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Economic value of U.S. fossil fuel electricity health impacts

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ABSTRACT

Fossil fuel energy has several externalities not accounted for in the retail price, including associated adverse human health impacts, future costs from climate change, and other environmental damages. Here, we quantify the economic value of health impacts associated with $PM_{2.5}$ and $PM_{2.5}$ precursors (NO_x and SO_2) on a per kilowatt hour basis. We provide figures based on state electricity profiles, national averages and fossil fuel type. We find that the economic value of improved human health associated with avoiding emissions from fossil fuel electricity in the United States ranges from a low of $0.005–$0.013/kWh in California to a high of $0.41–$1.01/kWh in Maryland. When accounting for the adverse health impacts of imported electricity, the California figure increases to $0.03–$0.07/kWh. Nationally, the average economic value of health impacts associated with fossil fuel usage is $0.14–$0.35/kWh. For coal, oil, and natural gas, respectively, associated economic values of health impacts are $0.19–$0.45/kWh, $0.08–$0.19/kWh, and $0.01–$0.02/kWh. For coal and oil, these costs are larger than the typical retail price of electricity, demonstrating the magnitude of the externality. When the economic value of health impacts resulting from air emissions is considered, our analysis suggests that on average, U.S. consumers of electricity should be willing to pay $0.24–$0.45/kWh for alternatives such as energy efficiency investments or emission-free renewable sources that avoid fossil fuel combustion. The economic value of health impacts is approximately an order of magnitude larger than estimates of the social cost of carbon for fossil fuel electricity. In total, we estimate that the economic value of health impacts from fossil fuel electricity in the United States is $361.7–886.5 billion annually, representing 2.5–6.0% of the national GDP.

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1. Introduction

The full social cost of fossil fuels is much higher than the retail price due to negative externalities on both human health and the environment. Externalities are costs or benefits borne by society which are not included in the purchase price of a commodity. In the case of fossil fuels, externalities include human health impacts, environmental degradation, and welfare (e.g., visibility) impacts associated with fossil fuel extraction, transportation, and combustion. Owing to growing concern over climate change impacts in particular, several government entities have assessed a social cost of carbon in order to account for this externality in internal decision-making. As government entities, private companies, and policy-makers seek to internalize costs associated with fossil fuels, inclusion of health impact figures will lead to a more complete and accurate assessment.

Several U.S. states, including California, Oregon, and Colorado, have existing or historical policies for a "carbon adder," in which the public utilities commissions consider the social cost of carbon when comparing prices for fossil fuel and renewable electricity. While carbon adder policies are used for planning purposes and do not fully internalize the social cost of carbon into the retail price, these policies can still create shifts in state electricity procurement. The figures we provide here could be used to support a "health adder" policy which could compliment existing "carbon adder" policies to more fully account for adverse climate and health impacts associated with fossil fuel usage.

We provide an estimate of the economic value of air quality-caused health impacts resulting from the use of fossil fuels in the U.S. by source type and by state. These estimates include valuation of premature mortality and other health endpoints, workdays lost, and direct costs to the healthcare system associated with direct emissions of $PM_{2.5}$, and NO_x and SO_2 as $PM_{2.5}$ precursors. Values are provided on a per kilowatt hour basis to provide policy-relevant estimates that can be easily compared to retail costs. Other studies that provide economic values for the health impacts of electricity on a per kilowatt hour basis (Muller et al., 2011; National Research Council, 2010; Rabl and Spadaro, 2000) do not examine the variation at the state or plant level. The two U.S. studies on the topic (Muller et al., 2011; National Research Council, 2010) both use a source-receptor (SR) model which does not account for nonlinearities resulting from photochemical reactions. The economic values of health impacts developed here rely on benefit per ton figures (Fann et al., 2009) developed using a Community Multiscale Air Quality (CMAQ) photochemical grid model methodology utilized by U.S. EPA for regulatory air pollution actions.

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Our approach provides a new independent estimate that improves upon previous SR model estimates and provides more thorough analysis of variance between sources and states.

2. Materials and methods

2.1. Data and methods

There are many studies which seek to quantify the economic value of health impacts associated with air pollution. The estimated values in the literature have a wide range resulting from several key differences, including: (1) the population density; (2) the type of model used to assess ambient air concentrations associated with a particular emission event; and (3) the concentration–response (CR) function used to estimate adverse health impacts associated with a given change in ambient air quality.

The Fann et al. (2009) benefit per ton figures used here were developed for the U.S. population using a CMAQ air quality model which assessed the economic value of adverse health outcomes through the BenMAP tool (U.S. EPA, 2011d). CR functions are input into the BenMAP tool and are derived from epidemiology studies. Two estimates of the coefficient for the CR function (Laden et al., 2006; Pope et al., 2002) were used to provide two primary estimates for mortality.[2] Although we do not assess a wide range of possible health impacts by using different CR coefficients, the two values we use here can be seen as bracket values as they fall on the upper and lower ends of the range assessed in the U.S. EPA expert judgment paper on $PM_{2.5}$ CR functions (Industrial Economics Inc., 2006). Thus, these two values capture the range of uncertainty and have been used by the U.S. EPA in Regulatory Impact Assessments as anchor values for this reason. Fann et al. (2009) monetized premature mortality by applying a value of statistical life of $6.2 million, later updated to a value of $7.4 million (2006$) (U.S. EPA, 2011a; U.S. EPA, 2011b). Premature mortality was the largest factor in quantifying the economic value of adverse health impacts, though work days lost and direct costs to the healthcare system were also included.

