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Monetized health benefits attributable to mobile source emission reductions across the United States in 2025

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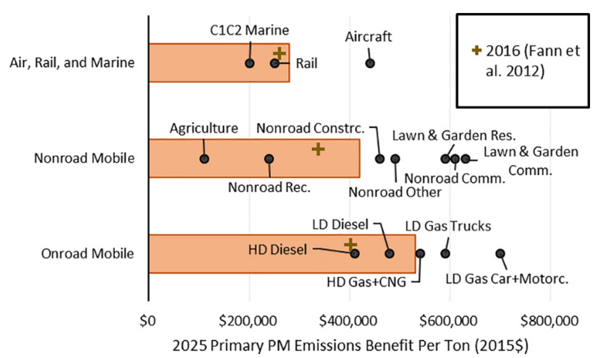
HIGHLIGHTS

- Mobile sources emit pollutants associated with adverse health outcomes.
- $PM_{2.5}$-related benefit per ton (BPT) values estimated for 16 mobile source sectors
- BPT estimates provide a reduced-form tool for monetizing health impacts.
- Can be used to assess health benefits of alternative air quality control scenarios
- Regional (East/West) mobile source BPT values also presented for each sector

GRAPHICAL ABSTRACT



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ABSTRACT

By-products of mobile source combustion processes, such as those associated with gasoline- and diesel-powered engines, include direct emissions of particulate matter as well as precursors to particulate matter and ground-level ozone. Human exposure to fine particulate matter with an aerodynamic diameter smaller than 2.5 μm ($PM_{2.5}$) is associated with increased incidence of premature mortality and morbidity outcomes. This study builds upon recent, detailed source-apportionment air quality modeling to project the health-related benefits of reducing $PM_{2.5}$ from mobile sources across the contiguous U.S. in 2025. Updating a previously published benefits analysis approach, we develop national-level benefit per ton estimates for directly emitted $PM_{2.5}$, SO_2/pSO_4, and NO_X for 16 mobile source sectors spanning onroad vehicles, nonroad engines and equipment, trains, marine vessels, and aircraft. These benefit per ton estimates provide a reduced-form tool for estimating and comparing benefits across multiple mobile source emission scenarios and can be applied to assess the benefits of mobile source policies designed to improve air quality. We found the benefit per ton of directly emitted $PM_{2.5}$ in 2025 ranges from $110,000 for nonroad agriculture sources to $700,000 for onroad light duty gas cars and motorcycles (in 2015 dollars and based on an estimate of PM-related mortality derived from the American Cancer Society cohort study). Benefit per ton values for SO_2/pSO_4 range from $52,000 for aircraft sources (including emissions from ground support vehicles) to $300,000 for onroad light duty diesel emissions. Benefit per ton values for NO_X range from $2100 for C1 and C2 marine vessels to $7500 for “nonroad all other” mobile sources, including industrial, logging, and oil field sources. Benefit per ton estimates increase approximately 2.26-fold when using an alternative concentration response function to derive $PM_{2.5}$-related mortality. We also report benefit per

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ton values for the eastern and western U.S. to account for broad spatial heterogeneity patterns in emissions reductions, population exposure and air quality benefits.

1. Introduction

The transportation sector, which includes on-road vehicles, nonroad vehicles, aircraft, trains, and marine vessels, emits pollutants that degrade air quality (Dallmann and Harley, 2010; Zawacki et al., 2018). The by-products of mobile source combustion processes include direct emissions of particulate matter as well as particulate matter and ozone precursors. Human exposure to fine particulate matter with an aerodynamic diameter smaller than 2.5 μm ($PM_{2.5}$) is associated with increased incidence of premature mortality and morbidity outcomes (Dockery et al., 1993; Pope et al., 2002; Krewski et al., 2009; Lepeule et al., 2012; West et al., 2016; U.S. EPA, 2009a). Characterizing the benefits of improved air quality resulting from reduced or avoided mobile source emissions is an important step in assessing operational procedures (Gouge et al., 2013; Ashok et al., 2017), technology adoption (Tessum et al., 2014), and policies designed to improve air quality (US EPA, 2014).

Full-scale benefits assessments entail detailed and complex analytical steps that characterize each stage of the emissions-to-impact pathway, including quantifying emissions, changes in ambient pollution concentrations and mixing rates, population exposure to pollutants, risks of adverse health outcomes and (often) the economic value of those outcomes. Understanding the effect of emissions on resulting ambient concentrations requires the use of computationally intensive atmospheric chemistry and transport models such as the Comprehensive Air Quality Model with Extensions (CAMx) or the Community Multi-Scale Air Quality model (CMAQ). These models simulate the physical and chemical processes that affect air pollutants and their precursors as they disperse and react in the atmosphere (Byun and Schere, 2006; ENVIRON, 2010). Monetizing the health impacts of changes in pollutant concentrations requires integrated benefits mapping tools that account for population distribution, baseline incidence rates of health endpoints, mortality and morbidity effect estimates, and incidence cost estimates associated with these health endpoints or detailed economic data (Davidson et al., 2007; Saari et al., 2015). The complexity of these models can make full-scale benefits assessments time and resource prohibitive.

