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Transition of Electric Mobility in Colombia: Technical and Economic Evaluation of Scenarios for the Integration of E-taxis in Bucaramanga

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ABSTRACT

Globally, the transport sector has been directed towards electric mobility by policies, regulations, development strategies and economic incentives. The transport sector has an important strategic role in the economic development of a country, the sustainability of this sector has an impact on political and scientific discussions due to its environmental impact. In Colombia, the global targets for reducing polluting emissions begin to drive the renewal of the automotive park towards electric mobility, therefore, this research was carried out with the aim of carrying out a technical and economic analysis of scenarios for the e-taxis in Bucaramanga, the incentives applied in the two projects developed in the two most important cities of Colombia were taken as the basis to compare possible implementation scenarios in the short and medium term. Three technologies (gasoline, gas and electric) were evaluated that were tested using the TAC/km indicator, the financial viability was assessed based on two financial kindness criteria (NPV and IRR). The results obtained allow to conclude two strategies that make it possible to incorporate the e-taxis in Bucaramanga, (1) exemption from payment of taxi registration, in case of incorporation of a new vehicle; (2) economic incentive of more than 20% at the time of purchase of the EV, accompanied by a 25% increase in the cost of the minimum service fee, in the case of the replacement of a taxi.

Keywords: Electric taxi Colombia, E-taxi policies, Electric mobility, Electric vehicle, Public transport sector
JEL Classifications: Q01, Q4, Q42

1. INTRODUCTION

The transport sector has an important strategic role in the economic development of a country, the sustainability of this sector has an impact on political and scientific discussions. The negative environmental impact of the massive flow of goods and people, the use of fossil fuels and the fleet of vehicles in old age, deteriorate air quality, being the main motivation for political and scientific debates (Carteni et al., 2020). Diversification in the energy matrix that supplies the transport sector is relevant to introduce itself to electric mobility, even if it presents new risks, technological challenges, and commercial trends (Nieuwenhuis et al., 2020).

The world estimates 1 billion vehicles and only 1% of these are electric vehicles, yet world leaders in the car market such as China, Europe and the USA are developing and implementing subsidies and public policies to enable the procurement of electric vehicles more easily (Henderson, 2020; IEA, 2018), in turn, there is a great deal of public intervention in new commercial trends in supply chains, renewable and non-renewable energy supplies, and the adaptation of urban spaces for the recharging of electric vehicles (Henderson, 2020; Keith et al., 2019; Kuby, 2019).

For Colombia, global emission reduction targets are beginning to drive the renovation of the automotive park to electric mobility in some of its major cities, focusing on the public transport sector. This research presents a technical and economic analysis of scenarios for the integration of electric taxis in Bucaramanga, one of the five most important cities in Colombia.

2. AN APPROACH TO GLOBAL ELECTRIC MOBILITY

Globally, the transport sector has been directed towards electric mobility using policies, regulations, development strategies and economic incentives. Table 1 presents a list of relevant incentives, policies, regulations, and strategies in countries that have already begun the transition to electric mobility with the vision of promoting the use of electric vehicles and reducing polluting emissions.

3. ELECTRIC MOBILITY IN COLOMBIA

Colombia detected that its automotive park has potential for improvement to contribute to the 20% reduction in polluting emissions by 2030, according to the United Nations Conference on Climate Change (La República, 2018), because the average age of vehicles in Colombia is approximately 16 years according

Table 1: Global benchmarks of incentives, policies, and strategies to promote the use of electric vehicles

