Prospective towards implementation of electric vehicles in Colombia

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Abstract. The effects of climate change have led to reduces fossil fuel in vehicle, developing new technologies such as the electric vehicles. The research presents an identification of barriers and inhibitors according to international experiences, an evaluation with the MICMAC method and the identification of key factors to achieve development of electric vehicles in Colombia. The results allow to identify the elements of high influence, which may guide intervention strategies and be the basis for the formulation of guidelines and policies. The results conclude that the business models for the purchase and sale of energy are the catalyst for the encouraging of the stakeholders, the improvement of the distribution network and the management of the electricity market.

1. Introduction

The increase of greenhouse gases and the volatility of the price of oil have allowed to develop alternatives for the reduction of fossil fuel consumption. Alternatives have been developed such as technological improvements in the injection system [1], efficiency in the combustion engine [2], use of biofuels [3] and migration to electric vehicles [4]. The latter achieves a reduction of CO2 produced by the combustion process and fuel demand for the urban transport sector, key factors for climate change and energy security.

The implementation of electric vehicle technology entails new challenges such as the management of existing infrastructure to allow changes and avoid bottlenecks; the study of the current state helps governments in strategic planning for future scenarios. With the lessons learned, it can identify characteristics that are necessary for the inclusion of new technologies; Colombia is a country that is doing its first investigations and pilot tests on this topic.

According to National Single Transit Registry (RUNT) [5], Colombia has a vehicle fleet of 14,671,694 vehicles, where 5,425 are electric vehicles; of which 872 are automobiles and 1,385 are vehicles such as vans and buses. The departments with the highest number of records are Antioquia (1,329), Bogotá D.C. (1,146), Cundinamarca (1,067), Valle del Cauca (743) and Bolívar (236) [5], These figures show the need and the existence of difficulties to encourage the integration of these technologies.

The research presents an identification of key elements that allow the development and integration of the technologies associated with electric vehicles in Colombia and the use of Cross Impacts Matrix-Multiplication Applied to a Classification (MICMAC) method, based on qualitative study between the variables and interactions identified between the Electric Vehicles and the Colombian Power System, these results will allow to be the base for the formulation of guidelines for the different agents of the market.

The work begins with section 1 where the motivation to carry out a qualitative study on the factors that affect the market of electric vehicles for their development in Colombia is presented, section 2 sets out the stages and the procedure of this analytical research. The legal framework for electric vehicles is presented in section 3. In section 4 the results of the methodological phases are presented, it begins with the identification of the variables and interactions identified between the Electric Vehicles and the Colombian Power System, then the MICMAC method is used to identify the key factors, and ends with the need to integrate users due the lack and ignorance in business models of electricity transactions. Section 5 denotes the limitations of the study and future research directions associated with the electric vehicle market.

2. Methodology

The research design involves the description of the Colombian legal framework and the identification of the interactions between the electric vehicle and the electricity market; through the lessons learned in different sources of information, it identified variables that allow defining strategic guidelines for the strengthening of the electric vehicle market. Procedural systematization is organized in three phases of research, namely:

Table 1. Systematization of the methodology.

Step	Remark	Phase
1	Review the regulatory framework.	*2.1. Identification phase* It involves the documentary review of lessons learned, which will allow identifying the factors that will affect the electric vehicle market. International experiences from one country to another show that ignorance of these processes can generate a chain of doubts or conceptual and procedural gaps regarding the strategic vision of greater relevance in correspondence with the intended objectives [6].
2	Identification of the interactions between the Electric Vehicles and the Colombian Power System.	
3	Identification of variables.	
4	Make the cross-impact matrix using the variables.	*2.2. Analytical phase* The identified factors and the Cross-Impact Matrix Multiplication Applied to Classification (MICMAC) method are used to identify the characteristics of the variables and define the strategic axes; these elements are catalysts for organizational development and allow the identification of facilitators, inhibitors and barriers. The analysis identifies strengths and weaknesses of the sector, regarding processes such as planning and policy formulation, which will be inputs for the definition of short, medium and long term plans.
5	Make the driving power and dependence diagram.	
6	Identification of key factors.	
7	Analyze the key factors.	*2.3. Propositional phase* The variables located in the conflict zone of the structural analysis are identified, these variables are the strategic elements and their intervention will allow the adoption of priority strategies for the development of the electric vehicle market in Colombia.
8	Identify and propose improvements.	

3. Colombian legal framework

The ministries of Mines and Energy [7] and Transport [8] oversee the electric vehicle market; the regulations have been made around the tariff measures for the importation of these technologies, in table 2 the regulations are presented.

Table 2. Regulatory framework for electric vehicles in Colombia.

