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To cite this article: E A Velandia Durán *et al* 2019 *J. Phys.: Conf. Ser.* **1414** 012014

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Comparison between electric vehicle technology and gasoline in regular operation. Pilot experience in public service

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Abstract. Urban transport is an indispensable component for the development of cities, however, the massive use of motorized modes of transport with polluting technologies has generated the non-sustainability of the sector. Colombian cities are no strangers to this problem and as an improvement strategy, the testing and implementation of electric transport technologies is considered as an opportunity for modernization, efficient use of energy, reduction of emissions and energy diversification taking advantage of the energy resources available in Colombia. In Bogotá, the taxi fleet, due to its high energy demand and responsibility in polluting emissions, is a segment where electric vehicles can offer benefits to the operator, the citizen and the city. A description of Bogotá's taxi fleet, the presentation of electric vehicle technology and a comparison between a gasoline vehicle and an equivalent electric vehicle in regular operation are presented, as well as some results from the pilot's early years. The technology has demonstrated reliability and efficiency, benefits to drivers and significant savings in greenhouse gases, but requires new incentives for massification.

1. Introduction

Transport technologies dependent on fossil fuels, urban configurations and development policies supported by the dynamics of motorization have generated problems of urban sustainability in different contexts. Some facts that demonstrate this situation are the deterioration of urban air quality; increase in greenhouse gas emissions; saturation of road capacity and high occupation of public space by vehicles; deterioration of soils and watercourses with waste such as used oils, batteries and plastics; increased transport costs in the domestic basket; impacts on animal species that cohabit in urban areas [1].

Globally, there are visible initiatives to test and start up electric taxis in real urban operation schemes. In Shenzhen (China), a pilot with 40 e-taxis was started in 2010; by the end of 2011, the fleet had increased to 300 units and the electric fleet continues to grow today. In Latin America, Mexico City has considered starting a pilot with 100 Nissan Leaf e-taxis. Among the incentives considered by the government are the elimination of tenure and vehicle verification, tax exemption, support for obtaining financing, parking and preferential circulation and circulation permit in restricted areas. In Ecuador, the city of Loja is a pioneer in the use of electric taxis with BYD and KIA typologies. Other cities that have joined the initiative are Santiago de Chile and Montevideo.

In Colombia, the transport sector is the largest energy user and the one that projects the greatest growth trends in the long term. By 2018, transport used 40% of primary energy ($\pm 91\%$ gasoline and



diesel) and was responsible for 15% of CO₂ emissions. In Medellín, Colombia, the mayor's office plans to incorporate at least three thousand electric taxis in the medium term beginning in 2019.

Bogota's transport relies heavily on liquid fossil fuels and a smaller share of natural gas in public service vehicles, taxis, fleets and private vehicles. Under this energy structure, the sector was responsible for the emission of 6 million tonnes of CO₂, 1400 tonnes of material and it is estimated that mobile sources were responsible for 80% of CO₂, CO and NO_x emissions [2].

35% of taxi services are less than 4 km away and the average distance is 6.6 km. Regarding technology, the fleet of Bogota uses mainly gasoline vehicles, however, a percentage of the fleet has been converted to natural gas vehicle (NGV). About 70% of vehicles with cylinders greater than 1400 cc have NGV system, while 35% of low-cylinder vehicles have NGV system. In general, 58% of the fleet uses gasoline, 40% uses NGV and 2% diesel. [3].

In general, the operation of the taxi service is unregulated. Although in the city there are about 60 yellow zones and a high availability of vehicles with communication equipment, the lack of regulation by local authorities and the low culture of users and drivers by a regulated operation, encourage an inefficient operation with a high percentage of kilometers without passenger.

Energy dependence on fossil fuels (national price low parity policy at international prices) and intensive use of energy make the taxi fleet an important factor in the generation of polluting emissions. Bogota's taxi fleet is responsible for 22% of NO_x emissions and only a gasoline taxi in Bogota can emit about 16 tons of CO₂ per year [2].

In this context, the use of electric vehicles in the taxi fleet can be a strategy within a plan to reduce the negative externalities of the fleet. Additionally, the use of electric energy in urban transport in Colombia favors the development of new businesses and provides benefits in terms of energy efficiency, reduction of greenhouse gas emissions and exploitation of Colombian hydroelectric potential [4]. With the rapid development of electric vehicles, increasing electric vehicle charging load will have extensive impacts on the power grid [5]. However, emissions from pure electric vehicles are more environmentally friendly than those from conventional fuel vehicles [6].