Country	City/State	Incentives, policies, and strategies
Italy (Scorrano et al., 2020)	Florence	ECOBONUS: $4,513.62 - 6,770.43 USD 70 free taxi records Government subsidy for the purchase of electric vehicle
Netherlands (Dam et al., n.d.)	Amsterdam	Privileges at busy taxi stations such as Leidseplein Station Subsidy of $11,291.15 USD for purchase of electric taxis
Italy (Danielis et al., 2018)	-	Subsidy of $5,645.48 USD for electric vehicle purchase Annual grant of $451.61 USD for parking and vehicle recharging locations
France (Crist, 2012)	Paris	Subsidy of $5,645.48 USD for electric vehicle purchase
South Korea (Park et al., 2014)	-	50% discount allowance for electric taxi purchases from taxi service providers
USA (Park et al., 2014)	-	Subsidy of $7,500 USD for purchase of electric vehicles Subsidies for the installation of Wallbox for electric vehicle buyers
China (Yang et al., 2018)	Changsha	Subsidy of $254.26 USD/kWh of vehicle battery capacity.
China (Yang et al., 2018)	Beijing	The policy is specifically designed to subsidize the adoption of BEV in the taxi fleet and shorten the life of Combustion Gas Vehicle (CGV) taxis from 8 to 6 years. If a CGV taxi is withdrawn within 7 years, you can receive a minimum subsidy of ¥10,000 per vehicle and tax exemption on the purchase in addition to government subsidies
China (Li et al., 2016)	Shenzhen	Government program that incentivizes: Research and development of electric vehicles, charging infrastructure and new business/utility models Subsidies on the purchase of electric vehicles
China (Yang et al., 2013)	-	Policies, Regulations and Strategies (2001-2012) for electric vehicles managed by the Ministry of Industry and Information Technology of the People's Republic of China, National Development and Reform Commission, Ministry of Science and Technology of the People's Republic of China and the Ministry of Finance of the People's Republic of China
China (Zheng et al., 2012)	-	Governance plan called "Plan of Shaping and Revitalizing the Auto Industry" It was developed in 13 cities in China The goal was to manufacture 0.5 million vehicles with alternative fuels in 3 years
Norway (Mersky et al., 2016)	Oslo	Exemption from registration tax Free public parking is possible on site Toll exemptions IVA exemption Access to the bus lane Reduced ferry fares Charging station constructions
United States (America, 2019; Zhang et al., 2014)	California, Washington, Massachusetts, New Jersey, Oregon, Colorado, Montana, South Carolina	Economic incentives from $500 USD to $6,000 USD reflected in: Income tax credit, Sales tax exemption, Purchase rebate, Conversion cost credits and High-Occupancy Vehicle Lane
Canada (Hardman et al., 2017)	-	Economic incentives from $3,850 USD - $6,850 USD at points of sale
Germany (Hardman et al., 2017)	-	$5,500 USD economic incentives at points of sale
Japan (Hardman et al., 2017)	-	$7,800 economic incentives reflected in points of sale and IVA exemption
Netherlands (Hardman et al., 2017)	-	Economic incentives between $1,110 - 22,000 USD in sales taxes and IVA exemptions
United Kingdom (Hardman et al., 2017)	-	Economic incentives between $7,500 -10,000 USD at points of sale

to the Colombian Association of Motor Vehicles (ANDEMOS) (Dinero, 2016), the Colombian government has made efforts to promote the renovation of the motor park through pilot projects in cities of the country with a focus on Taxi Fleet Companies (TFC), independent taxi drivers and the mass transit sector (electric buses) (Sclar et al., 2020). The main projects that Colombia has developed to promote the transition of the transport sector to electric mobility are the Project of Bogotá and Project of Medellin.

3.1. Project of Bogota

The Project of Bogota consisted of the pilot operation of 50 e-taxis within the city without the mobility restrictions and the exemption from registration[1] applied to conventional taxis, with a temporality of 3 years from the validity of the 677 of 2011 (de Bogotá, 2011), then the current term was extended 2 years by District Decree 407 of 2012 (de Bogotá, 2012), for a total of 5 years, which was subsequently extended again for 5 years more, for a total of 10 years, by District Decree 376 of 2013 (de Bogotá, 2013).

3.2. Project of Medellin

The project of electric taxis in Medellin was presented on May 3, 2019 by the mayor of Medellin and the company "EMPRESAS PÚBLICAS DE MEDELLÍN (EPM)," in order to introduce 1500 electric taxis in its first 3 years through the replacement of taxis that use conventional fuels such as gasoline. EPM provided an economic incentive of $5,584.13 USD to offset an electric vehicle's increased initial investment than internal combustion engine vehicles (ICE). In addition, Resolution 2019500009417 issued by the Medellin Mobility Secretary determined that the minimum fare for individual motor land-based public transportation for passengers in electric vehicles is worth $2.07 USD different from the $1.67 fare that conventional taxis have (Alcaldía de Medellín, 2019). The incentives have generated a great reception by conventional taxi owners to migrate to the electric vehicle, and by users who positively value their comfort.

4. TECHNICAL AND ECONOMIC EVALUATION FOR THE INTEGRATION OF E-TAXIS IN BUCARAMANGA

To technically evaluate the integration of electric vehicles in the transport sector of Bucaramanga, it was decided to apply a TFC that had a long history in this sector, this TFC has 31 taxis that use two types of fuel: gas and gas, where its most representative vehicle model is the Hyundai i10.

The limited time of use to test the ten TFC vehicle sample gave way to a characteristic route. The development of the characteristic route was made from a heat map with the most frequent routes or routes used by taxi[2] drivers. The mobile application "My track" was the tool used for the acquisition of data measured in real time during each day of the taxi travel, the data obtained were processed using the Map Source and Microsoft Excel software (3D Map add-on), where the first software extracted the coordinates of the routes made by the taxi sample and through the Microsoft Excel 3D Map add-in the information was examined to obtain the route overlay and thus the heat map that subsequently allowed the obtaining of the characteristic route.

Three vehicles with different technologies were used (Table 2) to simultaneously route the characteristic route, making appropriate measurements to determine actual energy consumption and associated costs.

