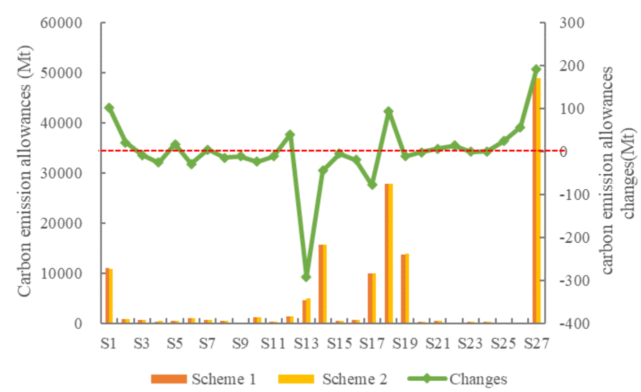

Fig. 8 Comparison of different allocation schemes

5.2 Carbon allowances allocation comparison with literature

Fig. 9 presents a comparison of Zhang and Hao [1] analysis of the carbon allowance allocation for industrial sectors with ours. The results of this comparison show that we allocate more allowances for sectors of S1 with higher carbon leakage risk, S14 and S19 due to their relatively lower capacity for carbon emission reduction and their lower R&D investment intensity, and allocate less allowances for sectors of S13 because of their lower abatement costs and S27 for their relatively higher capacity for carbon emission reduction.

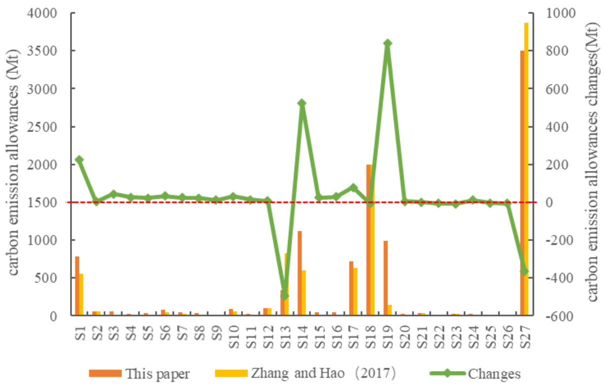

Fig. 9 Comparison of the allocation of China's carbon allowance derived from the literature

6. CONCLUSIONS

Based on China's 2030 carbon intensity target, in this study, we first establish a new multi-criteria allocation scheme based on the principles of equity, efficiency, and feasibility, and integrate the abatement cost and carbon leakage risk indicators in the context of the carbon market. Subsequently, China's 2030 carbon intensity target under NDCs is transformed into a reduction target for industrial sectors. Finally, a ZSG-DEA model is used to allocate the carbon allowances from 2017 to 2030 for 27 industrial sectors. Our main conclusions are the following:

(1) All sectors achieve a maximum DEA efficiency of 1 after the final reallocation. Most of the carbon allowances are concentrated in six sectors. (2) Negative SCE appears in 16 sectors, indicating that these sectors have major shares of the overall emission reduction. (3) The abatement costs of these sectors vary widely, while their carbon leakage risks are relatively low. This result indicates that the allocation method in this study can better help the carbon market reduce emissions at a lower cost, while preventing carbon leakage to a certain extent. (4) Based on the above results, we propose that the order of inclusion of industrial sectors covered by the national carbon market be related to their shares of the overall emission reduction, abatement costs, and carbon leakage risks. The sectors are classified into three categories.

ACKNOWLEDGEMENT

This work was supported by the National Key R&D Program of China [grant number 2018YFC1509005]; Humanity and Social Science Youth Foundation of the Ministry of Education in China [grant number 19YJC790017]; National Social Science Foundation of China [grant numbers 18ZDA107].

REFERENCE

[1] Zhang YJ, Hao JF. Carbon emission quota allocation among China's industrial sectors based on the equity and efficiency principles. Ann Oper Res 2017.
[2] Zhou J, Li Y, Huo X, Xu X. How to allocate carbon emission permits among China's industrial sectors under the constraint of carbon intensity? Sustain 2019;11.
[3] Zhao S, Shi Y, Xu J. Carbon emissions quota allocation based equilibrium strategy toward carbon reduction and economic benefits in China's building materials industry. J Clean Prod 2018;189:307–25.
[4] Ji X, Li G, Wang Z. Allocation of emission permits for China's power plants: A systemic Pareto optimal method. Appl Energy 2017;204:607–19.
[5] Li M, Wang P. Research on carbon emission quota allocation in power industry. IOP Conf. Ser. Earth Environ. Sci., vol. 300, Institute of Physics Publishing; 2019.
[6] Wu F, Huang N, Zhang F, Niu L, Zhang Y. Analysis of the carbon emission reduction potential of China's key industries under the IPCC 2 °C and 1.5 °C limits. Technol Forecast Soc Change 2020;159:120198.
[7] Zhao R, Min N, Geng Y, He Y. Allocation of carbon emissions among industries/sectors: An emissions intensity reduction constrained approach. J Clean Prod 2017;142:3083–94.
[8] Sun YP, Xue JJ, Shi XP, Wang KY, Qi SZ, Wang L, et al. A dynamic and continuous allowances allocation methodology for the prevention of carbon leakage: Emission control coefficients. Appl Energy 2019;236:220–30.
[9] Zhou P, Wang M. Carbon dioxide emissions allocation: A review. Ecol Econ 2016;125:47–59.
[10] Qian H, Zhou Y, Wu L. Evaluating various choices of sector coverage in China's national emissions trading system (ETS). Clim Policy 2018;18:7–26.
[11] Lin B, Jia Z. Does the different sectoral coverage matter? An analysis of China's carbon trading market. Energy Policy 2020;137:111164.
[12] Lin B, Jia Z. The impact of Emission Trading Scheme (ETS) and the choice of coverage industry in ETS: A case study in China. Appl Energy 2017;205:1512–27.
[13] Fang K, Zhang Q, Long Y, Yoshida Y, Sun L, Zhang H, et al. How can China achieve its Intended Nationally Determined Contributions by 2030? A multi-criteria allocation of China's carbon emission allowance. Appl Energy 2019;241:380–9.