2. Methodology

Electric mobility has been identified in Bogota as a technological option that would allow the reduction of polluting emissions into the air and that contribute to climate change. In this sense, during 2011 and 2012 was structured, under the leadership of the district administration, which would be the first pilot of electric taxis in Colombia and one of the first of its kind in Latin America. With the support of the local electric sector (Codensa S.A. E.S.P.), the automotive industry (BYD), cooperation (Clinton Foundation C40), taxi affiliated companies in Bogota and the national government, the regulatory framework and business model for the pilot project of 50 electric taxis was structured. After the start of operations, Codensa S.A. E.S.P. took data from the pilot.

Based on the drivers' perceptions, the operational data captured in the first years of the pilot's operation, a comparison was made between electric technology and gasoline type combustion technology for the taxi service, allowing the identification of the competitiveness of electric technology and the benefits in energy and environmental terms, as well as the policy and infrastructure requirements for its massification in the country. This type of elements has been fundamental in the structuring of new initiatives of electric taxis in the main cities of the country.

3. Result and discussion

3.1. Transport and service operation

Bogotá is home to 18% of the Colombian population, a quarter of the national gross domestic product (GDP) and nearly 1.5 million vehicles. In its daily dynamics, nearly 17.6 million journeys are made (including journeys on foot greater than 3 minutes and articulation with neighboring municipalities), of which 46% are made on foot; for its part, public transport participated with 30% (20% collective transport, 9% "Transmilenio (TM)", 1% intermunicipal transport) and 10% vehicle as shown in Figure

1. It should be noted that 56% of trips made by vehicle are made by public transportation, while private vehicles and taxis account for 26% of trips in Bogotá/region [7].

With regard to the individual form of operation, a taxi can operate under two concepts: long shift and short shift. On long shifts, a driver who works 14 hours a day can cover about 240 km (about 80% of vehicles); on double shifts, two drivers in 24 hours cover a total of 400 km. This means that an average taxi can travel 7 times more than a private vehicle, *i.e.* 84000 km per year. Under these considerations, the taxi fleet, which represents 4% of Bogotá's vehicle fleet, has a route equivalent to 25% of the vehicle fleet, a figure that evidences the relevance of this mode of transport in energy and environmental terms.

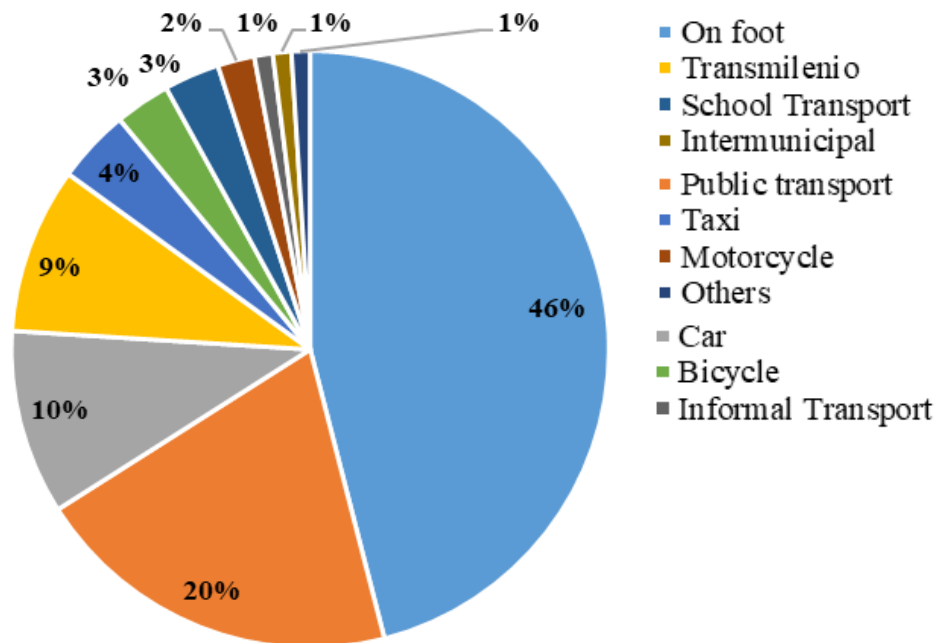


Figure 1. Modal distribution of daily trips in Bogota.

3.2. Battery electric vehicle technology

Electric vehicles are nearly 90% energy efficient. The greater efficiency of electric traction lies in the better use of the energy potential of the fuel (electric energy) and the simplicity of the processes of energy transformation. In this configuration the vehicle is energetically dependent on batteries that can be recharged from the domestic electrical network, fast recharging stations and through energy regeneration during braking.