The selected vehicles were evaluated in six scenarios as shown in Table 3, global considerations were assumed for all scenarios and some particular considerations varying by scenario (Table 4). The financial kindness procedures chosen to evaluate the scenarios were Net Present Value (NPV) and Internal Rate of Return (IRR).

Table 2: Technical specifications for selected vehicles

Technical specifications	Gasoline	Gas	Electric
Model	Hyundai i10	Hyundai i10	BYD e5
Cylinder (cc)	1245	1245	-
Battery capacity (kWh)	-	-	60
Power (cv)	87	87	160
Torque (Nm)	120	120	310

Table 3: Scenarios to be evaluated in each period

Scenarios	Initial year	Final year
1. New taxi, natural person.	2019	2028
2. TFC vehicle replacement.	2019	2028
3. Taxi replacement, natural person.	2019	2028
4. New taxi, natural person.	2026	2035
5. TFC vehicle replacement.	2026	2035
6. Taxi replacement, natural person.	2026	2035

Table 4: Global and particular considerations

Global considerations
3.1. Project life of 10 years
3.2. Initial investment of 100% without bank financing
3.3. Projected maintenance and operating costs from the 4.42% Consumer Price Index (CPI) (historical average 2003 - 2019). USD 31/12/2019 (Colombia, 2019)
3.4. 15% discount rate.
3.5. Scenarios 4, 5 and 6 consider the technological maturation of batteries, therefore the price of the vehicle decreases (Fraile-ardanuy et al., 2018)
Particular considerations
A. TFC assumes operating and maintenance costs
B. The taxi is driven by its owner
C. Exemption from the cost of registration (Project of Bogotá)
D. Cost of fuel assumed by the driver
E. TFC owns the taxi records
F. $5,584 incentive for purchasing an electric vehicle (Project of Medellin)
G. The driver has his taxi record
H. Initial investment is equal to the cost of the vehicle
I. The driver's daily income is $45.77[3] USD
J. TFC gets $24.41 USD of daily driver's fare
K. The driver's daily income is $59.33 USD (projected from the average historical CPI 2003-2019)
L. TFC gets the daily driver's rate of $31.64 USD (projected from the average historical CPI 2003-2019)

1 Pay-per-seater for operate as a taxi public service vehicle.
2 The average distance traveled in a day by a taxi driver is 200 km/day.
3 Direct private interviews with TFC taxi drivers made it possible to know the average value of their daily income.

Below are the equations used to economically evaluate the scenarios raised previously, thus obtaining the maintenance costs (Table 5), costs per operation (Table 6) and the initial investment for the purchase of a taxi according to the type of energy (Table 7):

$$CM_A = CMM + CMSFLL + CMEA + CME \quad (1)$$

Where, CM_A: Annual maintenance cost (USD/year), *CMM*: Cost per maintenance of the engine (USD/year), *CMSFLL*: Cost for suspension maintenance, brakes and tires (USD/year), *CMEA*: Cost for maintenance of structure and accessories (USD/year), *CME*: Cost for electrical maintenance (USD/year).

$$CO_A = CA + CST + CT + CSOAT + CTO \quad (2)$$

Where, CO_A: Cost per annual operation (USD/year), *CA*: Administration cost (USD/year), *CST*: Insurance taxi cost (USD/year), *CT*: Cost per techno-mechanical review (USD/year), CSOAT: Cost per SOAT (USD/year), *CTO*: Cost per trading card (USD/year).

$$CCRC = \frac{CRC \times PC}{RC} \quad (3)$$

Where, *CCRC*: Fuel cost per kilometer according to characteristic route (USD/km), *CRC*: Characteristic route consumption (gal; m^3; kWh), *PC*: Fuel price (USD/gal; USD/m^3; USD/kWh), RC: Characteristic route distance (km).

$$TA = TD \times DA \quad (4)$$

Table 5: Maintenance costs for 2019

System	Gasoline		Gas		Electric	
	USD	%	USD	%	USD	%
Engine	$588.9	62.9	$619.4	64.0	$96.9	24.1
Suspension, brakes, and rims	$212.9	22.7	$212.9	22.0	$172.0	42.8
Structure and accessories	$36.6	3.9	$36.6	3.8	$35.1	8.7
Electronic	$98.3	10.5	$98.3	10.2	$98.3	24.4
Total annual cost	$937	100	$967	100	$402	100

Table 6: Costs per operation for 2019

Operational Requirements	Gasoline		Gas		Electric	
	USD	%	USD	%	USD	%
Administration	$201.40	28.8	$201.40	28.8	$201.40	30.1
Insurance	$256.32	36.6	$256.32	36.6	$256.32	38.3
Techno-mechanics	$60.45	8.6	$60.45	8.6	$30.22	4.5
SOAT[4]	$120.23	17.2	$120.23	17.2	$120.23	18.0
Operation card	$61.03	8.7	$61.03	8.7	$61.03	9.1
Total annual cost	$699.42	100	$699.42	100	$669.20	100

