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The theory-practice gap of black carbon mitigation technologies in rural China

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ABSTRACT

Black carbon mitigation has received increasing attention for its potential contribution to both climate change mitigation and air pollution control. Although different bottom-up models concerned with unit mitigation costs of various technologies allow the assessment of alternative policies for optimized cost-effectiveness, the lack of adequate data often forced many reluctant explicit and implicit assumptions that deviate away from actual situations of rural residential energy consumption in developing countries, where most black carbon emissions occur. To gauge the theory-practice gap in black carbon mitigation – the unit cost differences that lie between what is estimated in the theory and what is practically achieved on the ground – this study conducted an extensive field survey and analysis of nine mitigation technologies in rural China, covering both northern and southern regions with different residential energy consumption patterns. With a special focus on two temporal characteristics of those technologies – lifetimes and annual utilization rates, this study quantitatively measured the unit cost gaps and explain the technical as well as sociopolitical mechanisms behind. Structural and behavioral barriers, which have affected the technologies' performance, are discussed together with policy implications to narrow those gaps.

1. Introduction

Large developing countries like China and India face dual challenges of mitigating greenhouse gases emissions and combating air pollution, which could serve as two driving forces for black carbon mitigation (Xu, 2017). Though having a short residence time in the atmosphere, black carbon can have significant warming impacts on the climate (Bond et al., 2013; Ramanathan and Carmichael, 2008). In a 20-year timespan, its global warming potential (GWP) is estimated to be 3,200, which will gradually drop to 900 in a 100-year time horizon (Bond et al., 2013). Scientists have called for black carbon mitigation to win time for politically tougher, economically more costly climate change mitigation (Shindell et al., 2012; Shoemaker et al., 2013). Some suggest that black carbon mitigation can be one of the 50-year stabilization wedges, equivalent to 25 billion tons of carbon (Grieshop et al., 2009; Pacala and Socolow, 2004). In addition, black carbon emissions are associated with adverse health effects because it is a component of fine particulate matter ($PM_{2.5}$) (Shindell et al., 2012; Highwood and Kinnersley, 2006; Kopp and Mauzerall, 2010). Thus, black carbon mitigation also plays an important role in public health management. Regarding the emission source, in developing countries, fossil fuel combustion (traffic combustion) and residential combustion constitute two major sources of black carbon emission (Liu et al., 2011; Shen et al., 2015).

More efforts are still needed to mitigate black carbon emissions. Though six major greenhouse gases are regulated by the Kyoto Protocol and halocarbons are largely addressed in the Montreal Protocol, black carbon—as one of the short-lived pollutants with strong climate effects—remains largely unregulated. In response to this regulation gap, there are increasing international efforts to tackle this problem including the Global Alliance for Clean Cookstoves hosted by the United Nations Foundation since 2010 and the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC) launched by the United Nations Environment Programme in 2012. From a global perspective, controlling emissions in developing countries has been proved to be more cost effective than that in developed countries (Baron et al., 2009). With a large share of black carbon emissions in developing countries coming from the residential burning of biomass and coal, many international and domestic efforts have been directed to improving energy efficiency and switching to clean fuels (Edwards et al.,

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2004).

Tackling a problem as complex as black carbon mitigation requires both policy and technical solutions (Xu and Liu, 2016). Policy solution depends on active engagement of governments. Though individual choices of fuels and technologies are closely related to income level and other socioeconomic factors (Pachauri and Jiang, 2008; Johansson et al., 2012), governments can influence a society's energy structure by deploying a wide range of policy instruments. Some of those instruments are market-based, with governments providing extra economic incentives and financial supports while leaving major decisions to consumers (Rai and McDonald, 2009). Other approaches may take the form of national planning or compulsory regulations (Song et al., 2014; Sinton et al., 2004). Technical solution, on the other hand, involves assessing mitigation technologies and identifying cost-effective measures. Researchers have developed different modelling tools, especially those bottom-up ones with marginal abatement cost (MAC) curves, to quantitatively estimate an optimal set of cost-effective mitigation technologies and communicate their findings to policymakers.

Though the legitimacy of mitigation policy is hinged on the reliability of scientific models, many explicit and implicit assumptions included in those models render the findings less reliable and instructive than they would otherwise have been. Modelling involves a vast array of uncertainties, and the existence of many reluctant yet unverified assumptions has led to a widening gap between different model estimates and between theoretical and real-world (Farmer et al., 2015; Dai et al., 2016; Jefferson, 2014). Revesz and others (Revesz et al., 2014) pointed out one of the gaps—a lack of understanding of responses in developing countries—has caused the underestimation of climate change damage in social-cost models. Gillingham and others (Gillingham et al., 2015) conducted a comprehensive study of uncertainties in climate change by using a multi-model comparison and found that “parametric uncertainty is more important than uncertainty in model structure”.