The massive use of electric vehicles not only seeks a reduction in fuel consumption, the reduction of pollutant emissions and waste as lubricants, but also projects the reformulation of the concept of use of renewable sources and distribution of electricity. Wind and solar energy sources, as well as "Smart Grids" will be an alternative that approaches the use of electricity in urban transport. One of the barriers in the massification of electric vehicles is in the price of the vehicle.

The cost of a Battery electric vehicle (BEV) can be 2.5 times the cost of an equivalent internal combustion vehicle. This differential is directly associated with the cost of batteries and recharging equipment. Likewise, the energy density of the batteries generates an additional pressure related to the design of the vehicle: greater autonomy demands greater volume of the batteries, a fact that impacts on the cost of the vehicle and consumption.

3.3. E-Taxis approach for Bogotá

In Bogotá, an operation with e-taxis may be possible taking into account the technological availability, topographic conditions and characteristics of taxi trips in the city, local incentives and the articulation

of important factors such as national and local government, energy sector companies and the automotive industry.

Today, the use of electric technologies in the taxi fleet is considered a strategy within a plan to reduce the externalities of the transport sector at the local level, with positive impacts in terms of greenhouse gas (GHG) reduction, use of available hydro-energy potential (energy efficiency) and installed electric infrastructure.

Taking into account its benefits, the national and district governments have generated different policies to facilitate the implementation of BEV technology in the local operational context. Bearing in mind that BEV technology is not developed locally, and that price is a barrier to its massification in the Colombian context, national regulations tend to reduce the additional costs assigned to any vehicle that enters the country for commercialization [8].

For 2019, a BYD - E6 vehicle has an estimated cost in Bogota of USD\$ 45000, price that does not include tariff and VAT, this as part of the benefits of the national government to electricity technologies. The Nissan Leaf reference has a price close to USD\$ 35000 (excluding taxes). In contrast, the most widely used combustion vehicle in the city is sold at prices approaching US\$ 16000. Although there are differences in investment that favor the combustion vehicle, the costs in fuel and maintenance allow generating benefits to the operator of the electric vehicle. This operational scheme seeks to reduce vacuum energy consumption and increase the occupancy rate per kilometer travelled. The last reference E6 (BYD, 2018), considers an autonomy close to 400 kilometers, typology that operates in Bogota in special public transport services [9].

Under the proposed operating scheme, a single recharge is expected at night to take advantage of the driver's rest time, possible lower electricity prices and increase battery life with a daily recharge cycle. However, the installation of recharging equipment is considered in some areas of the city to guarantee emergency recharging. The recharging equipment in public roads must have government incentives not to be transferred to the user in the first years of implementation of the technology and generate incentives for urban use.

The cost of recharging equipment for the batteries is estimated at USD\$ 2500 per vehicle and an additional cost for connection and security. Considering an operation with a single daily recharge and a daily travel of 150 km, an e-taxi could represent savings of 60% with respect to the gasoline vehicle as indicated in Table 1; BEV energy efficiency does not consider the use of air conditioning or devices external to the vehicle. Likewise, if one considers that the vehicle used has a greater autonomy and can travel more kilometers per day, the savings in money for the vehicle operator will be greater.

Over time, the savings from the use of electricity over gasoline is projected incrementally taking into account the trend in the price of fossil fuel with rates that exceed the average rates of the price of electricity.

Table 1. Comparative annual costs by energy according to technology.

Indicator	Gasoline	Electric
Energy efficiency	40 km/gal	0.2 kWh/km
Route	150 km	150 km
Days/year	350	350
Annual route	52500 km/year	52500 km/year
Fuel consumption per vehicle	1313 gallons	10500 kWh/km

With regard to batteries, replacement is required when their storage capacity is reduced to such an extent as to affect the vehicle's operability. These batteries represent a cost of about 40% of the electric vehicle. For a regulated long shift operation, with a daily recharge, it is estimated that the replacement would take place after 10 years. In the Colombian market, BYD has offered a 10-year guarantee that allows investors to have peace of mind [9].

It is important to note that batteries can have a secondary use by recognizing the existence of a storage capacity remaining after being replaced in the vehicle, a fact that offers a possible lifesaver. Likewise,

projections made by the U.S. Department of Energy estimate that the cost of batteries will be reduced in the medium and long term as a result of economic dynamics and developments in efficiency and recycling of compounds, under which replacement may not represent pressures to the vehicle owner [10].