Table 7: Initial investment for the purchase taxi according to the energy

Item	Gasoline	Gas[5]	Electric
Vehicle price	$15,867	$16,632	$32,650
Taxi registration (Ministerio de transporte., 2001)	$27,463	$27,463	$27,463
Initial investment	$43,330	$44,095	$60,113

4 Compulsory Traffic Accident Insurance (SOAT).

5 The additional cost of the gas vehicle is due to the cost per conversion to this fuel.

Where, *TA*: Annual work (km/year), *TD*: Daily work 200 (km/day), *DA*: Working days per year (day/year), 312 day/year.

$$CC_A = TA \times CCRC \quad (5)$$

Where, CC_A: Annual fuel cost (USD/year).

$$TAC = CM_A + CO_A + CC_A ; TAC_i = \sum CM_{A_i} + CO_{A_i} + CC_{Ai} \quad (6)$$

Where, *TAC*: Total annual cost (USD/year), *i*: Year in which it is evaluated.

$$\frac{TAC}{km} = \frac{TAC}{TA} ; TAC_i / km = \frac{TAC_i}{TA} \quad (7)$$

Where, *TAC/km*: Total annual cost per kilometer traveled over the life of the vehicle (USD/km).

5. RESULTS

The heat map (Figure 1) shows the overlap of the routes made by the monitored vehicles, determining the characteristic route (Figure 2) that was traveled to establish the comparison of the consumption of the vehicles for each type of technology, Table 8 exposes the results obtained.

Table 9 shows the annual fuel costs calculated for the three types of vehicles (gasoline, gas and electric) from the characteristic route and the consumption required to travel. Table 10 summarizes the results obtained by evaluating the 6 scenarios presented as global, particular, and financial kindness criteria (NPV and IRR).

In the financial comparison of scenario 1 (Figure 3) it was observed that for a natural person, the most viable option based on the NPV (gasoline $9,706,750 USD; gas $17,827.31 USD; electric $7,660,860 USD) is to buy a taxi that uses gas as energy; however, if an incentive such as the Project of Bogota is applied, purchasing

Figure 1: Heat map of the route overlay from the TFC sample

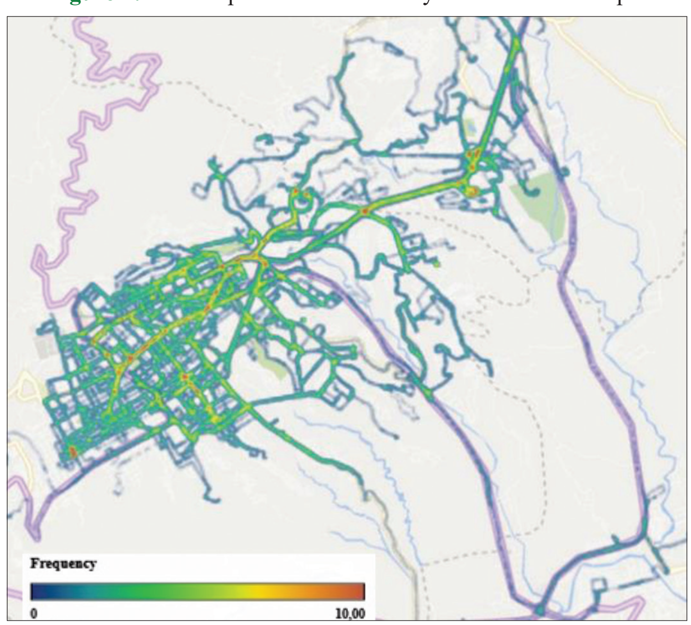


Figure 2: Characteristic route

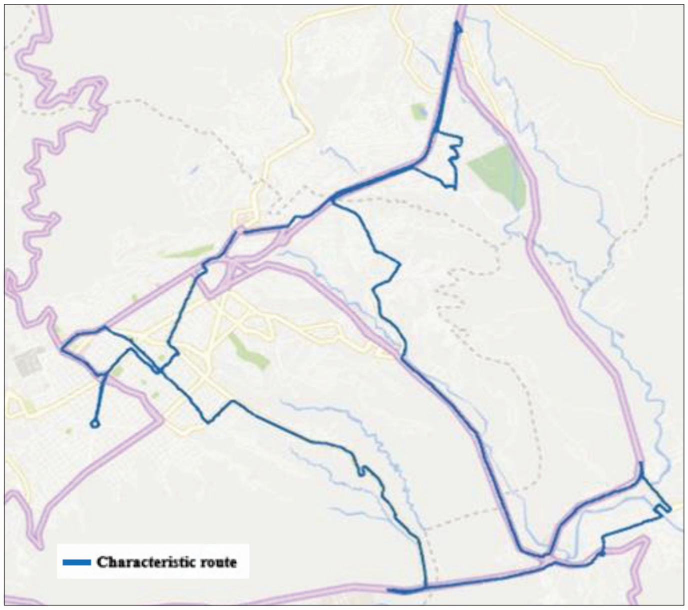


Table 8: Actual consumption according to characteristic route

Aspect	Gasoline	Gas	Electric
Consumption	4,520 (gal)	13.228 (m^3)	31,462 (kWh)
Characteristic route	44.6 (km)	44.6 (km)	44.6 (km)

