The Electricity Journal 29 (2016) 72–88

Contents lists available at ScienceDirect

The Electricity Journal

journal homepage: www.elsevier.com/locate/electr

CO_2 emissions associated with electric vehicle charging: The impact of electricity generation mix, charging infrastructure availability and vehicle type

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ARTICLE INFO

Article history:
Available online 1 July 2016

Keywords:
CO_2 emissions
Carbon-dioxide
Electric vehicles
Plug-in electric vehicles
PEV
Plug-in hybrid electric vehicle
PHEV
Battery electric vehicle
BEV
Modeling
Electricity grid

ABSTRACT

The emission reduction benefits of EVs are dependent on the time and location of charging. An analysis of battery electric and plug-in hybrid vehicles under four charging scenarios and five electricity grid profiles shows that CO_2 emissions are highly dependent on the percentage of fossil fuels in the grid mix. Availability of workplace charging generally results in lower emissions, while restricting charging to off-peak hours results in higher total emissions.

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1. Introduction

With the aim of reducing greenhouse gas emissions associated with the transportation sector, decision-makers at the national, state, and local levels are supporting a multitude of policy measures to increase adoption of light-duty electric vehicles (DOE, 2015; DeShazo et al., 2015; RAP/ICCT (Regulatory Assistance Project and the International Council on Clean Transportation), 2013; Zhou et al., 2015). The actual emission-reduction benefits associated with plug-in electric vehicles (PEVs) in a specific location are dependent on multiple factors. Using a wide variety of methodologies and assumptions, numerous studies have investigated the impact of the electricity generation fuel mix used for charging, time of charging, and vehicle type (Hacker et al., 2009; Parks et al., 2007; Anair and Mahmassani, 2012; Tulpule et al., 2013; Nealer et al., 2015; Wood et al., 2015; Jochem et al., 2016).

A 2012 Union of Concerned Scientists (UCS) study concludes that emissions from electric vehicles are less than those of an average conventional vehicle, regardless of mix of fuels used to generate the electricity on which they are charged (Anair and Mahmassani, 2012). While the authors of the study acknowledge the impact of location and time of day that charging occurs, they do not specifically calculate PEV emissions for different grid mixes, stating:

Because the hourly variations in emissions intensity are not consistent across regions, times of day, or seasons, it is not practical to develop general consumer guidelines on when the lowest emissions intensity will occur throughout the day. For now, we recommend that EV consumers use their regional grid emissions, averaged over the course of the year, as a guide to estimating their personal EV global warming emissions.

Several studies have quantified the importance of location and time of day when estimating PEV emissions. Tulpule et al. (2013) concludes that day charging with solar-powered charging stations in Ohio could realize CO_2 emissions reductions of up to 90% versus home charging during evening hours. Jochem et al. (2016) finds that total life-cycle external costs of PEVs are highly dependent on the electricity mix and the charging strategy employed.

While a commonly used methodology bases emissions estimates on the annual average electricity generation mix (Hacker et al., 2009), an alternative approach bases calculations on the electricity fuel source that is on the margin (meaning the

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http://dx.doi.org/10.1016/j.tej.2016.06.005
1040-6190/Published by Elsevier Inc.

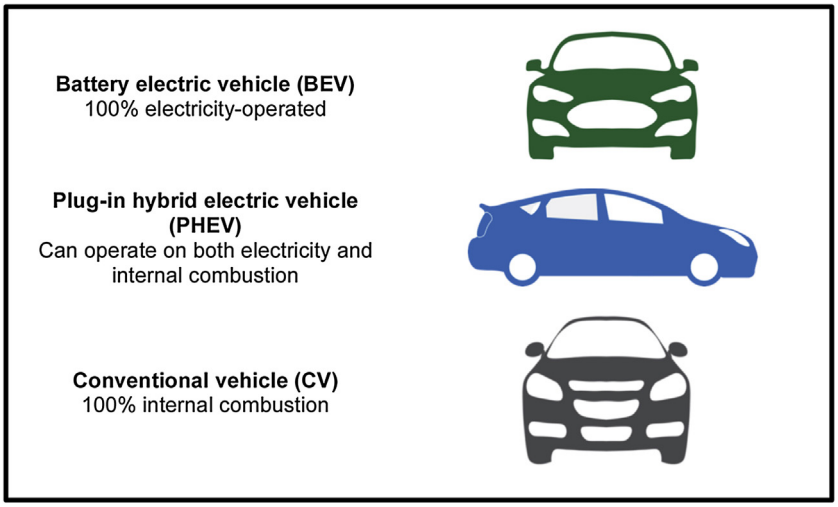

Fig. 1. Descriptions and symbols for vehicles studied.

