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Climate-based policies may increase life-cycle social costs of vehicle fleet operation

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ABSTRACT

Sustainability guidelines and regulations in the United States often focus exclusively on carbon or petroleum reductions. Though some of these policies have resulted in substantial progress toward their goals, the effects of these efforts on other social and environmental externalities are often ignored. In this study, we examine the life-cycle air pollutant emissions for alternative fuel and vehicle purchase scenarios at a military installation near a typical urban area in the United States (U.S.). We find that scenarios which minimize petroleum use or greenhouse gas emissions do not concomitantly minimize criteria air pollutant emissions. We also employ social cost methodologies to quantify economic externalities due to climate change and health-related air pollutant impacts. Accounting for the social costs of climate change and air pollution from vehicle use reveals that criteria air pollutants may have a greater total impact than greenhouse gas emissions in locations similar to the urban area examined in this study. Use of first-generation biofuels, particularly corn grain ethanol, may reduce net petroleum use at the cost of increased total health impacts. More comprehensive policies may be needed to ensure that sustainability policies result in a net benefit to society.

1. Introduction

Automotive fuel use represents a substantial fraction of energy-related greenhouse gas emissions globally (20%) and in the United States (28%); it also accounts for the majority (69%) of U.S. petroleum use (EIA, 2013). Major policy interventions, such as the U.S. Renewable Fuels Standard, focus on transportation fuels and vehicles to achieve climate change mitigation and energy security goals. Additionally, the Department of Defense (DoD) has developed internal goals to achieve 30% reductions in petroleum use by non-tactical vehicles by 2020. The DoD has worked to achieve this goal by eliminating underutilized vehicles and integrating a variety of electric and bio-fuel capable vehicles into military base operations (Executive Order No. 13693, 2015; Blakeley, 2012; Kendall, 2013; DOD, 2014). Although most service branches have exceeded their midpoint goals, Air Force petroleum use in 2013 was 1.7% higher than 2005 baseline levels despite the acquisition of nearly 10,000 E85 capable vehicles and 2000 hybrid-electric vehicles (Kendall, 2013).

Vehicle tailpipe emissions are also leading sources of air pollution, notably particulates (PM), ozone (O_3), and carbon monoxide (CO) (Brinkman et al., 2005; EPA, 2014). Since tailpipe emissions are typically at ground level, exposure rates can be much higher than for other pollution sources, thus leading to an estimated 58,000 early deaths annually in the U.S. (Caiazzo et al., 2013). Because of these impacts and the quantity of fuel consumed in the U.S., the use phase often dominates life-cycle assessments of health and environmental impacts of transportation, including total greenhouse gas emissions (Chester and Horvath, 2009; Hawkins et al., 2013). While the role of internal combustion vehicles in air pollution and the potential of alternative fuels to mitigate greenhouse gas emissions are both widely acknowledged and relatively well understood, current understanding of the potential tradeoffs between these two goals is limited. Although climate change mitigation and energy security policies are generally expected to be compatible with air pollution and health cost reductions (McCollum et al., 2013), there is evidence that first-generation alternative fuels such as corn ethanol lead to higher health costs due to air pollution than conventional fuels (Hill et al., 2009).

Methods are now available to determine the costs to society of externalities, such as the health and mortality effects of air pollution, which can be used to assess health, climate, and economic effects on a common basis (Heo, 2015; Krewski et al., 2009; Lepeule et al., 2012). Because these effects are dependent not only on the quantity of pollution emitted but also the population exposed, applying social cost methods to vehicle fleet decision-making requires an understanding of

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the spatial distribution of feedstock, fuel, and energy generation (Heo, 2015; Muller, 2014). Estimates of the social costs of conventional and alternative-fueled vehicles emphasize the importance of the vehicle use phase and particularly the fuel source in determining the severity of health effects, which may range from less than $0.01/L (from electric vehicles (EVs) using solar or wind power) to as much as $0.56/L gasoline equivalent (from EVs using coal power) (Michalek et al., 2011; NRC, 2010; Small and Kazimi, 1995; Tessum et al., 2014).

In this study, we examine the life-cycle social costs of air pollution and climate change from operation of the non-tactical vehicle fleet at a U.S. military installation. The wide variety of fuel sources and alternative-fuel vehicles (AFVs) available create a large decision-making space for fleet managers and other decision-makers in the DoD attempting to balance financial costs with energy security and health concerns. Using total cost of ownership, life-cycle assessment, and social cost techniques, we develop and compare fuel and vehicle purchase scenarios on the basis of financial viability, petroleum reduction, climate mitigation, and social costs of vehicle purchase and operation. Although the focus of our case study is on a single military installation, the insights gained are relevant to any organization, in both public and private sectors, with a large vehicle fleet.