Table 9: Fuel costs for 2019

Fuel	Price	Unit	Daily consumption	Unit	Annual cost[6]	Unit
Gasoline	$2.78	(USD/gal)	4.520	(gal)	$3,916	(USD)
Gas	$0.46	(USD/m^3)	13.228	(m^3)	$1,888	(USD)
Electric	$0.16	(USD/kWh)	31.462	(kWh)	$1,616	(USD)

6 312 working days a year according to the direct private interviews with TFC taxi drivers.

an electric taxi is the best option considering the NPV (gasoline $9,706,750 USD; gas $17,827.31 USD; electric $35,123.83 USD).

Figure 4 presents the financial comparison of scenario 2 that the most viable option for the TFC is to buy a taxi that uses gasoline as energy according to the NPV (gasoline $19,174.29 USD; gas $18,231.41 USD; electric $ 11,278.74 USD), although if policies are integrated as in the project of Medellín, buying an electric taxi is the best alternative depending on the NPV (gasoline $19,174.29 USD; gas $18,231.41 USD; electric $21,958.78 USD).

The financial comparison of scenario 3 (Figure 5) presents the replacement of a taxi driver's vehicle, in which it was detailed that the most viable option according to the NPV (gasoline $37,169.72 USD; gas $45,290.28 USD; electric $35,123.83 USD) is to renew your vehicle for one that uses gas as fuel, however, if policies such as the Project of Medellin are incorporated, the best choice according to the NPV (gas $37,169.72 USD; gas $45,290.28 USD; gasoline electric $46,038.90USD) are electric vehicle and gas vehicle.

In the financial comparison of scenario 4 (Figure 6) it was observed that for a natural person, the most viable option is to buy a taxi that use electricity as energetic according to the NPV (gasoline $18,536.42 USD; gas $18,788.64 USD; electric $25,611.36 USD).

Figure 7 presents the financial comparison of scenario 5 it was determined that for the TFC, the most viable option is to buy a taxi that uses electricity as energy according to the NPV (gasoline $12,233.71 USD; gas $11,049.82 USD; electric $27,426.84 USD).

The financial comparison of scenario 6 (Figure 8) presents the replacement of a taxi driver's vehicle, in which it was detailed that the most viable option according to the NPV (gasoline $54,271.30 USD; gas $54,517.66 USD; electric $58,988.94 USD) is to renew your vehicle for one that uses electricity as energy.

As a result, the TAC/km is presented, which is set out in Figure 9, demonstrating that electric vehicles have a positive gap that tends to increase relative to ICE vehicles over the years.

Table 10: Results obtained for each scenario evaluated according to particular considerations and financial kindness criteria

Scenarios	Particular Considerations	Fuel type per vehicle	Initial investment (USD)	NPV (USD)	IRR (%)
1	B-C-I	GASOLINE	$43,330.46	$9,706,750	17
		GAS	$44,094.55	$17,827.31	19
		ELECTRIC	$60,113.39	$7,660,860	16
		ELECTRIC (PROJ. BOG)	$32,650.42	$35,123.83	24
2	A-D-E-F-J	GASOLINE	$15,867.49	$19,174.29	24
		GAS	$16,631.58	$18,231.41	24
		ELECTRIC	$32,650.42	$11,278.74	18
		ELECTRIC (PROJ. MEDELLIN)	$21,970.38	$21,958.78	23
3	B-D-F-G-H-I	GASOLINE	$15,867.49	$37,169.72	30
		GAS	$16,631.58	$45,290.28	31
		ELECTRIC	$32,650.42	$35,123.83	24
		ELECTRIC (PROJ. MEDELLIN)	$21,970.38	$46,038.90	29
4	B-D-K	GASOLINE	$56,168.84	$18,536.42	18
		GAS	$57,159.31	$18,788.64	18
		ELECTRIC	$62,817.53	$25,611.36	19
5	B-D-G-H-K	GASOLINE	$20,568.87	$12,233.71	20
		GAS	$21,559.34	$11,049.82	20
		ELECTRIC	$29,550.16	$27,426.84	23
6	A-D-E-H-L	GASOLINE	$20,568.87	$54,271.30	31
		GAS	$21,559.34	$54,517.66	30
		ELECTRIC	$29,550.16	$58,988.94	28

Figure 3: Scenario 1 - Financial comparison of vehicles (gasoline, gas and electric)

