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Carbon dioxide emissions allocation: A review

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ABSTRACT

Carbon dioxide (CO_2) emissions allocation plays a fundamental role in determining reduction responsibility at economy level or emission permits at firm level. Past decades have seen the development and applications of various methods for CO_2 emissions allocation. This paper provides a literature review of CO_2 emissions allocation with emphasis on the evolution of allocation methods used. It begins with a summary of the most popular allocation principles and criteria that lay a foundation for the development of allocation methods. We then classify the existing allocation methods into four groups, namely indicator, optimization, game theoretic and hybrid approaches. The main features and findings of past studies are identified and summarized. While the fairness principle prevails in earlier studies, the efficiency principle has been found to receive increasing attention recently. We also present a comparison of the empirical results based on ten popular indicator methods to show how indicator choice affects the allocation results. Issues related to selecting appropriate methods in CO_2 emissions allocation are finally discussed. Further research may be carried out to strike a balance between fairness and efficiency so that the allocation results become more widely acceptable and economically feasible.

1. Introduction

Climate change, resulting from the growing concentrations of greenhouse gases (GHGs) in the atmosphere, has been regarded as one of the major challenges in the 21st century. Scientists have shown that it brings about environmental degradation and natural disasters threatening human safety and health (Walther et al., 2002). In order to avoid more dangerous long-term effects of climate change, the Intergovernmental Panel on Climate Change (IPCC) has emphasized the importance of limiting the increase of global average temperature not greater than 2 °C. The target requires a reduction of global GHGs emissions, mainly carbon dioxide (CO_2), by at least 50% until 2050, which implies that future emission space would become extremely stringent (Pan et al., 2014a). As a consequence, there is a strong political desire for the allocation of restricted emission space in order to achieve global GHGs emission reduction target.

A necessary but challengeable step is to reach a consensus on the responsibility sharing of CO_2 emission reductions between different countries. Although it has universally been agreed that all the countries need to take responsibilities in reducing global CO_2 emissions (Chakravarty et al., 2009), previous international climate change conferences have not reached an explicit agreement on the burden sharing after Kyoto Protocol. Within a country, debates also exist on the responsibility sharing of emission reductions between different regions/cities. At firm level, carbon emission trading (CET) has widely been regarded as a cost-effective tool for realizing CO_2 emission reduction (González-Eguino, 2011). In practice, the European Union Emission Trading Scheme (EU ETS) as the biggest emission trading market took effect in 2005.[1] As the largest CO_2 emitter, China launched its pilot ETS in seven provinces and cities in 2013/2014 and will establish its national ETS in 2017. In the existing CET systems, an open question always arises on how to allocate CO_2 emission permits among the participating firms at the beginning of each trading period (Cramton and Kerr, 2002; Böhringer and Lange, 2005; Zetterberg et al., 2012).

Undoubtedly, the allocation of CO_2 emissions may be performed at different levels, e.g. the burden sharing between countries, the decomposition of national emission reduction target into regional ones, and the distribution of tradable emission permits between firms in a CET system (Bohringer and Lange, 2005; Baer et al., 2008; Yi et al., 2011). Since earlier 1990s, there has been a continuous research interest in examining the issue of CO_2 emissions allocation that led to a great deal of publications in diverse international journals. The purpose of this study is to provide an up-to-date review of past studies on CO_2 emissions allocation, with particular emphasis on the classification and evolution of

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[1] In the first two phases (2005–2007 and 2008–2012), emission permits were allocated to the participating firms mainly by grandfathering. When allocating permits to new entrants, benchmarking would be adopted. In the third phase (2013–2020), full auctioning is applied to the electricity sector and a "transitional free allocation" based on benchmarking is used for other sectors (Zetterberg et al., 2012).

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allocation methods used. It is expected that this review study will be helpful to scholars for identifying the key features of past studies and understanding the similarities as well as the differences between different allocation methods.

The remainder of this study is organized as follows. Section 2 describes the main principles and criteria used for CO_2 emissions allocation. Section 3 classifies the main allocation methods into four groups, namely indicator, optimization, game theoretic and hybrid approaches, and describes the main developments of each group. In Section 4, the key features of past studies in methodological aspect and application scheme are discussed. We also conduct a comparison of the allocation results by several popular indicators to show how the results are affected by indicator choice. Section 5 concludes this study with brief discussions on method choice and potential future research topics.

2. Principles of Emissions Allocation

One primary issue in CO_2 emissions allocation is to determine the allocation principle to be followed. In literature, different allocation criteria have been advocated and applied, which may broadly be divided into two categories, namely fairness and efficiency principles. Fairness principle is often linked to more general concepts of distributive justice (Rose, 1990). Efficiency principle is mainly relevant to the economic efficiency of emission reduction, e.g. the minimization of total abatement cost. Although fairness and efficiency principles have their special focuses, several scholars such as Welsch (1993) and Zhou et al. (2014) argued that efficiency may also be treated as a type of fairness.

