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How can energy prices and subsidies accelerate the integration of electric vehicles in Brazil? An economic analysis

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ABSTRACT

A sensitivity analysis indicates that the variables that most influence the payback period on purchases of battery electric vehicles are gasoline prices and financial incentives granted in the form of an exemption from the annual tax payment. Currently, the arithmetic mean value of the payback period for the purchase of BEVs is 24.23 years in 27 analyzed state capitals, suggesting broad-based adoption remains years away.

1. Introduction

The use of fossil fuels in conventional vehicles, which are those which convert liquid fuels energy, such as diesel and gasoline, into mechanical energy by means of an internal combustion engine (ICE), has increased greenhouse gases (GHG) emissions and other pollutants into the atmosphere, most critically carbon dioxide (CO_2), where the observed increase in its concentration in the atmosphere has risen 40% from 280 ppm in the pre-industrial revolution period to 391 ppm by the year 2011, with an average growth rate of 2.0 ± 0.1 ppm per year within the period of 2002 and 2011 (IPCC, 2014). As regards annual GHG emissions worldwide, the increase was from 27 Gt CO_2eq/year to 49 Gt CO_2eq/year between 1970 and 2010, which corresponds to an increase of approximately 81%, where the transportation sector emissions were accountable for 14% of total GHG emissions in 2010, with approximately 6.9 Gt CO_2eq/year (IPCC, 2014).

In Brazil, total GHG emissions were 1.2 Gt CO_2eq in 2012, with the transportation sector being accountable for 16.7% of such emissions, which corresponds to 0.2 Gt CO_2eq/year. If only the road transportation sector was taken into account, emissions would have been 0.18 Gt CO_2eq in 2012, or 15% of the country's total emissions (MCTI, 2014). In view of the significant contribution of the transportation sector to such emissions, transportation modes that reduce GHG emissions and air pollutants merit serious study, particularly electric vehicle (EV) technology.

The term electric vehicle encompasses hybrid electric vehicles (HEV) and plug-in electric vehicles (PEV). HEVs use an internal combustion engine and batteries that are recharged as part of normal operation of the vehicle; they cannot be recharged by the electricity network. PEVs can be plug-in hybrid electric vehicles (PHEV) or battery electric vehicles (BEV). PHEVs can have both electric and internal combustion engines, while BEVs only have electricity-driven engines (Bonges and Lusk et al., 2016). In the case of PHEVs, the ICE is used when the battery is being partially used, especially under conditions of sudden acceleration. Extended-range electric vehicles (EREV) are a special type of PHEVs with a high-capacity battery that is able to power the vehicle until it is fully dead, point at which the vehicle switches to ICE operation mode. Therefore, PHEVs run on gasoline during the period of battery discharge, while EREVs do not (Noori et al., 2015). Both BEVs and PHEVs (including EREVs) can be recharged by the electricity network.

Examples of HEVs are the Toyota Prius, Ford Fusion Hybrid, and Lexus CT. Examples of PHEVs are the Chevrolet Volt, Ford Fusion Energi, and Mitsubishi Outlander PHEV, with the Chevrolet Volt considered an EREV. The Nissan Leaf, Tesla Model S, BMW i3, Renault Zoe, and Kia Soul EV are examples of BEVs.

While Brazil is the eighth-largest vehicle manufacturer and the fourth-largest consuming market in the world, only 843 new electric and hybrid cars were licensed in the year 2015, representing only 0.04% of the total of licensed cars in the country (ANFAVEA, 2016). This shows that the necessary conditions for integrating electric vehicles in the country have not been created yet, and that there is still room to develop policies to support the proliferation of such vehicles into the Brazilian market, as has occurred in other countries. In 2014, electric vehicles sale accounted for over 300,000 units worldwide, dominated by the United States (over 100,000 units), China (over

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50,000 units), Japan (over 30,000 units) and Norway (around 20,000 units) (ICCT, 2015).

Several studies on electric vehicles have been conducted in Brazil and around the world. Silvia and Krause (2016) analyzed the impact that different political interventions could have on the adoption of battery electric vehicles in urban regions of the United States, and concluded that, although the replacement of conventional gasoline vehicles for electric vehicles brings public benefits, including the reduction of urban pollution and GHG emissions and increased energy security, it offers no private equivalent benefits.

Research conducted by Rusich and Danielis (2015) has estimated the total cost of ownership (TCO) and energy consumption during the life cycle of different automotive technologies available in Italy in 2013, and found that conventional vehicles have the lowest total cost of ownership, while battery electric vehicles feature better energy efficiency in the context of the Italian electricity generation matrix. It was also observed that battery electric vehicles are economically attractive to consumers when the annual distance traveled by the vehicle is at least 20,000 km, a much greater distance than the average in Italy, and that battery electric vehicles would only be economically competitive within the current average annual distance traveled by Italian vehicles if subsidies were granted and battery prices reduced by 42%.

Working off official estimates in Brazil, Baran and Legey (2013) believe the use of electric vehicles could reduce gasoline consumption by up to 40.7% by the year 2030, and increase electricity consumption in 31.3%, representing a 28.9% decrease in total energy consumption by the national fleet, or about 24.6×10^6 toe/year.