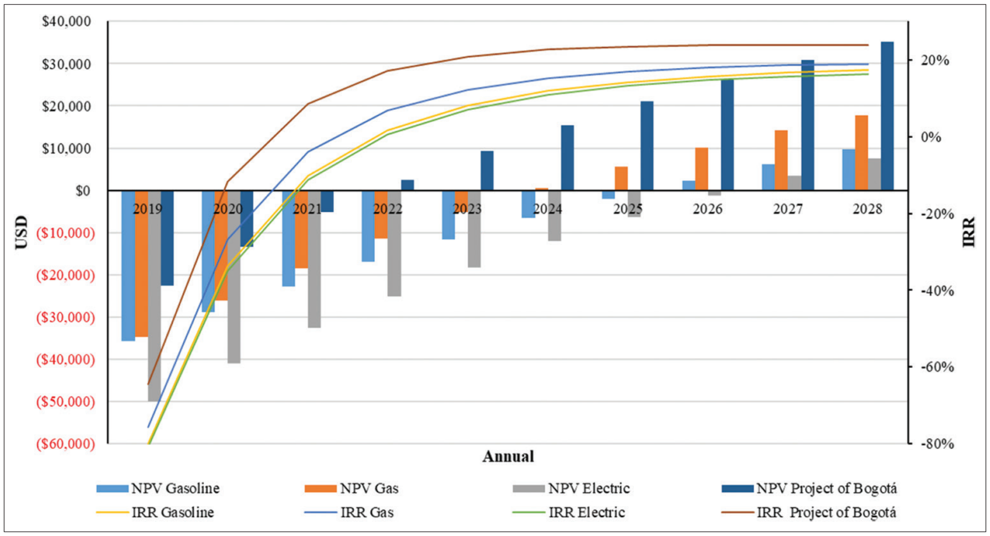


Figure 4: Scenario 2 - Financial comparison of vehicles (gasoline, gas and electric)

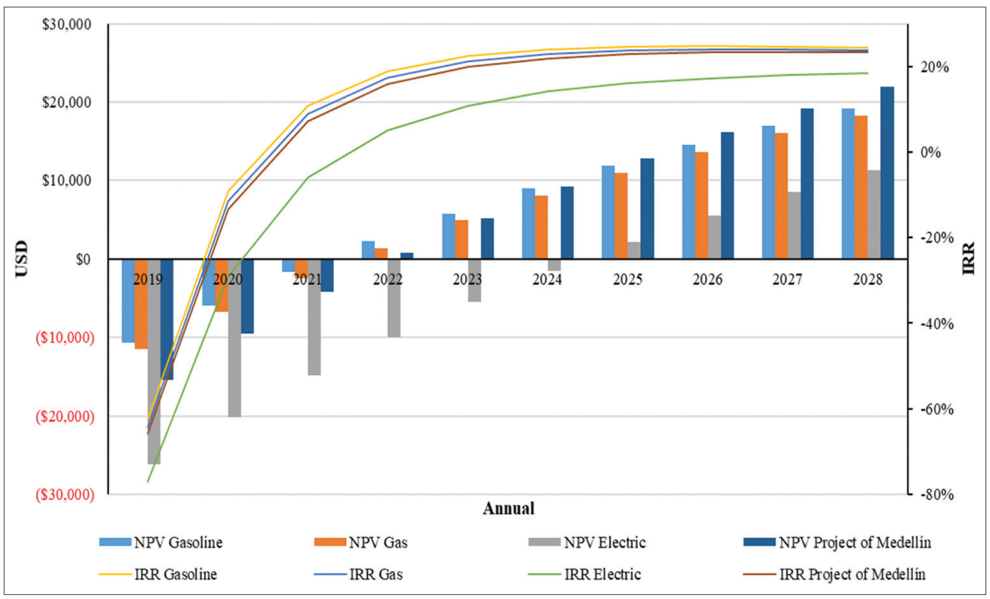


Figure 5: Scenario 3 - Financial comparison of vehicles (gasoline, gas and electric)

