Transportation Research Part D xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Transportation Research Part D

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

Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles

Alberto Moro*, Laura Lonza

European Commission, Joint Research Centre (JRC), Via Enrico Fermi 2749, 21027 Ispra (VA), Italy

ARTICLE INFO

Keywords:
Well-to-Wheels (WTW)
Life Cycle Assessment (LCA)
Battery Electric Vehicle (BEV)
Electric Vehicle (EV)
Electricity
Greenhouse gas (GHG) emissions

ABSTRACT

The Well-To-Wheels (WTW) methodology is widely used for policy making in the transportation sector. In this paper updated WTW calculations are provided, relying on 2013 statistic data, for the carbon intensity (CI) of the European electricity mix; detail is provided for electricity consumed in each EU Member State (MS). An interesting aspect presented is the calculation of the GHG content of electricity traded between Countries, affecting the carbon intensity of the electricity consumed at national level. The amount and CI of imported electricity is a key aspect: a Country importing electricity from another Country with a lower CI of electricity will lower, after the trade, its electricity CI, while importing electricity from a Country with a higher CI will raise the CI of the importing Country. In average, the CI of electricity used in EU at low voltage in 2013 was 447 gCO_2eq/kWh, which is the 17% less compared to 2009. Then, some examples of calculation of GHG emissions from the use of electric vehicles (EVs) compared to internal combustion engine vehicles are provided. The use of EVs instead of gasoline vehicles can save (about 60% of) GHG in all or in most of the EU MSs, depending on the estimated consumption of EVs. Compared with diesel, EVs show average GHG savings of around 50% and not savings at all in some EU MS.

1. Introduction

The transportation sector is expected to provide one of the largest contributions to the reduction of greenhouse gas (GHG) emissions according to scenarios supporting policy-making (IEA, 2016a). Environmental policies, to reduce these emissions and diversify energy sources, often promote the use of alternative fuels (including electricity). In order to quantify possible GHG and energy savings, policy makers need to consider sound and shared scientific methodologies allowing comparisons among "cleaner" (with a lower carbon intensity) and conventional technologies. At the regulatory level, Well-To-Wheels (WTW) analysis is the dominant methodology used to assess GHG and energy savings in transport. WTW methodology is used for example by the European Union (EU) for the Fuel Quality Directive (European Union, 2015) and for the Renewable Energy Directive (European Union, 2009), in the United States the Environmental Protection Agency bases its regulatory actions on the WTW approach (EPA, 2007) of the GREET model (Elgowainy et al., 2010). The WTW methodology is used to assess policy options also in other geographic areas, such as in China (Huo et al., 2011).

In the European Union (EU) the WTW analyses performed by the JEC consortium is one of the reference inputs used to provide quantitative information to the regulatory process: the JEC WTW version 4a (JEC, 2014a,b). This consortium comprises the Joint Research Centre (JRC) of the European Commission, EUCAR, the European council for automotive R & D, and CONCAWE, the

* Corresponding author.
E-mail address: alberto.moro@ec.europa.eu (A. Moro).

http://dx.doi.org/10.1016/j.trd.2017.07.012
Received 4 November 2016; Received in revised form 18 April 2017; Accepted 20 July 2017

research division of the European Petroleum Refiners Association. The most recent JEC WTW report is based, for electricity mix calculations, on 2009 data, and geographically on European average data. The use of the average electricity mix is the most practical way to assess CO2 emissions of EVs (Jochem et al., 2015) so is commonly used for national regulatory purposes, rather than time-dependent approaches (as indicated in Ensslen et al., 2017) more suitable to specific local analyses. This EU averaged approach is correct to address general EU policies but can be considered not satisfactory to optimize policies at national level. Member States (MSs) of European Union are increasingly interested to assess the impact (ex-ante and ex-post) of their own environmental policies. Since inside the European Union there is a strong variability of many techno-economic factors (e.g. the composition of the electric mix), not always EU averaged data allow calculations describing the specificities of single countries. This is particularly true for policies supporting electric vehicles: GHG savings resulting from the use of electric vehicles (EVs) instead of vehicles equipped with internal combustion engines (ICE) can largely vary for different MSs, depending on the carbon intensity of the electricity mix consumed at national or regional level (as said, i.e., by Weiss et al. (2015)).

