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Episodic air quality impacts of plug-in electric vehicles

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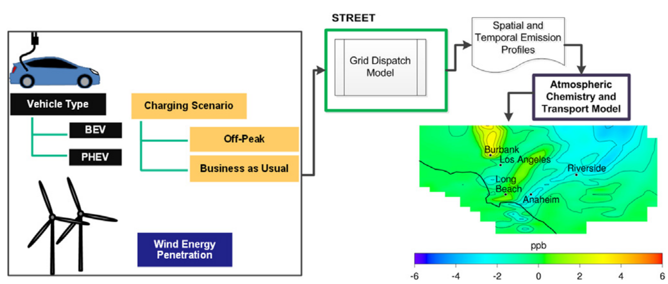
HIGHLIGHTS

- Dispatch and air quality impact of generators are modeled for future cases.
- PEVs will generally have a positive impact on urban air quality.
- Area-wide ozone and $PM_{2.5}$ averages decrease with integration of PEV and wind.
- Charging profile's impact on air quality is very small.
- Localized increase in 8-h average ozone is observed in some cases.

GRAPHICAL ABSTRACT



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ABSTRACT

In this paper, the Spatially and Temporally Resolved Energy and Environment Tool (STREET) is used in conjunction with University of California Irvine – California Institute of Technology (UCI-CIT) atmospheric chemistry and transport model to assess the impact of deploying plug-in electric vehicles and integrating wind energy into the electricity grid on urban air quality. STREET is used to generate emissions profiles associated with transportation and power generation sectors for different future cases. These profiles are then used as inputs to UCI-CIT to assess the impact of each case on urban air quality.

The results show an overall improvement in 8-h averaged ozone and 24-h averaged particulate matter concentrations in the South Coast Air Basin (SoCAB) with localized increases in some cases. The most significant reductions occur northeast of the region where baseline concentrations are highest (up to 6 ppb decrease in 8-h-averaged ozone and 6 μg/m^3 decrease in 24-h-averaged $PM_{2.5}$). The results also indicate that, without integration of wind energy into the electricity grid, the temporal vehicle charging profile has very little to no effect on urban air quality. With the addition of wind energy to the grid mix, improvement in air quality is observed while charging at off-peak hours compared to the business as usual scenario.

1. Introduction

Environmental concerns such as air quality and global climate change, along with political concerns, have given rise to elevated interests in alternative transportation. Plug-in electric vehicles (PEVs) are considered as a viable option by many researchers (Electric Power Research Institute, 2001; McKinney et al., 2011; U.S. Department of Energy, 2006; Zhang et al., 2011), and also by the U.S.

Abbreviations: BEV, Battery Electric Vehicle; PEV, Plug-in Electric Vehicle; PHEV, Plug-in Hybrid Electric Vehicle; SCAQMD, South Coast Air Quality Management District; SoCAB, South Coast Air Basin; STREET, Spatially and Temporally Resolved Energy and Environment Tool; UCI-CIT, University of California Irvine – California Institute of Technology; VMT, Vehicle Miles Traveled.

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government (U.S. Department of Energy, 2009) to replace conventional vehicles. These vehicles include plug-in hybrid electric vehicles (PHEVs) as well as purely battery electric vehicles (BEVs). Since these vehicles are directly connected to the electricity grid, their interaction with the grid is of utmost importance in assessing their overall environmental and economic impacts, especially when deployment numbers become significant (Electric Power Research Institute, 2007; Parks et al., 2007; Peng et al., 2012). Studies that have investigated the impacts of deploying PEVs (Electric Power Research Institute, 2001, 2007; Jansen et al., 2010; Kintner-Meyer et al., 2007; Razeghi et al., 2011, 2014; Samaras and Meisterling, 2008; Sioshansi and Denholm, 2009a, 2009b; Sioshansi and Miller, 2011; Stephan and Sullivan, 2008; Valentine et al., 2011) suggest that PEVs, when considering both the emissions from the vehicles and the electricity required to charge the vehicles have a net emission advantage over conventional vehicles (Jansen et al., 2010; Razeghi et al., 2011; Samaras and Meisterling, 2008; Sioshansi and Denholm, 2009a, 2009b; Sioshansi and Miller, 2011; Stephan and Sullivan, 2008; Valentine et al., 2011). The majority of these studies use an average grid mix (Kintner-Meyer et al., 2007) or the marginal generation technology to determine the amount of annual emissions increased from the electric power generation sector due to PEVs (Electric Power Research Institute, 2007). Jansen et al (Jansen et al., 2010). developed a more sophisticated temporal dispatch strategy which used historical data and dispatch order of various resources to determine the electricity generated from each resource at each hour. These results showed that, although the addition of PHEVs to the light-duty fleet might result in an increase in the intensity of emissions ($lbMWh^{-1}$) from electricity generating sector at specific hours, the overall impact is favorable (i.e. the net impact of deploying these vehicles is decreased emissions from the transportation and electricity generation sectors).

