U.S. Onroad Transportation CO_2 Emissions Analysis Comparing Highly-Resolved CO_2 Emissions and a National Average Approach: Mitigation Options and Uncertainty Reductions

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ABSTRACT

In order to accurately quantify and regulate emissions in the U.S. onroad transportation sector, its spatial heterogeneity must be characterized. To portray a spatially-explicit fleet distribution, driving patterns, and mitigation strategies, we compare a high-resolution onroad emissions data product (Vulcan) to a national averaging of the Vulcan result. This comparison is performed for light- and heavy-duty vehicle classes, and rural and urban road groups. We find that the use of national averages incurs state-level biases for road groupings that are almost twice as large as for vehicle groupings. The uncertainty for all groups exceeds the bias, and both quantities are positively correlated with total state emissions. States with the largest emissions totals are typically similar to one another in terms of emissions fraction distribution across road and vehicle groups, while smaller-emitting states have a wider range of variation in all groups. State-specific errors in reduction estimates as large as ±60% corresponding to ±0.2 MtC are found for a national-average emissions mitigation strategy focused on a 10% emissions reduction from a single vehicle class, such as passenger gas vehicles or heavy diesel trucks. These differences highlight the importance of spatial resolution for achieving consistently effective emissions reductions. Climate agreements that fully account for uncertainties in emission estimates as well as regional differences will be best suited to enact effective policy.

INTRODUCTION

Carbon dioxide (CO_2) is the most abundant anthropogenic greenhouse gas and projections of fossil fuel energy demand show CO_2 concentrations increasing indefinitely into the future[1]. Because localities have considerable control over transportation planning and policy, interest in the potential of the transportation sector to offer effective mitigation options is increasing on both local and national levels[2].

After electricity production, the transportation sector is the second largest CO_2 emitting economic sector in the United States, accounting for 32.3% of the total U.S. emissions in 2002 [3]. Over 80% of the transportation sector is composed of onroad emissions, with the remainder of emissions shared by the nonroad, aircraft, railroad, and commercial marine vessel transportation [4].

Both national and local legislation have recognized the importance of the transportation sector. In order to construct effective mitigation policies for the onroad transportation sector and more accurately predict

CO_2 emissions for use in atmospheric transport models and measurements, analysis must incorporate the three dominant components that determine onroad transport CO_2 emissions: vehicle miles traveled (VMT), vehicle fuel efficiency and emissions regulation strategies.

Studies to date, have either focused on only one of these three components, have been completed only at the national scale, or have not explicitly represented CO_2 emissions [5-7].

Southworth [6] analyzed VMT and CO_2 emissions for the 100 largest metropolitan areas in the U.S. but only disaggregated vehicles into trucks and passenger cars and used a single national estimate of vehicle fuel efficiency for each of the two vehicle types.

Puentes [5] presented a thorough analysis of national-level VMT from 1966 to 2008 and further subdivided the analysis into vehicle classes, road classes and the largest metropolitan areas but there was no analysis of CO_2 emissions.

Stone [7] discussed the impact of Hybrid Electric Vehicle (HEV) introduction on urban mobile CO_2 emissions. The study involved a sample of eleven cities located in six states in the Midwestern United States. However, there was no variation in the vehicle fleet across the six states and hence, the vehicles had the same CO_2 emissions per mile of travel.

We overcome many of the previous limitations by analyzing onroad CO_2 emission differences between a new, high-resolution emissions data product and a "low-resolution" or "national-average" approach, typical of previous studies. Our aim is to demonstrate the quantitative impact of a highly-resolved approach on emissions estimation and mitigation in the U.S. onroad transportation sector. We perform this analysis at the state spatial scale and disaggregate results by road, vehicle, and fuel classifications. We also make a series of recommendations to lower and better quantify the uncertainty associated with our high-resolution emissions data product.

BODY

Methodology

Data

The onroad CO_2 emissions analyzed here are a product of the Vulcan Project, an effort aimed at quantifying hourly fossil fuel CO_2 emissions for the entirety of the United States at fine space/time resolution [3]. The onroad mobile emissions are constructed from a series of existing databases and modeling efforts to generate CO_2 emissions for the year 2002 at the spatial scale of a U.S. county every hour for the entire U.S. Further spatial allocation is performed in order to place these emissions onto U.S. roads and onto a common 10 km x 10 km spatial grid.

Emissions calculation

The Vulcan onroad transportation emissions calculation utilizes the total vehicle miles traveled (VMT) from the National Mobile Inventory Model (NMIM) County Database (NCD) in which the data is provided for each combination of 28 vehicle types, 6 road types, county, and month (see Appendix A for details).

