THE EFFECT OF CRITERIA POLLUTANT AND GREENHOUSE GAS DAMAGE BASED FEES ON EMISSIONS FROM THE US ENERGY SYSTEM

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1. INTRODUCTION

Energy use in the US is influenced by many factors, but not all consequences are considered when making energy decisions. Externalities are activities that affect the well-being of an unrelated group or individual outside the market mechanism. The emissions of pollutants have effects on both local air quality and global climate. Damages are the monetary value of externalities, such as the value of medical bills from adverse health effects. This study evaluates how incorporating life cycle emissions and damages into the cost of energy would change energy use and air pollutant emissions in the US. Damages from criteria pollutants (NO_x, SO_2, particulate matter ($PM_{10\text{-}2.5}$ and $PM_{2.5}$)), and VOCs) as well as greenhouse gases (GHGs) are accounted for by applying emissions fees equal to their estimated external damages. Such fees encourage practices that reduce externalities.

Here we consider internalizing externalities by using MARKAL to model damage based fees on emissions. Carbon fees have been found to increase revenue and reduce CO2 emissions (Congressional Budget Office 2013a,b; Sumner et al. 2009). Air quality and climate goals should be considered together to improve co-benefits and identify potential disbenefits (Akhtar et al. 2013; Bell et al. 2008; Brown et al. 2013; Chen et al. 2013; Markandya et al. 2009; Nemet et al. 2010; West et al. 2013; Klaassen and Riahi 2007; Nam et al. 2013; Leinert et al. 2013).

2. MODEL METHODS

2.1 The MARKAL model

The EPA US 9 region MARKAL model is used to evaluate changes to the US energy system through the year 2055 when fee cases are compared to a case with no fees. MARKAL represents energy use and emissions in the industrial, residential, commercial, electric, and transportation sectors across the US from 2005-2055, and determines the lowest cost way to satisfy demand for energy services. Researchers in several other countries have used MARKAL or similar models to examine how electricity usage and production might change if emissions and other fees are applied. Responses in these studies (Rafaj and Kypreos 2007; Pietrapertosa et al. 2009; Klaassen and Riahi 2007) include a shift in the electricity generation mix, decreased true cost of electricity, and emissions reductions.

The MARKAL model uses linear optimization to determine the least cost solution to fulfill the energy needs of the US (Loulou et al. 2004). The model is defined by a set of linear inequalities and assumes a competitive market so the least cost energy will be used to meet demand. The model is demand driven, which means all end use demands must be satisfied for every time period in the solution, but both generation and conservation technologies can be used to satisfy the specified demand. The objective function in MARKAL is minimization of the total system cost, discounted over the planning horizon. The total cost includes investments in technology, operation and maintenance costs, energy imports and production, revenue from exports, delivery costs of fuel, taxes, and subsidies. The EPA US 9 region database (Environmental Protection Agency 2013) is used as a basis for all scenarios considered. The database represents the US energy system for the years 2005-2055 in five year increments. Constraints are used to model existing regulations, including Corporate Average Fuel Economy (CAFE), Clean Air Interstate Rule (CAIR), and state Renewable Portfolio Standards (RPS).

2.2 Changes to MARKAL

In the industrial sector, technologies were added to the database used here that are technologically available, but were not included in the original EPA database. The technologies added include emissions controls, efficiency improvements, and renewable fuel technologies. Although all possible emissions reduction technologies are still not represented, the

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augmented database provides a more representative picture of the types of responses available in the industrial sector (i.e., fuel switching, efficiency improvements, control technologies) and allows the model to respond more fully to the fees. Emissions control technologies are added to boiler and process heat energy use and can be used to reduce emissions of SO_2, NO_x, and PM (Amann et al. 2004). Improved efficiency is represented by more efficient industrial boilers (US EPA 2010). Industrial solar process heat technologies were also added. Emissions control options were added for refineries as well.

