Journal of Cleaner Production 205 (2018) 163–178

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

A bi-objective programming model for carbon emission quota allocation: Evidence from the Pearl River Delta region

Lixu Li [a], Fei Ye [a, *], Yina Li [a, **], Kim Hua Tan [b]

[a] School of Business Administration, South China University of Technology, Guangzhou, 510640, China
[b] Operations Management and Information Systems Division, Nottingham University, Business School, United Kingdom

ARTICLE INFO

Article history:
Received 22 March 2018
Received in revised form
5 August 2018
Accepted 8 September 2018
Available online 11 September 2018

Keywords:
Carbon emission quota allocation
Bi-objective programming model
Cost-oriented model
Asset-oriented model
Pearl river delta

ABSTRACT

As a core component of the emission trading scheme (ETS), the initial allocation of carbon quotas is extremely important. Currently, most allocation methods mainly focus on the realization of a single performance goal, which will result in conflicts between different levels of participants. To overcome this limitation, a bi-objective programming model (BPM) with two sub-objective functions of abatement costs and carbon assets is proposed. Meanwhile, cost-oriented model (CM) and asset-oriented model (AM) are implemented as comparison approaches that represent the minimization of regional abatement costs and the maximization of individual interests, respectively. The empirical results of the Pearl River Delta (PRD) region reveal that BPM is the most efficient and feasible approach to some extent. More precisely, BPM can motivate the enthusiasm of all participants while optimizing abatement costs. With the increase of regional total quotas, the advantage of BPM becomes more and more prominent. The contribution of this paper is to present a novel method for carbon emission quota allocation, which fills the gap in the existing literature. Furthermore, the proposed method that can be deployed in other similar regions assists policymakers in enacting an effective emission reduction policy and in better understanding the objectives of economy, energy and environment.

1. Introduction

With the development of industrialization and urbanization, carbon dioxide (CO_2) emissions have risen sharply during the past decade (IPCC, 2014). To maintain the worldwide sustainable development, various organizations and countries have enacted relevant laws and regulations to limit CO_2 emissions (Zhou et al., 2017a; UNDP, 2015). Among the three major regulation policy tools including emission trading scheme (ETS), administrative order policy and carbon tax, ETS is regarded as the most economical and effective mechanism (Liu et al., 2015; Sartor et al., 2014). China, as the largest CO_2 emitter, is preparing to establish a unified national ETS by the end of 2017 (Xia and Tang, 2017). Once the unified national ETS is completed, China will surpass the European Union Emissions Trading System (EU ETS) to become the largest ETS in the world (Zhao et al., 2017).

As a core element of the ETS, the initial allocation of carbon quotas is extremely important. Currently, the main allocation methods for China's ETS in practice are grandfathering and benchmarking (Ji et al., 2017) based on historical carbon emissions and industrial average carbon emissions, respectively (Liao et al., 2015). However, both methods have some drawbacks. For example, grandfathering cannot cover the new capacity of enterprises (Fan et al., 2016), while the standard of benchmarking is difficult to determine because of data shortage (Liu et al., 2015). Therefore, how to design a suitable allocation method tailored to the real circumstance has become a huge task for the Chinese government.

To optimize the initial allocation of carbon quotas, many scholars have explored different allocation methods in theory, including indicator approach, optimization model, game model and hybrid methods (Zhou and Wang, 2016). Based on different equality perspectives, historical carbon emissions, population, and GDP/per capita GDP are usually selected as indicators that represent the principles of sovereignty/grandfathering, egalitarianism and ability to pay/economic activity, respectively (Zhou et al., 2013; Zhao et al., 2010; Phylipsen et al., 1998). Combining different principles together, multi-criteria decision analysis (MCDA) that is dominated

* Corresponding author.
** Corresponding author.
E-mail addresses: yefei@scut.edu.cn (F. Ye), bmliyina@scut.edu.cn (Y. Li).

https://doi.org/10.1016/j.jclepro.2018.09.069
0959-6526/

Nomenclature

Abbreviations

ADF	Augmented Dickey-Fuller
AM	Asset-oriented Model
BPM	Bi-objective Programming Model
BSGP	Bureau of Statistics of Guangdong Province
CCTN	China Carbon Trading Network
CM	Cost-oriented Model
CO_2	Carbon dioxide
CSC	China State Council
EKC	Environmental Kuznets Curve
EROI	Energy Return on Investment
ETS	Emission Trading Scheme
EU ETS	European Union Emissions Trading System
IPCC	Intergovernmental Panel on Climate Change
MAPE	Mean Absolute Percentage Error
MCDA	Multi-criteria Decision Analysis
NBSC	National Bureau of Statistics of China
OLS	Ordinary Least Square
PRD	Pearl River Delta
UNDP	United Nations Development Programme

