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Air quality impacts of electric vehicle adoption in Texas

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ABSTRACT

Widespread adoption of plug-in electric vehicles (PEVs) may substantially reduce emissions of greenhouse gases while improving regional air quality and increasing energy security. However, outcomes depend heavily on the electricity generation process, power plant locations, and vehicle use decisions. This paper provides a clear methodology for predicting PEV emissions impacts by anticipating battery-charging decisions and power plant energy sources across Texas. Life-cycle impacts of vehicle production and use and Texans' exposure to emissions are also computed and monetized. This study reveals to what extent PEVs are more environmentally friendly, for most pollutant species, than conventional passenger cars in Texas, after recognizing the emissions and energy impacts of battery provision and other manufacturing processes. Results indicate that PEVs on today's grid can reduce GHGs, NO_x, PM_{10}, and CO in urban areas, but generate significantly higher emissions of SO_2 than existing light-duty vehicles. Use of coal for electricity production is a primary concern for PEV growth, but the energy security benefits of electrified vehicle-miles endure. As conventional vehicle emissions rates improve, it appears that power grids must follow suit (by improving emissions technologies and/or shifting toward cleaner generation sources) to compete on an emissions-monetized basis with conventional vehicles in many locations. Moreover, while PEV pollution impacts may shift to more remote (power plant) locations, dense urban populations remain most strongly affected by local power plant emissions in many Texas locations.

Background and introduction

Plug-in electric vehicles (PEVs) are becoming more popular in the United States and around the world. As of early 2013, the U.S. held an estimated 70,000 PEVs, nearly 40% of the world's total of over 180,000 (IEA, 2013). Since PEVs were reintroduced more strongly into the passenger vehicle market in the early 21st century, researchers and policy makers have been considering the short- and long-term impacts of PEVs on energy, electricity and transportation infrastructure, and the environment. Much of the discussion includes uncertainty regarding consumer adoption and technological development of vehicles and energy infrastructure and whether or not PEVs can reduce the externalities of driving. Despite these uncertainties, many believe that PEV market shares will continue growing in the next few decades (Balducci, 2008; Musti and Kockelman, 2011; Becker and Sidhu, 2009) and that this trend, in most cases, will reduce greenhouse gas (GHG) emissions (Anair and Mahmassani, 2012; Stephan and Sullivan, 2008; Samaras and Meisterling, 2008) and improve air quality (Sioshani and Denholm, 2009; Thompson et al., 2009).

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Even as many adopt an optimistic tone towards PEVs, others cite some concerns. Anair and Mahmassani (2012), for instance, note that PEVs can pollute more than some of the cleanest conventional vehicles (CVs) when fueled by "dirtier" electricity grids (powered mostly by coal). They suggest that in such locations (e.g., Colorado and the U.S.'s Midwest) driving an efficient (gasoline-powered) hybrid-electric vehicle (earning over about 35 mpg) will produce fewer GHG emissions than a PEV charged from the regional power grid. However, they also note that places like the Pacific Northwest, which sources a large portion of electricity from non-emitting hydroelectric dams, enjoy very low per-mile GHG emissions relative to CVs.

Other concerns with PEVs include the energy demands and pollution involved in battery production and disposal and the greater energy required to produce lighter-weight materials (Hawkins et al., 2012). There is also the potential for driving rebound due to reductions in costs and perceived environmental impacts, causing some owners to increase their energy consumption (Greening et al., 2000). This concern is similar for drivers of PEVs and increasingly efficient CVs as well.

Furthermore, such limitations are seen in the context of an increasingly clean CV landscape, diminishing PEVs' perceived environmental advantages. Vehicles powered by fossil fuels are producing fewer emissions and becoming more fuel efficient, thanks to increasingly strict standards. Understanding and predicting these trends is crucial to anticipating the transportation sector's energy demands, air quality impacts, and greenhouse gas emissions. While much has been written on this subject, uncertainty remains regarding how electric vehicles impact specific markets and regions.

This work offers a modeling framework to translate electrified driving (and battery charging) to equivalent per-mile emissions of GHGs and pollutants, and their spatial distribution (from tailpipes to power plants). The model is applied to the Texas region, with its mostly isolated power grid (covering most of the state) and many populated (and still growing) urban areas, where air quality is a concern.

Electricity generation in Texas

As pointed out by Anair and Mahmassani (2012), PEVs' emissions impacts depend on the power grid used to charge the vehicle batteries. Texas's electricity grid covers nearly 90% of the state's population, and serves as an excellent study location, since regional demand can be directly linked to a single grid (as opposed to other, interconnected grids that distribute power across multiple independent system operators, or ISOs). The Electric Reliability Corporation of Texas (ERCOT) is one of the U.S.'s nine ISOs and manages the Texas grid by dispatching power and anticipating short- and long-term electricity demands. 195 of Texas's 254 counties lie within the ERCOT grid, which includes Dallas-Fort Worth, Houston, San Antonio, and Austin, constituting the nation's 4th, 5th, 25th, and 35th most populous metropolitan statistical areas (MSAs) (Census 2010).

Emissions and air quality

One criticism of PEVs is that they are not "zero emissions" vehicles: they produce significant emissions during manufacture, and shift operating emissions from the tailpipe to other locations. Some have argued that PEVs can be worse for the environment, by producing more life-cycle GHG emissions, though the impacts may be obscured by geographical distance and the fact that many impacts occur during upstream production phases (Hawkins et al., 2012; National Research Council, 2010). Regardless of how overall PEV energy demands compare to those of CVs, it is true that PEVs shift many of their operating emissions (for all miles that are "electrified") from the point of usage (a roadway) to a sometimes very distant point source. PEV users driving off battery power and others in their usage area benefit from zero tailpipe emissions, but populations surrounding the power generator for any electrified miles will generally be subject to more air pollution. The accounting framework is complicated by the inclusion of plug-in *hybrid* electric vehicles (PHEVs), since their drive-cycles (and thus emissions) can (and regularly do) fluctuate between battery and gasoline sources of motive power. The emissions shifting situation, over space, also presents ethical dilemmas and may encourage more driving, by reducing users' perceptions of their environmental impacts (Hertwich, 2008). However, reducing exposure of highly populated urban areas (where many more human lungs are present) may be a real benefit of such emissions exporting.

Many U.S. regions are interested in improving air quality to avoid violating the EPA's National Ambient Air Quality Standards (NAAQS). With many Texas regions currently in non-attainment or near-non-attainment for ozone, while experiencing continuing population and VMT growth, PEVs present an opportunity for improved air quality and lower energy demands. This study aims to quantify some of these impacts, and provides a framework for informing local and regional air quality plans.

Methods

This research translates anticipated PEV demands to emissions over time and space, from tailpipes and power plants across Texas's electricity grid. The emissions impacts are evaluated relative to conventional (gasoline-powered) passenger vehicles (CVs). Several different model components are considered here, including charging behaviors, power production, and emissions from both vehicle manufacture and vehicle operations.

This approach focuses on marginal PEV emissions by considering a single vehicle's charging impacts. The method assumes a single PEV consumes electricity already being generated, thus inheriting a mix of all units' emissions online at charging time. This simplification avoids estimating both the total number of PEVs charging and the complex generating processes