Table 1 summarizes some commonly used allocation criteria with their interpretations and operational rules, which are compiled from earlier studies such as Rose (1990, 1998), Rose and Stevens (1993), Ringius et al. (1998, 2002), Berk and den Elzen (2001), Rose and Zhang (2004), and Vaillancourt and Waaub (2004).[2] It can be observed from Table 1 that quite a few criteria have ever been employed for CO_2 emissions allocation. Most of them follow the fairness principle while taking different perspectives, e.g. sovereignty, egalitarianism, horizontal equity, vertical equity and polluter pays. An exception is the merit criterion following the efficiency principle, based on which emission permits are distributed in proportion to the reciprocal of emission intensity. In addition, most of the criteria are used for CO_2 emissions allocation at country level. While grandfathering is mainly used for the distribution of emission permits at firm level, in operation it is indifferent from the sovereignty criterion that is used at country level.

It should be pointed out that each criterion given in Table 1 can be implemented by using different indicators. On the other hand, an indicator may also be used for implementing different allocation criteria. For example, the sovereignty criterion can be implemented based on historical CO_2 emissions or energy consumption. The indicator of CO_2 emissions can also serve for more than one criterion, e.g. sovereignty and polluter pays. Different combinations of allocation criterion and reference indicator usually have different welfare implications, which explains the difficulty in reaching a consensus on the responsibility sharing between entities only by one indicator. As such, many emissions allocation methods have been proposed based upon one or more allocation criteria, which are schematically summarized in the next section.

3. Emissions Allocation Methods

Under the umbrella of fairness and efficiency principles, many different methods have been proposed for CO_2 emissions allocation. In this study, we classify the existing methods into four groups, namely indicator, optimization, game theoretic and hybrid approaches (see Fig. 1).[3]

3.1. Indicator Approach

Indicator approach, the most commonly used emissions allocation approach, means that emission permits or reduction targets are allocated based on certain indicator(s). It consists of single and composite indicator approaches. In the single indicator approach, an individual indicator is used to distribute emission permits or reduction targets among participating entities (Rose, 1990; Rose and Stevens, 1993; Rose et al., 1998). The composite indicator approach integrates multiple indicators representing different criteria into a composite indicator, based on which the aggregate emission permits or reduction targets are allocated to each participant (Ringius et al., 2002; Vaillancourt and Waaub, 2004).

3.1.1. Single Indicator Approach

Owing to its simplicity and ease of use, the single indicator approach has been widely used to allocate CO_2 emission permits or reduction targets since the 1990s (Miketa and Schrattenholzer, 2006). In practice, the indicators selected for use are quite broad in scope. As shown in Table 2, an indicator may generate a few allocation methods or rules, which are dependent upon the allocation criteria followed. For example, in the case of GDP indicator, the amounts of emission permits allocated to participating entities are proportional to their GDP when the economic activity criterion is adopted. However, when the ability to pay criterion is used, the amounts of emission reductions allocated become proportional to GDP. In the followings, we shall summarize the main developments of some popular indicators.

3.1.1.1. Population. Population-based allocation rules have been widely advocated in CO_2 emissions allocation at country level. Grubb (1990) first developed an allocation method for tradable CO_2 emission permits on an adult per capita basis. Later, Agarwal and Narain (1991) highlighted the use of equal per capita allocation rule at country level, which was used by Bertram (1992) to allocate tradable CO_2 emission permits. Since then, many scholars have contributed to examine equal per capita allocation scheme in both methodological and application aspects. Examples of such studies are Larsen and Shah (1994), Edmonds et al. (1995), Rose et al. (1998), Azar (2000), Baer et al. (2000), Leimbach (2003), Rose and Zhang (2004), Böhringer and Welsch (2006), Sørensen (2008), Chakravarty et al. (2009) and Zhou et al. (2013).

Acknowledging the strengths of per capita allocation scheme, some scholars argued that CO_2 emissions allocation needs to take into account the fairness between different generations. For instance, Grübler and Fujii (1991) considered discounted historical responsibility and proposed equal future per capita emission permits allocation method. By contrast, den Elzen et al. (1992) developed equal per capita cumulative emission permits allocation rule, by which everyone is allowed to emit the same amount of CO_2 emissions annually, independent of time or place lived. Since equal per capita cumulative emissions allocation rule accounts for the historical responsibility of developed countries, several studies, e.g. Ding et al. (2009), Yu et al. (2011), Pan et al. (2014a) and Wei et al. (2014), advocated to use it in negotiating the emission reduction responsibility of different countries.

Considering the fact that per capita CO_2 emissions vary across different counties, Meyer (2000) proposed the contraction and convergence (C&C) approach for CO_2 emissions allocation. The rationale of the C&C approach is that global CO_2 emissions need to be cut down substantially

[2] It should be pointed out that the list of criteria given in Table 1 is definitely not complete. Other criteria, e.g. willingness to pay (Vaillancourt and Waaub, 2004), are not included since they were rarely implemented in earlier studies.

[3] While the classification is rather encompassing, it does not cover all the existing emissions allocation methods, e.g. the Boltzmann distribution method proposed by Park et al. (2012).