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How accounting for climate and health impacts of emissions could change the US energy system

Kristen E. Brown*, Daven K. Henze, Jana B. Milford

University of Colorado, 1111 Engineering Drive, Boulder, CO 80309-0427 USA

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ABSTRACT

This study aims to determine how incorporating damages into energy costs would impact the US energy system. Damages from health impacting pollutants (NO_x, SO_2, particulate matter – PM, and volatile organic compounds – VOCs) as well as greenhouse gases (GHGs) are accounted for by applying emissions fees equal to estimated external damages associated with life-cycle emissions. We determine that in a least-cost framework, fees reduce emissions, including those not targeted by the fees. Emissions reductions are achieved through the use of control technologies, energy efficiency, and shifting of fuels and technologies used in energy conversion. The emissions targeted by fees decrease, and larger fees lead to larger reductions. Compared to the base case with no fees, in 2045, SO_2 emissions are reduced up to 70%, NO_x emissions up to 30%, $PM_{2.5}$ up to 45%, and CO_2 by as much as 36%. Emissions of some pollutants, particularly VOCs and methane, sometimes increase when fees are applied. The co-benefit of reduction in non-targeted pollutants is not always larger for larger fees. The degree of co-reduced emissions depends on treatment of life-cycle emissions and the technology pathway used to achieve emissions reductions, including the mix of efficiency, fuel switching, and emissions control technologies.

1. Introduction

Air pollution associated with energy production and use affects local air quality and global climate. Direct health impacts of air pollution include premature mortality (e.g., Krewski et al., 2009) and asthma exacerbation (e.g., Mar et al., 2004). Global climate change affects temperature and weather patterns (e.g., Kirtman et al., 2013), crop loss, and increased prevalence of certain diseases. These consequences are externalities – effects on the wellbeing of an unrelated group or individual outside the market mechanism that controls the price of energy. Damages are the monetary value of externalities. Health related damages from electricity generation in the US in 2005 have been estimated at over $62 billion (NRC, 2010). Greenhouse gas (GHG) related damages from electricity generation in 2005 were $118 billion, calculated using the 2010 Social Cost of Carbon with a 2.5% discount rate (IWG SCC, 2013).

Incorporating damages into energy costs would encourage practices that reduce the externalities. The most efficient policies are directed at the externality itself, such as a fee on emissions rather than on electricity. This allows the policy to most effectively reduce the externality instead of reducing the surrogate. By considering fees based on damages instead of an emission or technology goal, even if fees cause an increase in the price of electricity, the overall social cost related to electricity will decrease because external costs are lowered.

Guided by these general economic principles, previous studies have explored how energy systems might develop in response to application of fees to internalize external damages. Such studies (Klaassen and Riahi, 2007; Nguyen, 2008; Pietrapertosa et al., 2009; Rafaj and Kypreos, 2007) have used integrated energy system models to estimate changes to energy usage and production if fees are applied. They found that internalizing externalities might reduce energy consumption, change generation technologies, increase use of control technologies, and yield co-benefits through reduced emissions of un-taxed pollutants. Brown et al. (2013) focused on internalizing damage costs in the electric sector in the US but did not consider how the system would respond to fees implemented across all energy sectors. Jenkins (2014) discussed limitations of using fees to internalize externalities including political acceptability, overlap with existing policy, and household willingness to pay that might render fees non-optimal. On the other hand, Murray et al. (2015) examined the multi-decadal implications of

Abbreviations: AEO, Annual Energy Outlook; CAFE, Corporate Average Fuel Economy; CCS, Carbon Capture and Sequestration; DICE, Dynamic Integrated Climate-Economy model; EGU, Electric Generating Unit; EPA, Environmental Protection Agency; FGD, Flue Gas Desulphurization; GHG, Greenhouse Gas; HIP, Health Impacting Pollutant; LNB, Low NOx Burner; MACT, Maximum Achievable Control Technology; MARKAL, Market Allocation model; PIER, Public Interest Energy Research; PM, Particulate Matter; SCC, Social Cost of Carbon; SCR, Selective Catalytic Reduction; SNCR, Selective Non-Catalytic Reduction; VOC, Volatile Organic Compounds; VSL, Value of Statistical Life

* Corresponding author.
E-mail addresses: Kristen.E.Brown@Colorado.edu (K.E. Brown), Daven.Henze@Colorado.edu (D.K. Henze), Jana.Milford@Colorado.edu (J.B. Milford).

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near-term policies to reduce CO_2 emissions, including tradeable and non-tradeable emissions rate limits as well as modest emissions fees. They found non-tradeable rate limits had the most lasting effect, as they led to some coal plant retirements. Carbon fees had a more neutral effect on the future electricity system and corresponding policy options. While Brown et al. and Murray et al. focused on the electricity sector, applying fees more broadly could yield greater emissions reductions and benefits, or afford more cost effective emissions reductions. This will also ensure that reduced emissions in the electric sector are not outweighed by increased emissions elsewhere.

The dual impacts of air pollution on human health and climate, and differences between regulatory frameworks designed to address health impacting pollutants (HIP) versus GHGs, raises questions regarding how fees on emissions of one category may impact the other. Different pathways to specified emissions reductions can have different co-benefits or even regional disbenefits (Driscoll et al., 2015). Carbon policies that allow reductions from multiple sectors are estimated to achieve larger co-benefits and reduce the cost of compliance (Thompson et al., 2014; Saari et al., 2015). Studies examining how air quality and climate goals might be met symbiotically (Chen et al., 2013; Kleeman et al., 2013; Nam et al., 2013; Zapata and Muller, 2013) found that energy efficiency and fuel switching measures usually lead to co-benefits. Directly encouraging energy efficiency can also lead to emissions reductions (Wang and Brown, 2014; Melo and Jannuzzi, 2015), but can be difficult to model, particularly in the industrial sector (Kesicki and Yanagisawa, 2014). As a counterexample, however, Leinert et al. (2013) found that Ireland might emit excess NO_x when reducing GHG emissions due to shifting from gasoline to diesel vehicles.