Legal regulations	Remarks
Law 023 (2010)	Tariff reduction measures are established for the importation of transport systems that use electric power for their traction. The governors and mayors may contemplate the elimination of traffic restrictions.
Resolution 186 (2012)	Tax incentives are established for the technological reconversion of the vehicle fleet and the use of hybrid and electric transportation systems.
Decree 1116 (2017)	Electric vehicles will not pay duty and a sales tax of 5%. The hybrid vehicles will pay a tariff rate of 5% and a consumption tax of 8% or 16% in case of exceeding a Free On Board (FOB) price of US $ 30,000.

The measures adopted encourage the importation of electric vehicles, but the infrastructure, the electric and automotive market do not present the necessary conditions for the growth of this initiative. The prospective are to establish the exemption from vehicular taxes and traffic lights, subsidies for the purchase of electric vehicles and the replacement of conventional automobiles, and the installation of recharging systems in public and private places [9].

4. Results

4.1. Identification of factors

The understanding of the interactions between the object of study and the development environment allow identifying elements that can facilitate or inhibit their development in the market; Figure 1 shows the interactions that exist between an electric vehicle and the elements of the Colombian electric power system.

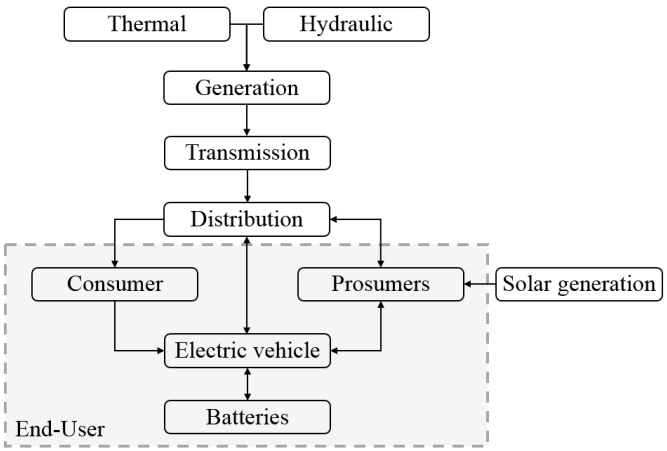

Figure 1. Interactions between the Electric Vehicle and the Colombian Power System.

The generation of electricity in Colombia comes mainly from hydroelectric power plants located in isolated and thermal power plants zones have a high cost due to the acquisition of fuels [10]; the energy is carried by the transmission and distribution system reaching the end-users. The inclusion of electric vehicles will lead to the participation of end-users, they may be consumers or prosumers. If the users

own an electric vehicle, they will charge their batteries with energy from the grid or from their own production, mainly photovoltaic (PV) generation. The vehicle storage system is the key element for the interaction of users and the distribution system, allowing processes to purchase and sale of energy to the network. This indicates the need for Smart Grid, to give flexibility and to encourage users to a new energy storage business model. The variables presented in table 3 are proposed due the interactions identified.

Table 3. Variables identified for the implementation of electric vehicles in Colombia.

Code	Variables	Remark
V01	Displacement of electric power blocks.	Storage systems allow the displacement of generated energy to be used in times of high demand and low capacity generation [11, 12].
V02	Uncontrolled increase of the PV generation.	The increase in facilities and PV generation can generate an effect called "duck curve", which can affect electrical power systems [12, 13].
V03	Price of electric energy.	The model used to establish the price of electric power does not favor the reduction of prices, despite having a high contribution of hydraulic generation.
V04	Lack of infrastructure for intelligent measurement.	Currently there are no bidirectional measurement systems installed in most of the Colombian territory; there is the government's willingness to carry out the migration [12].
V05	Limited technological offer in the electric vehicle sector.	There is not a wide range of electric vehicles and components that incentivize users and generate free competition in the automotive market.
V06	Solar energy production by residential users.	There is not a high participation of residential users to install PV generation systems [12, 14].
V07	Lack of a system for the final disposal of electronic equipment.	Control for the final disposal of electronic equipment that has reached its useful life and reduce the environmental impact.
V08	Lack of charging stations.	The limited existence of charging stations for electric vehicles. 28 stations throughout Colombia and none in the Caribbean region [14, 15].
V09	Lack of energy business models.	Lack of knowledge and existence of business models for the purchase and sale of electric power for the end-user [16].
V10	Control in quality standards for electric power service.	The integration of PV generation technologies and storage systems can cause anomalies and failures in distribution systems [12, 13].
V11	Regulation for mobility and control of electric vehicles.	The existence of a special regulation can encourage use [14].
V12	Oil as competition	The price of oil generates uncertainty in the energy security of fuels, royalties and government plans.

Sources: [17, 18, 19, 20]

4.2. Structural analysis: identification of key issues

The method of structural analysis is composed of three steps, the first is the identification of a set of variables that characterize the system, in Table 3 the variables are observed; the second is a description of the relationship between the variables, and the interaction matrix is made with the identified variables. A group of participants collaborated to evaluate the degree of influence between them, 0 for a null influence up to 5 for a very high influence; the degree of dependence and driving power was calculated, in table 4 and figure 2 you can observe the result of the interaction matrix and the diagram between the dependence vs the driving power. Finally, the identification phase of the key variables, the variables

located in the conflict zone are selected due to their high dependence and high driving power; because they have a significant influence on the others.

