Journal of Cleaner Production xxx (2016) 1–16

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Empirical carbon dioxide emissions of electric vehicles in a French-German commuter fleet test

Axel Ensslen [a, *], Maximilian Schücking [a], Patrick Jochem [a], Henning Steffens [a], Wolf Fichtner [a], Olaf Wollersheim [b], Kevin Stella [b]

[a] Chair of Energy Economics, French-German Institute for Environmental Research (DFIU), Karlsruhe Institute of Technology (KIT), Hertzstraße 16, Karlsruhe, 76187, Germany

[b] Project Competence E (PCE), Karlsruhe Institute of Technology (KIT), Hermann-von-Helmholtz-Platz 1, Eggenstein – Leopoldshafen, 76344, Germany

ARTICLE INFO

Article history:
Received 10 November 2015
Received in revised form
14 June 2016
Accepted 15 June 2016
Available online xxx

Keywords:
CO_2 emissions
Electric vehicle
Commuting
France
Germany

ABSTRACT

According to many governments electric vehicles are seen as an efficient mean to mitigate carbon dioxide emissions in the transport sector. However, the energy charged causes carbon dioxide emissions in the energy sector. This study demonstrates results from measuring time-dependent electricity consumption of electric vehicles during driving and charging. The electric vehicles were used in a French-German commuter scenario between March and August 2013. The electric vehicles ran a total distance of 38,365 km. 639 individual charging events were recorded. Vehicle specific data on electricity consumption are matched to disaggregated electricity generation data with time-dependent national electricity generation mixes and corresponding carbon dioxide emissions with an hourly time resolution. Carbon dioxide emission reduction potentials of different charging strategies are identified. As carbon dioxide emission intensities change over time according to the electric power systems, specific smart charging services are a convincing strategy to reduce electric vehicle specific carbon dioxide emissions. Our results indicate that charging in France causes only about ten percent of the carbon dioxide emissions compared to Germany, where the carbon intensity is more diverse.

1. Introduction

Electric vehicles (EV) are considered as an eco-innovation that has the potential to reduce environmental problems caused by the transportation sector (Jochem et al., 2016; Lane and Potter, 2007; Rezvani et al., 2015). The potential for CO_2 emission reductions depends on the CO_2 emissions generated for charging the EV compared to the emissions from conventional Internal Combmagnitude in different countries (Doucette and McCulloch, 2011; Faria et al., 2013; Nordelöf et al., 2014). For example CO_2 emission intensities of electricity generation largely differ between France and Germany (Fig. 1) due to severe differences in the underlying electricity generation mixes (ENTSOE-E, 2014). Heavy fluctuations of electricity fed-in by photovoltaic and wind turbines can be observed in Germany whereas the high share of nuclear power effect corresponding CO_2 emission intensities in France.

Quantifying CO_2 emission reduction potentials of EV are of particular interest with regards to European greenhouse gas emissions reduction targets. However, this task remains challenging like ongoing discussions on the appropriateness of standardized driving cycles to measure CO_2 emissions of EV and ICEV show.

The objective of this paper is to contribute to this discussion by quantifying CO_2 emission reduction potentials of EV used for commuting in the French-German cross-border context based on time-dependent empirical EV energy consumption data as well as data on CO_2 emissions of the national power plant portfolios.

2. Literature review on EV specific CO_2 emissions

Literature discussing CO_2 emission reduction potentials of EV deployment usually compares the calculated values to other potentially substituted vehicle technologies. Most do so by comparing them to an identical or similar ICEV model (Doucette and McCulloch, 2011; Faria et al., 2013). Others set them in reference to regulatory limits (e.g. Euro VI) or fleet targets for ICEV

* Corresponding author.
E-mail addresses: axel.ensslen@kit.edu (A. Ensslen), maximilian.schuecking@kit.edu (M. Schücking), patrick.jochem@kit.edu (P. Jochem), henningsteffens@gmx.de (H. Steffens), wolf.fichtner@kit.edu (W. Fichtner), olaf.wollersheim@kit.edu (O. Wollersheim), kevin.stella@kit.edu (K. Stella).

http://dx.doi.org/10.1016/j.jclepro.2016.06.087

Please cite this article in press as: Ensslen, A., et al., Empirical carbon dioxide emissions of electric vehicles in a French-German commuter fleet test, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.06.087