In this paper, we evaluate how incorporating external costs into the cost of energy could change energy use and emissions in the US. Ranges of damage estimates from the literature are used to construct scenarios prescribing emission fees for GHGs and HIPs. A modified version of the EPA US 9 region MARKAL (MARKet ALlocation) model is used to evaluate resulting changes to the US energy system through 2055. Emissions reductions can be achieved through application of control technologies, changing fuels or conversion technologies, and improved efficiency. We compare emissions reductions with fees on HIPs, GHGs, and both simultaneously. We examine co-reductions and increases in non-targeted pollutants as well as reductions in targeted pollutants. Our fee structure and modeling system are specific to the energy system (from fuel extraction through processing, energy conversion, and end use); hence, we do not consider non-energy related emissions reduction pathways in sectors such as agriculture, waste disposal, or most industrial processes. Most anthropogenic emissions in the US are associated with energy production, conversion, or use including 83% of GHG emissions (US EPA and CCD, 2016), 95% of NO_x emissions, 60% of VOC emissions, 48% of primary $PM_{2.5}$ emissions, and 91% of SO_2 emissions (OAQPS, 2015); therefore, although we restrict our analysis to the energy sector, we capture the majority of anthropogenic emissions.

2. Methods

2.1. Health related damages

HIP emissions considered here are NO_x, $PM_{2.5}$, PM_{10}, SO_2 and VOCs. Hazardous air pollutants can also cause adverse health effects but are not considered here. Three sets of sector-specific, damage-based fees are considered (Table 1). All monetary values in the paper are for year 2005 USD. Damage values for pollutants should be location dependent because emissions that lead to pollutant concentrations near population centers will affect more people than those that generate rural pollution. Location-dependence is partly captured in this study by using different damage values for different sectors, e.g., with higher damage values for industrial and transportation emissions than for electric sector emissions.

Table 1
Health impacting pollutant damages used as fees. (All values in 2005 USD/t unless otherwise specified.) The [a] represents values that were taken from a different literature source than the rest of that set of fees, see sources in text. These fees are constant through time once they are applied.

$/ton	Sector	NO_x	PM_{10}	$PM_{2.5}$	SO_2	VOC	Natural Gas Use M$/PJ
Low	Electric	364	195	2261	1866	240	
Sect-	Industrial	547	378	4343	2274	436	
or	Transportation	593	444	5147	2476	510	
Spec-	Upstream	501	339	3917	2205	395	
ific	Refinery	547	378	4343	2274	436	
Fees	Residential						0.059[a]
	Commercial						0.025[a]
Mid Fees	All	1970	1115	21520	9750	1720[a]	
High	Electric	4700	4110[a]	117100	31500	2330[a]	
Sect-	Industrial	5500	4110[a]	234300	35100	2330[a]	
or	Transportation	6600	4110[a]	324400	17100	2330[a]	
Spec-	Upstream	5600	4110[a]	225267	27900	2330[a]	
ific	Refinery	5900	4110[a]	279300	59500	2330[a]	
Fees	Residential	11700	4110[a]	324400	87400	2330[a]	
	Commercial						0.579[a]

[a] Marked values represent represents values taken from a different literature source than the rest of that set of fees, see sources in text.

We selected the fees used here to represent the range of values reported in recent literature. Low sector-specific fees are derived from Muller et al. (2011). Mid-range fees are from NRC (2010), except the mid-range VOC fee is based on the geometric mean of VOC damages from Muller and Mendelsohn (2007) and Fann et al. (2009). High fees are based on damages from Fann et al. (2012) except that VOC damages are from Fann et al. (2009). PM_{10} values in the high fee case are based on NRC (2010) values multiplied by a factor representing the average increase of Fann et al. (2012) over NRC (2010). These adjustments allow us to apply fees to the same set of pollutants in all cases. Damages for the residential and commercial sectors are sometimes only applied as fees to natural gas used, corresponding to the way damages have been reported for these sectors. Most energy use in these sectors is in the form of electricity or natural gas, so we assume that these estimates capture most of the damages. The damages in Table 1 in the natural gas use column are derived from NRC (2010) by multiplying by a ratio as described above for PM_{10}.

Sources of discrepancies in reported damage estimates include whether age is taken into account when applying the Value of Statistical Life (VSL) to pollution-caused mortalities. Using a uniform VSL can produce 50% higher marginal damages than differentiating by age (Muller et al., 2011). Only Muller et al. (2011) differentiate VSL based on age. Which emissions sources are considered can also cause differences in estimated damages. Muller et al. (2011) and Fann et al. (2012) consider a wide range of sources while NRC (2010) focuses on EGUs combusting coal and natural gas. There are also variations in the areas considered for population exposure. Since mortality from $PM_{2.5}$ is a significant component of damage estimates, the choice of corresponding concentration-response functions is also important. NRC (2010) and Muller et al. (2011) used results from Pope et al. (2002) and Woodruff et al. (2006) to relate $PM_{2.5}$ exposure to mortality; Fann et al. (2012) used health impact functions from Krewski et al. (2009). Fraas and Lutter (2013) found that uncertainty in the concentration-response functions may be larger than that encompassed by the range of studies considered here. Buonocore et al. (2014) showed that variability of damage estimates between individual facilities may be important for evaluating the benefits of alternative energy technologies (e.g., Siler-Evans et al. (2013)). Although we do not have the ability to incorporate this level of variability into our modeling framework, we partially account for this