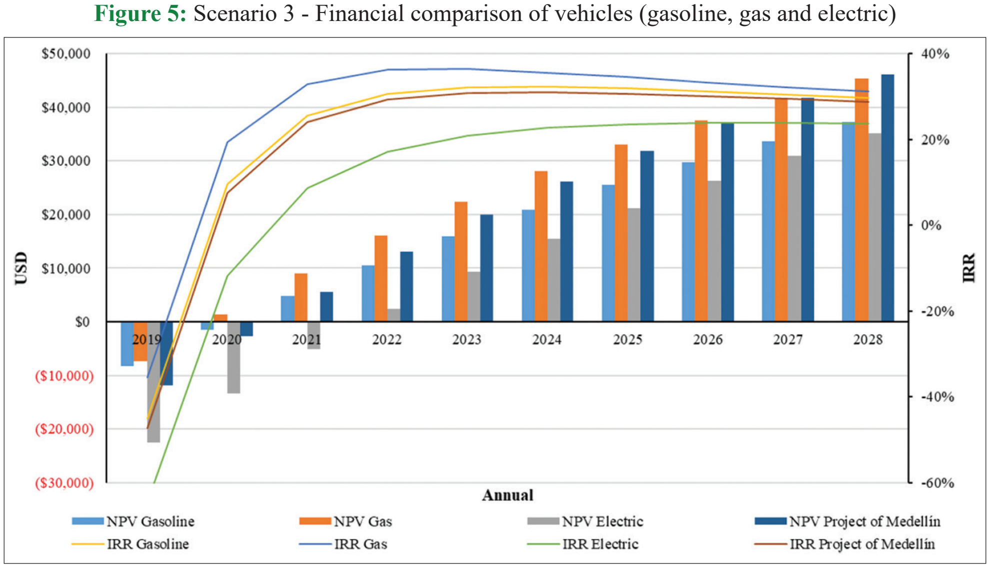


Figure 6: Scenario 4 - Financial comparison of vehicles (gasoline, gas and electric)

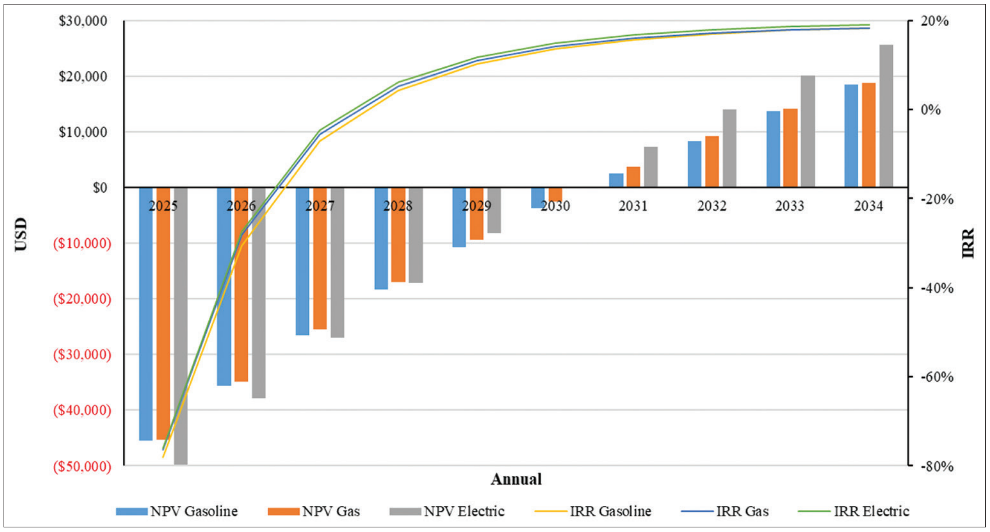


Figure 7: Scenario 5 - Financial comparison of vehicles (gasoline, gas and electric)

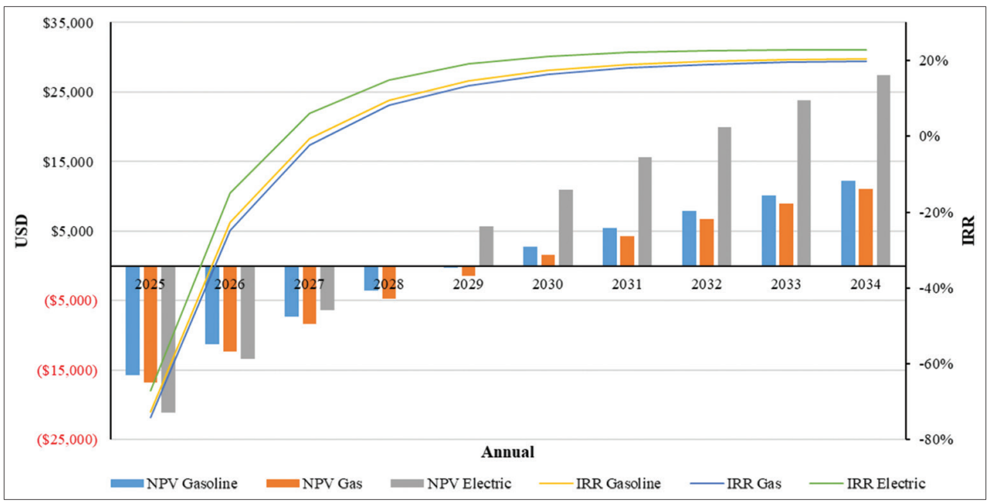


Figure 8: Scenario 6 - Financial comparison of vehicles (gasoline, gas and electric)

