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Users, Vehicles Electrics, and Energy Markets in Colombia

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ABSTRACT

The Colombian government approved Law 1964 of 2019, which is expected to favor the massification of electric vehicle technologies. Since 2010, this technological migration has begun, which has not managed to have a substantial impact on the automotive sector. The research reviewed the industry's regulatory framework and identified variables that impact the market. Through the MICMAC methodology, they are evaluated to establish the key variables that can influence the other variables. The results obtained identify that the price of electricity and the lack of knowledge or business models are critical elements in improving the development of the electric vehicle sector. These results indicate that it is necessary to propose methodological changes to decrease the price of electricity and promote the development of business models so that users take an active role in the market.

Keywords: Urban Transport, Energy Policy, Transitions Management, Energy Markets
JEL Classifications: K29, Q48

1. INTRODUCTION

Environmental impacts associated with energy development create environmental impacts mainly related to the generation of polluting emissions, society, such as industrial social equity (Guerrero et al., 2021) and access to energy services (Łapniewska, 2019), and purchasing power economics and business opportunities for utilities private investors (Lekavičius et al., 2019). Integrating renewable energy and energy-efficient technologies positively impacts the environmental (Garnica et al., 2018; Rocha et al., 2022) but ensuring secure economic viability and network access for disadvantaged users is the major challenge facing this transition (Grover and Daniels, 2017).

Topics such as the instability of oil prices and the decrease in greenhouse gas emissions (Mughal et al., 2021) have encouraged research on the reduction of fossil fuel consumption (Eras et al., 2019; Madrigal et al., 2018); in areas such as the efficiency of the combustion engine (Sevik 2016), the use of biofuels (Velásquez-Piñas et al., 2018), the improvement of the injection system (Mixture. Arat, 2015) and the migration to electric vehicles (Poullikkas, 2015).

The Colombian government established strategic objectives to impact the axes of Advanced Measurement Infrastructure (AMI), Automation of the Distribution Network (ADA), Distributed Energy Resources (DER), and Electric Vehicle (EV) (UPME, 2016). The government made changes to its legal framework to promote renewable energies (Ministerio de Minas y Energía, 2019), the electricity market (IRENA, 2019), and EVs (Ministerio de Minas y Energía., 2019). These modifications focus on the participation of energy service providers in improving the capacity, reliability, and efficiency of the country's electrical systems for the technological migration of infrastructure.

The legal framework for EV began with Law 023 of 2010 (*Ley 023 de 2010*, n.d.); it was modified by Law 1964 of 2019 (Ministerio de Minas y Energía, 2019) incentives for their use were created and strengthened. This framework impacts the production of CO2 and the demand for fuel in the transport sector but increases the consumption of electrical energy; The Colombian generation matrix is composed mainly of hydroelectric and thermal plants (UPME, 2018) and is waiting to enter generation plants with solar and wind renewable energy (ENEL, 2019).

According to the Single National Traffic Registry (in Spanish as *Registro Único Nacional de Tránsito* - RUNT), Colombia has a fleet of 16,042,336 vehicles, of which 10,612 are EVs; of which 1,726 are automobiles, 1,377 are motorcycles, and 1,866 are vehicles such as trucks and buses. However, EVs do not represent 0.1% of the total vehicle fleet (RUNT, 2021) and represent a delay in the goals proposed by the government (MinEnergía, 2020).

Identifying the variables for managing "bottlenecks" and enhancing the sector's development are essential to achieving government goals. Research is proposed to identify critical variables and establish strategies for their management, facilitating the integration of EV-related technologies in Colombia from the perspective of residential users. The results will build the foundation for developing government strategies and guidelines, incentivizing users to participate in EV development and the energy sector.

2. METHODOLOGY

The methodology comprises three research phases; it begins with describing the Colombian legal framework for EVs and the interactions in the Colombian electrical system. This interaction allows us to identify variables in the EV market in Colombia identified in international experiences. In the second stage, the MICMAC method is used to classify and identify the critical variables that allow better organizational development (Uribe and Arévalo, 2017). Finally, management strategies are proposed for the key variables identified, which will allow more active participation of users in the value chain and influence the fulfillment of the objectives proposed by the government.

3. RESULTS

The Ministry of Mines and Energy and the Ministry of Transportation create the regulatory policy to purchase and use EVs in Colombia. The current regulations are taxed and focused on tariff measures to reduce import costs; Table 1 presents the Colombian regulatory framework.

