Applied Energy 228 (2018) 1122–1135

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Bi-level allocation of carbon emission permits based on clustering analysis and weighted voting: A case study in China

Zhiying Feng[a], Wenhu Tang[a,*], Zhewen Niu[a], Qinghua Wu[a,b]

[a] School of Electric Power Engineering, South China University of Technology, Guangzhou 510640, China
[b] Department of Electrical Engineering and Electronics, The University of Liverpool, Liverpool L69 3GJ, UK

HIGHLIGHTS

- A novel bi-level allocation scheme of carbon emission permits is proposed.
- This scheme considers pressure, capacity, responsibility and potential.
- 30 regions are clustered into 4 classes based on carbon emission characteristics.
- The schemes based on historical emissions, population and GDP are considered.
- It balances the scheme selections of each region using a weighted voting model.

ARTICLE INFO

Keywords:
Carbon emission permits
Clustering analysis
Weighted voting model
Multi-index comprehensive evaluation

ABSTRACT

A rational regional allocation scheme of carbon emission permits is important for establishing the nationwide carbon emission trading system (ETS) of China. Considering the vast area and great regional differences in China, a novel bi-level allocation scheme based on clustering analysis and a weighted voting model is proposed in this research. At the first level, 30 regions in China are clustered into four classes according to their characteristics of carbon emissions, which include emission reduction pressure, capacity, responsibility and potential. Then the total carbon emission permits are allocated to each class of regions. At the second level, carbon emission permits are allocated to each province (municipality) within a class. The weighted voting models are developed for both the two levels, where the allocation schemes based on historical emissions, population and GDP are selected by each region according to the different voting rights of each region. The voting rights of each region for choosing its inclined scheme are quantified through a multi-index comprehensive evaluation, which employs the entropy method at the first level due to the lack of prior knowledge and the analytic hierarchy process (AHP) at the second level to increase policy flexibility. The combination of subjective weighting evaluation method (AHP) and objective weighting evaluation method (the entropy method) increases the flexibility of the abatement policy while guaranteeing the objectivity of decision-making process. Case studies of the allocation for carbon emission permits in China by 2020 and 2030 are carried out under the proposed allocation scheme. The derived allocation results show that the proposed allocation scheme can provide a balanced consideration to equality and efficiency, which are compared with those in reported literatures. The proposed allocation scheme can not only encourage all regions to reduce carbon emission intensity, but also achieve in meeting the carbon emission demand of the population in each region.

1. Introduction

Numerous evidence has been accumulated to indicate that changes in many physical and biological systems are linked to anthropogenic warming [1], including species' distributions [2], species extinction [3], extreme weather [4,5], grain yield reduction [6] and so on. Greenhouse gas (GHG) emissions are the main culprit of anthropogenic warming and climate change. Carbon dioxide emissions contribute to about 99% of total GHG emissions in the energy industry [7].

Paris Agreement was approved in the Paris climate change conference on December 12, 2015 and signed on April 22, 2016 in New York. The agreement provides a framework for global climate change actions after 2020. Until November 2017, 195 members of United Nation Framework Convention on Climate Change (UNFCCC) have

* Corresponding author.
E-mail addresses: epzyfeng@mail.scut.edu.cn (Z. Feng), wenhutang@scut.edu.cn (W. Tang).

https://doi.org/10.1016/j.apenergy.2018.07.005
Received 6 April 2018; Received in revised form 18 June 2018; Accepted 1 July 2018

signed this agreement, and 170 have become Party to it. As the largest carbon-emitting country, China has promised to decrease its carbon emissions per unit of GDP by 50–55% by 2020 and by 60–65% by 2030 based on the 2005 level [8]. China planned to gradually establish a nationwide carbon emission trading system (ETS) to achieve these goals. After US president Donald Trump announced his intention to withdraw from the Paris Climate Change Agreement, China will play a significant role in the reduction of global carbon emission.

Carbon emission permits specify emission reduction targets for each emission subject, prompting them to formulate more practical emission reduction programmes. A number of literatures discussed the allocation scheme of carbon emission permits in different ranges, which can be divided into three categories according to their applied levels, i.e. the international level, the interregional level and among industrial sectors.

In the international level, there is no consensus on how to allocate the global carbon emission permits between developed and developing countries currently. To tackle this problem, researchers proposed various schemes under different considerations. Shuai et al. developed the STIRPAT model to analyze the impacts of population, affluence and technology on carbon emission of 125 countries at different income levels to provide different emission reduction proposals for different countries [9]. Pang et al. utilized the ZSG-DEA model to reallocate carbon emission quotas with the purpose of achieving a global Pareto improvement [10], which only considered the principle of efficiency without considering the equity principle. The Boltzmann distribution was employed to allocate carbon emission permits among countries in [11], which only considered the population factor of each country and doesn't take other factors influencing carbon emission into account. Researchers from Tsinghua University proposed a two-convergence approach to allocating the future emission amount among countries [12,13], which catered to the developing countries and is hard to be accepted by the developed countries. Pan et al. compared several allocation schemes on the equity-efficiency tradeoff side using the Equitable Access to Sustainable Development model [14,15].

