International Journal of Difference Equations (IJDE).
ISSN 0973-6069, Volume 18, Number 1, (2023) pp. 281-297

http://www.ripublication.com/ijde.htm

Feasibility Analysis of Electric Vehicle Charging Infrastructure in Colombia

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Abstract

The rapid expansion of electric vehicle (EV) adoption is driven by increasing global concerns over greenhouse gas emissions, air quality, and the need for sustainable transportation. In Colombia, the EV market has grown significantly, spurred by government incentives and the introduction of various EV models. This paper investigates the feasibility of implementing charging infrastructure for electric vehicles in the region, taking into account the current electrical conditions, charger specifications, and available space for installation. A linear regression analysis is conducted to estimate the growth of EV sales based on population growth and vehicle acquisition trends. The results indicate that as EV sales increase, charging infrastructure in strategic locations, such as shopping centers and public parking spaces, must expand to prevent congestion and accommodate the growing demand. Furthermore, the study examines different scenarios to assess the potential challenges and opportunities of expanding EV charging infrastructure. These include saturation of EV charging devices, gradual increase in the combustion vehicle margin, and the independent installation of charging stations according to studies and budgets. The paper also highlights the need for standardization and regulation in the Colombian EV market to ensure safety and efficiency in charging infrastructure. By providing a comprehensive analysis of the current state and future growth of EV charging infrastructure, this paper aims to stimulate interest and further research into sustainable transportation solutions in Colombia.

Keywords: Charging infrastructure, Colombia, electric vehicles, feasibility analysis, linear regression, standardization, sustainable transportation.

1. INTRODUCTION

The emission of polluting gases into the atmosphere is one of the primary causes of the greenhouse effect and climate change. Currently, transportation is responsible for approximately 25% of global emissions [20]. As a result, electric vehicles (EVs) have emerged as a promising solution to reduce the carbon footprint of mobility. However, in Latin America, one of the main challenges for the adoption of electric mobility is the lack of charging infrastructure, particularly in residential areas [5]. This scarcity not only limits the convenience of EV owners but also hinders the expansion of the EV market and the reduction of pollutant emissions in the region [14].

The absence of charging systems for electric vehicles in residential areas can significantly impact users. Limited access to a charging system at home can severely restrict their ability to use the vehicle, as they are forced to rely on public charging infrastructure, which may be unavailable, congested, or simply inadequate [9]. Moreover, the time and energy required to locate and utilize public charging stations can pose a significant obstacle for EV owners, potentially deterring some from acquiring an EV in the first place [13].

As a result, electric vehicle manufacturers may find less demand for their products and may be less inclined to invest in the production and improvement of EVs [2]. The expansion of charging points for electric vehicles is a requirement for their energy solvency. The charging autonomy margin is limited, making the implementation of these sources a strategic solution, primarily in the residential sector [19].

There are several reasons why implementing charging systems in residential areas can be an essential solution:

1. **Increase in electric vehicles**: With the rising popularity and use of EVs, it is necessary to have convenient charging locations. This is especially true in urban and residential areas where owners do not have easy access to public charging stations [3].

2. **Time and cost savings**: Having a charging system in a residential area can save time and money. Instead of commuting to a charging station, owners can charge their vehicles in the comfort of their homes. Additionally, residential charging systems are often more affordable than public chargers [18].

3. **Contribution to the environment**: Implementing charging systems in residential areas encourages the use of electric vehicles, which can, in turn, reduce pollutant emissions. By facilitating charging accessibility, a shift towards a more

sustainable transportation system can be promoted [6].

4. **Increased convenience for owners**: Having a charging system in a residential area can make the lives of residents more pleasant and convenient. Instead of worrying about finding a charging station, residents can simply use one upon arriving home [15].

5. **Added value to residential properties**: The implementation of charging systems can add value to real estate, especially in the current market, as more people are considering purchasing electric vehicles.