Dias et al. (2014) assessed the impact on electricity demand and emissions as a result of electric vehicles introduction in the State of Sao Paulo by using the simulation tool "*Long range Energy Alternatives Planning System*" (LEAP). In energy terms, it has been found that, if the state government in São Paulo compulsorily stipulated that 100% of the car fleet must be made up of electric vehicles by the year 2035, there would be a 40 TW h increase in electricity consumption compared to the status quo while, environmentally, such an initiative would reduce CO_2eq emissions in 17.3 million tons.

Nevertheless, it should be observed that neither the aforementioned items of research nor others available in the literature carry out an in-depth economic analysis from the consumers' perspective, i.e. how far each Brazilian city is from integration of EVs in its road matrix, since consumers would only be attracted to purchasing EVs if these were economically viable. There is great variation in prices of electricity, gasoline, and annual taxes among the capitals of each Brazilian state, so that an individual analysis of economic aspects of each city is vital to implementing effective public policies.

Therefore, the aim of this work is to present an overview of the economic aspects of BEV purchases from the consumers' perspective in all Brazilian state capitals in order to fill in a gap in the literature, so that decision-makers can have subsidies and hard data to plan the integration of electric vehicles in the country.

2. Methodology

2.1. Economic analysis

The economic viability analysis of purchasing battery electric vehicles is performed by calculating the payback period for each Brazilian capital. The following equation is used to calculate the payback period of purchasing a battery electric vehicle:

$$PB = \frac{CI}{R} \tag{1}$$

where PB is the payback period [years], CI is the cost of investment in BEVs [US$] and R is the annual revenue generated from BEVs [US$/year].

For the mathematical development (1), the following equations are used:

$$R = ADT\bullet(C_{ICEV}-C_{BEV}) + (T_{ICEV}-(1-D)\bullet T_{BEV}) \tag{2}$$

$$C_{ICEV} = \frac{P_{gas}}{FE_{ICEV}} \tag{3}$$

$$C_{BEV} = \frac{W_{bat.BEV}\bullet P_{elec}}{TR_{BEV}} \tag{4}$$

$$TR_{BEV} = W_{bat.BEV}\bullet FE_{BEV} \tag{5}$$

where ADT is the annual distance traveled [km/year], C_{ICEV} is the specific cost of using conventional vehicles by distance traveled [US$/km], C_{BEV} is the specific cost of using battery electric vehicles by distance traveled [US$/km], T_{ICEV} is the annual tax of conventional vehicles [US$/year], D is the discount percentage on annual tax payment granted to battery electric vehicles [%], T_{BEV} is the annual tax of battery electric vehicles [US$/year], P_{gas} is the price of gasoline [US$/l], FE_{ICEV} is the fuel economy of conventional vehicles run on gasoline [km/l], $W_{bat.BEV}$ is the amount of electricity required to recharge the batteries of electric vehicles [kWh], P_{elec} is the price of electricity [US$/kWh], TR_{BEV} is the total range of electric vehicles [km] and FE_{BEV} is the fuel economy of battery electric vehicles [km/kWh].

By using (2)–(5), the payback period of battery electric vehicles can be rewritten as follows:

$$PB = \frac{CI\bullet FE_{ICEV}}{ADT\bullet\left(P_{gas}-\frac{FE_{ICEV}}{FE_{BEV}}\bullet P_{elec}\right) + FE_{ICEV}\bullet(T_{ICEV}-(1-D)\bullet T_{BEV})} \tag{6}$$

2.2. Data

The residential electricity and gasoline prices, annual taxes of conventional and battery electric vehicles, as well as the discount percentage on annual tax payment that is granted to BEVs used in this study are shown in Table 1.

The assumptions related to the data on vehicles and their intensity of use are shown in Table 2.

3. Results and discussion

3.1. Evolution of energy prices

Energy prices directly affect the economic viability of purchasing electric and hybrid vehicles in such a way that a detailed analysis of the evolution of electricity and gasoline prices becomes important to identify the behavior of past prices and estimate future prices of such products.

In Brazil, electricity prices are set by its National Electricity Regulatory Agency (ANEEL in its Portuguese acronym), which annually publishes Ratifying Resolutions that determine energy rates for residential, commercial and industrial consumers. Such resolutions are published on an individual basis in different months for each of the country's power distributors. The graph in Fig. 1 presents the historical evolution of residential electricity prices in Brazil and in five of its important cities (ANEEL, 2017).

The graph in Fig. 1 shows a rise in average electricity prices in Brazil, with an average increase of 5.52% per year between 2009 and 2015.

The Brazilian market in fuels and biofuels is regulated by the National Agency of Petroleum, Natural Gas and Biofuels (ANP). Contrary to what occurs in the electricity market where rates are set by ANEEL, ANP has no control over the prices of any fuel, so that each distributor is free to set different prices.

The graph in Fig. 2 presents the historical evolution of gasoline prices in Brazil and in five important cities (ANP, 2017).

The graph in Fig. 2 depicts a rise in gasoline prices in Brazil at an