Different from the international allocation of carbon emission permits, the allocation policies are relatively easy to be carried out within a country, because a central government has stronger capabilities of legislation and law enforcement. Therefore, the national allocation scheme of carbon emission permits can be more detailed. The developed countries established carbon emission trading systems in the early years of the 21st Century, with more theoretical and practical experience. A regional burden sharing scheme of GHG emission abatement in the US was proposed in [16], which compared six permit allocation formulas (Gross Regional Product (GRP) based, inverse-GRP based, emissions based, population based, energy-use based and energy-production based) to analyze the absolute and relative economic regional impacts. Edwards et al. used a computable equilibrium model to evaluate the economics of various methods for allocating permits among 12 sectors in the UK [17]. As power generation companies are main emitters of carbon dioxide, Zhou et al. analyzed the potential profit impacts and the possible compensation to generation companies through modeling the Australian Electricity Market under a carbon emission permit trading scheme to study the optimal percentage of carbon emission permits that should be freely allocated [18].

Different from the developed countries, there is a huge difference in terms of economic development and energy structure among regions in China. Therefore, the regional allocation of carbon emission permits in China is quite complex. A number of literatures attempted to provide policy suggestions or impact analysis of carbon emission reduction in China. Yu et al. used a particle swarm optimization (PSO) algorithm and a fuzzy c-means (FCM) clustering algorithm to cluster 30 regions of China based on several factors affecting emission characteristics [19,20], and utilized the Shapley value decomposition to allocate regional emission permits [19]. The clustering methods discussed in [19,20] selected 13 factors and 5 indicators to cluster 30 provinces in China respectively, but they both didn't take the historical emission responsibility and urbanization level into consideration. The Shapley value method combined with the entropy and gravity models was adopted in [21], which didn't take urbanization levels into consideration and didn't consider the demographic factor in terms of emission reduction responsibility. Yang et al. proposed an allocation approach based on gradual efficiency improvement and emission reduction planning principles [22], which paid less attention on equity. The impact of carbon emission abatement policies, including carbon emission trading and carbon permit allocation rules, in China were discussed in [23–25]. Three indicators (capacity, responsibility and potential) were selected to evaluate the degrees of equity and efficiency of each emission unit [26,21,27,28], where accumulated carbon emissions were taken to represent the emission reduction responsibility without considering demographic factors and the current emissions.

More attention was further explored to allocate the carbon emission permits among industrial sectors. The Boltzmann distribution was exploited in the allocation of carbon emission permits among enterprises [29] and power plants [30]. As coal-fired power generations contribute more than 80% to China's carbon emission [31], the carbon emission in power systems was studied. Six scenarios were simulated to forecast the national electricity demand and power-related carbon emissions in China up to 2030 in [32]. Bai et al. decomposed the energy-related carbon emissions into direct emissions and indirect emissions, which considered the imbalance between power generation and power consumption of a region [33]. Huang et al. studied the effectiveness of different mixtures of GHG emission regulations and renewable energy promotion policies based on a dynamic simulation platform of power economy and power systems [34]. The LMDI model and a decoupling index were applied to probe the relationship between power generation and carbon dioxide emissions [35].

The literatures mentioned above mainly considered one allocation scheme in their studies, which failed to reflect the preference of each emission unit (country, province or enterprise). To address this problem, this paper proposes an allocation model based upon weighted voting to consider the scheme preference of each region in China. In this model, three allocation schemes (historical emission based, GDP based and population based) are taken into account to be selected by each region. The voting rights of each region are quantified by the comprehensive carbon emission indices, which are weighted indices of four indicators (emission reduction pressure, capacity, responsibility and potential). Considering the great diversity of carbon emission characteristics among China's regions, clustering analysis and differentiated allocation policies are applied in different classes of regions.

The remainder of this paper is organized as follows. Section 2 introduces the methodology and data definitions of the proposed bi-level allocation method for calculating carbon emission permits. Section 3 demonstrates the clustering results and allocation results under this scheme. Finally, conclusions and policy implications are drawn in Section 4.

2. Essential methodologies of the proposed bi-level allocation scheme

2.1. Three fundamental allocation schemes to be selected

This study chooses three allocation schemes, including historical emission based, GDP based and population based schemes as the fundamental schemes to be selected by each region. The above three schemes are rooted in the equity principles of "Sovereignty", "Vertical" and "Egalitarian" as reported in [36]. In addition, the three selected schemes are intuitive and clear compared with other fundamental allocation schemes such as the "Consensus schemes" and "Kantian allocation rule scheme" as reported in [36].