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Analysis of CO_2 emissions and techno-economic feasibility of an electric commercial vehicle

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HIGHLIGHTS

- Total cost of ownership of electric vehicle is 2.5 times higher than diesel vehicle.
- Purchase and battery are nearly 3/4 of costs of ownership of electric vehicles.
- In the best scenario, payback of electric vehicle occur after 13 years operation.
- Carbon dioxide emissions from electric vehicle is 4.6 lower than diesel vehicle.
- Increased autonomy of electric vehicles improve advantages on carbon emissions.

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ABSTRACT

In order to attain emissions reduction targets to improve air quality and reduce global warming, electric vehicles (EVs) arise as alternatives to conventional vehicles fueled by fossil fuels. In this context, this work presents a comparative study between an EV and its conventional version, a medium-duty, diesel engine powered vehicle, from road tests following a standard cycle in urban driving conditions. The performance parameters evaluated are EV electric energy consumption and carbon dioxide (CO_2) emissions from electricity generation and, for the conventional vehicle, exhaust CO_2 emissions and energy consumption calculated from fuel consumption and heating value. Five scenarios were built to conduct an economic viability study in terms of payback and net present value (NPV). Considering the conditions applied, the results from the environmental analysis showed that CO_2 emissions from the EV was 4.6 times lower in comparison with the diesel vehicle. On the other hand, the economic analysis revealed that the viability of the EV is compromised, mainly due to the imported parts with unfavorably high exchange rates. In the best scenario and not considering revenue from commercial application, the calculated payback period of the EV is 13 years of operation.

1. Introduction

The balance between the use of energy and the environment and issues related to global warming and air pollution are main requirements to the transportation sector. Thus, vehicle manufacturers are kept under pressure to develop cleaner propulsion systems and more efficient technologies. In this context, vehicles that use alternative fuels and electric vehicles (EVs) are in the focus in recent years. The International Energy Agency (IEA) sets policies to decrease equivalent carbon dioxide (CO_{2eq}) emissions and many countries adopted the introduction of EVs in the market as an important goal [1]. In 2009, for example, the German government set the goal of one million EVs on the streets by 2020, but until 2014 the units of pure electric vehicles were about 19,000 plus 33,000 hybrid vehicles [2]. Thus, the government has introduced some incentives for the purchase of EVs, such as tax exemption, free parking and subsidies at the time of vehicle acquisition, among others.

An important aspect to take into consideration is that EVs can serve as stored system for the power grid when used in the vehicle to grid (V2G) mode, create monetary savings opportunities and minimize negative environmental impacts of both the energy and transportation sector [3]. Despite the many benefits of V2G, it has a negative impact on battery degradation, which is very

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Nomenclature

Cbtv	traction battery cost (R$/kW h)
$Ccbs_e$	annual energy cost (R$)
$Ccbs_{d,0}$	initial Diesel cost (R$/l)
$Ccbs_e$	annual electricity consumption cost (R$)
$Ccbs_{e,0}$	initial electricity cost (R$/kW h)
Ccel	cost of recharging station (R$)
Ccom	purchase cost (R$)
$Cman_d$	annual diesel vehicle maintenance cost (R$)
$Cman_e$	annual electric vehicle maintenance cost (R$)
$CO_{2(i)}$	CO_2 emission (g/h)
CO_{2eq}	the equivalent carbon dioxide (kg)
CU_j	unit cost of maintenance (R$)
CU_{jimp}	unit cost of import maintenance (€)
EF_e	efficiency in electricity transmission (%)
$F/A_{(i)}$	ratio fuel/air (–)
FEP_{ee}	emission factor from electricity production ($kgCO_{2eq}$/kW h)
$FP_{(i)}$	corrector factor (–)
FT_j	exchange frequency (–)
GWP_{CH4}	global warming potential of CH_4 (–)
GWP_{CO2}	global warming potential of CO_2 (–)
GWP_{NO2}	global warming potential of NO_2 (–)
$HC_{(i)}$	HC emissions (g/h)
i	test mode number (–)
j	maintenance item (–)
y	year (–)
$m_{e(i)}$	exhaust gas flow (kg/h)
$m_{f(i)}$	fuel flow (kg/h)
$NO_{X(i)}$	NOx emissions (g/h)
$PBTCO_{2eq}$	annual emissions due to production/disposal traction battery ($kgCO_{2eq}$)
$PEECO_2eq$	annual emissions due to electricity consumption ($kgCO_{2eq}$)
$Pefc_d$	diesel vehicle efficiency (km/l)
$Pefc_e$	electric vehicle efficiency (kW h/km)
$PRCO_{2eq}$	emission well-to-wheel of the diesel vehicle ($kgCO_{2eq}$)
$PTCO_{2eq}$	emission well-to-tank of the diesel vehicle ($kgCO_{2eq}$/l)
QA	annual distance traveled (km)
Qj	quantity of maintenance item j (–)
Qjimp	quantity maintenance imported item (–)
TCer	exchange rate Real/Euro (R$/€)
$TCO_{d,y}$	total cost of diesel vehicle ownership (R$)
$TCO_{e,y}$	total cost of electric vehicle ownership (R$)
Tinf	annual inflation rate (%)
$Tinf_d$	annual diesel inflation rate (%)
$Tinf_e$	annual electricity inflation rate (%)
TR	annual return rate (%)
$TRCO_{2eq}$	emission tank-to-wheel of the diesel vehicle ($kgCO_{2eq}$/l)
TR_{km}	distance required for the exchange of vehicle components (km)
ρ_{S10}	diesel S10 density S10 (kg/l)

