Energy xxx (2016) 1–6

Contents lists available at ScienceDirect

Energy

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

Simulation of the impacts on carbon dioxide emissions from replacement of a conventional Brazilian taxi fleet by electric vehicles

Ana Carolina Rodrigues Teixeira, José Ricardo Sodré*

Department of Mechanical Engineering, Pontifical Catholic University of Minas Gerais, Av. Dom José Gaspar, 500, 30535-901, Belo Horizonte, MG, Brazil

ARTICLE INFO

Article history:
Received 9 December 2015
Received in revised form
15 July 2016
Accepted 20 July 2016
Available online xxx

Keywords:
Electric vehicle
CO_2 emissions
Energy
Fuel consumption
Sustainable development

ABSTRACT

This work evaluates the effects of the replacement of engine-powered vehicles by electric vehicles on carbon dioxide (CO_2) emissions and energy consumption. A case study of a taxi fleet replacement was conducted with the aid of the AVL Cruise software. The simulation was performed under different scenarios of total or partial fleet replacement along a period of 15 years. The scenarios were designed considering favorable and unfavorable conditions for electricity production from a clean source, thus influencing the CO_2 emission factor adopted. The simulations showed that the electric energy consumption by the electric vehicles is about four times lower than fuel energy consumption by the conventional vehicles undergoing a standard test schedule. At the end of the period considered the electric vehicles will produce lower CO_2 emissions than the conventional vehicle fleet by a factor of 10, even considering the most unfavorable scenario of electric power generation. An economic analysis shows that the present value of electric vehicles over the years is lower than that of conventional vehicles, except for the first year after vehicle acquisition.

1. Introduction

To improve air quality, increasingly strict regulation laws require reduced automotive emissions, which has influenced the development of clean technologies [1]. Those technologies include electric vehicles (EVs), hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) [2]. The possible reduction of carbon dioxide (CO_2) emissions with the use of those technologies also contribute to reduce global temperature increase, one of the key factors for climate change [3]. In order to reduce automotive emissions many countries adopt increasingly strict regulating laws [4]. The need to reduce carbon emissions motivates the use of renewable energy sources in the electricity matrix [5]. The demand for sustainable actions inspires the rise of solutions with higher energy efficiency [6]. Those solutions are generally characterized by less oil dependence and reduced fuel consumption [7]. In this sense, there are many studies on EVs as a possible viable alternative, especially in countries with clean electricity matrix [8].

The positive and negative aspects of the replacement of engine-powered vehicles by electrical vehicles are identified for specifics fleets [9]. One of the advantages of EVs is the absence of exhaust emissions [10]. Another advantage is the reduced noise during operation [11]. The reduction of both noise and emissions also help to reduce health risks [12]. In comparison with conventional vehicles, EVs require minimal maintenance [13]. In addition, they have lower operation cost and higher efficiency [14]. The advantages are increased with the possibility of using the EVs in distributed generation [15]. The use of electricity produced from fossil fuels reduces their advantages [16].

One of the disadvantages of EVs is their lower autonomy, in comparison with conventional vehicles [17]. Also, EVs need the development of recharging infrastructure, which already exists for conventional vehicles [18]. Increasing use of EVs demands increased electricity provision [19]. Sustainability aspects of the use of EVs requires adequate battery disposal/recycling [20]. Finally, the main barrier for EVs is their high initial costs [12].

EVs are good alternatives in countries with low emission electricity matrix and cities with small geographic extension, since in this case they can operate all day with a single recharge. According to Tarroja et al. [21], it is preferable to produce the electricity used in EVs from renewable sources, depending on availability and load demand.

The use of EVs may provoke increased emissions from electric power generation. Monteiro et al. [22] point out that the largest CO_2

* Corresponding author.
E-mail addresses: acrt88@hotmail.com (A.C.R. Teixeira), ricardo@pucminas.br (J.R. Sodré).

http://dx.doi.org/10.1016/j.energy.2016.07.095

producers are power plants, responsible by around 40% of the world electricity production. Therefore, for the use of EVs it is desirable low-emission electricity matrices, which is the case of Brazil, for instance, where CO_2 emissions from electricity generation are low (about 135 gCO_2/kWh) in comparison with other countries. In countries such as Poland and Greece, the CO_2 emission factor from electricity generation is around 850 gCO_2/kWh.

A study developed by Varga [23] used the AVL Cruise software to simulate four different types of electric vehicles to determine the energy consumption using the New European Driving Cycle (NEDC). The results for energy consumption ranged from 0.104 to 0.127 kWh/km. This data was used to calculate CO_2 emissions from those vehicles in Romania based on electric power plant emissions during the period from 2004 to 2008, producing values that varied from 84 to 115.9 g/km.