In the transportation sector, the hurdle rates for new light duty vehicle purchases were lowered from the original 40-44% to 18%. Also, the representation of state Renewable Portfolio Standards (RPS) has been updated according to the DSIRE database (North Carolina Solar Center 2014) to include recent changes. Coal fired power plant lifetime is limited to 75 years from initial use. The modified database also has an expanded treatment of upstream emissions. In general, the added emission are related to renewable or less common fuels that had less robust upstream characterization in the EPA database. See Brown et al. (2014) for more details on database changes, including upstream emissions values.

3. DAMAGES AS FEES

Damages from two categories of pollutants are considered for this study – criteria pollutants and GHGs. The criteria pollutant (and precursor) emissions considered are NO_x, $PM_{2.5}$, PM_{10}, SO_2, and VOCs. Damages from criteria pollutant emissions are related to human health impacts of pollutant exposure; hence, damages are location dependent because emissions located near population centers will often affect more people than emissions in rural areas. Although damages are not varied by location in this study, using different damage values for different sectors captures some location dependence. For instance, industrial emissions tend to be closer to population centers than emissions from electricity generation.

Two sets of damage estimates for criteria pollutants, presented in Table 1, are considered because there are discrepancies in the damage values in the literature. In general the low fees are based on damages from Muller et al. (2011) and the high fees are based on damages from Fann et al. (2012). The high PM_{10} fees and the natural gas fees are based on NRC (2010) and the high VOC fees are from Fann et al. (2009). The upstream fees are an average of electric, industrial and transportation fees. Differences in values between studies is due to methodology and assumption differences such as the population studied, application of the value of statistical life, and which concentration-response functions were used. The discrepancies are discussed further in Brown et al. (2013) and Fann et al. (2013). The damages used here are applied as fees on emissions in the model starting in 2015. In figures, the two criteria pollutant fee cases are referred to as Crit Low and Crit High.

Table 1: Criteria pollutant fees, in M$/kt except natural gas use column (year 2005 USD)

	Sector	NOx	SO2	PM10	PM2.5	VOC	Natural Gas Use M$/PJ
Low Fees	Electric	0.36	1.87	0.20	2.26	0.24	
	Industrial	0.55	2.27	0.38	4.34	0.44	
	Transportation	0.59	2.48	0.44	5.15	0.51	
	Upstream	0.50	2.21	0.34	3.92	0.40	
	Refinery	0.55	2.27	0.38	4.34	0.44	
	Residential						0.059
	Commercial						0.025
High Fees	Electric	4.70	31.50	4.11	117.10	2.33	
	Industrial	5.50	35.10	4.11	234.30	2.33	
	Transportation	6.60	17.10	4.11	324.40	2.33	
	Upstream	5.60	27.90	4.11	225.27	2.33	
	Refinery	5.90	59.50	4.11	279.30	2.33	
	Residential	11.70	87.40	4.11	324.40	2.33	
	Commercial						0.579

GHG damage values are shown in Table 2. These are taken from the Social Cost of Carbon (SCC) used in regulatory impact analysis by the US government (Interagency Working Group on Social Cost of Carbon 2013). We have considered the central two of the four sets of SCC damages as fee scenarios. The fees were applied to CO_2 and CH_4. The fees were adjusted for CH_4 using the 100 year global warming potential (GWP) of 28 (Myhre et al. 2013).

Table 2: GHG fees in $/ton (year 2005 USD)

	CO_2 Low	CO_2 High	CH_4 Low	CH_4 High
2015	35.76	54.58	1001	1528
2020	40.46	61.17	1133	1713
2025	45.17	65.87	1265	1844
2030	48.93	71.52	1370	2002
2035	53.64	76.22	1502	2134
2040	58.34	81.87	1634	2292
2045	62.11	86.57	1739	2424
2050	66.81	92.22	1871	2582
2055	66.81	92.22	1871	2582

4. RESULTS

Five cases were run in MARKAL: a base case, high and low GHG fee cases, and high and low criteria pollutant fee cases. Results are shown for 2010 to represent the current energy system and for 2040 after the fees have been in place for 25 years.

