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Life cycle emissions and cost model for urban light duty vehicles

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ABSTRACT

The growth of vehicle sales and use internationally requires the consumption of significant quantities of energy and materials, and contributes to the deterioration of air-quality and climate conditions. Advanced propulsion systems and electric drive vehicles have substantially different characteristics and impacts. They require life cycle assessments and detailed comparisons with gasoline powered vehicles which, in turn, should lead to critical updates of traditional models and assumptions. For a comprehensive comparison of advanced and traditional light duty vehicles, a model is developed that integrates external costs, including emissions and time losses, with societal and consumer life cycle costs. Life cycle emissions and time losses are converted into costs for seven urban light duty vehicles. The results, which are based on vehicle technology characteristics and transportation impacts on environment, facilitate vehicle comparisons and support policy making in transportation. Substantially, more sustainable urban transportation can be achieved in the short-term by promoting policies that increase vehicle occupancy; in the intermediate-term by increasing the share of hybrid vehicles in the car market and in the long-term by the widespread use of electric vehicles. A sensitivity-analysis of life cost results revealed that vehicle costs change significantly for different geographical areas depending on vehicle taxation, pricing of gasoline, electric power and pollution. Current practices in carbon and air quality pricing favor oil and coal based technologies. However, increasing the cost of electricity from coal and other fossil fuels would increase the variable cost for electric vehicles, and tend to favor the variable cost of hybrid vehicles.

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Introduction

The growth of vehicle sales and use internationally requires the consumption of significant quantities of energy and materials, and contributes to the deterioration of air quality and climate conditions. In 2011, the transportation sector accounted for 28% of carbon dioxide (CO_2) equivalent emissions produced by fossil fuels; the majority of these emissions came from light duty vehicles (EPA, 2012). In 2008, cars accounted for 55% of the 247 million light duty vehicle fleet in the U.S. (Davis et al., 2011). The high demand for personal mobility leads to a high consumption of petroleum distillates. Petroleum is a non-renewable source; it accounted for 92.8% of all transportation energy sources in 2011 (Davis et al., 2012). These facts highlight the connections among mobility, environment and energy.

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Two promising factors that have the potential to alter the increasing trend of energy consumption and emissions are improvements in fuel economy due to high fuel prices and regulations, and electric drive systems for light duty vehicles. Between 1998 and 2008, vehicle fuel economy improved every year by an average of 0.5% in the U.S. (Davis et al., 2011) and the trend accelerated after the long (2009–2010) economic recession and the oil price "spike" of 2008–2009. U.S. government regulation requires an average of 54.5 miles per gallon by 2025 for the U.S. auto fleet and CAFE, the Corporate Average Fuel Efficiency requirement, set a pre-target of 35.5 miles per gallon by 2016 (Gehm, 2012). While CAFE regulations aim to diminish fuel consumption and environmental impact from road vehicles, the reduced cost of driving (i.e., fuel expenditures) may lead to increased vehicle utilization. Therefore reductions in vehicle emissions and energy use per mile resulting from CAFE regulations will likely be outpaced by increased vehicle miles traveled. Sustainable transportation planning should integrate CAFE regulations with a policy package of pricing measures, which are dynamically linked to vehicle characteristics and transportation impacts on environment (climate change and air quality), and reflect the full cost of driving to society.

Last year, 100,000 plug-in electric vehicles were sold; nearly twice as many as sold during 2012. According to industry estimates, the U.S. plug-in electric vehicles market will pass the 200,000 sales milestone by spring 2014 – nearly two years faster than hybrid electric vehicles reached this milestone after their introduction 10 years ago (DOE, 2014). The introduction of electric and alternative fuel vehicles in metropolitan areas necessitates study and comparison of these vehicles with traditional gasoline and diesel vehicles. Subsidies and preferential treatment for certain types of vehicles should be supported by analysis that reveals the full impact on society. An assessment of transportation efficiency should include both monetary costs and external costs in the social and environmental domains (Lawrence and Kornfield, 1998). To this end, an accounting model that integrates vehicle life cycle emissions and costs is developed. Life cycle emissions and cost analysis reveal the impacts of different light duty vehicles on society.

Societal and consumer life cycle cost (LCC) studies and life cycle emissions estimations for various transportation vehicle types formed the foundation of the proposed methodology. Ogden et al. (2004) and Delucchi (2003) considered alternative vehicle technologies, including engine and fuel options. An essential undertaking of these studies was the level of detail of vehicle components for performing life cycle analysis. Ogden et al. (2004) formulated strategies towards the car of the future by estimating societal LCCs. They compared alternative fuel vehicles with a base vehicle and accounted for uncertainty using a range of possible conditions. Goedecke et al. (2007) focused on internal combustion engine, hybrid electric vehicles, and different fuel types to estimate societal and consumer LCC for Thailand by providing estimates relative to a base vehicle. Delucchi (2003) and Goedecke et al. (2007) defined societal LCCs as the sum of vehicle initial cost and fuel cost excluding tax, and external costs from pollution. Ogden et al. (2004) added oil supply insecurity.

This paper describes a dynamic model for estimating life cycle emissions and costs for existing different vehicle types. The model provides a detailed life cycle analysis of vehicles and explicitly associates emissions with travel at different urban speeds. Both direct and indirect costs are modeled separately as societal and consumer life cycle costs or LCC. In this model LCC are broadened to include indirect costs such as damage to health through air pollution (a societal cost) and loss of productivity through loss of time for users (a consumer cost). Time loss for maintaining and fueling/charging vehicles differs between vehicle technologies and it is often neglected in the comparisons of transportation vehicles. To explore different policy effects and technological improvements, users can control variables such as the loss of time.

The model focuses on seven urban light duty vehicles and three fuel types, including gasoline, electricity and hydrogen. Adding diesel, ethanol, compressed natural gas (CNG) and liquefied petroleum gas (LPG) powered vehicles to the model is simple as long as detailed data like those for their gasoline or electric counterparts are available. Absolute values for societal and consumer LCC are estimated to compare the performance of different vehicle types, and tradeoffs. A sensitivity analysis on variables with the largest impact on societal and consumer LCC is conducted to test the sensitivity of the results to assumptions. The method is useful not only for research but also for guiding short, intermediate and long term decision making for sustainable transportation planning.

Methodology and estimation of life cycle emissions and costs

The methodology for estimating societal and consumer LCC of urban light duty vehicles is summarized in Fig. 1. The rationale for estimating the social and consumer LCC per vehicle type differ; therefore the total values cannot be considered cumulatively. Societal LCC analysis excludes taxes and assesses the potential social impacts of vehicles and their magnitude over their lifetime. Consumer LCC analysis reveals the total cost by vehicle type to its users when direct and indirect costs are considered. Both societal and consumer LCC can be used for cost-benefit analysis and evaluation of transportation policies and projects, for vehicle taxation programs, and for evaluating vehicle competiveness.

Societal LCC include the present value of:

- Vehicle first cost.
- Lifetime operation costs including fueling, insurance and maintenance costs. Taxes for operational costs are excluded.
- Lifetime external costs include air pollutants and GHG emissions.