To obtain onroad transportation CO_2 emission factors (grams CO_2/mile driven), EPAs MOBILE6.2 onroad combustion model was utilized [8,9]. The product of VMT and corresponding CO_2 emission factor yields the county CO_2 emissions for each road and vehicle type combination. This can be expressed as, Equation (1) $C_C^{V,X} = VMT_C^{V,X} \times CF^V$

where $C_C^{V,X}$ = CO_2 emissions for vehicle type *V* on road type *X* in county *C*

$VMT_C^{V,X}$ = the total vehicle miles traveled in county *C*, for vehicle class *V* and road type *X*

CF^V = the CO_2 emission factor (mass of CO_2/mile) for vehicle type *V*

Each county-specific fleet is therefore defined by the combination of the vehicle type mix and their respective VMT.

Comparison Method

In order to compare results from the Vulcan high-resolution emissions data product to a "low-resolution" or "national-average" approach, we simulate results by creating average CO_2 emissions factors for aggregate vehicle and road type groups. Vehicles are grouped into either a light-duty (LD) or heavy-duty (HD) vehicle group (all fuels combined) and an urban or rural road group (see Appendix A for details). All groups are analyzed at the U.S. state spatial scale. The difference between these two approaches can be considered a bias that can be quantified for each of the vehicle and road groups. We attempt to quantify two qualities of this bias: 1) the ratio of the bias from each of the aggregate vehicle and road groups to the CO_2 total in a given state and 2) the ratio of the bias from each of the aggregate vehicle and road groups to the national total group-specific CO_2 emissions.

Equation (2)
$$\Delta\%_S^G = 100 * \frac{LEM_S^G - VEM_S^G}{VEM_S}$$

Equation (3)
$$\Delta\%_S^G = 100 * \frac{LEM_S^G - VEM_S^G}{VEM_N^G}$$

where $\Delta\%_S^G$ = the percent difference between the Vulcan CO_2 and national-average CO_2 emissions for state *S* and group *G*

VEM_S^G = the CO_2 emissions for state *S* and group *G* obtained from the Vulcan data product

LEM_S^G = the CO_2 emissions for state *S* and group *G* obtained from the national-average approach

VEM_S = the total (summed across all groups) CO_2 emissions for state *S* obtained from the Vulcan data product

VEM_N^G = the national total CO_2 emissions for group *G*

Positive values for Equations 2 and 3 imply that the national-average approach overestimates emissions relative to the Vulcan estimate, and vice-versa. Equation 2 quantifies the difference in state-level CO_2 emissions between the national-average approach and the Vulcan estimate for each of the groups relative to the Vulcan state total. Equation 3 quantifies the difference in state-level CO_2 emissions between the national-average approach and the Vulcan estimate for each of the groups relative to the Vulcan national total. Hence, Equation 2 provides information about what is driving the biases present at the state-level while Equation 3 provides information about where across the nation, the biases are most important.

Uncertainty

There are two central variables in the calculation of onroad transportation CO_2 emissions in the Vulcan system, each with an associated uncertainty. The first is the uncertainty associated with the estimate of VMT. The other is the assignment of the CO_2 emission factor to vehicle class. The uncertainties are centered symmetrically about the calculated Vulcan result with an equal magnitude of uncertainty in both the positive and negative directions.

VMT Uncertainty

The VMT uncertainty stems from the precision of the measurements and estimates of VMT produced by the FHWA. These estimates may be found in Appendix C of the HPMS Field Manual. Samples designated at a "90-10" confidence interval and precision level contain VMT estimation within ±10 percent of the true value, 90 percent of the time. In order to convert these values to a one-sigma VMT variation, the stated confidence interval and precision level were combined into a single estimate of uncertainty as follows:

Equation (4) $U_x = V_x / S_x$

where U_x = the uncertainty percent value associated with road type X

V_x = the percent variation from the true value for road type X (10 for 90-10)

S_x = the number of standard deviations within a normal distribution that is within variation V_x of the true value for road type X ("90" for 90-10).

In case of road types with missing data, the lowest confidence and precision level (80-10) was used.

Age Distribution Uncertainty

The CO_2 emission factor per mile driven is derived from the results of the MOBILE6.2 combustion model and is a function of fuel carbon content (grams CO_2/gallon of fuel), a vehicle fuel efficiency (miles/gallon of fuel), a vehicle age distribution, and a carbon oxidation factor. The age distribution has an impact on fleet emission levels due to the fact that for a particular vehicle class, a newer fleet has higher fuel efficiency than an older fleet.