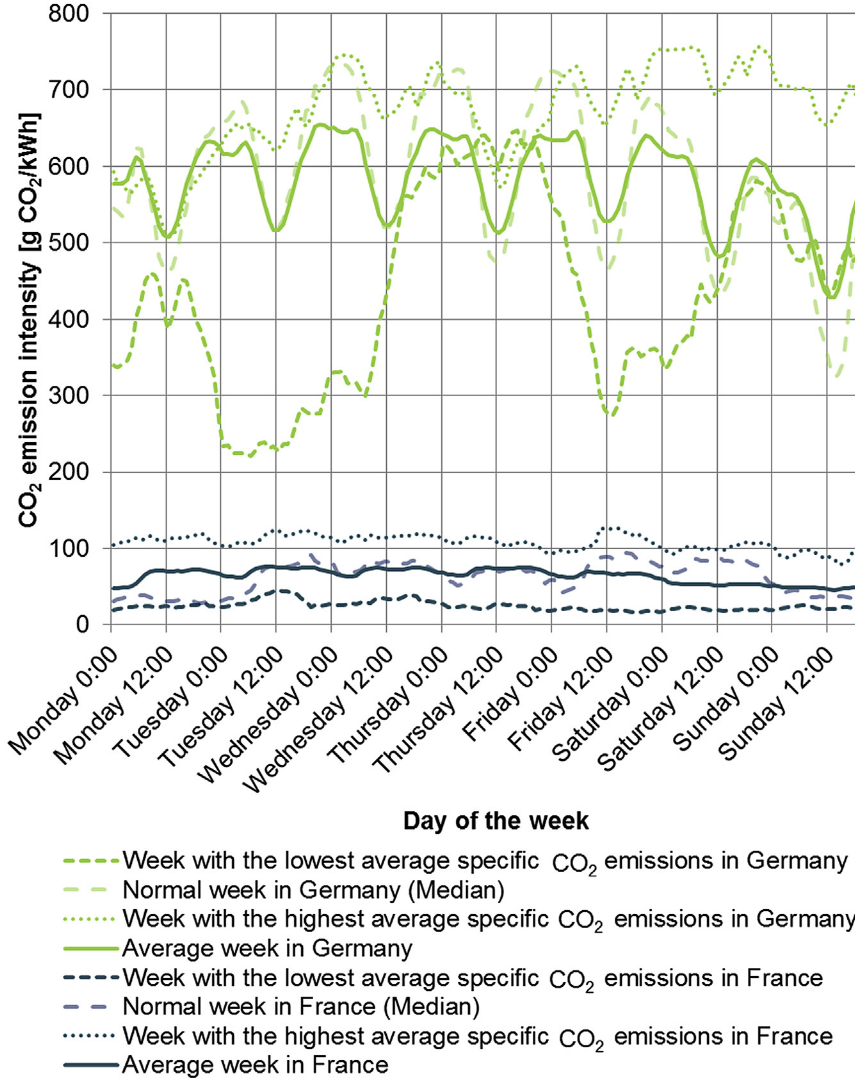

Fig. 1. CO_2 emission intensities of electricity generation in France and Germany in 2013.
(Sources: EEX Transparency, 2015; RTE, 2014).

(Donateo et al., 2014, 2015; Jochem et al., 2015). Some illustrate the potential by calculating the point of ecological break-even in dependence of driven mileage (Bickert et al., 2015). Yet others expand the basis for comparison to other new technologies such as hybrid electric vehicles (HEV), plug-in hybrid electric vehicles (PHEV), or fuel cell electric vehicles (FCEV) (Campanari et al., 2009; Ma et al., 2012; McCarthy and Yang, 2010; Sharma et al., 2012).

Most outcomes of previous studies indicate some kind of reduction potential. A significant dependence on the carbon intensity of electricity generation can be found. A high share of low-carbon energies in the energy mix, such as renewables or nuclear power, significantly favors the EV emission values (Faria et al., 2013). To lower the CO_2 emissions, especially for a carbon intensive energy mix such as Germany, a change towards renewable energies is needed (Bickert et al., 2015) or the implementation of specific low carbon charging strategies, such as load shifting (Jochem et al., 2015; Robinson et al., 2013).

However, these results are not consistent as they highly depend on the method and setting of the research. Table A1 in the Appendix provides an exemplary overview of different studies focusing on emissions of EV. The results of these studies are divers, because they differ in the following dimensions: region, system boundaries, specific energy consumption, definition of emission intensity (i.e. time resolution, average or marginal), and type of pollutants.

The system boundaries have two main sub-dimensions: the product life cycle and process chain of energy production. A life cycle assessment (LCA) of EV usually considers all emissions of their production process and all upstream materials used, the emission caused by operation, and the emissions caused by their recycling and disposal (e.g. Bickert et al., 2015; Hawkins et al., 2013; Muneer et al., 2015). Other studies focus only on the emissions caused during operation neglecting the upstream and downstream.

The second dimension considers the extent to that the value chain of the energy carrier (i.e. fuel or electricity) is considered. For EV the literature distinguishes between four different perspectives: tank-to-wheel (TTW), grid-to-wheel (GTW), plant-to-wheel (PTW) and well-to-wheel (WTW) (Fig. 2).

TTW as the most limited only considers the efficiency of the energy conversion stored in the battery. Additionally to the TTW perspective, GTW considers efficiency losses from the grid into the battery. PTW additionally considers the losses in the process of energy generation, transport and conversion. WTW as the most holistic approach considers all the energy consumption (and emissions) from resource depletion, electricity generation, transport, conversion, and vehicle usage. While energy conversion for generating electricity to run EV takes place in power plants (PTW)

Please cite this article in press as: Ensslen, A., et al., Empirical carbon dioxide emissions of electric vehicles in a French-German commuter fleet test, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.06.087