The applicability of marginal abatement cost approach: A comprehensive review

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ARTICLE INFO

ABSTRACT

The Marginal Abatement Cost (MAC) methodology is widely used in climate change policies. Policy-makers rely on MAC to assess feasible strategies and related costs to achieve emission reduction goals. This paper introduces a variety of MAC methodologies, aiming at solving diverse problems, which utilizes various calculable-logic, thus producing different results and implications. This study applies a mind-mapping method to capture differentiation of MAC methods, and systematically classify MAC methodologies. The applicability path analysis was proposed, based on principles such as stakeholder type, decision-making objectives, cost concept, strategy mode and information scope. Our goal is to assess the applicability of different methodologies, to reduce misuse by policy-makers, and to serve as a guide for subsequent research, which might prompt and lead to the derivation of more consequential results in future studies. The results of this study suggest that the complex method is not always better than the simplified method because policy-makers are required to select the appropriate method according to the type of information needed. It may even be suggested that MAC could be reliable by ranking relative-value of options compared with baseline, rather than focusing on the absolute value of individual measures.

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1. Introduction

In light of the global attention placed on greenhouse gas (GHG), the volume of research on MAC methodologies sprung up significantly. Each of the methods has different advantages and disadvantages, which can address the different concerns policy-makers may have. Since many MAC methods in the literature focus on different themes, scopes of study and computational logic, the quality and information should be identified carefully. By examining literatures from the last ten years, we intend to systematically analyze the MAC methodologies proposed, including classification, research trend and applicability, which can be subsequently classified under five dimensions, namely, stakeholder type, decision-making objectives, cost concept, strategy mode and information scope.

Climate change has played an important role in environmental sustainability. However, GHG reduction and economic development are often in conflict with each other. To reduce the impact on economy, countries often seek cost-effective measures to achieve greenhouse gas reduction, and the Marginal Abatement Cost Curve (MACC) has become a prominent tool to evaluate such balance. The MACC originated from the oil crisis in the 1970s, when researchers started exploring the relationship between energy-saving potential and relative cost. In 1982, Meier developed the first cost curve for electricity consumption savings, called saving curve or conservation supply curve (Kesicki and Strachan, 2011; Wächter, 2013; Levihn, 2015). Policy-makers could find out economic and feasibility measures from the curve which assist in reducing energy consumption. In 1990s, the concept was further extended to analyze the issues of global climate change (Jackson, 1991). Constructing a relationship curve between reduction potential of emissions vs. relative cost allows researchers to formulate the trade-off between economic feasibility and environmental protection (Kwon and Yun, 1999). In 1994 when the United Nations Framework Convention on Climate Change (UNFCCC) was fully enforced, with some developed and developing countries facing international pressure to shoulder responsibility in abating greenhouse gas emissions. MAC was used to identify GHG cost-effective reduction potential between countries of different social, environmental and economic status,

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and it also contributed to the emission reduction negotiation among nations (Ellerman and Dacoux, 1998).

In environmental economics, MAC is defined as necessary costs to pay per additional unit of emissions reduction (McKitrick, 1999). It is used jointly with the marginal benefit curve (MBC) to determine the optimal pollution reduction level (Eory et al., 2013). In comparison to the latter, MAC could be regarded as the supply curve for emission reduction (Delhotal et al., 2008; Nordrum et al., 2011), which represents the relationship between the quantity of emission-reduction and price to pay for GHG. Any point along a MAC represents the marginal cost of abating an additional amount of emissions, MAC is not used to decide the optimal emission level. It has been used to measure the feasibility and the relative costs of reaching emission reduction targets. An important feature of MAC is to clearly illustrate the relative cost-effectiveness of all available options. This is derived by ranking ordering options according to the cost per unit of emission reduction, after which short term measures or long-term technology innovation strategies are eliminated step by step. MACC can be considered an important tool to connect target setting and policy implementation.

