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A bottom-up method to develop pollution abatement cost curves for coal-fired utility boilers

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ABSTRACT

This paper illustrates a new method to create supply curves for pollution abatement using boiler-level data that explicitly accounts for technology cost and performance. The Coal Utility Environmental Cost (CUECost) model is used to estimate retrofit costs for five different NO_x control configurations on a large subset of the existing coal-fired, utility-owned boilers in the US. The resultant data are used to create technology-specific marginal abatement cost curves (MACCs) and also serve as input to an integer linear program, which minimizes system-wide control costs by finding the optimal distribution of NO_x controls across the modeled boilers under an emission constraint. The result is a single optimized MACC that accounts for detailed, boiler-specific information related to NO_x retrofits. Because the resultant MACCs do not take into account regional differences in air-quality standards or pre-existing NO_x controls, the results should not be interpreted as a policy prescription. The general method as well as NO_x-specific results presented here should be of significant value to modelers and policy analysts who must estimate the costs of pollution reduction.

1. Introduction

Energy models exploring future scenarios of technological change in the electric sector must quantify the economic trade-off between the cost to retrofit existing coal-fired power plants with control technologies and the cost to build newer, cleaner electric power plants. Often, a challenge for energy modelers is to develop marginal abatement cost curves (MACCs) of pollution. MACCs represent the estimated cost of abatement as a function of the emissions level and are an important tool for energy modeling and environmental policy analysis. However, MACCs are often generated using economic techniques that do not include explicit technological considerations, which can lead to an inaccurate characterization of abatement cost. This paper sets out to answer the following question: can detailed technology cost and performance data be used to create MACCs from the bottom up? We present a new method to create MACCs that applies a unit-level engineering-economic assessment tool to determine retrofit costs and abatement levels associated with specific NO_x controls on a large subset of US coal-fired utility boilers. The boiler-level retrofit data is then used as input into an integer linear program (Murty, 1995), which determines the optimal distribution of retrofits across all boilers as a function of the NO_x abatement level. The result is a MACC that reflects the minimum system-wide cost to achieve a particular level of NO_x reduction.

We chose to demonstrate the new method by building an abatement cost curve for NO_x emissions. NO_x formation is complex and abatement costs depend, in part, on a complex combination of coal type, coal composition, boiler design, plant size, and plant utilization factor. In addition, several mature NO_x retrofit technologies exist for coal-fired utility boilers. The focus on NO_x emissions provides a rich decision space in which marginal abatement costs depend on complex technical details. Since the analysis presented here does not account for pre-existing controls, state or federal air-quality standards, the need to apply tighter controls in air-quality hot spots, or existing markets for emissions trading, the MACCs developed here should not be treated as a policy prescription, but as an illustration of a novel methodology for developing bottom-up, technology-based MACCs.

While changes in the electric power sector will likely be driven by a future climate policy, the timing and extent of new capacity installations in the electric sector will depend in part on the pollution control retrofits that may need to be installed on existing coal-fired power plants in response to increasingly stringent air pollution regulations. Emissions of nitrogen oxides (NO_x) have been associated with various environmental and

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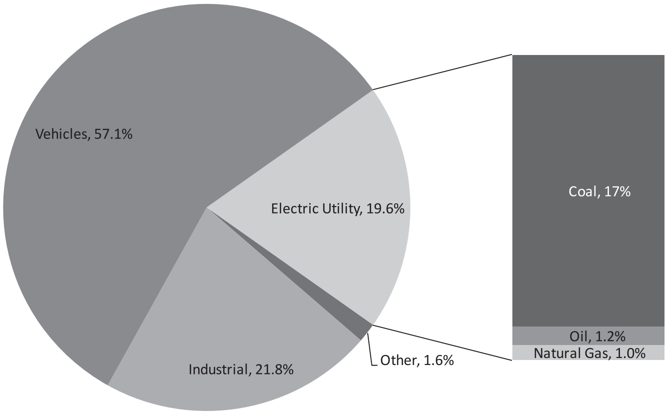

Fig. 1. Sources of US NO_x emissions in 2007. The bar graph inset breaks down emissions in the electric sector according to fuel type. All percentages represent the portion of total national NO_x emissions.

public health impacts, such as an increase in drinking water nitrate, eutrophication, acid rain, formation of ground-level ozone, degraded visibility and regional haze, and the formation of secondary fine particles in the atmosphere (Molina and Molina, 2002; Price et al., 1997). In 2007, a total of 17 million tons of NO_x was emitted in the US (EPA, 2009). The transportation sector was the largest contributor (~57%) to total NO_x emissions, followed by the industrial (~22%) and electric utility (~20%) sectors. Fig. 1 shows the contribution to US NO_x emissions from various sources in 2007. The electric utility industry was responsible for emitting about 4.7 million tons of NO_x, of which about 87% came from the combustion of coal. Because coal-based power generation currently accounts for roughly half of total US electricity production, it is the single largest stationary source category in the US, contributing about one-fifth to total NO_x emissions.

