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Considering future regional air quality impacts of the transportation sector

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ABSTRACT

Regional air pollution is strongly impacted by transportation emissions. Policy mechanisms to reduce emissions are required to reach environmental quality goals. Projecting the drivers (e.g., technical, economic, societal, regulatory) that will impact future emissions is challenging, and assessing regional air quality (AQ) is complicated by the need for detailed modeling tools and data inputs to simulate chemistry and transport of pollutants. This work assesses the contribution of emissions from transportation sources to ground-level concentrations of ozone and fine particulate matter via two methods. First, impacts are quantified for three U.S. regions including California using output from an economic optimization model to grow a base year emissions inventory to 2055. Second, impacts are considered for California using state-level projections with an updated emissions inventory and modeling suite in 2035. For both, advanced AQ models are used, showing that the impacts of light duty vehicles are moderate, reflecting shifts to more efficient and lower emitting technologies. In contrast, heavy duty vehicles, ships, and off-road equipment are associated with important ozone and $PM_{2.5}$ burdens. Emissions from petroleum fuel production and distribution activities also have notable impacts on ozone and $PM_{2.5}$. These transportation sub-sectors should be the focus of future emissions reduction policies.

1. Introduction

Policies to improve regional air quality (AQ) and reduce associated health risks represents a cornerstone of U.S. environmental quality efforts (Bachmann, 2007). Energy sectors, including the transportation sector, are responsible for the bulk of pollutant emissions driving current U.S. AQ concerns, including ground level concentrations of ozone and particulate matter less than 2.5 µm ($PM_{2.5}$) (U.S. EPA, 2005). The transportation sector encompasses the movement of persons or goods by various technology types including light-duty vehicles (LDV), medium-duty vehicles (MDV), heavy-duty vehicles (HDV), rail, ship, aircraft, and other vehicles (e.g., off-road equipment).

With petroleum fuels currently dominant, combustion processes associated with conventional transportation technologies result in significant atmospheric releases of gaseous and particulate pollutants. Emissions of criteria air pollutants from transportation comprise a large fraction of domestic totals, including carbon monoxide (CO), oxides of nitrogen (NO_x), and volatile organic compounds (VOC) (David et al., 2014). Additionally, some transportation sources emit large amounts of sulfur oxides (SO_x) and particulate matter, including $PM_{2.5}$, which carry considerable human health risk (Kleeman et al., 2000; Hasheminassab, 2013). While emissions from transportation directly impact society via induced health effects, materials degradation, aesthetics, etc., further contribution to these burdens occurs via the formation of secondary pollutant species, including ozone and secondary PM. Ozone forms in the troposphere via photochemical interactions between NO_x and VOCs in the presence of sunlight (Finlayson-Pitts and Pitts, 1997) and represents one of the most challenging pollutants to mitigate – many regions of the U.S. currently experience non-attainment for federal criteria pollutant regulatory standards for ozone (U.S. Environmental Protection Agency, 2015). Further, exposure to ozone is known to induce a range of detrimental health outcomes (Moore et al., 2008), while meeting the health-based standards have been shown to provide significant societal benefits (Hubbell et al., 2005). Similarly, $PM_{2.5}$ has been shown to increase a number of serious disease burdens and represents a foremost regional AQ concern (Pope and Dockery, 2006; Laden et al., 2000) that is also often present in concentrations above federal standards in many regions of the U.S. (U.S. Environmental Protection Agency, 2015).

In addition to direct emissions from vehicles, the production of transportation fuels yields pollutant emissions and resulting AQ impacts (Chambers et al., 2008; Rivera et al., 2011). The reliance on petroleum

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fuels requires the existence of an extensive production and distribution system in the U.S., including the regions of study in this work. Petroleum refineries convert crude oil into an assortment of products used in transportation, e.g., gasoline, aviation fuel, distillate fuels, and residual fuels (Speight, 2013). Refining products require a variety of processes (e.g., distillation, reforming, hydrocracking, coking, blending) that result in a diverse range of pollutant emissions including CO, NO_x, PM, SO_x, VOCs, and numerous air toxic compounds, e.g., benzene, toluene (McCoy et al., 2010). Furthermore, emissions associated with the production, storage, transport, and distribution of conventional petroleum fuels are known to contribute to regional AQ problems (Daum et al., 2004; Simons et al., 2015; Mac Kinnon et al., 2016; Smargiassi et al., 2014). Emissions from petrochemical facilities may be underreported and therefore AQ impacts may currently be underestimated (Jobson et al., 2004; Ryerson et al., 2003; Kleinman et al., 2002a). Thus, there is a need for more information regarding the potential effects on regional AQ from petroleum transportation fuels in the framework of policy development.

The U.S. has made significant progress in addressing such concerns through regulatory controls and technological advancements targeting reductions in emissions of gaseous and particulate pollutants (U.S. EPA, 2011b). California (CA) has developed and implemented numerous policies aimed at reducing emissions from various transportation sectors with examples including the Zero Emissions Vehicle (ZEV) Mandate (Collantes and Sperling, 2008), the Goods Movement Emission Reduction Plan (CARB, 2006a) and Sustainable Freight Action Plan (California Sustainable Freight Action Plan, 2016), and the At-Berth Regulation (California Air Resources Board, 2014). Similarly, policy examples at the Federal level include the National Program incorporating both Corporate Average Fuel Economy (CAFE) standards and GHG standards for LDV (Xie and Lin, 2017). Nonetheless, additional targeted and comprehensive pollution reduction policies and regulations for the transportation sector are required as demand increases in response to population and economic growth (Uherek et al., 2010). Transportation sub-sectors differ with regards to distributions and intensities of emissions including purpose, energy conversion technology and fuel characteristics, spatial and temporal patterns of operation, regional demands, etc. Further, future year sub-sector technological evolution and pattern changes of the major emission drivers will not be equivalent and thus some sub-sectors may grow in relative importance to regional AQ while others may lessen. For example, alternative, low-emitting technologies may be easier to develop and apply in the LDV sector than to ship or rail technologies with greater physical constraints, much longer typical service life, and different commercial market considerations.