The incentives to have an EV are Vehicle Tax no greater than 1%, VAT is 5%, the rate is 0%, Consumption tax is 0%, Discount on SOAT and technical-mechanical review, Exception in-vehicle measurements restriction (pick and plate), preferential parking, municipalities with more than 500,000 inhabitants will have a minimum of five fast-charging stations, and EV import companies must guarantee the cost of spare parts (MinEnergía, 2020).

Table 1: Legal and regulatory frameworks related to EVs in Colombia

Legal and regulatory frameworks	Commentaries
Law 023 of 2010	It establishes measures to cut tariffs on the import of EVs for mobility. In addition, it allows governors and mayors to consider removing restrictions on movement.
Resolution 186 of 2012	Tax incentives apply to the technological reconversion of the fleet and the use of hybrid and electric transport systems.
Decree 1116 of 2017	Electric vehicles will pay no duty and a 5% sales tax.
Law 1964 2019	Hybrid vehicles will pay a tariff rate of 5% and a consumption tax of 8% or 16% if they exceed a FOB price of US$30,000.

However, the infrastructure of recharging points and the electrical and automotive market do not present the necessary conditions for the development of this initiative to date.

3.1. Interactions of Electric Vehicles with the Power System

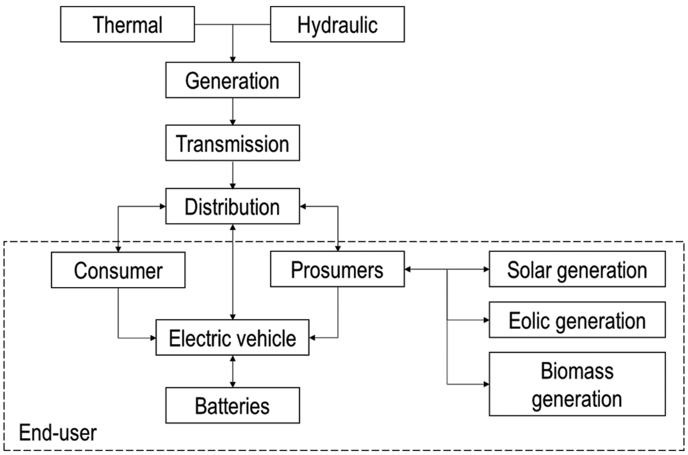
Understanding the interaction relationship between the research subject and the development environment can help identify factors that may facilitate or inhibit the development of the research object in the market. Figure 1 shows the interaction between the EV and the Colombian electrical system.

Electricity generation comes from hydraulic plants placed in nearby areas in Colombia; the adequate generation capacity is 17,564MW, where 68% is hydraulic and 30% thermal (XM, 2021). Electricity is transported in transmission and distribution systems to final consumers, classified as residential, commercial, or industrial (MinEnergía, 1994). The price of electricity charged to residential users is to be paid as a monthly price (Correa-Giraldo et al., 2021), despite having a daily market (Andrés et al., 2016), and its value is regulated by the scarcity price (*CREG 156*, 2016; Guerrero et al., 2021; XM, 2020).

Consumers are the same users of the transport sector; therefore, they have an essential role in achieving a more significant insertion of EVs due to their role as consumers or prosumers. The latter can generate energy for its consumption and injection into the network (Zafar et al., 2018). These strategies that promote distributed generation are required. Therefore, it is necessary to update the distribution and transmission system according to technological requirements (Mao et al., 2021; Tsili and Papathanassiou, 2009).

Recharging points additionally require regulatory measures that grant degrees of freedom to the electricity market, either through special rates, plans, or contracts for the purchase of energy, changes in the electricity price formation scheme (IEA, 2020; Martín Pérez, 2009); the latter will facilitate the participation of solar generation systems by residential users. Colombia uses Net-Metering and is regulated by resolution 030/2018, using energy credits (*Resolución 030*, 2018; López et al., 2020). The EV has a battery that could be an essential element for buying and selling; depending on the variation in the price of electricity, it could generate a business model for storage at times of high generation and low price, helping to manage generation and demand.