Yuan et al. [24] simulated an electric vehicle using the AVL Cruise software and evaluated CO_2 emissions for different driving cycles (New European Driving Cycle – NEDC, 1975 U.S. Federal Test Procedure – FTP-75, Japanese Modal Cycle – JC-0, and Worldwide Harmonized Light Duty Test Cycle – WLTC) and driving ranges in China. The authors used a high CO_2 emission factor range (736 g/kWh to 1147 g/kWh), taking coal as the main source of power generation in the country. The emission factor used was 855 g/kWh, although the authors recognized that this value varies in the different parts of the country. Simulated results showed electric vehicle energy consumption around 0.16 kWh/km and CO_2 emissions about 105 g/km in the FTP-75 driving cycle. The authors concluded that, for the Chinese energy matrix, the use of EVs could reduce CO_2 emissions only for operation in distances shorter than 250 km, if compared to conventional vehicles.

The objective of this work is to analyze further the impacts of the replacement of conventional vehicles by electric vehicles on energy consumption and CO_2 emissions. The study is performed using the AVL Cruise software to simulate two similar vehicle models, one powered by an internal combustion engine and the other electric. The benefits of replacing conventional vehicles by EVs are verified using as a case study a taxi fleet of a Brazilian city, where hydroelectric power plants account for over 70% of electricity generation. The use of a renewable source of electricity is expected to increase the advantages of EVs in comparison with previous works, where the studies considered electric matrices based on fossil fuels. The extent of the reduction of CO_2 emission from the use of EVs powered by an electric matrix based on renewables is presented using different scenarios of gradual fleet replacement. An economic analysis was performed to verify the costs of replacement.

2. Methodology

The emissions of CO_2 from two vehicles of similar model were compared, one conventional, powered by an internal combustion engine (vehicle A), and the other electric (vehicle B). Table 1 presents the details of each vehicle. Vehicle A is the model that best represents the average taxi fleet in operation, which, in reality, is composed by different vehicle models. Both vehicles, A and B, were simulated under the Federal Test Procedure 75 (FTP-75) driving cycle using the AVL Cruise software. CO_2 emissions from vehicle A was calculated considering complete combustion [25], as follows:

$$CO_2(kg/h) = C_F \dot{m}_F (M_{CO_2}/M_F) \tag{1}$$

The fuel consumption map of vehicle A, available from the manufacturer, was used to evaluate the equivalent energy consumption considering the fuel as a blend of composition 78% gasoline and 22% ethanol (E22), according to:

Table 1
Details of vehicles.

Parameter	Specification	
	Vehicle A	Vehicle B
Bore × stroke	70.0 mm × 64.9 mm	–
Compression ratio	12.15:1	–
Volume displacement	1.0 L	–
Rated power	53.7 kW @ 6250 rpm	15 kW
Rated torque	93.2 Nm @ 4500 rpm	50 Nm
Fuel	E22	–
Battery type	–	Sodium-Nickel-Chlorine
Voltage	–	253 V
Energy		19.2 kW h
Recharge time	–	8 h

$$E_F = \frac{\dot{m}_F \cdot Q_{LHV} \cdot t}{3600 \cdot d} \tag{2}$$

As no database is available in Brazil for other pollutant gas components emitted from power generation, CO_2 is the only component here evaluated, as it was done in previous studies [26,27]:

$$CO_2(t_{CO_2}/km) = f_{CO_2} \cdot E_E \tag{3}$$

Four scenarios of different replacement rates of a conventional engine powered taxi fleet by electric vehicles were designed as a case study. The conventional fleet is composed by 213 vehicles, and the period of evaluation is 15 years. The fleet replacement rates adopted were 25%, 50%, 75% and 100%, with all vehicles being replaced in the beginning of the period of evaluation. Two scenarios were optimistic and two pessimistic (Table 2), and differ from each other according to the adopted CO_2 emission factor and average distance traveled by taxi per day. For each scenario daily travel distances of 200 km and 400 km by each taxi were considered, representing the minimum and the maximum values. In holiday months, the taxis were assumed to travel an additional distance of 100 km per day.

In the first scenario, a low CO_2 emission factor of 30 gCO_2/kWh was considered, corresponding to the use of hydroelectric power to supply over 70% of the electricity demand. In scenario 2, the CO_2 emission factor was slightly higher than in scenario 1 (50 gCO_2/kWh) to consider a small replacement of hydroelectric power by thermoelectric power as a response to dry winter conditions, which reduce the capacity of hydroelectric power plants. In the third and fourth scenarios, the assumption of low rain levels per year means that most of the hydroelectric power is replaced by thermoelectric power, leading to the adoption of higher emission factors.

For the calculations, the EVs electric energy consumption and the fuel consumption of the conventional vehicles were taken as constant parameters. Each month was considered to have an average of 30 days. The EVs batteries were taken as fully charged early in the day. In all scenarios, an annual growth rate of 5% was assumed for the emission factors.

Table 2
Scenarios of vehicle fleet replacement.

Scenario	CO_2 emission factor (gCO_2/kWh)	Weather conditions	Distance traveled by a taxi for a day (km)
1	30	Favorable	200–400
2	30–50		
3	90	Unfavorable	
4	90–140		

Please cite this article in press as: Teixeira ACR, Sodré JR, Simulation of the impacts on carbon dioxide emissions from replacement of a conventional Brazilian taxi fleet by electric vehicles, Energy (2016), http://dx.doi.org/10.1016/j.energy.2016.07.095