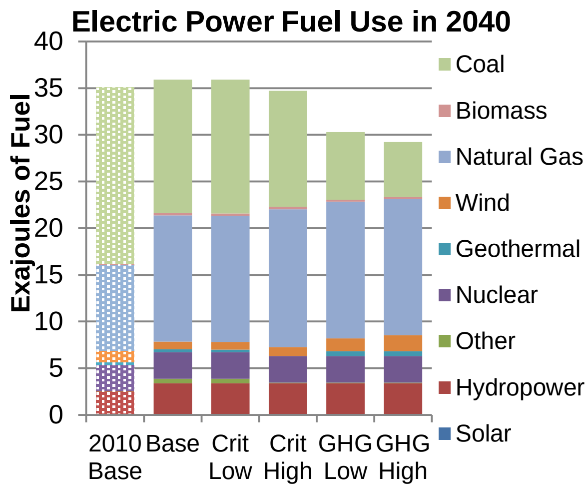

Figure 1: Fuel use in 2010 and 2040 for electricity generation.

In the electric sector, total fuel use is similar in 2010 and 2040 (Figure 1) for base and criteria pollutant fee cases. The output of electricity is greater in 2040; the increase is achieved through more efficient generation. Natural gas becomes a larger portion of the fuel to generate electric power as older coal fired power plants are replaced by new natural gas plants. Coal use in this sector decreases dramatically with most fees, especially the GHG fees. Natural gas and wind use increase to offset this reduction in coal, but there are also improvements in efficiency.

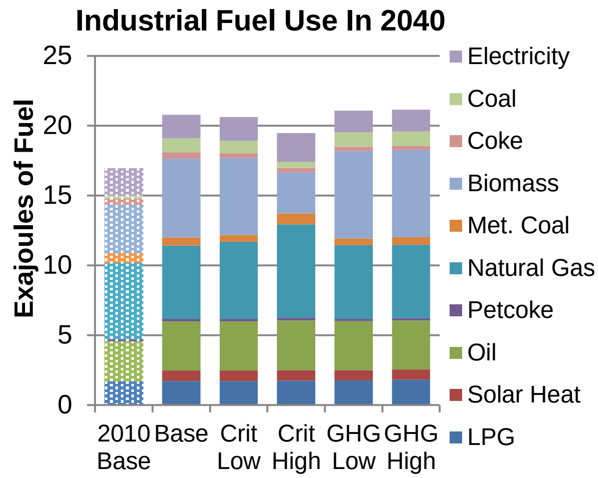

Figure 2: Fuel use in 2010 and 2040 in the industrial sector.

The model indicates that industrial fuel use will increase over the next few decades to meet increased demand (Figure 2). The mix of industrial fuels will stay roughly the same over this time period, although industrial solar process heat joins the mix by 2040. Although the amount of natural gas used will remain similar, it constitutes a smaller share of industrial fuel in the 2040 base case as the currently low prices increase over time. In the industrial sector, fuel use changes most in the high criteria pollutant fee case. There is a large increase in natural gas use and electricity use, which replaces biomass and coal. Efficiency improvements in this case reduce the total amount of industrial fuel used compared to the base case by 6% in 2040.