Fuel Efficiency Uncertainty

The other source of uncertainty considered for the CO_2 emission factor is the vehicle fuel efficiency or the well-known "MPG" rating for a given vehicle type and model year. For Vulcan uncertainty estimation, we use the percent difference between the "5-cycle" and "Current EPA Label" estimates obtained from tests performed by the EPA (see Appendix A for details). The percentage difference values are assumed to be symmetric uncertainties (both "hi" and "low") and are considered one-sigma variations.

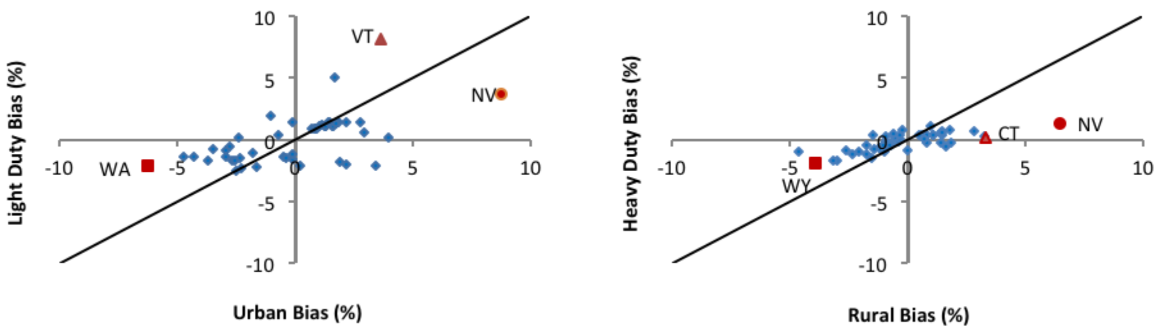
Results

Bias of a national-average approach

Figure 1 shows the state-specific biases (Equation 2) of the national-average results relative to the Vulcan data product organized into the road and vehicle type groups. The spread of positive and negative biases for both the road and vehicle type groups are driven by the road and vehicle type compositions of each state, which differ from the national-average. Figure 1 also highlights the correlation between the road and vehicle type group emissions biases that results from the underlying relationships. For example, traffic on urban roads is comprised mostly of LD vehicles ($r=0.64$; $p < 0.0001$), while rural roads have a comparatively larger percentage of HD vehicle traffic ($r=0.74$; $p < 0.0001$) [10].

In the case of the vehicle group bias, the magnitudes are driven by states having a greater/lesser proportion of LD/HD vehicles within their total state fleet when compared to the national-average. For example, the LD vehicle class has emission factors ranging from 177.4 grams CO_2/mile (motorcycles) to 577.0 grams CO_2/mile (LD diesel trucks). If the amount of motorcycles in a state is greater than the national-average, the national-average approach will yield a positive emissions bias compared to the Vulcan approach. The standard deviation of these biases is 2.0% and 0.8% for the LD and HD groups, respectively.

Figure 1. State-specific biases of the national-average results relative to the Vulcan data product for road and vehicle aggregate groups. a) light duty vs. urban groups; b) heavy duty vs. rural groups. A one-to-one line is present in each panel as a reference and large values are denoted by red symbols.

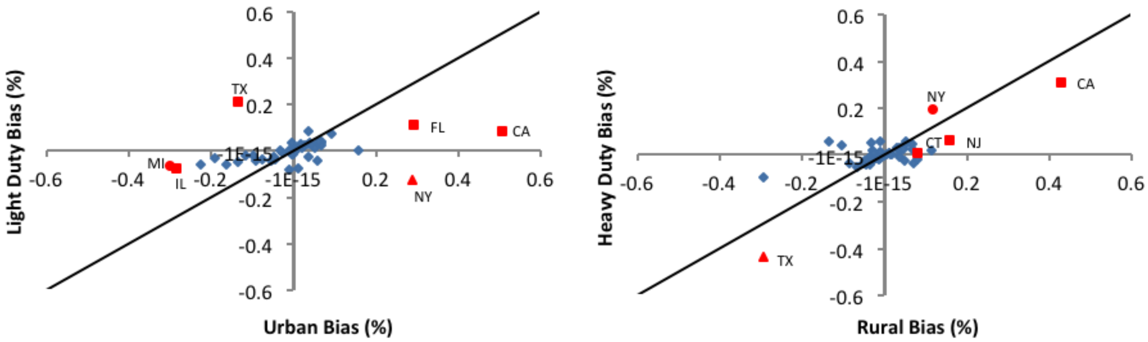


a) b)