In Colombia, the delayed adoption of electric vehicles (EVs) can be attributed to several factors. First, the lack of governmental and fiscal incentives for the purchase and use of EVs has limited their market adoption. Unlike other countries, Colombia has not established policies and measures that encourage the use of these vehicles, such as tax exemptions, the construction of charging infrastructure, and research in EV development [21]. Furthermore, the high initial acquisition cost of EVs and the lack of knowledge in this technology have also discouraged their use. Lastly, the absence of an adequate and efficient charging network is another factor that has constrained the adoption of EVs in Colombia. However, despite these challenges, there is a growing interest in EVs across the country, and it is expected that over time, the implementation of appropriate policies and measures will allow for greater market penetration and a broader adoption of the technology in Colombia.

In this context, one of the regions in Colombia with the highest availability of zero-emission vehicles is known as Sabana Centro. This area comprises municipalities close to the capital district, Bogotá, and includes the city of Zipaquirá, where an increase in the use of EVs is evident.

The supply and population demand in Zipaquirá have increased in urban infrastructure due to various factors. Firstly, growing urbanization and the rising population in the region have led to higher demand for residential services, such as shopping centers, parks, hospitals, and schools. Secondly, the improvement of communication and transportation routes, as well as the construction of new road corridors, have made Zipaquirá more attractive for real estate investment and the development of new infrastructure projects. Thirdly, the region's economic growth and business development have attracted a larger number of workers, including professionals seeking to live in a city with an increasingly diverse range of services and opportunities. All of these factors have driven the growth of urban infrastructure in Zipaquirá, responding to the needs of a growing population [11].

Given the context in Colombia and the importance of electric vehicle charging infrastructure, this study aims to analyze the feasibility of implementing EV charging infrastructure in residential areas of Colombia, with a particular focus on the Sabana Centro region. We will assess the current state of electric mobility in the region and identify the barriers and opportunities for residential charging infrastructure development. Furthermore, this study will explore the potential benefits of such infrastructure in terms of environmental impact, user convenience, and property value. By addressing the challenges in Colombia's electric mobility landscape, this research aims to provide valuable insights and recommendations for policymakers, urban planners, and stakeholders involved in the adoption and expansion of EVs in the country. With a comprehensive feasibility analysis, our findings will contribute to the development of effective strategies for overcoming the obstacles and promoting a more sustainable and efficient transportation system in Colombia.

2. PROBLEM STATEMENT

The advancement of energy technologies is continuously progressing as the population increases and economic, social, and political needs arise. Throughout history, civilizations have relied on energy resources to ensure the development of various sectors, including industrial, production, and transportation [16]. One of the primary factors contributing to global warming is greenhouse gas (GHG) emissions, which are predominantly associated with fossil fuels. According to the National Council of Economic and Social Policy (CONPES), pollution is most severe in major cities such as Bogotá and Medellín, where emissions account for 78% of the total [4]. This pollution leads to adverse health effects, such as respiratory diseases. Consequently, environmental protection efforts are increasingly focused on reducing GHG emissions through clean mobility, which entails transitioning from fossil fuels to renewable resources, such as electric vehicles (EVs). The shift towards electric mobility improves air quality and serves as an efficient means of contributing to environmental conservation [7]. In Colombia, electric vehicles have been imported since 2011, and the incorporation of this technology began in 2012 with the pioneering company Codensa or Enel X. This company has initiated the development of electric transportation (taxis, buses, motorcycles, corporate fleets, and bicycles) in Bogotá, Medellín, and Cali, allowing for the validation of energy efficiency, maintenance costs, autonomy, and charging systems [10].

The feasibility of implementing an EV charging system in a residential setting requi- res analyzing the existing electrical conditions and the specifications needed for diffe- rent charging systems, as well as considering the availability of installation space. However, with the wide range of EVs, makes, and autonomy levels [17], higher power chargers can provide faster charging, accumulating energy in a shorter time. Charger criteria include fast charging (80-120 kW), rapid charging (50 kW), and semi-rapid charging (7.35-25 kW). In the future, charging capacities are expected to reach 350 kW. Despite the numerous advantages and improvements in lithium-ion battery (LIB) technology, EVs generally still have a lower range than conventional internal combusti- on engines, with lengthy charging and discharging times. Furthermore, charging insta- llations can be costly, which is why public charging stations are often equipped with rapid chargers, whereas residential charging is typically considered nominal. Power restrictions in residential properties necessitate slow and semi-rapid charging equipment with simple infrastructure, such as wall-mounted charging stations [1].