Scientists working on MAC curves also need to deal with uncertainties and their impacts on the theory-practice gap. Part of the uncertainties are caused by insufficient information on the costs of individual technologies, which are critical for mitigation modelling and can vary substantially across technologies and regions (Baron et al., 2009; Rypdal et al., 2009). This problem of lack of data is common especially in developing countries, where most of black carbon emissions occur. Very often unit mitigation costs for various technologies, hereafter referred to as unit costs for simplicity, are extrapolated from those of developed countries, which can result in a biased estimation of the costs in developing countries (Rypdal et al., 2009). Moreover, in developing countries including China, India, Mongolia, and South Africa, the overall thermal performance of stoves was tested under narrowly defined operation conditions, and systematic and conceptual errors have been found in those stove testing standards and protocols (Zhang et al., 2017). Systematic errors, inconsistent measurement, and lack of comparability also increase the difficulty for modelling.

Part of the theory-practice gap is caused by a complex array of socioeconomic barriers. Some well-known discussions on those barriers can be found, for example, in the studies of energy efficiency (Hirst and Brown, 1990; Dietz, 2010; Gillingham et al., 2009). Especially for rural energy consumption where much of black carbon emissions occurs, in practice there is always a gap between what the optimal levels are in technological potential and what can be achieved on the ground. Scholars attribute the efficiency gap to two types of barriers—structural barriers and behavioral barriers (Hirst and Brown, 1990). Behavioral barriers originate from energy end-users' attitudes, perceptions, and incentive, whereas structural barriers are often rooted in government policies and organization practices (Hirst and Brown, 1990). Because of those structural and/or behavior barriers, energy efficient technologies that can potentially reduce fuel consumption may not be well adopted. The same structural and behavior barriers can explain the gaps in other energy-related parameters.

Due to data unavailability, many researchers had no choice but to build models by using extrapolated data and ideal scenarios to estimate mitigation costs, construct bottom-up MAC curves, and evaluate policy measures (Kesicki, 2010). Take the assessment of household biogas digesters in China as an example. When calculating the unit costs of this technology, the lifetime of a digester is assumed to be approximately 20 years, which is close to its maximum potential lifespan (Yang and Chen, 2014; Wang and Zhang, 2012). This kind of assumptions needs to be reviewed to increase the accuracy of modelling and simulation. If the assumptions deviate greatly from the reality, significant errors can occur, which may in turn lead to false conclusions and a problematic course of public action. Considering the poor emission database in developing countries, the gap between theoretical estimation and ground truth and its implications for policy-making do deserve special attention.

Most researchers admit the existence of those gaps, but few studies have conducted quantitative analysis to examine the key factors that affect the magnitude of the theory-practice gap in black carbon mitigation. To improve our understanding of real-life situations, we conducted an extensive field survey and analysis of nine black carbon mitigation technologies in rural China, covering both northern and southern provinces with different residential energy consumption patterns. This study aims to quantitatively measure unit mitigation costs of different technologies on the ground and to assess the theory-practice gaps. The sociopolitical mechanism behind those gaps will also be examined together with the discussion of their policy implications. The rest of the paper is organized as follows. Section 2 introduces data and methodology. Section 3 quantifies the theory-practice gaps of nine black carbon mitigation technologies for providing cooking, space heating and water heating services. Section 4 explains the gaps by focusing on two influential factors—lifetime (the number of years that a technology is or will be utilized before suspension) and annual utilization rate (the ratio of days in a year that a technology is in use to the total days that it could be used). Section 5 discusses the sociopolitical mechanisms behind those gaps.

2. Data and methodology

2.1. Data

For examining the unit cost gaps of various technologies in rural China, a household survey was conducted in three provinces—Hebei, Guizhou and Guangxi. Hebei province is located in the northern part of China whereas Guizhou and Guangxi provinces are located in the south. A total of seven counties, 24 villages and 695 households were visited during the periods between the years 2014 and 2015. The basic information of the surveyed sites are summarized in Table 1 and their geographical locations are shown in Fig. 1. Household questionnaires were used to collect basic quantitative information, including the number of permanent residents, types of used technologies, the lifetimes and annual utilization rates of those technologies, and annual fuel consumption (such as straw, firewood, coal and others). Semi-structural interviews were conducted to collect qualitative data, including the reasons for shorter-than-expected lifetimes and annual utilization rates. It is worth noting here that instead of asking people about their annual energy assumption, this study asked the number of permanent residents in order to estimate the household's basic energy consumption. That is because each household uses a variety of technologies simultaneously which makes it difficult to distinguish whether the reported fuel consumption represents that of baseline technologies, or that of mitigation technologies, or a combination of the two. Besides individual villagers, village heads and the managers of centralized biogas systems were also interviewed to gain insights into the issues related to the organization and management of the mitigation projects.

Although the 24 villages and 695 households can hardly provide comprehensive representativeness of entire rural China with nearly 600