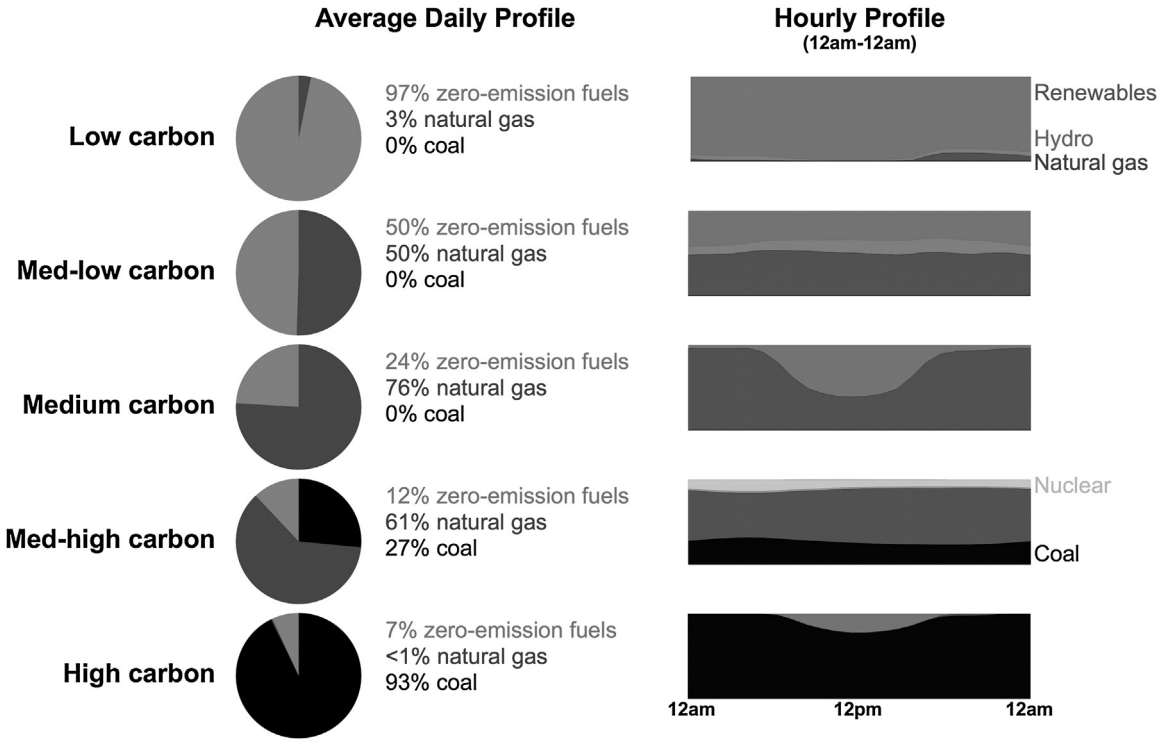

Fig. 2. Modeled grid profiles representing varying levels of carbon intensity.

electricity load that PEVs add to the existing load).[5] Holland et al. (2015) take this approach, finding significant variation in the marginal emissions associated with PEVs in different locations, thus reinforcing the notion that electricity grid mix has a notable impact on emissions. The authors also point out the potential for the transfer of the emissions benefits of EVs from one location to another, as a result of regional electricity imports and exports. Parks et al. (2007) and Denhom et al. (2013) also use the marginal emission methodology. Both studies conclude that the availability of daytime charging increases the percentage of miles that plug-in hybrid electric vehicles (PHEVs) drive on electricity and results in greater petroleum displacement.

The analysis described in this article investigates the emissions impacts by time of day and charging scenario for five different electricity grid mixes and multiple vehicle types, based on an hourly generation profile that represents the average electricity generation mix over the course of a year.[6] This method allows us to

[5] As pointed out in the Union of Concerned Scientists study, these calculations based on the marginal fuel source provide insight into the impact of large-scale PEV deployment on electricity grids, but basing calculations on the average electricity generation mix may be more suitable to inform policy and consumer decision-making.

[6] The vehicles modeled represent efficiencies anticipated for 2025.