Reduced-form approaches can make benefits assessments more tractable by providing computationally efficient techniques that can reasonably and appropriately approximate a full-scale analysis. Benefit per ton (BPT) estimates represent the monetized health benefit of avoiding one ton of emissions from a particular source or source sector. This approach is one example of reduced-form assessment instruments that have been used to characterize the benefits of emission reductions in the US, in Europe, and worldwide (Holland et al., 2005; Fann et al., 2009; Fann et al., 2012; Shindell, 2015; Heo et al., 2016). Benefit per ton estimates are typically generated by running an emissions scenario through a full-scale photochemical air quality model and estimating the environmental health burdens associated with the resulting air pollution. The sum of the monetized impact of these burdens is then divided by the mass of the emissions (or emission changes) associated with that scenario to characterize the marginal benefit of a unit reduction of that emission species (or the marginal cost of an additional unit emission) (Fann et al., 2012).

This study builds upon a detailed source-apportionment air quality study (Zawacki et al., 2018) to present projections of benefits from $PM_{2.5}$ attributable to mobile source emissions across the Contiguous U.S. in 2025. Updating a previous benefits analysis approach presented in Fann et al. (2012), we develop benefit per ton estimates of directly emitted $PM_{2.5}$, $SO_2 + SO_4$, and NO_X for 16 specific mobile source sectors spanning onroad vehicles, nonroad engines and equipment, trains, marine vessels, and aircraft. These self-consistent per-unit-emission benefit estimates provide a reduced-form tool for assessing emission reduction scenarios across multiple mobile source sectors. The benefit per ton estimates presented here improve upon previous estimates, which have been limited to a specific source sector such as aviation (Penn et al., 2017) or have aggregated mobile sources into broader sectoral categories (Fann et al., 2012). This paper describes the approach for calculating species-specific benefit estimates, highlighting advances over previously published benefit per ton estimates. Section 3 presents and summarizes model results while Section 4 discusses important implications and caveats.

2. Methods

To calculate benefit per ton estimates of mobile source emissions, we first modeled $PM_{2.5}$ air quality concentrations in the Contiguous United States using the source apportionment module in the CAMx photochemical air quality model to tag 17 unique mobile-source sectors. Further, this study estimates the extent of premature mortality and morbidity attributable to $PM_{2.5}$, monetizing these impacts using an established model of willingness-to-pay and cost-of-illness values of each health endpoint. Finally, for each sector and each $PM_{2.5}$-related emission species, the resulting monetized benefits are divided by the mass of the emissions to derive a cost-per-unit emission metric. The following section describes the methods and data sources used in these calculations in detail.

Emissions inputs for 2025 are projected from a 2011 emissions inventory generated from EPA's 2011 v6.2 emissions modeling platform, which is based on version 2 of the 2011 National Emissions Inventory (NEI) (US EPA, 2015a). Wildland fires were based on satellite information for location and timing (Baker et al., 2016a) and biogenic emissions were based on day and hour specific temperature and solar radiation (Bash et al., 2016). Mobile source emissions are categorized into 17 sectors based on in-use characteristics, fuel use, and vehicle type and are presented in Table 1.

Aviation emissions are classified as aircraft emissions, which cover commercial aircraft landing and take-off emissions up to 3000 ft, and aircraft ground support emissions at airports. Aircraft emission at altitudes above 3000 ft are not modeled, although there is increasing evidence that high-altitude emissions contribute to local air quality (Barrett et al., 2010). Due to the small amount of aircraft ground support emissions relative to other mobile source categories, ground support and landing and take-off emissions have been combined into one category for the purposes of estimating an aircraft-related benefit per ton value (presented in the next section). However, aviation emissions for these two flight phases are presented separately in Table 1. This explains the discrepancy between having categorized mobile source emissions into 17 sectors while only presenting 16 sector-specific benefit per ton values.

Marine vessel emissions from diesel engines above 800 hp with displacement less than 30 l per cylinder are designated as Category 1 and Category 2 (C1 & C2 marine). Category 3 (C3 marine) emissions come from engines above 30 l per cylinder, typically used for propulsion on ocean-going vessels. For both marine engine categories, emissions out to the U.S. Economic Exclusion Zone are included. We exclude C3 marine emissions that occur in Non-U.S. waters from the benefit per ton calculation since domestic policy will not directly control emissions