Greek symbols

μ	Regional abatement rate (%)

Latin symbols

A	Abatement volume (tons)
CI	Carbon intensity (ton/10^4 *Yuan*)
EC	Energy consumption (10^4 tons of standard coal)
GDP	Gross Domestic Product (10^8 *Yuan*)
MAC	Marginal Abatement Costs (*Yuan*/*ton*)
p	Carbon price (*Yuan*/*ton*)
Q	Quotas (tons)
R^2	Goodness of Fit
R	National abatement rate (%)
r	Abscissa
TAC	Total Abatement Costs (10^4*Yuan*)
V	Carbon assists (10^4*Yuan*)

Subscripts/ Superscript

base	Base year
i	Participant's number
l	Lower bound
t	Year
u	Upper bound

by information entropy method (Li et al., 2018; Qin et al., 2017) has become the mainstream of the composite indicator approach. However, the composite indicator approach cannot reflect the specific goal that policymakers want to achieve, nor does it have a uniform standard to determine the weight of each indicator (Zhou and Wang, 2016). Consequently, optimization model and game model are developed.

With respect to optimization model, efficiency and abatement costs are two conventional optimization goals. To maximize allocation efficiency, Zeng et al. (2016) allocated carbon quotas among 30 provinces in China by hiring a ZSG-DEA model with fixed carbon emissions and non-fossil energy consumption. Similarly, Zhang and Hao (2017) also applied an input-oriented ZSG-DEA model, but their allocation was built on the industry level. With the aim of reducing abatement costs, Fan et al. (2016) simulated the marginal emission abatement cost curve of China in 2015 and 2020 with a CHINAGEM model and calculated the equilibrium carbon price. Liu and Lin (2017) estimated the marginal emission abatement cost curves by a parametric directional output distance functions and proposed a novel nonlinear programming model in China's building construction industry. In terms of game model, the Shapley value method is the most common method in empirical research. Zhang et al. (2014) adopted the gravity model to calculate the regional connection and assigned initial quotas using the Shapley value method. Liao et al. (2015) further compared the discrepancies among the Shapley value method, grandfathering and benchmarking, and pointed out that the Shapley value method was considered to be a theoretical equity reference. However, because the Shapley value method is an alliance cooperation game (Chang et al., 2016), it will lead to unfairness if the participants of ETS are different types of enterprises. Furthermore, the marginal profit of each participant is difficult to ascertain. Therefore, the Shapley value method is only for reference and has less available in practice. Finally, some methods (e.g., Zhou et al., 2017b) that combine multiple groups of the above methods together can be regarded as the hybrid methods.

Although the above literature provides unique ideas for the allocation of carbon quotas, most of them mainly focus on a single performance goal, such as realizing fairness allocation (Chen et al., 2016), minimizing abatement costs (Liu and Lin, 2017) and maximizing profits (Liao et al., 2015) or efficiency (Zhang and Hao, 2017). However, different performance goals sometimes are incongruous or even contradictory (Salehi et al., 2017). For example, sovereignty principle and ability to pay principle, egalitarianism principle and economic activity principle, as well as minimizing abatement costs and maximizing efficiency. Consequently, carbon emission quota allocation is not an isolated process for achieving a single performance goal, it should be a comprehensive process in which all levels of participants work together and reach a consensus. Remarkably, there are two significant factors that cannot be overlooked among various performance goals. One is the cost factor (i.e., abatement costs) that is the purpose of the existence of ETS (Fan et al., 2016), and the other is the enthusiasm of the participants (i.e., individual interests) that is the basis for the operation of ETS (Liu et al., 2015). However, these two factors sometimes will create conflicts because the clean participants usually have a higher economic level, while the dirty participants often locate in developing stage. Therefore, the purpose of this paper is to find a balance between overall interests (i.e., social abatement costs) and individual interests, so as to realize an effective and feasible allocation of carbon quotas.

Technically, this paper develops a bi-objective programming model (BPM) with two sub-objective functions of abatement costs and carbon assets. Meanwhile, cost-oriented model (CM) and asset-oriented model (AM) are applied as comparison approaches, which represent the minimization of social abatement costs and the maximization of individual interests, respectively. To verify the validity of the proposed method, this paper selects the Pearl River Delta (PRD) region where the intraregional development is extremely imbalanced as a representative example. The empirical results show that BPM is the most efficient and feasible approach to some extent, because the allocation of BPM is a non-inferior solution (Hombach and Walther, 2015) that can achieve a trade-off between overall interests and individual interests. In general, this paper presents a novel method for carbon quota allocation, which fills the gap in the existing literature. Simultaneously, the proposed