This article aims to conduct calculations and analyses using linear regression based on population growth and vehicle acquisition trends to project EV sales growth in the present and upcoming years. As electric vehicle sales increase, there must be a parallel expansion of charging systems in stations, shopping centers, and other strategic locations to prevent congestion when purchasing the product. Through our analysis and investigation, we intend to assess the feasibility of implementing EV charging stations in Cundinamarca [12].

3. METHODS

3.1. Linear Regression Calculations

Linear regression is a method used to model the relationship between a predictor variable and a response variable. The predictor variable, often denoted as x, is also known as the independent variable. The response variable, denoted as y, is also referred to as the dependent variable [8]. Linear regression is a mathematical model that employs a straight line to describe the functional relationships between the variables x and y. In other words, it predicts the behavior of these two variables as described by the following equation:

$$y = \beta_0 + \beta_1 x + \epsilon \tag{1}$$

In this equation, y represents the dependent variable, x represents the independent variable, β_0 and β_1 are the regression coefficients, and ϵ is the residual error term. The goal of linear regression is to estimate the coefficients β_0 and β_1 such that the error term ϵ is minimized, which in turn produces a line that best fits the observed data points.

Linear regression can be used in a wide range of applications, including predicting future trends, analyzing the impact of variables on a given outcome, and understanding the relationships between variables in a dataset. In the context of electric vehicle research, linear regression can be utilized to model and predict the growth of electric vehicle sales based on factors such as population growth, vehicle acquisition trends, and the expansion of charging infrastructure. By analyzing these relationships, researchers can gain valuable insights into the factors that drive the adoption of electric vehicles and develop strategies to promote their widespread use.

The procedure to follow can be divided into four stages:

1. The approximation is made by plotting the points on a Cartesian plane, which shows the relationship between the two variables (Table 1). According to the data on population growth projections, there is a positive correlation when compared to electric vehicle sales over the next five years, considering the increasing demand for autonomous and connected vehicles in smart city ecosystems.

2. Next, the equation of the line that best describes these points is determined. The correlation coefficient R, which is a measure of association between the random variables x and y (year and population growth data for this case), has a value of 0.9738. This indicates a strong relationship between the variables, and consequently, a low percentage of error. The correlation could be further studied by considering additional factors, such as the influence of advancements in robotics and control systems on electric vehicle development.

3. The variability of the sample around the regression line is then calculated. By evaluating the residuals, it is possible to understand the model's accuracy and identify any potential outliers or trends that may require further investigation or adjustments, such as the integration of robotics technologies in electric vehicle manufacturing. These data are analyzed by the following equations (Eqs. 1 and 2):

$$ordinate = y - bx \tag{2}$$

$$slope \longrightarrow b = \frac{\Sigma xy - nxy}{\Sigma x^2 - nx^2} \tag{3}$$

4. Finally, if the values of the two variables are plotted on a coordinate graph, *clouds of points* can be obtained, as shown in Fig. 1. This graphical representation can help visualize the relationship between the variables and provide insights into the role of robotics and control systems in shaping the future of electric vehicles.

Table 1: Distribution table

Year	x	y	xy	x^2
2018	8.8	130,537	1,148,726	77.44
2019	7.5	24,450	183,375	56.25
2020	6.5	146,352	951,288	42.25
2021	-5.5	152,195	-837,073	30.25
2022	-4.5	156,983	-706,424	20.25
2023	-3.5	161,445	-565,058	12.25
2024	-2.5	165,912	-414,780	6.25
2025	-1.5	170,262	-255,393	2.25
2026	-0.5	174,415	-87,208	0.25
2027	0.5	178,315	89,158	0.25
2028	1.5	181,932	272,898	2.25
2029	2.5	185,235	463,088	6.25
2030	3.5	188,216	658,756	12.25
2031	4.5	191,040	859,680	20.25
2032	5.5	193,809	1,065,950	30.25
2033	6.6	196,539	1,297,157	43.56
2034	7.7	199,232	1,534,086	59.29
2035	8.8	201,869	1,776,447	77.44
	18	2,998,738	7,434,674	324