Figure 1: Electric Vehicle interactions in Colombia's power system



3.2. Identify Variables

The vehicle storage system is considered a key element in generating more significant interaction between users and the distribution system, allowing energy to be stored and delivered to the grid at high demand, buying and selling energy. Smart-Cities are required (Enel X, 2018) to promote sustainability and efficiency in energy use, give flexibility, and encourage users to a new energy storage business model. Table 2 presents the selected variables.

3.3. Structural Analysis and Identification of Key Variables

The MICMAC method is used, which is a method to perform structural analysis for decision making. The interaction matrix is constructed using the variables described in Table 2. Values of 0 indicate no interaction, 1 for very low, 2 for low, 3 for medium, 4 for high, and 5 for very high. For the construction of this matrix, it had the collaboration of a panel of experts, who, through a survey, delivered their weightings. The mode and median were used as criteria for selecting the value of the interaction.

Table 2: Identified variables for introducing electric vehicles in Colombia

Code	Variables	Remark
V01	Displacement of electrical energy blocks.	Displacement generates energy to high demand and low generation using storage systems.
V02	Uncontrolled increase in P.V. generation.	Increasing installations and P.V. generation can generate the "duck curve," affecting electrical systems.
V03	Electricity price.	The model used to establish electricity prices does not favor price reductions, despite a substantial contribution from hydraulic production.
V04	Lack of infrastructure for smart metering.	Bidirectional measurement systems are not installed in most Colombian territories; the government is willing to migrate.
V05	Limited technology provision to EV.	The market lacks many EVs and components to encourage users and create free competition.
V06	Residential users with solar energy generation.	There is no high participation of residential users in installing P.V. generation systems.
V07	No final electronic device handling system.	Control the disposal of electronic equipment that eventually reaches the end of its life and reduce its impact on the environment.
V08	Lack of charging stations.	The limited existence of charging stations for EVs. Twenty-eight stations throughout Colombia and none in the Caribbean region.
V09	Unknowing of energy business models.	Lack of knowledge and existence of end-user electricity trading business models.
V10	Control in the quality standards for the electrical energy service.	Integration of storage systems and technologies P.V. integration can cause irregularities and failures in the distribution system.
V11	Regulation for the mobility and control of EV.	The existence of a particular regulation can encourage use.
V12	Oil as competition	Oil prices create uncertainty about the energy security of fuels, royalties, and government plans.
V13	Maintenance training courses	Training programs for users must be created which allow the user to have technical and mechanical knowledge of the EV that he owns.
V14	Trained and certified staff	Employees performing overhaul and repair for this type of vehicle must be trained technicians; it will help get more excellent reliability.
V15	Additional suppliers for the sale of spare parts.	The government establishes that EV dealers must guarantee spare parts, which can create a monopoly in the market.
V16	Ignorance of the benefits of an EV by users.	Users should be aware of the difference that purchasing an EV brings to a traditional EV
V17	Preferential rate for users	An energy cost savings goal should be established with user participation as a reward for EV use.
V18	Democratization of energy	The user can participate in the energy market through the purchase or sale, thus stipulating a bidirectional process.
V19	Mechanisms for reducing recharge times	The battery recharge time is typically 5–7 h, which means the vehicle needs a "quick charge" day.
V20	Promotion of social acceptance	Lack of knowledge on the part of consumers and users about the operation of EVs.

Sources:(Agbonaye, 2019; Mouli *et al*., 2016; Chen *et al*., 2022; Fernández Palomeque, 2011; Iswanto *et al*., 2022; Mersky and Otros, 2016; Obi & Bass, 2016; Simone *et al*., 2013; Sugawara and Nikaido, 2014)

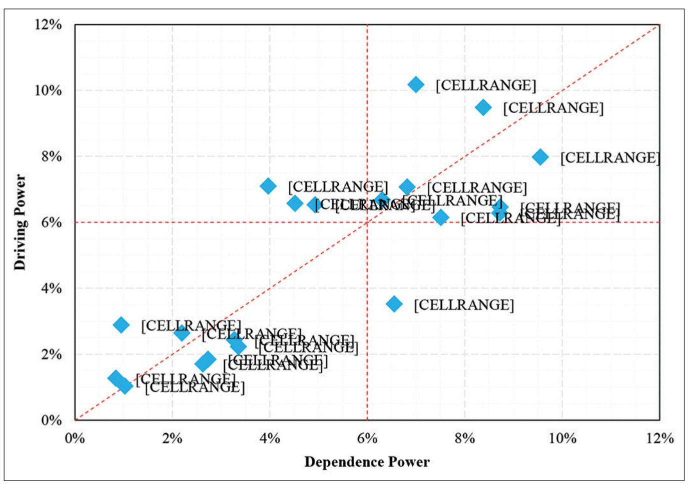
According to Table 3, the interaction matrix is iterated until one of its values is achieved. The new matrix calculates the percentage contributions of dependence and driving power for each variable, which are the X and Y coordinates of the dispersion diagram. Figure 2 presents the modeling of dependence and driving power.

