A spatial assessment of vehicles' climate change and air pollution damages across the United States

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Overview

The transportation sector is currently the largest contributor of CO_2 emissions in the United States (U.S.). Similarly the health and environmental consequences associated with the transportation sector are of critical importance, since the transportation sector accounts for more than half of carbon monoxide (CO) and nitrogen oxides (NO_x) emissions in the U.S., as well as nearly a quarter of volatile organic compounds (VOCs) and 6% of primary $PM_{2.5}$ emissions. Increased emissions and concentrations of GHGs and CAPs are of concern to society and to policy makers, as they lead to poor urban air quality, increasing hazards of infrastructure, and elevated risks of mortality and morbidity in exposed populations. However, the social impacts of these pollutants are not the same across pollutant type, space, or time. Greenhouse gases (GHGs), for example, have global dispersion, stay in the atmosphere for decades to centuries, and their impact is the same regardless of the location of the source. Criteria air pollutants (CAPs), on the other hand, are short lived and their consequences depend on the location of the sources, which drives exposure, especially for those segments of the populations that are sensitive to $PM_{2.5}$ and ground-level ozone.

In 2010, a report from the U.S. National Academies estimated that air emissions from on-road vehicles in the U.S. resulted in a cost of ~$110 billion from climate change and air pollution (CC&AP) damages. Since then, a number of studies have examined the climate change damages and/or air pollution damages incurred from using biofuels, compressed natural gas (CNG) vehicles, diesel vehicles, plug-in hybrid electric vehicles (PHEVs) and/or battery electricity vehicles (BEVs), as well as gasoline vehicles. These studies generally find that BEVs with grid-average electricity are likely to increase CC&AP damages compared to gasoline, but BEVs powered by dedicated natural gas or renewable electricity sources can reduce CC&AP damages. However, these existing studies investigated passenger cars only and all relied on GREET model for emissions estimates. To date, there is no systematic, spatially-explicit assessment of climate change and air pollution (CC&AP) monetized damages from on-road vehicles in the U.S.

Methods

We estimate county-level life cycle CC&AP monetized damages due to major GHGs (CO_2, CH_4, N_2O) and CAPs (CO, NO_x, SO_2, $PM_{2.5}$, VOC) of five fuels (gasoline, diesel, CNG, liquefied natural gas (LNG), and electricity from the current U.S. grid) and corresponding vehicle technologies (internal combustion engine vehicles (ICEVs), hybrid electric vehicles (HEVs), and BEVs) for five representative vehicle classes (passenger cars, SUVs, transit buses, short-haul tractor-trailers, and long-haul tractor-trailers). The functional unit for the analysis is one vehicle mile traveled (VMT) and the study reference year is 2014 (the most recent year with full data).

The boundary of the life cycle emissions inventory includes primary energy extraction, fuel production and transportation, and vehicle use. We include the manufacturing process of lithium-ion batteries for HEVs and BEVs. We assume all other vehicle components are similar across vehicle technologies for a given vehicle class. The authors built spatialized emissions inventory using emissions data from U.S. Department of Energy, U.S. Environmental Protection Agency, peer-reviewed journal publications, and technical reports from national laboratories in the U.S. The details of the emissions inventory are discussed in the full paper due to page limit.

We use a marginal damage approach to estimate the climate change monetized damages associated with CO_2, CH_4, N_2O and the health and environmental monetized damages caused by SO_2, NO_x, CO, $PM_{2.5}$, and VOC. The monetized damages of an emissions species emitted at a particular location and height is calculated as follows: $damages = emissions \times marginal\ damages$ The marginal damages of GHGs are the same regardless of source location and height but the marginal damages of CAPs are sensitive to where they are emitted. We use two integrated assessment models for the social costs of air pollutants (AP2 and EASIUR). We then attribute the monetized damages associated with each fuel-vehicle pathway per one unit VMT. The metric for comparison is $ of CC&AP damages per VMT. All monetary values are converted to 2010 dollar using the consumer price index (CPI). Finally, while our analysis assumes the values of a statistical life is $\$_{2010}8$ million and the social cost of carbon is $\$_{2010}37.8$/t CO_2, we perform a sensitivity analysis to explicitly test for the effect of these assumptions on our results.