The road group bias is driven by a combination of two factors: 1) the amount of rural versus urban VMT within each state relative to the national average and 2) the vehicle class distribution comprising the rural/urban VMT and its difference from the national average. Hence, states having a larger amount of rural VMT relative to the national average, but for which the vehicle class composition of the rural VMT matches the national average, will still result in a negative bias. If the vehicle class composition within the rural VMT contains a greater proportion of higher-emitting LD vehicle types than the national average, this will compound the negative bias. Similarly, states in which the amount of rural VMT matches the national average may still arrive at a bias were the vehicle class composition within the rural VMT to contain a larger proportion of higher-emitting LD VMT than the national average. These factors account for the larger bias values in the road groups. The standard deviation of these biases is 3.2% and 2% for the urban and rural groups, respectively.

Figure 2 shows the biases of Figure 1 but normalized by the national total, group-specific fossil fuel CO_2 emissions (Equation 3). When normalized by national totals, the biases highlight states with large amounts of onroad emissions that also deviate significantly from the national average. For example, although Connecticut has the fifth largest rural road group bias (Figure 1a), the state accounts for less than 0.25% of the national emission total and hence, is not an outlier value in Figure 2b.

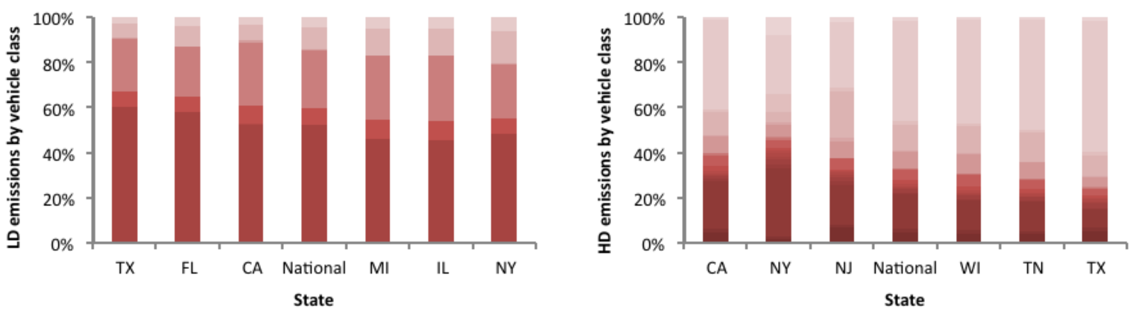
Figure 2. As in Figure 1 but normalized by the national total CO_2 emissions in each road and vehicle group. A one-to-one line is present in each panel as a reference and large values are denoted by red symbols.



a) b)

The vehicle class distribution is a significant contributor to the observed LD and HD biases (Figure 3). States that exhibit a positive LD bias (Figure 2a: Texas, Florida, California) have large contributions from the lowest-emitting vehicle classes. Conversely, the states showing a negative LD bias (Michigan, Illinois, New York) have larger fractions than the national average of emissions from the highest-emitting vehicle classes. A similar pattern is shown in Figure 3b for the HD group.

Figure 3. Distribution of emissions from each vehicle classes within a vehicle group. Lighter colors denote higher-emitting vehicles per mile traveled. a) light-duty group; b) heavy-duty group.



a) b)

<u>Onroad fossil fuel CO_2 emissions uncertainty</u>

In order to place the uncertainty of the Vulcan onroad CO_2 emissions in context, we calculate a “normalized” uncertainty for each state. This quantifies uncertainty from each of the uncertainty contributors (VMT, age distribution, fuel efficiency) and from each of the aggregate road and vehicle type groups as a fraction of the state total CO_2 onroad emissions. This can be expressed as,

$$\Delta\%_S^{U,G} = 100 * \frac{HEM_S^{U,G} - VEM_S^{U,G}}{VEM_S}$$

Equation (5)

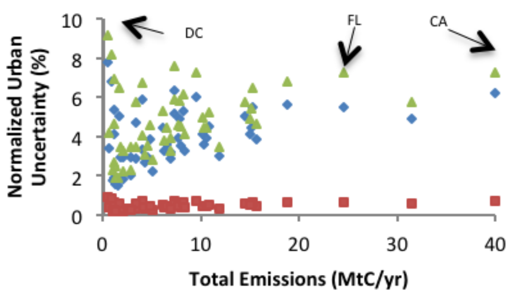
where $HEM_S^{U,G}$ = the high uncertainty Vulcan CO_2 emissions for state *S*, group *G*, and uncertainty type *U*

$VEM_S^{U,G}$ = the central Vulcan CO_2 emissions for state *S*, group *G*, and uncertainty type *U*

VEM_S = the central Vulcan CO_2 emissions for state *S*

The uncertainty type is either uncertainty due to VMT, age distribution, fuel efficiency, or the combination of all three uncertainty factors. A group represents either the aggregate vehicle type group (HD or LD) or aggregate road type group (rural or urban). The normalized uncertainty is presented in Figure 4.