sensitive to charging times and energy throughput. The application of V2G contributes to increase the frequency of battery replacement [4]. Another point to be considered is that the increased number of EVs on the streets may cause problems in the power system, such as peak loads, losses and congestion. Some authors have been studying charging strategies such as modeling the demand dispatch calculation [5], allocation of EVs parking lots [6], demand forecast in parking lots [7] and simultaneous allocation of distributed renewable resources and EVs in parking lots [8].

Many studies focus on the evolution of the EV market in different regions and countries, such as USA [3], Iceland [9], Canada [10] and Netherlands [11]. The evolution of EVs participation in the Nordic market during the period from 2012 to 2013 was determined using statistics methods to evaluate the purchase probability of an electric vehicle in different socioeconomic types [3]. The results showed that the decisive factors were the evolution of fuel and EV prices and government incentives. In an adverse scenario (low cost of fuel and high EV price), the introduction of EVs in the market would be possible only with tax exemption. In the Netherlands, the relationship between several factors and the adoption of 30 shared EVs was studied [11]. The developed model showed that financial incentives and recharge infrastructure are decisive factors for the adoption of EVs, but none of the factors studied can guarantee increased EV sales.

Besides the economic factor, the social factor is decisive in the expansion of EVs [12]. The willingness to explore a new product and a new technology depends on customer stability and lifestyle. The consumer preference for environmentally and emerging technologies are not pre-formed and static, but dynamic built through knowledge and exposure in social interactions.

The evolution of EVs market share also raises considerations about the impacts on grid distribution. For the Netherlands it was projected that an increase of 30% of EVs fleet can increase the national grid peak load by 7% and household peak load by 54% [13]. In Italy, the charging demand is increasing between 6 and 12 a.m. when the users reach the job and plug the vehicle into the grid for charging [14]. In Brazil, it was reported that an introduction of 10% of EVs in the fleet can increase by 2% the electricity demand [8].

On the other hand, there can be electricity waste if it is not stored when the demand is lower than the current electricity level [3]. When operating in a V2G system, EVs have the capability to be used as energy storage system feeding back to the grid the idle energy of their traction batteries [15–18]. Thus, EVs deployment poses both a challenge and an opportunity for the operation of power grids Daina et al. [19]. A way to overcome the grid peak load is charging the vehicle at off-peak hours, although some studies point out that this practice has the drawback of higher emissions factor when power generation is not from renewable sources [14,20,21]. Nevertheless, in a scenario with power generation by natural gas, off-peak charging pattern results in 8% reduction in greenhouse gas (GHG) emissions if compared to uncoordinated charging [13].

Power generation mix is the major factor to take into account in EV's emissions factor calculations. EVs emission is strongly dependent on the time of the day the vehicle is charged because of variation in the power generation mix [14]. In Germany, the influence of EV charging on the specific CO_2 emission factor was analyzed for the period between 2020 and 2030, with no additional renewable power generation capacities due to EV fleet market share increase [20]. It was concluded that EV charging electricity factor is bigger than overall power consumption emission factor. Also in Germany, considering power generation from renewable sources, EV emissions were found to be 62–64% lower than conventional vehicles [22]. It was also concluded that EV emissions is lower than conventional vehicles only with annual driving distances higher than 4000 km for German current grid mix.

The maximum CO_{2eq} emissions from electric power generation to maintain the global warming potential (GWP) of EVs below the internal combustion engine vehicles was calculated for the electric