In the following section, we discuss several existing methods used to construct MACCs. Since our method for creating MACCs from the bottom up depends strongly on retrofit cost and performance, Section 3 provides useful technical information regarding currently available NO_x abatement technologies. Sections 4 and 5 describe the data sources, tools, and methods employed for this study. Section 6 presents an analysis of the resultant MACCs. Finally, Section 7 draws conclusions and suggests future work related to the development of bottom-up MACCs.

2. Marginal abatement cost curves: a tool for modeling and policy analysis

A MACC provides the cost of reducing an additional unit of pollutant from a given emissions level. Each additional unit of emission reduction generally has incrementally higher cost, leading to the formation of a convex curve with increasingly positive slope. Such curves are a useful tool for modeling, formulation, and analysis of energy and environmental policy because they provide an estimate of the cost to make incremental reductions from a given emissions level. Knowledge of such curves allows analysts to determine economically efficient levels of pollutant reductions. Being able to determine an efficient level of pollution abatement makes it possible to maximize net social benefits (Kwon and Yun, 1999; McKitrick, 1999). At the firm level, a MACC links a firm's emission levels to the cost of reducing one unit of emissions from the current levels, and therefore can be a key tool for firm related-economics (McKitrick, 1999). Similarly, at the system level, MACCs can be used to determine which sector(s) to focus on to abate emissions in the most cost-effective manner.

In recent years, MACCs for reducing greenhouse gas (GHG) emissions have become a standard tool to estimate and analyze the potential economic impacts of national GHG reductions policies (Johnson, 2002; Klepper and Peterson, 2006). MACCs are a key tool in the study of environmental economics and can be used to identify efficient and practical policy solutions aimed at reducing the net social cost of a policy (Lee, 2005).

Technically, a firm can reduce pollutant emissions by reducing output, or by investing in end-of-pipe (EOP) or change-in-process (CIP) control technologies–options which have very different costs. Selective catalytic reduction (SCR) is example of an EOP control technology, and combustion modification is an example of a CIP control. In general, methods to estimate abatement costs can be placed in three broad categories: microeconomic theory-based methods, such as the cost function approach (e.g., Gollop and Roberts, 1985) and distance function approach (e.g., Fare et al., 1993), econometric methods (e.g., Becker, 2005; Hartman et al., 1997), and engineering-economic methods (e.g., Beaumont and Tinch, 2004; Karvosenoja and Johansson, 2003). In the cost function approach, pollution—along with labor, energy, and capital—are treated as an input to the production process, and the marginal cost of emissions reduction is derived by estimating the change in the cost function as the emission level changes. Since firms fail to minimize their production cost in the presence of various regulations, the cost-function approach is likely to underestimate marginal abatement cost (Lee, 2005). Moreover the cost function approach requires a significant amount of information about input costs, which is often not readily available. Fare et al. (1993) have developed an output distance function approach, which has been very widely applied in the recent literature to estimate the marginal abatement cost of 'bad' output (e.g., Boyd et al., 1996; Hailu and Hailu, 2003; Hailu and Veeman, 2000; Kwon and Yun, 1999; Lee et al., 2002; Lee, 2005). Using this approach, the marginal abatement cost can be calculated as the shadow price of reducing the pollutant emissions by one unit or the opportunity cost of reducing the level of output by one unit. Two interesting applications of the output distance function approach to the power sector are presented by Coggins and Swinton (1996) and Kwon and Yun (1999). Both papers utilize an output distance function and its relationship to the revenue function to estimate marginal abatement costs.

While the cost function and output distance function methods can roughly indicate the cost of reducing emissions by way of reducing the output, these approaches do not explicitly consider any EOP or CIP control technologies to reduce emissions. For example, Coggins and Swinton (1996) clearly note their inability to incorporate important technology options such as scrubbers to arrive at their estimates of the cost of SO_2 allowances from coal-fired utilities. Because these approaches only consider changes in output, a specific EOP or CIP control may have a lower marginal abatement cost than the shadow price estimated using these approaches. Further, the actual opportunity cost of forgoing production may be higher than estimated in a case where plant efficiency decreases with a reduction in the output.

MACCs can also be developed by employing econometric methods. These methods utilize extensive plant-level data on capital expenditure and operation and maintenance costs associated with pollution control equipment to derive abatement cost estimates using statistical modeling. There are several pertinent applications of this method in the literature, which rely on data from the US Census Bureau's Pollution Abatement Costs and Expenditures (PACE) survey (e.g., Becker, 2005; Hartman et al., 1997). The abatement cost estimates thus obtained require a large amount of data collection, but have the same shortcoming as in