Figure 4. Vulcan state-specific normalized onroad fossil fuel CO_2 uncertainties versus emissions. a) normalized urban uncertainty vs. total emissions; b) normalized rural uncertainty vs. total emissions; c) normalized LD uncertainty vs. total emissions; d) normalized HD uncertainty vs. total emissions. VMT uncertainty (blue diamonds), fuel efficiency uncertainty (green triangles), fleet age uncertainty (red squares). The y-axis scales are different in each panel.



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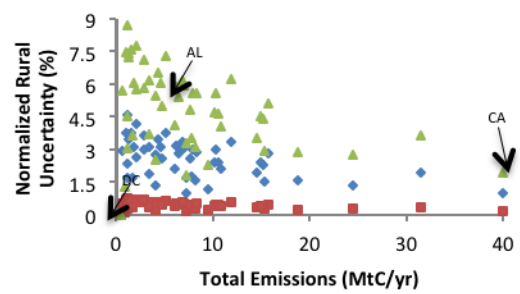

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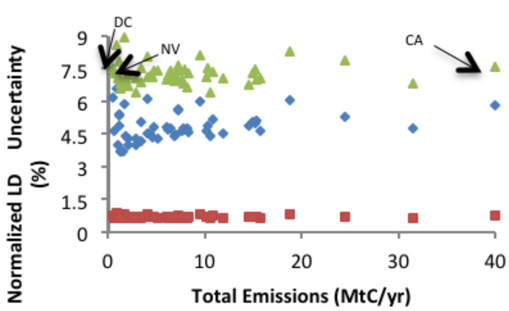

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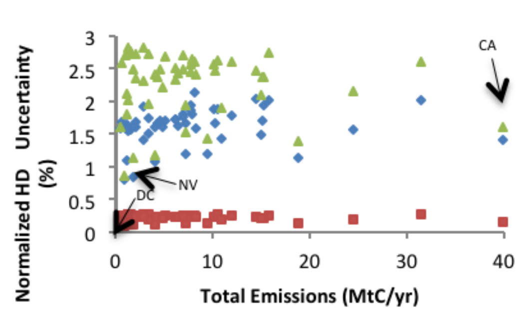


d)

As specified in the uncertainty construction, the largest contributors to the total uncertainty are the VMT and fuel efficiency uncertainties which are an order of magnitude larger than the Fleet Age uncertainty in all aggregate groups. The LD uncertainty generally shares characteristics of the urban uncertainty since the majority of vehicles on urban roads are within the LD group.

VMT uncertainty is dependent only on road type. Hence, the magnitude of the VMT uncertainty in the rural and urban road type groups (Figure 4a, 4b) reflects the proportion of state VMT on rural versus urban roads and these magnitudes are inversely related for a given state. Unlike the road group VMT uncertainty, the magnitude of the two vehicle group VMT uncertainties reflects the relative proportion of state VMT in the LD versus HD vehicle groups, and the distribution of each vehicle group on either urban or rural roads. VMT uncertainty magnitude reflects the correlation between vehicle type and road type. Hence, the VMT uncertainty for the LD group is much larger and closer to the urban VMT uncertainty (7.8%) when compared to the HD vehicle group, the vehicles of which are more likely to travel on rural roads.

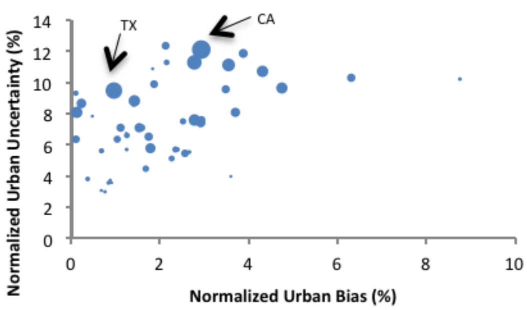
Fuel efficiency uncertainty is dependent on both vehicle and road type ("city" versus "highway") in the uncertainty construction used in this study. However, the magnitude of the uncertainty only varies with road type, being a fixed value across all vehicle types. As with the VMT uncertainty, the fuel efficiency uncertainty is greater for urban road types because of the greater proportion of "stop-and-go" traffic which results in greater fuel efficiency variation.