While most of the previous studies suggest that the deployment of PEVs results in an overall decrease in criteria pollutant emissions, analyzing the impact on air quality requires 1) a spatially and temporally resolved generator dispatch model, and 2) a sophisticated atmospheric chemistry and transport model. The majority of previous studies focusing on the dispatch strategies are not both spatially and temporally resolved, and those that are, lack the air quality modeling (Sioshansi and Denholm, 2009b; Sioshansi and Miller, 2011). In addition, the studies focusing on air quality use a simple dispatch methodology that does not capture the details of the grid operations (Tammy et al., 2011). In this paper, a detailed grid dispatch model is used along with an atmospheric chemistry and transport model.

For this purpose, a detailed grid dispatch model has been developed which solves the emissions both spatially and temporally for South Coast Air Basin (SoCAB) of California (Razeghi et al., 2011). Even though the area under study is relatively small, the SoCAB includes one of the largest metropolitan areas in the United States, with more than 16 million inhabitants. In addition, it is of particular interest since the basin is among the worst areas in terms of air quality in the United States. The SoCAB exceeded the 24-h $PM_{2.5}$ standard 15–30 days per year in the last 5 years (California Air Resources Board, 2013). Other reasons for choosing SoCAB are:

- The SoCAB grid mix is relatively clean,
- The SoCAB has historically been a hub for new technologies, and
- The SoCAB is subject to stringent policies like AB32 and AB118 which encourage both manufacturers and consumers to move toward alternative and low to non-carbon options.

This grid dispatch model is a part of the Spatially and Temporally Resolved Energy and Environment Tool (STREET). STREET is a comprehensive planning methodology developed at University of California, Irvine (UCI) to assess environmental and economic impacts of transportation and grid mix options. For example, STREET has been previously used to study the air quality impacts of fuel cell electric vehicles in the SoCAB (Stephens-Romero et al., 2009), and also in developing roll-out strategies associated with hydrogen fueling stations (Stephens-Romero et al., 2011).

In this paper, various transportation and electricity generation scenarios are developed for the year 2050. Using the grid dispatch model, temporally and spatially resolved emissions associated with each scenario are developed and then used as inputs to the University of California Irvine – California Institute of Technology (UCI-CIT) atmospheric chemistry and transport model (Ensberg et al., 2010; Vutukuru et al., 2006) to analyze the air quality impacts of PEVs.

2. Methodology

2.1. Grid dispatch model

With the introduction of PEVs into the light-duty fleet, the tail-pipe emissions of criteria pollutants will partially be transferred to the electricity grid. To fully grasp the impacts of electric vehicle charging on grid operations, emissions, and urban air quality, a dispatch model with both temporal and spatial resolution has been developed for the U.S. Western electrical grid serving the SoCAB (Razeghi et al., 2011). This model is capable of determining individual power plant generation profiles for a given electricity demand for the region in a future year.

The electricity demand of the SoCAB is calculated in two parts. First, the base electricity demand is forecasted based on historical data, population growth, and census data, and it is verified by projections made by the California Energy Commission (Kavalec and Gorin, 2009). The second part is the electricity demand of PEVs which depends on the type of the vehicle, charging profiles, and penetration in the light-duty fleet. Two types of vehicles are selected for this study: BEVs with a 100 mile (160 km) range, and PHEVs with a 40 mile (64 km) all-electric range. In the state of California 70% of drives have a daily vehicle miles traveled (VMT) of 40 miles or less, and 95% of drivers have a daily VMT of 100 miles or less (California Department of Transportation, 2012; U.S. Department of Transportation Federal Highway Administration), and thus the vehicles selected here, can be used by the majority of drivers for their everyday use. PHEVs have the characteristic of Chevrolet Volt and the BEVs have characteristics of a typical BEV (0.31 kWh/mi (DC) consumption and 0.85 charging efficiency).

The size of the fleet and emissions factors associated with conventional vehicles (including hybrid electric vehicles) for a future year are determined using the California Air Resource Board's Emission Factor (EMFAC) model (California Air Resources Board, 2007) which takes into account the improvements in the conventional vehicles' efficiency and tail-pipe emissions. In the base case, the penetration of PEVs is insignificant (less than 0.1%, equal to 2010 penetration), in all other cases PEVs comprise 40% of the light-duty fleet by replacing same amount of conventional vehicles. The conventional vehicles replaced by PEVs have emission factors equal to the average emission factors of *conventional* vehicles in the fleet. This penetration of PEVs in light-duty fleet is consistent with year 2050 southern California deployment penetrations studied elsewhere (McKinney et al., 2011; Ogden and Ramage, 2010; Santimi, 2007; Schremp et al., 2011).

Two particular charging scenarios are considered—"business-as-usual" and "off-peak" charging which have been used in previous studies (Jansen et al., 2010; Razeghi et al., 2011). In the business-as-usual charging profile, the vehicles are plugged in