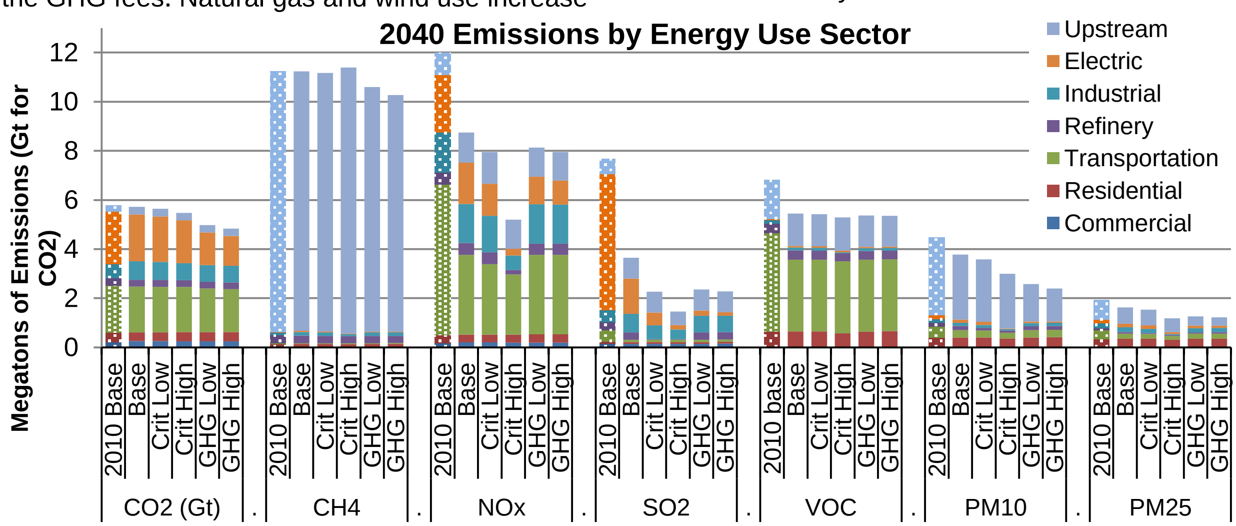

Figure 3: Emissions in 2010 and 2040 by sector.

As shown in Figure 3, CH_4 and CO_2 emissions are relatively unresponsive to criteria pollutant fees, but decrease with GHG fees. This shows that climate regulations are needed to achieve significant reductions in GHGs. Most methane emissions are related to extraction and transport of natural gas. Although the updated emissions factors used here account for some control technologies, the model does not have the option to use additional control technologies in the way the electric and industrial sectors do. With GHG fees, upstream methane decreases 6% for low fees and 9% for high fees in 2040 compared to the base case. CO_2 emissions decrease in every sector except residential when GHG fees are applied, but the electric sector reductions are largest, 30% or 36% lower in 2040 with low or high GHG fees compared to the base case.

Due to existing regulations, criteria pollutant emissions from the transportation and electric sectors are expected to decrease significantly by 2040. Beyond that, criteria pollutant emissions tend to be reduced with any sets of fees. When GHG fees are applied, changes in fuel use reduce the targeted GHG emissions and all the other emissions from the fuel. In contrast, criteria pollutant fees spur the application of control devices that reduce the targeted emissions but not other emissions.

5. DISCUSSION

These results can be considered as an indicator of how our energy system might change if damage-based emissions fees were implemented. Alternatively, we can consider the resultant emissions levels as a target to consider. Since these emissions were achieved in the model with fees based on damage values, emissions reductions to these levels can be achieved while providing as much health benefit to society as the increased cost of new technologies, given the currently available technologies.

There are limitations to this analysis. For instance, although improvements have been made, there are still technology choices that can be made in the real world that are absent from the model, including additional control technologies and a wider range of efficiency improvements. The electric power sector is fairly well characterized, but other energy use sectors have a less refined selection of technologies, and there are very few choices that can be made to reduce upstream emissions except to change the type or amount of fuel used. The model results are dependent on forecasts of fuel prices and costs of technology, which can be very uncertain.

These results will be further analyzed using the CMAQ and BenMAP models. Running CMAQ with emissions altered based on the model results will give an idea of the change in air quality that can be expected from the fees. We will also calculate the total benefit of the policies using BenMAP. It is possible that changes in location of emissions could change the exposure and therefore benefit value. Such modeling will also be informative on how frequently fees should be reevaluated. After several decades of emissions reductions, the marginal damages may differ from present day. This additional information will be useful information for any lawmakers considering implementing any of the fee policies considered in this research.

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