Fleet age uncertainty is dependent only on the vehicle type. It exhibits the smallest uncertainty due to the small observed variation in state-to-state fleet age distribution. However, despite the fact that the uncertainty in age distribution is small, it results almost exclusively from variation in the LD fleet as opposed to the HD fleet. HD fleets are commercially-owned and maintained by companies that have fleet management policies in place to maximize fleet efficiency [11].

Bias and uncertainty comparison

Figure 5 compares the normalized absolute bias (Equation 2) to the normalized uncertainty (Equation 5) for each of the aggregate groups.

Figure 5. Total normalized state-specific uncertainty versus total absolute normalized state-specific bias. Symbol size is proportional to total state emissions. a) urban; b) rural; c) LD; d) HD. Note that scales are different in each panel.



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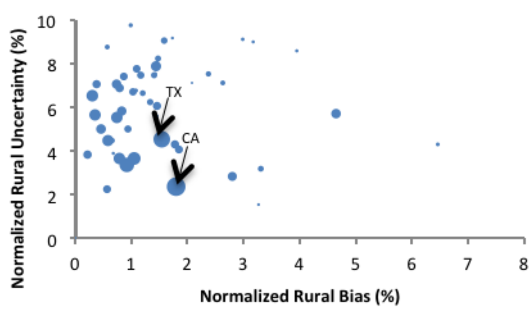

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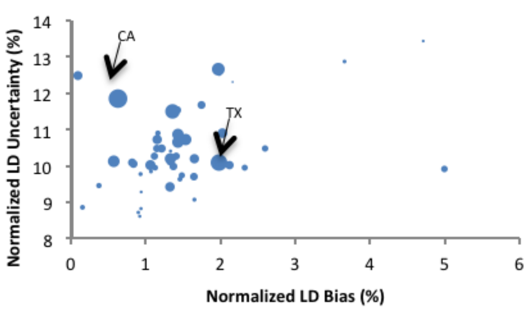

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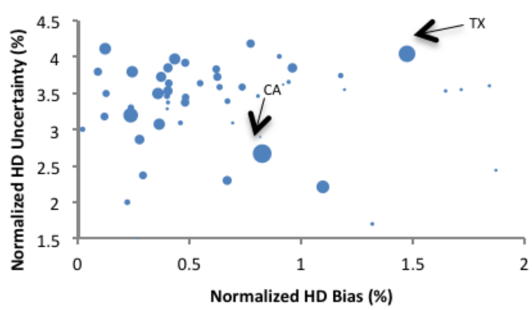


d)

In nearly all cases, the total Vulcan uncertainty exceeds the calculated bias and exhibits no obvious relationship. However, the largest-emitting states exhibit less variation in both normalized bias and uncertainty for the aggregate groups than the smallest-emitting states. A state may emit a small amount of emissions, with the majority of these emissions occurring on urban roads, while other small-emitting states have predominantly rural emissions. Likewise, similar trends are present for the vehicle groups, where small states display larger standard and relative standard deviations when compared to the same quantities for the larger states.

Discussion

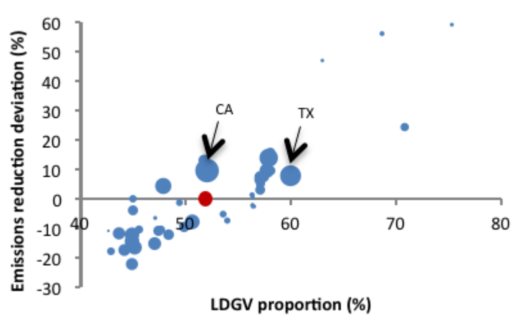
Policy Implications

Accurate emissions estimation with realistic, unbiased uncertainties are critical in assuring that reported emissions reductions are credible. The Kyoto Protocol sets forth emissions reductions targets of 7% from 1990 amounts by 2008-2012, a target that was agreed upon but not ratified by the United States. The California Senate proposed 8% reductions from 2005 amounts by 2020 and 15% reductions by 2035 [12,13]. These targets are the same size or smaller than the uncertainty found in the rural, urban, and LD groups. Therefore even if the targets proposed by the Kyoto Protocol and California Senate were achieved, the reductions would not necessarily be detectable for three out of the four road and vehicle groups.