Performing WTW calculations on the electricity consumed at national level, allowing comparisons between figures characterizing different countries (so using the same methodology), considering also upstream emissions (occurring to extract and transport fuels) and power losses along the grid, is not available in literature; particularly committing is the quantification of the GHG embodied in the electricity traded between Countries.

For example, the International Energy Agency (IEA), provides relevant reports with valuable calculations of GHG content of electricity produced for each Country, even if without upstream emissions (IEA, 2015b); but IEA stops its analysis at the level of gross electricity production. In other words, data refer to production before cross-border trading and not to the electricity actually available for consumption, therefore also not accounting for power losses of the electric grid. This makes these IEA figures not directly useful for assessing GHG savings from the use of EVs instead of ICEs.

Some authors suggested methods to properly consider the GHG content of the electricity traded (Soimakallio and Saikku, 2012), even if implemented with different assumptions. In this paper, the authors present updated (to year 2013) WTW calculations on the CI of EU electricity, by using the same methodology (including upstream emissions and power losses) adopted in the JEC WTW version 4a (2014a). The trade of electricity between countries (defined as in IEA, 2015a) is also considered. The analysis provides details for the carbon intensity of electricity of all EU MSs, from the gross electricity production level to the low voltage level, when electricity is used to recharge electric vehicles, according to the test procedure proposed by UN ECE (2013): “Method of measuring the electric energy consumption of vehicles powered by an electric power train only” (valid also for hybrid electric power trains).

These carbon intensity figures can be used for all the environmental applications requiring WTW input data on electricity. In this paper examples are provided of how carbon intensities affect GHG savings from the use of electric vehicles in EU.

2. Material and methods

In this section the JEC WTW methodology (Section 2.1) and the main input data and assumptions adopted for calculations (Section 2.2) are briefly introduced. In Section 2.3 different possible values of carbon intensity are illustrated and discussed. The impact (of CI and quantity) of the electricity imported by a country on the carbon intensity of its electricity supplied is formalized in Section 2.4.

2.1. The Well-to-Wheels methodology

The methodology considered in this paper is the Well-To-Wheel (WTW) presented in detail in the JEC WTW report version 4a (JEC, 2014a,b). This approach allows to quantify the energy required for and the GHG emissions resulting from the production, transport and distribution of conventional and alternative road transportation fuels (Well-To-Tank, WTT), and also to quantify the efficiency of different powertrains (Tank-To-Wheels, TTW). Compared to a comprehensive attributional Life Cycle Assessment (LCA) approach, WTW considers parts of the LCA impact categories “energy consumption” and “GHG emissions”. In the WTW approach, emissions related to the hardware construction, maintenance and decommissioning of fuel producing facilities and vehicles, including materials cycles, are not taken into account, nor are water requirements, acidification or emissions of pollutants if these do not affect the GHG emissions. The GHG taken into account are carbon dioxide, methane and dinitrogen monoxide. The WTW methodology can be seen as a simplified LCA, designed to assess only the energy consumption and the GHG emissions of road transport fuels.

2.2. Input data and boundary conditions

The first goal of this article is to detail WTW calculations on the GHG intensity of the electric energy consumed in the European Union, at a Member State level, referring to average values for the year 2013, the most recent and comprehensive statistical set of data available at the time of writing. Main input data and boundary conditions adopted are summarized here.

- Reference year: 2013 (annual average);
- Geographic boundaries: the 28 EU Member States;
- Granularity: Member State level;
- GHG credits assigned for heat produced by CHP (Combined Heat and Power) plants;
- Combustion emission factors from: IPCC (2006);
- Greenhouse gases considered in calculations: carbon dioxide (CO_2), methane (CH4), Nitrous Oxide (N_2O);