Table 4. Cross-impact matrix using the variables of Table 3

	V01	V02	V03	V04	V05	V06	V07	V08	V09	V10	V11	V12
V01	0	5	5	1	0	1	0	3	3	5	0	4
V02	4	0	5	3	1	2	4	1	4	5	0	0
V03	3	4	0	2	0	2	3	5	5	5	0	0
V04	5	5	3	0	2	4	2	5	5	5	0	0
V05	1	1	1	1	0	2	2	5	4	2	5	5
V06	4	4	4	2	2	0	4	0	5	5	0	3
V07	1	0	0	4	4	3	0	2	3	2	4	5
V08	5	1	5	3	5	3	1	0	4	4	5	4
V09	3	4	5	5	5	5	5	5	0	3	3	4
V10	3	4	5	5	3	3	0	3	3	0	4	0
V11	0	0	5	2	4	2	4	4	5	4	0	5
V12	2	4	5	2	3	3	0	5	2	0	3	0

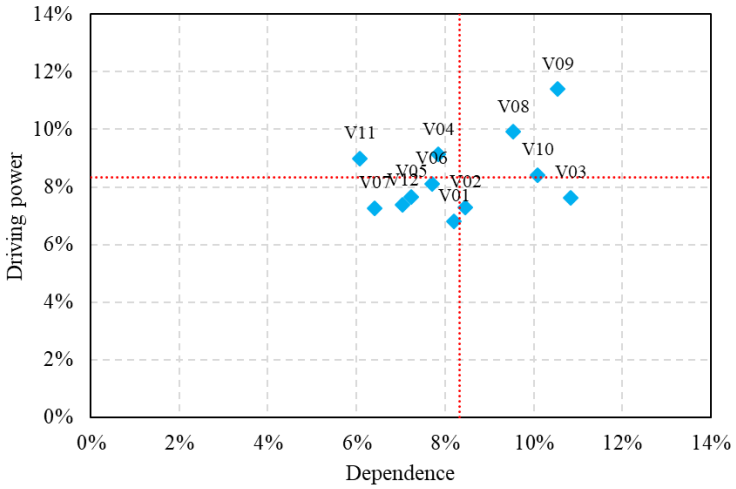

Figure 2. Driving power and dependence diagram.

Figure 2 shows the variables V08 (Lack of charging stations), V09 (Lack of energy business models) and V10 (Control in quality standards for electric power service) in the conflict zone; V09 is the furthest variable and refers to the mechanisms of participation in the electricity market, V08 and V10 are variables to make improvements in the infrastructure.

4.3. Energy models as a key factor for the implementation of electric vehicles

The lack and ignorance in business models of electricity transactions, presents the need to integrate users; this integration is weak due to the lack of knowledge and little incentive that exists now. Figure 1 shows end-users as a strategic element, their decision to own an electric vehicle can be incentivized to consider this purchase as an investment and not as an expense, you can have profits because energy transactions will favour the user in the maintenance and return of investment. By existing these models will increase the demand for electric vehicles and the growth of the necessary infrastructure; it will favour the installation of charging stations, the reliability of the electrical system and the technological update of the electric grids towards Smart grids.

Currently in Colombia, bidirectional meters and PV generation systems are installed, government entities have chosen net-metering as the mechanism for integrating prosumers; but the lack of incentives and clarity of the model has not allowed growth despite the high potential. There is a need to have electricity hourly rates, allowing the purchase of energy at times of low demand and high supply, and then be sold at times of high demand.

Energy models need policies to modify the regulations and methodologies used to define the price of electricity, define the requirements for the injection of energy into the grid, modify the current energy sales system to an intra-hour one and implement training to show the benefits of owning an electric vehicle

5. Conclusions

The work presented the identification of the interactions between the electrical system and electric vehicles, and the selection of twelve (12) variables; the MICMAC method was used to identify the variables located in the conflict zones and variable V09 was obtained as the most influential variable in the system.

The results suggest the restructuring of the electricity market to a model with hourly prices that allows to encourage the installation of generation and storage systems to move blocks of energy to areas of high demand and low supply. The acquisition of electric vehicles will be an attractive option to participate in the market; achieving growth in demand and supply. The end-user is an ally for the growth of the electrical infrastructure and in the support of generation and storage of electricity; the acquisition of electric vehicles will reduce the environmental impact due to CO2 emissions and reduce the demand for oil, strengthening energy security.

The best incentive for an end-user is their participation in the purchase and sale of electricity, motivating the purchase of equipment for generation and storage; the electric vehicle is an element that can improve the functioning of networks and ensure energy security due to fluctuations in the price of oil. For future research, technical studies and business models to improve the integration of electric vehicles and their integration into the network in Colombia.

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