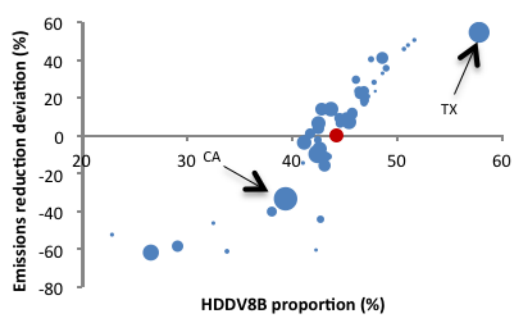
Transportation sector policy formulation based on a US national-average emissions approach is poorly suited for cities, states and regions that differ from the national mean. Policies based on the specific emission profiles of a county or state will address specific regional needs and idiosyncrasies and thereby, maximize emissions mitigation across the entire nation.

Figure 6 demonstrates the differential impact to state-level emissions of a nationwide 10% reduction in emissions from the Light Duty Gasoline Vehicle (LDGV) class and a Heavy-Duty Diesel Vehicle (HDDV8B) class. These two vehicle classes were chosen because they account for the largest fraction of emissions within their respective vehicle groups. These reductions are comparable to the fuel efficiency standards set forth by the EPA for LD and HD vehicles [14-16]. The reductions are expressed as the difference between the actual percent reduction and the expected emission reduction if using a national-average fleet composition. Figure 6 shows this difference as a function of the proportion each specific vehicle class represents within the larger vehicle groups used in this study.

Figure 6. The difference between the actual state emission reduction and expected (%) associated with a nationwide vehicle-specific 10% emissions reduction versus the proportion of vehicle class. a) reduction difference vs LDGV proportion of LD; b) reduction difference vs HDDV8B proportion of HD. Symbol size is proportional to total state emissions. The red symbol represents the national average.



a)



b)

Nationally, 51.9% of an average state's LD group emissions are due to the LDGV class. Figure 6a shows the large spread of LDGV proportion values, with some states having as little as 42.7% of their LD group emissions accounted for by LDGV class and some states as large as 75.2%. A 10% emissions reduction for the LDGV class would yield a 3.8% average reduction in total state emissions, but for a given state this value can range from 3.0 to 6.1%. This results in a range of deviation from expected emissions reductions of -25 to +60%. For example, the LDGV proportion in Texas exceeds the national average; the total reduction for this state would be subsequently underestimated by 0.1 MtC/yr.

Similarly, 44.2% of an average state's HD group emissions are due to the HDDV8B class (Figure 6b). This figure corresponds to a 1.2% total emissions reduction in an average state if a policy advocating a 10% HDDV8B emissions reduction were implemented. However, because the HDDV8B proportion ranges from 22.8% to 57.7% overall reductions vary by state from 0.5 to 1.8%. The range of deviation from expected reductions is ±60% from the national average. This would yield an overestimation of emissions reductions by 0.2 MtC/yr in the State of California.

Montgomery County, Maryland passed the first county-wide carbon tax in the U.S. in 2010 calling for payments of $5 per ton of CO_2 [17]. Using the national-average fleet as a baseline, the difference in expected and actual emissions reductions obtained by a 10% emissions reduction would cause California to be undercharged by nearly $800,000 under this policy due to its smaller fraction of HDDV8B vehicles. Conversely, Texas would overpay by $500,000 due to its larger fraction of LDGV vehicles.

4.2 Uncertainty Improvement

The largest source of onroad fossil fuel CO_2 emissions uncertainty in this study, VMT uncertainty, can be traced to a number of sources. Poorly placed or distant traffic monitoring stations may lead to vehicle miscounting. If stations are too far apart or placed illogically with respect to exit and entry points on a given road segment, vehicles may enter and/or exit without being recorded (undercounting). The opposite problem may occur if a vehicle enters just before the monitoring station and exits immediately or shortly after being counted (overcounting). In order to reduce all three of these sources of VMT uncertainty, a larger and more representative set of monitoring stations is required, with optimal placement. Uncertainty is introduced when state-level VMT estimates are downscaled to counties, as described in section 2.2. If there are significant differences in road network composition between individual counties and the state, bias results. One example of this is a situation in which the proportion of interstate to arterial roads varies significantly between an individual county and the state in which it is located [18-20].

An option to reduce the uncertainty associated with these problems is a periodic review of the variables involved in the VMT calculation. This assessment would be used to adjust the variables to current values that reflect actual conditions. Such a procedure would update scope of influence and lane-mile values for each station and ensure that any gaps in data readings are filled in the most accurate way possible. Additionally, the administration of driver surveys or a sampling of odometer readings for vehicles traveling within the domain associated with a particular station would contribute to a more realistic characterization of local VMT.