2. Methods

2.1. Vehicle fleet and fuel use data

The non-tactical vehicle fleet inventory for Wright-Patterson Air Force Base as of July 11, 2014, and total fuel purchases from September 26, 2014, to October 4, 2015, were provided by site staff. Vehicles were categorized by gross vehicle weight (GVW) into light duty (under 4545 kg or 10,000 lbs GVW) and heavy duty (4545 kg and above GVW) and into eight subtypes by vehicle function (Table 1). We matched individual vehicles with fuel purchases to construct a database of annual fuel use by vehicle type. Only vehicle categories which aligned well with conventional commuting, travel, and hauling profiles were selected for further analysis; this will help other vehicle fleet managers recognize the broad applicability of the insights gained from our study. The remaining vehicle subcategories, including aerospace ground vehicles, construction, maintenance, and miscellaneous vehicles, were excluded to avoid misrepresentation of vehicle cost and fuel efficiency and due to insufficient data availability. The selected vehicles thus make up 83% of light duty vehicles and 55% of heavy duty vehicles at the installation.

Table 1
Categorization of vehicles at the installation and associated AFLEET model vehicle pathways.

Vehicle Type	Vehicle Inventory at WPAFB	Corresponding AFLEET Model Category	Number of Vehicles Studied
Light Duty (LD)	**529**		**443**
Car	26	Passenger car	25
Passenger Truck / SUV	56	Passenger truck	52
Van	37	Light commercial truck	366
Truck	357		
Aerospace Ground Vehicles	12	–	–
Misc	41	–	
Heavy Duty (HD)	**213**		**97**
Maintenance / Winter	23	–	–
Construction	5	–	–
Truck	105	Delivery Step Van Delivery Straight Truck	24 73
Aerospace Ground Vehicles	35	–	–
Misc	44	–	–

Of the 540 vehicles included in the fuel purchase database, 247 were fueled with E85, 112 used a conventional E10 gasoline blend, 37 used conventional diesel fuel, 118 used a low biodiesel blend (B20), and 26 were all-electric vehicles. According to site records, each vehicle received only one fuel type. The distribution of vehicle fuel types at the study site (one of the largest US Air Force installations) closely resembles the average DOD non-tactical fleet. According to U.S. Department of Energy data on DOD non-tactical vehicles, over 40% are E85-capable flex-fuel vehicles, about 40% are conventional E10 and diesel fueled, and the rest are a combination of electric, hybrid, and natural gas vehicles (USDOE, 2015).

For the vehicle categories we selected, representative vehicles from the U.S. Federal Alternative Fuel Vehicle (AFV) Guide (GSA, 2015) were selected to generate a list of the lowest-cost vehicles for each type of fuel and functional category which would be available for purchase by the installation. The total fuel usage for each vehicle category was based on the total annual fuel use for all vehicles in that category at the installation. Annual vehicle mileage was based on the fuel use and the estimated fuel efficiency from similar vehicle models in the U.S. Federal AFV Guide. Alternative fuel prices are from The Office of Energy Efficiency &$2 Renewable Energy's April 2015 Clean Cities report (DOE, 2015). Gasoline and diesel prices are based on the Energy Information Administration (EIA) Weekly Price report for the U.S. Midwest, from January 5 to August 31, 2015 (EIA, 2015). To examine the effect of fuel price variability on total cost of ownership, we generated high and low fuel price values based on the maximum and minimum values for gasoline, diesel, natural gas, and electricity in the U.S. Energy Information Agency (EIA) quarterly price forecast for 2015–2016 (EIA, 2016). Low biofuel blends (E10, B20) were assigned price variability equal to that of gasoline and diesel, while high biofuel blends (E85, B100) and renewable electric power had double the price uncertainty of conventional fuels (Table S2). We assume that ethanol blends using combined corn grain and stover feedstocks are available at the same price as conventional corn grain ethanol blends.

2.2. Life-cycle air pollutant emissions

We used two models from Argonne National Laboratory: the Alternative Fuel Life-cycle Environmental and Economic Transportation (AFLEET) model and the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model (http://greet.es.anl.gov). The models determine financial viability, air pollutant emissions, petroleum reduction, and climate mitigation outcomes for fuels and vehicle fleet scenarios. AFLEET generates total cost of ownership, life-cycle petroleum use, greenhouse gas emissions, and air pollutant emissions during vehicle use (Burnham, 2013). We supplemented these results with GREET data for air pollutant emissions during fuel production and for life-cycle petroleum use and greenhouse gas emissions for combined corn and corn stover ethanol, which is not modeled in AFLEET. A summary of various processes considered in the LCA is depicted in Supplementary material (Fig. S1).

In addition to fuel types, we considered multiple feedstocks for ethanol production and electricity generation. Using GREET, we modeled ethanol produced from two facility types, corn grain and combined corn grain and stover. Although ethanol produced from perennial crops (e.g., switchgrass) may have lower greenhouse gas emissions, switchgrass ethanol is not widely available, whereas several large-scale combined corn grain and stover facilities are currently operating in the U.S. Electricity emissions for all-electric vehicles are calculated for current vehicles based on the ReliabilityFirst Corporation