In addition to quantifying the economic value of adverse health impacts of fossil fuel for electricity, we provide a preliminary analysis of health impacts of diesel vehicles, using the same pollutant scope and methodology employed for stationary sources. For mobile sources, emissions vary significantly depending upon the engine year, vehicle type, and usage pattern. Our preliminary analysis provides only an example calculation to show the scale of impacts from diesel vehicle exhaust.

2.2. Limitations

Our analysis provides a national estimate for some of the health impacts of fossil fuels, but in many ways falls short of providing a complete and accurate assessment for policy applications. Table 1 summarizes limitations of the analysis here, describing how simplifications made here compare to an idealized analysis that includes all health endpoints and considers local conditions. We do not attempt to include all externalities here, omitting impacts resulting from extraction and transportation of fossil fuels as well as impacts on climate change and human welfare.

Areas of high priority for future analyses relate to the use of a national average benefit per ton figure and the small scope of air emission health impacts evaluated. Because this analysis uses national average benefit per ton data, it can be used to compare power plants nationally or compare state energy mixes, but should not be used to determine absolute values for local impacts of individual plants. Local health impacts vary significantly across urban areas because of local atmospheric conditions, population density, and baseline health (Fann et al., 2009). Figures presented here will tend to overestimate the impacts in rural areas and underestimate the impacts in urban areas, though local atmospheric interactions may also play a significant role in the directionality of this factor. Future analyses may wish to apply some of the local benefits per ton figures Fann et al. (2009) provide, and explore opportunities to use other more localized data.

Table 1
Limitations. This table shows the limitations of the current work which represent areas ripe for improvement in future analyses. We provide estimates as to the magnitude and directionality of simplifications made relative to an idealized analysis which could provide complete and accurate assessments of health impacts.

Issue	Magnitude	Likely directionality
National benefit per ton used	High	Vary by location
Only include $PM_{2.5}$ precursors, not other environmental impacts	High	Underestimate
Benefits per ton estimates based on modeling of 2015 conditions	Medium	Overestimate
Incomplete information on energy imports is available	Medium	Uncertain
Benefits based on broad emission source categories	Medium	Uncertain
Do not account for transmission losses	Low	Underestimate
Only include power plant $PM_{2.5}$ data when NEI and acid rain data align	Low	Uncertain
Accept uncertainties from $PM_{2.5}$ benefits analysis methodology	Uncertain	Uncertain

In some areas, a reduction in $PM_{2.5}$ or NO_x can lead to a net negative benefit per ton (Fann et al., 2009; Muller et al., 2011), which could affect estimates for diesel vehicle economic value of health impact. However, this generally occurs in metropolitan areas with high levels of volatile organic compounds and is not likely to occur near stationary sources especially owing to high stack heights. In general, it is advisable to employ best practices of air quality management with a broad view across all pollutants and precursors.

The omission of many of the pollution streams from fossil fuels will tend to underestimate the health benefits of minimizing fossil fuel combustion. Pollution streams not accounted for include: air pollutants such as O_3 precursors, NO_2, greenhouse gasses, residual or hazardous waste products, and water-borne pollutants.

Other areas of current limitations include the use of a benefit per ton estimate based on projected conditions in a 2015 projection, unaccounted for electricity imports and exports, and lack of resolution around time of use energy demands. Benefit estimates may be slightly overestimated due to population growth between present day and 2015 with a 3% discount rate. The economic values of health impacts represent average, rather than instantaneous cost. Facilities providing power for peak demand periods will often operate at lower levels of efficiency, driving up the instantaneous adverse impacts of fuel during peak hours.

Limitations that likely do not have a large effect on results relate to the omission of data which was not robust, and the exclusion of transmission losses. This analysis only included the 2005 $PM_{2.5}$ data when NEI facility data closely matched the corresponding acid rain program figures and the facility was still in operation in 2009. Losses due to transmission and distribution account for 8–9% of net generation (U.S. EIA, 2011a), which are not accounted for here.

Finally, by incorporating data outputs from the Fann et al. (2009) study, the uncertainties outlined in that work and its references

[2] The all-cause mortality relative risk (RR) estimate provided by Laden et al. (2006) is RR = 1.16 (95% confidence intervals 1.07–1.26) per 10 μg/m^3 $PM_{2.5}$. The RR estimate provided by Pope et al. (2002) is RR = 1.06 (95% confidence intervals 1.02–1.11) per 10 μg/m^3 $PM_{2.5}$.