In the past decade, a variety of MAC methodologies has been introduced in different literature which targets the solving of diverse problems, utilizing various calculable-logic, thus producing different results and implications. Due to the steady flow of the research literatures, there have been reviews published by scholars in the field which provide a comprehensive and objective viewpoint. The last literature reviews emphasized on discussing the advantages, disadvantages and main influential factors of MAC methods. Kok et al. (2011) identified fourteen methodological issues into six groups, estimating the variation range of different MAC methodologies while examining the scope and assumptions in the transportation sector. Some studies used the meta-analysis method to examine the sensitivity of MAC estimates and the influential factors (Kuik et al., 2009; Vermont and Cara, 2010). There have also been comparative studies of different MAC methodologies to recognize the limitations, advantages and disadvantages in practical applications. Some studies were concerned about the robustness of the methodology and pointed out weaknesses in the current approach, particularly pertaining to non-system methods, and emphasized caution in interpreting MAC (Ward, 2014; Kesicki and Strachan, 2011; Kesicki and Ekins, 2012; Taylor, 2012). Browne and Ryan (2011) compared three kinds of environmental assessment tools, in which the MAC method was included, and concluded that it is difficult to find a tool that will adequately reflect the full extent and impact of policies. Sathaye and Shukla (2013) classified MAC methods and compared 20 different global models, and this identified various factors to affect the results of methods.

The aim of this study is (1) to establish systematic taxonomy of MAC methodology; (2) to identify the applicability and the functionality of different MAC approaches; (3) to assist policy-makers in selecting appropriate methods according to its stakeholders and limitations; and (4) inspire further research topics, which may lead to more conclusive results in MAC studies.

This paper is structured as follow: Section 2 describes the methodology and its associated statistics. Section 3 is divided into three subsections. First, we propose a systematic classification of methodologies in the field, a description of distinctive methodological features as well as the computational logic. Secondly, we explore the trend of the main applications and the connotation of the functions. The third subsection presents the innovation and improvement in MAC research. Section 4 establishes the path of selection and discusses the robustness of MAC. Finally, the paper concludes with Section 5.

2. Methods

The aim of the research programs in this study is to identify, interpret, and clarify the literature currently available on the topic of MAC. In determining the scope of this study, we focus on articles that are central and relevant to MAC, which include comprehensive reviews, comments and method-specific studies.

For literature collection framework, the relevant time frame, journal types, and keywords were identified. Focus was placed on literature published between 2004 and 2015; a collection of International Journals (Social Sciences Citation Index Journal) with title related to "Environment", "Climate" and "Energy" were chosen and filtered accordingly. A total of 86 papers from 31 journals that were found relevant to the research enquiry and each article was reviewed. There was significant growth in the number of papers, particularly in the last three years, which saw more than 10 papers per year, indicating a popular trend in MAC research. The results are shown in Fig. 1.

Using keywords in the journal title, Table 1 below revealed that "Energy" accounted for 52% of MAC articles, "Environment" for 19%, "Climate" for 5%, while any others made up 24%. There were a total of 23 papers published in "Energy Policy", which ranked first in all journals collected. By looking at the nationality of the first author, 56% of articles are from Europe, 19% from USA, 24% from Asia, and 1% from others. This lead to the observation that the study of MAC in the US and UK is ahead of other countries.

This study differs from previous approach by applying mind-mapping method to capture and cluster the main classification and conjunction of MAC methods. Mind maps were introduced in 1974 by Tony Buzan in a book titled "Use Your Head". This approach emphasizes on breaking down complex concepts into central vs. related concepts, prior classifying subjects and stratifying relationships in a system of networks. Mind maps have been widely used in brainstorming, problem analysis, and project management etc.

Owing to MAC's uniqueness, different stakeholders are often faced with the problem of the actual implementation of the decision-making method. Therefore, this study attempts to use the mind-mapping method to establish a hierarchical structure of MAC classification to allow a better understanding of the differences and the connections between various methods. From the literature review, its applicability for various methods is clarified in order to establish the integrity and the restrictions of MAC methods and to reduce bias in decision-making.

To guide the literature review, a series of questions are highlighted as follow:

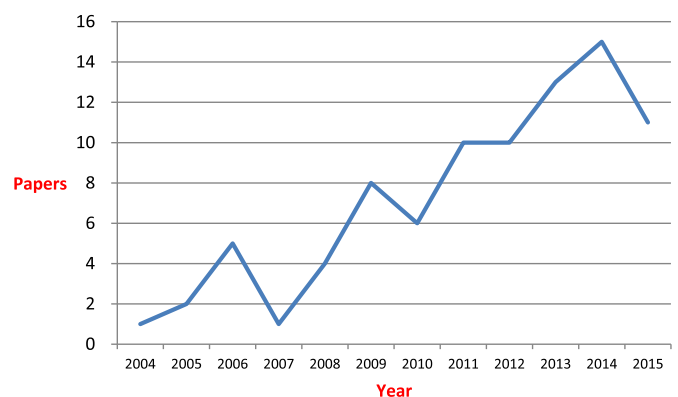- What is the implication of the research methods in terms of its definition and logics?

Fig. 1. Growth of MAC publications in international journal.