Figure 2 shows that the variables V03, V09, and to a lesser extent V17 are the variables that have high driving power and dependence power; these are the so-called link variables. These variables have the quality of being easier to manage and can have a more significant impact on the others. These variables are essential for managing and formulating government strategies to encourage users to participate in the EV sector.

3.4. Analysis of the Strategic Variables

Figure 2 shows that the variables V03 (*Electricity price*), V09 (*Unknowing of energy business models*), and V17 (*Preferential rate for users*) have high driving power and dependence power. This section presents an analysis of these strategic variables.

Figure 2: Driving power and dependence power diagram



3.4.1. Electricity price

Electric power is a fundamental element for industry operation and the different sectors of the economy. Additionally, it must have the capacity to meet any demand, have a competitive price, variety in the generating park and supply alternatives; These elements are key to having reliability in providing the service.

The energy price in Colombia is calculated with the sum of the different components, such as the Cost of Generation, Transmission, Distribution and Marketing, and others, such as Restrictions and Losses. Each of these costs varies from month to month, depending on the operation of the power system. This price is known by users month by month; it is a fixed rate regardless of consumption behavior or price during the entire billing period.

There are variations in the case of generation due to El Niño and La Niña phenomena, where rainy periods favor water generation and have a positive impact. In contrast, the other costs depend on the use of the network. The scarcity price regulates the price of electricity to control market volatility. Figure 3 presents the behavior of the price of electricity reported in the department of Atlántico, whose capital, Barranquilla, is a member of the World Council of Energy Cities. The Market Representative Rate is 1USD = 4200COP.

Figure 3 shows a progressive increase annually; until September 2021, the price of electricity is the same price used for billing; but in the following months, the equality is lost, and the difference is significant, where its maximum difference was 0.06 USD/kWh in December 2021. These increases represent a barrier to economic growth and the integration of electrical energy technologies.

3.4.2. Energy business models

The Colombian regulatory framework contemplates purchasing and selling energy through the stock exchange and contracts, commonly known as the Power Purchase Agreement (PPA). In the case of self-generation, the sale of surpluses is established. The

Table 3: Interaction matrix using the variables in Table 2

	V01	V02	V03	V04	V05	V06	V07	V08	V09	V10	V11	V12	V13	V14	V15	V16	V17	V18	V19	V20
V01	0	2	5	4	1	1	0	1	5	3	0	0	0	0	0	0	4	2	0	0
V02	5	0	5	3	0	1	0	0	3	5	0	0	0	0	0	4	3	3	0	2
V03	5	5	0	4	0	2	0	3	3	3	0	0	0	0	0	4	5	4	0	0
V04	3	3	3	0	4	0	5	4	4	0	0	0	0	0	0	2	4	2	0	0
V05	0	0	0	0	0	0	2	3	0	0	4	5	4	4	3	0	0	0	0	0
V06	5	5	5	5	0	0	0	0	3	4	0	0	0	0	0	0	3	2	0	0
V07	0	0	0	0	0	0	0	0	4	3	0	0	0	0	0	5	0	0	0	0
V08	2	0	4	3	0	0	0	0	4	3	2	3	0	0	0	0	5	0	5	4
V09	5	4	5	5	0	3	3	4	0	4	0	0	0	0	0	2	5	3	0	4
V10	4	5	5	5	0	3	0	4	1	0	0	0	0	0	0	4	0	0	0	0
V11	0	0	0	0	3	0	0	4	0	0	0	5	1	1	0	1	0	0	0	5
V12	0	0	5	0	5	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
V13	2	0	0	0	4	0	0	3	1	4	1	0	0	0	3	2	0	0	0	0
V14	0	0	0	0	2	0	0	0	0	2	0	0	5	0	4	0	0	0	0	0
V15	0	0	0	0	5	0	0	2	0	3	0	0	0	1	0	0	0	0	0	0
V16	0	0	2	0	0	0	5	0	3	2	5	0	4	0	0	0	0	0	0	4
V17	5	5	5	5	0	3	0	5	4	4	0	3	0	0	0	5	0	4	0	5
V18	4	0	5	5	0	3	0	0	5	5	4	0	0	0	0	3	0	0	0	0
V19	5	0	3	0	0	0	0	0	0	3	0	4	5	1	0	0	0	0	0	0
V20	3	2	0	4	2	3	1	2	4	0	5	3	5	4	2	3	2	2	0	0