Results

In **Figure 1**, we show the fuel-vehicle pathways that lead to the lowest life cycle monetized CC&AP damages in each county for different vehicle classes. We find that BEVs with grid electricity achieve the lowest life cycle damages for passenger cars, SUVs, and transit buses in Western U.S. and New England regions, while gasoline hybrid-electric light-duty vehicles (LDVs) and diesel hybrid-electric buses lead to the lowest damages for the remaining regions. Importantly, these assessments are performed assuming the electricity is balanced in each NERC region and assuming the average annual emissions factors in each NERC region. Thus the assessment does not capture the effect of emissions variation across time. CNG and diesel hybrid electric tractor-trailers each achieve the lowest CC&AP damages in some U.S. counties but the regions in which they achieve the lowest damages are sensitive to the marginal damages of CAPs. When the EASIUR model is used, diesel hybrid-electric trucks achieve the lowest damages in Rocky Mountain, Texas, and Southeast regions, and CNG and LNG HPDI tractor-trailers achieve the lowest damages in the Midwest, New England, and West Coast regions. However, when the AP2 model is used, CNG and LNG-HPDI tractor-trailers achieve the lowest damages in West Coast, Rocky Mountain, and Midwest regions, and in parts of the Texas and Southeast. This is largely due to the significant spatial differences in the marginal damages of CAPs between the two integrated assessment models (20) as well as the fact that tailpipe emissions from tractor-trailers contribute to a large share of life cycle CC&AP damages.

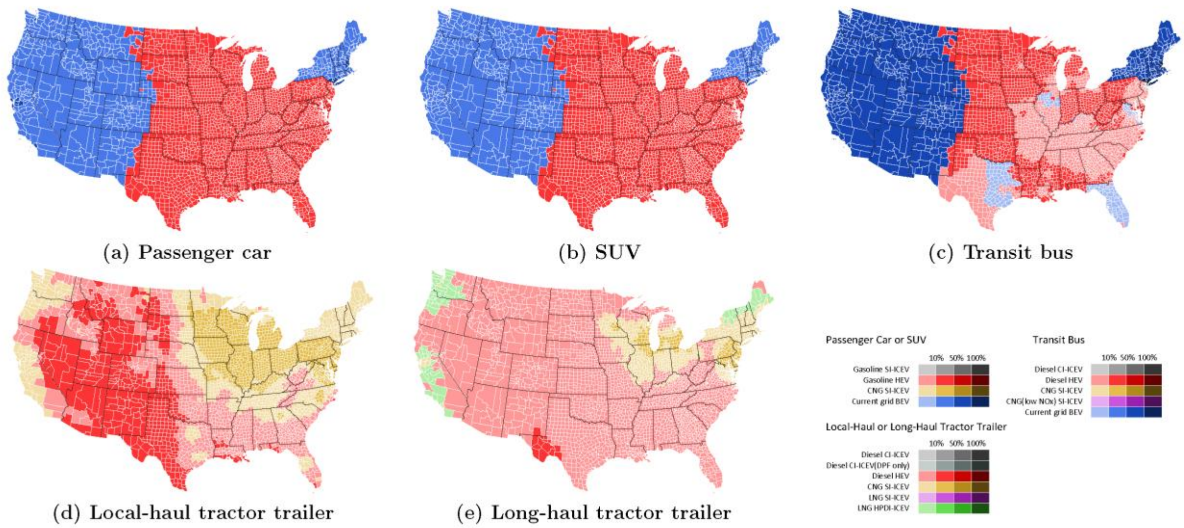

Figure 1. Fuel-vehicle pathways with the lowest monetized CC&AP damages in each county. We use EPA's emissions data, EASIUR model, and assume average electricity in each NERC region. The color shades represent relative difference (RD) between the lowest and the second-lowest monetized CC&AP damages achieved by any fuel-vehicle pathway in each county. RD = (second-lowest damages– lowest damages)/(lowest damages).

In the paper, we provide a systematic assessment on how the assumed social cost of carbon (SCC) and value of statistical life (VSL) affect our results. We find that for passenger cars and SUVs, our results are not very sensitive to the assumptions of SCC and VSL. This is because BEVs used in the West Coast and Rocky Mountain regions achieve the lowest climate change damages and the lowest air pollution damages, so whether one accounts for just climate damage damages or just air pollution damages the best fuel-vehicle pathway would be the same. However, this is not the case for HDVs: the fuel-vehicle combinations that lead to the lowest climate change damages are different from the combinations that lead to the lowest air pollution damages in most U.S. counties. As a result, when we change SCC or VSL, the number of counties for which a fuel-vehicle pathway results in the lowest CC&AP monetized damage change significantly for HDVs.

Conclusions

This paper estimates county-level life cycle climate change and air pollution monetized damages for ten fuel-vehicle pathways across the United States. Importantly, we find that there is no single fuel-vehicle pathway that achieves the lowest overall damages in all counties, suggesting the need of tailored policies and incentives for each region if the goal is to achieve large CC&AP damage reductions. We find trade-offs of fuel switching strategies between climate change mitigation and air pollution mitigation goals. In particular, light-duty vehicles see co-benefits of mitigating either climate change damages or air pollution damages but for heavy-duty vehicles there are conflicts between reducing climate change damages and mitigating air pollution damages.