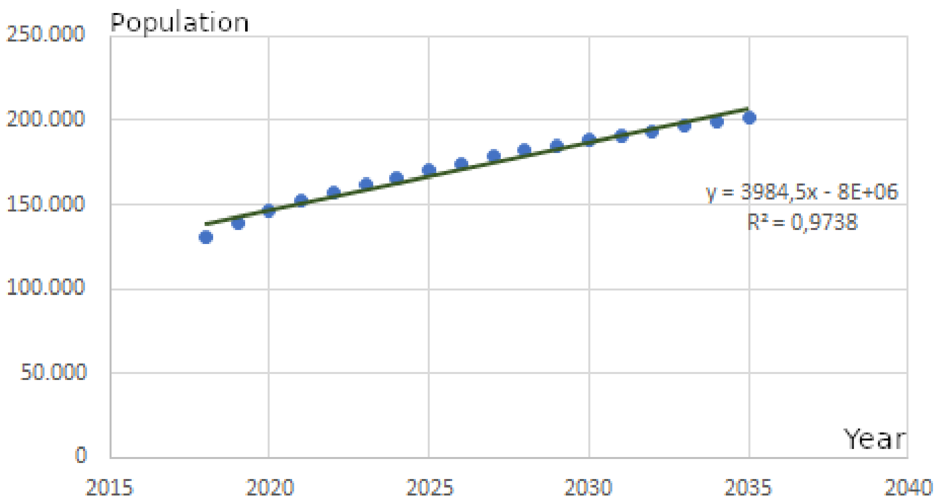

Figure 1: Population projection data from 2018 to 2035 in Zipaquirá by DANE

According to the 2023 report by the Colombian Association of Automotive Vehicles (ANDEMOS), there has been a noticeable evolution in the penetration of electric vehicles (EVs) and hybrid electric vehicles (HEVs) in Colombia. As shown in Table 2, there was a significant increase in the sales of electric vehicles from 2022 to 2023, with a total of 1346 vehicles sold, of which the majority were HEVs. In 2022, 951 electric vehicles were sold, and in the present year, the acquisition of this technology surged to 1098, demonstrating the ongoing energy transition and global development towards clean energy sources. The goal is to live in a society free from pollution, and the integration of EV manufacturing and control systems is expected to further propel this shift .

Table 2: Electric and hybrid vehicle sales from 2022 to 2023

	Technology type	2022	2023	Var. 22/23
1.	HEV	951	1,098	15.5%
2.	BEV	392	179	-54.3%
3.	PHEV	296	69	-76.7%
	Total	1,639	1,346	-17.9%

The historical statistics of electric vehicle adoption in the country can be found in the ANDEMOS database starting from 2016, with the knowledge that the introduction of this new fleet began in 2011 through Enel X. Table 3 displays the relationship between EV sales by year, highlighting the increasing trend and potential impact of technologies in the automotive industry, such as advancements in autonomous driving, battery management systems, and charging infrastructure.

Table 3: ANDEMOS electric vehicle sales bulletin 2022

TECNOLOGÍA	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total general
HEV		2		220	69	51	6	268	1.769	4.229	15.623	8.814	31.051
BEV	1	28	49	18	191	202	136	390	923	1.308	1.388	1.654	6.288
PHEV		5	1		3	25	54	274	442	468	1.771	1.104	4.147
Total general	**1**	**35**	**50**	**238**	**263**	**278**	**196**	**932**	**3.134**	**6.005**	**18.782**	**11.572**	**41.486**

With the data, a linear regression analysis is performed on the projection of electric vehicle sales in the municipality in the next five years, as shown in Table 4.

By utilizing linear regression, we can calculate the expected sales and analyze the trends based on historical EV sales data. According to the projection results presented in Table 4, the growth of EV sales is expected to be gradual, slower compared to the increase observed between 2017 and 2019. Fig. 2 illustrates the five-year sales projection using linear regression, providing insights into the future EV market and assisting stakeholders in making informed decisions and strategic planning.