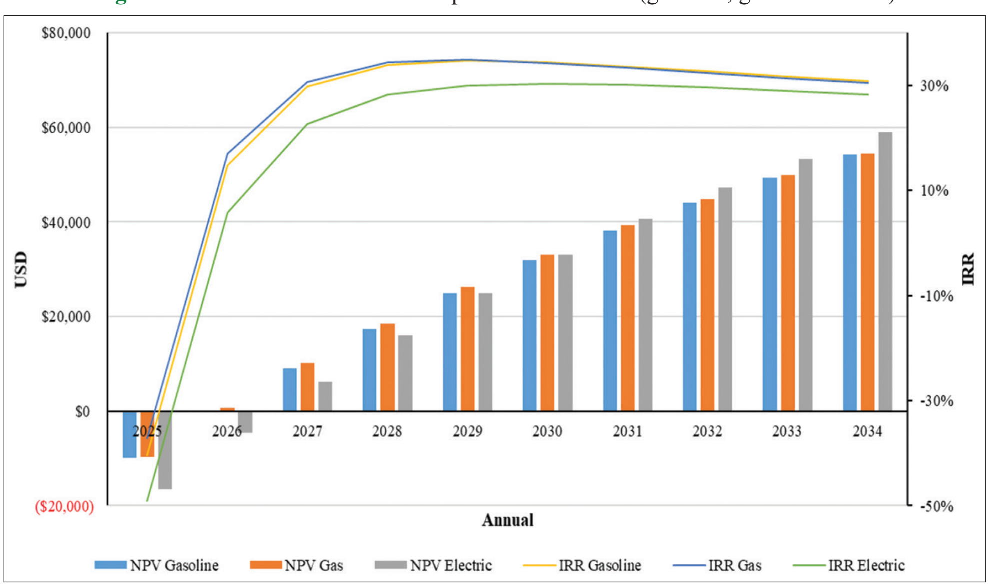
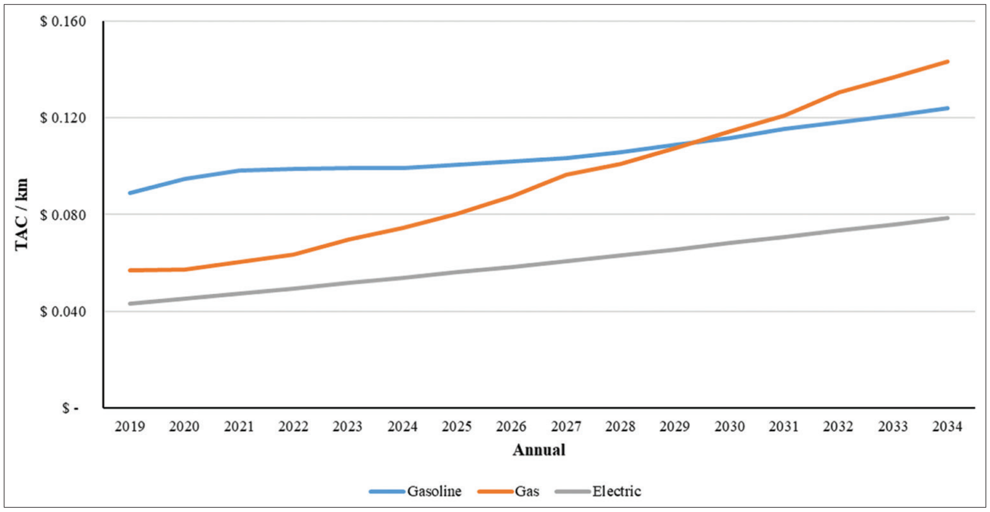


Figure 9: Total cost per km by vehicle type



6. CONCLUSIONS

Globally, the path to electric mobility has been laid out through policies, regulations, development strategies and economic incentives. China being a benchmark in the evolution of its motor park, driven by government plans with an emphasis on charging infrastructure, monetary stimulus, and R and D, migrating to a value chain generated from new business trends around electric vehicles.

For its part, Colombia belatedly entered the transition to electric mobility, starting in its two main cities, the Project of Bogotá with an unambitious goal did not have an exceptional start, making it necessary to extend the deadlines of special benefits; the project of Medellin supported by the public company EPM was more popular, associated with the increase in income received by taxi drivers, and the sustainable culture of its citizens.

The analysis of the TAC/km indicator for the city of Bucaramanga showed for electric vehicles a positive gap with respect to ICE vehicles, which tends to increase over the years, consistent with the results obtained in medium-term scenario analyses, where electric vehicles will be the most attractive product for taxi drivers and TFC's. In this context, it is currently feasible to incorporate e-taxis, if any of these strategies are applied: (1) exemption from payment of taxi registration, in case of incorporation of a new vehicle, (2) economic incentive of more than 20% at the time of purchase of the EV, accompanied by a 25% increase in the cost of the minimum service fee, in the case of the replacement of a taxi.

To increase the acceleration of the transformation of the Colombian motor park and the integration of the community into commercial trends surrounding electric vehicles, the Colombian government should carry out government programs that promote the capture of markets and electric vehicle technologies so that this niche market is globalized in Colombia.

Future studies of electric mobility could cover topics on the charging infrastructure in Colombia.

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