In terms of emissions, a BEV is the only option for zero urban emissions and its total emissions are associated with the sources of electricity generation. The estimated CO₂ savings from the use of an e-taxi with respect to a gasoline vehicle in regulated long shift operation is 7.2 ton/year, as indicated in Table 2. For the BEV, the average emission of the Colombian electricity generation sector was considered; however, the emission factor of the vehicle did not include emissions from production to the gasoline tank.

Table 2. Comparative annual CO₂ emissions by technology.

Indicator	Gasoline	Electric
Energy efficiency	40 km/gal	0.2 kWh/km
Annual Route	52500 km/year	52500 km/year
Fuel consumption per vehicle	4961 liters	10500 kWh/km
CO ₂ emissions factor	2.1 kg/l	0.288 kg/kWh
Reductions generated fleet	10.4 ton	3.02 ton

With the implementation of electric vehicles is considered a reduction of NO_x and CO₂ emissions in the city with significant benefits in air quality according to the degree of penetration of the technology. The benefits in energy and environmental terms are visible, however, for the operator the benefits are not completely attractive in financial terms. The savings in fuel and maintenance are identifiable but the financial costs are greater considering that you will have to pay for a higher priced vehicle, you will have to pay more taxes and your daily income will be reduced if you consider that they depend on the kilometers traveled daily.

Under these considerations, the incentives required by the operator are associated with the expansion of transport capacity exclusively for electric vehicles, preference for parking at sites such as the airport or areas of high demand for the service, offering the e-taxi service by the operator during the request for the service by telephone and the creation of special parking sites. In Bogotá, the dismantling of the "peak and plate" restriction for electric taxis decreed in 2012 favors the owner by having a greater number of working days.

The Bogotá Mayor's Office issued decrees 677 of 2011, 407 of 2012, 324 of 2012 and 376 of 2013, through which legal support was given to the development of the pilot. After this time, electric taxis could be registered and used as private vehicles. Within the pilot was approved in 2012 by the Ministry of Transport and the district secretariat of mobility, the increase of transport capacity (fleet limit) in 50 quotas provided that the vehicles were with BEV technologies and assigned within the pilot program to 10 years starting in 2013 [11]. For the charging of these vehicles, the local energy company Codensa S.A. implemented and operates a network of semi-rapidly charged "electrolineras" distributed in four strategic points of the city.

The reduction in mileage is associated with a change in drivers' operational strategy, partly associated with the fear of running out of charge in the batteries. With regard to energy efficiency, a yield of close to 4 km/kWh and an autonomy of more than 300 km/load have been identified, figures slightly lower than those presented by the supplier in its technical sheets. The results in energy terms have been encouraging and show the possibilities of technology in this segment of transport with high mileage use.

Based on the good results of the Bogotá experience, the city of Medellín is considering plans to start an electric taxi program. In the Aburrá Valley, metropolitan area, where Medellín is located, deaths attributed to urban air pollution generated costs estimated at COP\$ 2.8 billion, equivalent to 5% of the metropolitan area's GDP [12].

4. Conclusions

E-taxis offer an opportunity for the operator under certain operational and political conditions, the greatest environmental benefits for the city and important benefits for energy efficiency, innovation and competitiveness at the country level. The fuel cost differential and maintenance savings between an electric vehicle and a gasoline equivalent vehicle, added to the tax and regulatory operating benefits for electric vehicles at the national and local levels, offer opportunities that enable the use of BEV technology in the taxi service in Bogotá.

The knowledge and implementation of the new technology requires additional benefits to the existing ones related to financing and taxes, but the subsidy to components of electrical infrastructure is considered relevant. It is also essential to dismantle the contribution of 20% and 19% VAT to the price of kWh, taxes that reduce the economic savings of using electricity in transport. It is considered a participation of the city in facilitating public spaces for the installation of “electrolineras” and it is recommended an operation with regulated long shift electric taxis with benefits in dispatch shifts, preferential parking that represents additional economic benefits to the owner and visibility of the initiative from the authorities.

The electric vehicle demonstrates a high economic competitiveness compared to a gasoline vehicle; however, the gaps are reduced when the vehicle uses NGV. It is important to mention that NGV does not have a tax burden, there are incentives for vehicle conversion and its price has remained in a stable scenario. Although the maintenance cost of a NGV taxi is higher than the electric one, the savings for this concept and for fuel are not enough to cover the price differential in the initial investment.

It requires a policy of massification of technology in the taxi service recognizing the energy and environmental benefits. Under this policy, electricity infrastructure for public recharging could be driven by the electricity sector, which has the capacities for its development in the short term. In addition, a clear signal from the city to the market could increase the supply of electric vehicle types, reduce local vehicle prices, and increase support and maintenance capacities, which are currently limited.

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