Additionally, challenges associated with interpreting relationships between transportation source emissions and regional AQ impacts further complicate optimal policy development. The complexity of ozone (Finlayson-Pitts and Pitts, 1999) and PM (Schell et al., 2001) formation in the atmosphere requires detailed emissions dynamics, meteorology and topology information, and atmospheric modeling to simulate chemistry and transport to predict concentrations. The majority of available literature only quantifies emissions of transportation technologies in assessing potential AQ impacts (Wang et al., 2007a, 2007b, 2008; Peterson et al., 2011; Brinkman et al., 2005; Huo et al., 2009; Wang, 2002; Facanha and Horvath, 2007; Chester et al., 2010; Cooney et al., 2013). While previous studies have used atmospheric modeling to examine the AQ impacts of transportation sources (e.g., LDVs (Stephens-Romero et al., 2009; Cook et al., 2010; Brinkman et al., 2010; Thompson et al., 2011; Knipping, 2007b), HDVs (Millstein and Harley, 2010), ships (Vutukuru and Dabdub, 2008); (Song, 2010)), the transportation sub-sectors are considered individually in these efforts, which prevents comparative assessment of sub-sector impacts. Further, studies are generally conducted for one region (Stephens-Romero et al., 2009; Thompson et al., 2011), or at the national (Cook et al., 2010; Jacobson, 2008; Duvall et al., 2007) or global level (Koffi et al., 2010). An important contribution was made comparing five different transportation categories for the impacts of diesel particulate emissions in California (CA), but ozone and secondary PM were not considered (Marshall et al., 2014). The significant resources (e.g., computational, personnel) needed to appropriately model future typically limits the availability of this required information to a small number of organizations involved in planning regional AQ mitigation strategies. Furthermore, there is often a trade-off between technical detail and scope that can prevent full resolution of impacts, e.g., regional-scale with high technical resolution vs. national-scale with less technical detail (Anenberg et al., 2016).

There is a need for more insight into how each sub-sector of transportation contributes to regional AQ challenges, particularly in coming decades as policies are developed for various mitigation strategies. The current work is distinguished by quantifying the contribution to regional ground-level ozone and $PM_{2.5}$ of various transportation sources via modeling platforms allowing for comparison within three different U.S. regions, and a subsequent evaluation for one of the regions with augmented detail. For the first time, the work identifies priority targets for pollutant mitigation strategies that can assist decision makers in formulating policies. Finally, differences in the methods used to project and resolve transportation sector emissions inventories provide insight into methodological considerations for supporting AQ assessment within policy development framework.

2. Materials and methods

To assess future regional AQ impacts of transportation-related sources, emissions must be projected and spatially and temporally resolved to facilitate input into an advanced model of atmospheric chemistry and transport. For this work, two separate methods are used to provide insight into AQ impacts in different regions and to facilitate insights into methodological choices with implications for policy. The goal of these sub-sector spanning scenarios is to provide overall insights into the AQ impacts of the various transportation sub-sectors in future years. To assess the impacts of each transportation sub-sector, scenarios are constructed accounting for the removal of emissions from a given sub-sector (i.e., LDV, HDV, ships) while holding all other sectors and sub-sectors constant with the baseline. This allows the resulting impacts on AQ to quantified and resolved.

The quantity and spatial distribution of future transportation emissions will be driven by socio-economic, regulatory, technological, environmental and regulatory factors (Loughlin et al., 2011). Assessing AQ impacts in future years requires the projection of emission sources economy-wide by consistent methods. Thus, emission projections, whether representing business-as-usual (BAU) or alternative scenarios, should account for these factors to the extent practicable. First, a comprehensive accounting of regional emissions evolution under BAU conditions is needed to provide a Reference Case for comparison with control cases. Next, emissions must be grown to the target year from current levels and spatially and temporally resolved to account for direct perturbations using an emissions processing tool. Finally, a thorough assessment of AQ requires simulation of atmospheric chemistry, e.g., the photochemical formation of ozone, oxidation of VOCs, and formation of organic aerosol precursors.

2.1. U.S. regional method

An overview and comparison of the two methods is presented in Table 1. The first method is used to evaluate different regions of the U.S. (the "U.S. regional method") in 2055 including CA, an aggregate of five Northeastern U.S. states (NEUS), and Texas (TX). Regions were selected due to the presence of existing AQ challenges coupled with significant differences in regional energy demands, utilized technologies and fuels, regulatory constraints, etc.

Baseline AQ is established accounting for BAU continuation of current technological, energy, and economic trends via output from a data-intensive, energy system optimization model, the MARket ALlocation (MARKAL) model (Fishbone and Abilock, 1981; Loulou et al., 2004; Victor et al., 2018; Mahmud and Town, 2016). The approach for the U.S. regional method 2055 Reference Case follows the methodology described by (Loughlin et al., 2011) and used in (Mac Kinnon et al., 2016). Briefly, the