Analyses of new fuel efficiency regulations for the HD fleet and revised CAFE standards have the potential to aid the formulation of a more accurate fuel efficiency estimate, thereby lowering the fuel efficiency uncertainty [15,16]. Available data on annual vehicle sales by class may help to accurately represent the particular fleet makeup of each state or region. Such a portrayal, in conjunction with a larger, more representative sampling of vehicle classes, would provide the level of detail necessary for a more comprehensive and accurate uncertainty estimate.

Because the traffic on each road type can vary by location, fuel efficiency uncertainty has spatial dependence. City roads are classified as small roads regardless of the city in which they are located.

However, a city road located in a major urban center may experience significantly different traffic patterns from those on small town roads. These disparities go unaccounted for in the fuel efficiency uncertainty calculation and affect its accuracy. In order to account for these obvious differences, revisions and expansions must be made to the current road type classification system. By accounting for location-specific differences, improved uncertainty will enable more informed policy decisions to be made on the basis of a more comprehensive and accurate assessment of road network biases.

CONCLUSIONS

As one of the largest sectoral sources of fossil fuel CO_2 emissions in the United States, onroad fossil fuel CO_2 emissions, are an important component of carbon cycle budget studies and figure prominently in policies designed to mitigate greenhouse gas emissions. Although onroad CO_2 emissions in the United States have been studied extensively, these efforts lack sub-national spatial detail. Such detail is essential because both scientific questions and greenhouse gas policies are being explored at the urban landscape scale and current analysis cannot adequately support quantitative decisions at these scales. Onroad CO_2 emissions are dependent on a variety of driving factors, all of which are known to vary significantly at these smaller spatial scales. Hence, in order to study, project and mitigate onroad CO_2 emissions, a high-resolution onroad emissions data product is paramount.

We find that using group-specific national averages is consistently associated with state-level emissions bias; however, the range of bias estimated is strongly dependent on how the emissions are classified. A vehicle group classification yields a state-level normalized bias range of -2.6% to 8.1% while a road group classification yields a state-level normalized bias range of -6.3% to 16.8%. When normalized to the national total, these differences account for bias ranges of -0.4% to 0.3% for a vehicle type classification and -0.3% to 0.5% for a road type classification. These biases are the direct result of regional heterogeneity in road and fleet composition. There exists a positive correlation between HD and rural biases and between LD and urban biases because urban traffic is comprised mainly of LD vehicles and rural traffic has a comparatively larger HD component.

Three sources of uncertainty are quantified in this study: vehicle miles traveled (VMT), fleet age, and fuel efficiency. VMT and fuel efficiency normalized (by state total emissions) uncertainty range from 2 to 12% and are approximately 5 to 10 times larger than fleet age uncertainty. The total normalized uncertainty is 2 to 15 times larger than the normalized bias. Uncertainty quantification and reduction measures focused on VMT and fuel efficiency would yield the maximum benefit. VMT uncertainty reduction strategies involve a revision of the formula for conversion of vehicle counts to VMT, as well an increased number of traffic monitoring stations with optimal placement to minimize inaccuracies in vehicle counting. A fuel efficiency uncertainty improvement strategy would involve creating more spatially explicit calculations of possible fuel consumption scenarios and driving habits.

Although it is desirable to reduce uncertainty, it is of equal importance to improve the accuracy of uncertainty estimates. This can be accomplished by a more accurate spatial portrayal of the sources of uncertainty through methods such as a more representative sampling of vehicle classes and assessments of regionally-explicit VMT estimates. Downscaling the temporal domain for comparison to the county level is a realistic and attainable goal due to the nature of the Vulcan data product. Due to the heterogeneous distribution of roads and vehicles within a state, this level of resolution is necessary for policy formulation at this level.

Policy measures aimed at reducing emissions from a particular group within the vehicle fleet must take into account regional differences in fleet composition. Vehicle-specific mitigation strategies based upon national-average fleet composition have been shown to display errors of up to 60% in expected state level emissions reductions for the passenger car and heaviest diesel truck classes. If a 10% emissions reduction from an individual vehicle class is assumed, these estimation errors can be as large as ±60% corresponding to ± 0.2 MtC reductions in state totals.

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KEY WORDS

Transportation CO_2 emissions

Transportation emissions bias and uncertainty

Transportation sector policy

ACKNOWLEDGEMENTS

This work was supported by NASA grant NNX06AB37G and NSF CAREER award 0846358. We would like to thank Broc Seib and William Ansley for assistance with information systems and the Rosen Center for Advanced Computing for in-kind support.