Figure 3: The behavior of the price of electricity in the department of Atlántico

first corresponds to the mechanism where spot energy is traded between generators and marketers. In contrast, the second option is an agreement between two parties where are agreed upon terms such as quantity, price, and electricity delivery conditions. On the other hand, self-generation has been considered since Law 143 of 1994 and Law 1715 of 2014, which favored the connection of On-Grid photovoltaic systems by residential users.

PPAs are the most flexible mechanism for establishing business models. These models have their options to improve if there are changes in the energy market conditions, such as the limits to be regulated and non-regulated users, hourly or intra-hourly prices, implementation of regulations for storage systems, and the same update of the distribution network.

According to international experiences, users can opt for other rate mechanisms established by contracts with energy trading companies, allowing them to change the conventional scheme and achieve security in the face of price volatility.

3.4.3. Preferential rate for users

The Colombian electricity price uses a subsidy and contribution scheme. The economic contribution depends on the socioeconomic stratum, and the amount of subsidized energy depends on the user's geographical location (Guerrero et al., 2021). This system has a financial weight due to the resources allocated to the payment of these subsidies; creating preferential rates based on subsidies is not feasible.

The PPA is a mechanism that can offer preferential rates to users and, in turn, benefit companies in the generation sector. Another mechanism is to use hourly or intra-hourly prices; users will analyze their consumption patterns and evaluate what may be the best strategy to reduce costs. In both options, it is observed that the user has decision-making power, and the responsibility of achieving a better rate falls on him.

These options can impact the restructuring of the energy market, on the scheme of subsidies and contributions, generate awareness of the rational use of energy, and liberalize the electricity market.

3.5. Users and Electrical Vehicles

Colombia currently has the technological updating of electrical networks to form Smart Cities by installing bidirectional meters, P.V. generation systems, and Net-Metering as an integration methodology.

End users are a strategic element because they can enhance their impacts through business models and electricity transactions if there is management in the electricity markets. The latter requires doing a didactic task to show the technical and economic benefits that may exist when participating in the electricity market; and achieve a change of perspective by analyzing generation systems, storage systems, and EVs not as an expense but as an investment that has the potential to generate profits and optimize returns on investment.

The strategies should start to motivate users and the energy market and reduce the price of electricity, either through preferential rates or the implementation of hourly or intra-hour prices. This last option does not require an additional budget but rather an investment in the transmission and distribution network operation. As there are hourly or intra-hourly rates, the different consumers will have the option of managing their demand curve. For the owner of an EV, it could be used as a storage system to purchase and sell electrical energy.

The role of end-users is essential to developing the EV market. According to the results obtained, it should start by organizing the energy model seeking to reduce the costs of electricity, favor the active role of users, and the growing generation and storage systems. Encouraging this first stage will facilitate the growth and management of the other variables.

4. CONCLUSIONS

The EV is an attractive option to reduce CO_2 emissions and oil demand, and strengthen energy security; its implementation requires expanding the electrical infrastructure, generation systems, and electrical energy storage systems. In this research, the end-user is proposed as an ally and strategic element to achieve these objectives.

The work identified and selected twenty variables among the existing interactions between the electrical system, end-users and EV. The variables were classified using the MICMAC method, and variable V03 was identified as the most significant influence.

The greatest incentive for end-users is to participate in purchasing and selling electricity. This incentive will lead to purchasing power generation and storage systems and thus EVs. This result suggests studying energy market business models and strategies to influence electricity prices.

Research suggests that there must be changes in the electricity market to impact the price of electricity. The proposed strategy is to adopt an hourly pricing model to drive power generation and storage system installation and the growth of prosumer users, making it possible to manage demand by moving energy blocks to areas of high demand and low supply. This adoption must be complemented by a regulation on the services of the storage systems and the definition of their remuneration.

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