Table 4: Projected EV Sales in the Municipality for the Next five Years

Year	Sales of electric vehicles in the country using linear regeression
2011	0
2012	34
2013	50
2014	238
2015	266
2016	279
2017	196
2018	932
2019	3.134
2020	6.005
2021	18.782
2022	11.572
2023	11.505
2024	12.743
2025	13.981
2026	15.220
2027	16.458
2028	17.696

Xi	X	Y	XY	X2
Years		Sales of electric vehicles		
2011	-5,5	0	0	30,25
2012	-4,5	34	-153	20,25
2013	-3,5	50	-175	12,25
2014	-2,5	238	-595	6,25
2015	-1,5	266	-399	2,25
2016	-0,5	279	-139,5	0,25
2017	0,5	196	98	0,25
2018	1,5	932	1398	2,25
2019	2,5	3134	7835	6,25
2020	3,5	6005	21017,5	12,25
2021	4,5	18782	84519	20,25
2022	5,5	11572	63646	30,25
	12	41488	177052	143

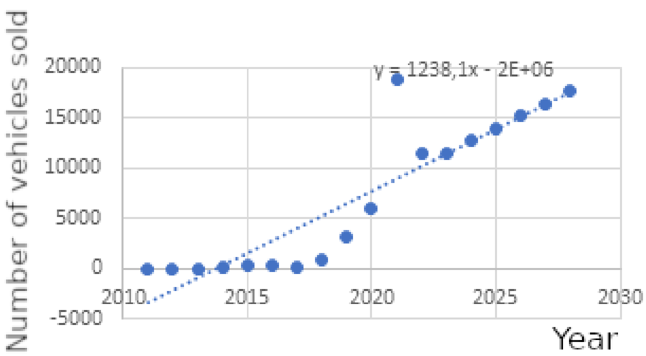

Figure 2: Five-year EV sales projection using linear regression

The scatter plot in Fig. 3 displays the sales data from 2011 to 2022, revealing an exponential growth trend due to the limited available data points. A scatter plot is a graphical representation that helps identify the relationship between two variables and detect possible patterns or trends. The exponential shape suggests that the growth rate of EV sales has been accelerating over time.

Based on the linear regression analysis, we can draw several conclusions regarding the EV sales growth rate in Colombia. The growth rate can be calculated by comparing the annual sales figures of EVs in the country. For instance, the growth rate between 2021 and 2020 is $\frac{18,782-6,005}{6,005} \times 100\% = 212.7\%$, indicating a more than twofold increase in sales. However, the growth rate between 2022 and 2021 is negative: $\frac{11,572-18,782}{18,782} \times$

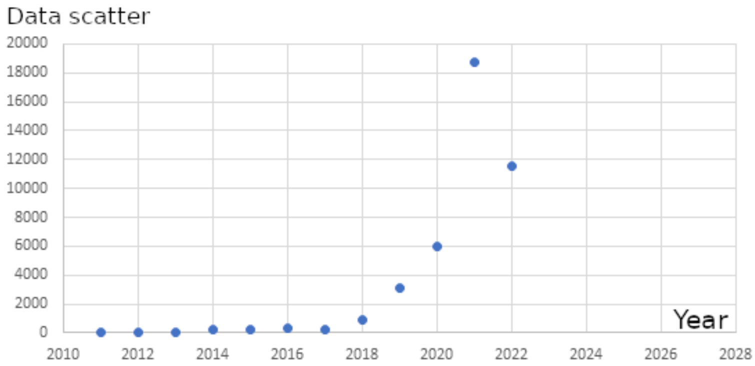

Figure 3: Scatter plot of EV sales data from 2011 to 2022

100% = −38%, which shows a decline in sales below 100%, creating a significant deficit for various car manufacturers.

Using the linear regression results, we can estimate the average annual growth rate of EV sales in Colombia for the five-year period from 2023 to 2027: $\left(\frac{16,458}{11,505}\right)^{\frac{1}{5}} - 1 =$ 75.09%. This projection serves as a valuable insight for stakeholders to plan and strategize accordingly.

The standard deviation is a measure of dispersion, quantifying the degree to which individual data points deviate from the mean. A smaller standard deviation indicates that the data points are closely clustered around the mean, whereas a larger standard deviation suggests that the data points are more widely dispersed. Based on the linear regression analysis, the standard deviation of EV sales in Colombia over the five-year period is calculated as 1.751. Comparing this value to the dispersion of five data points (Fig. 4), we can observe that the standard deviation is relatively small, suggesting a tight clustering of data points around the mean.

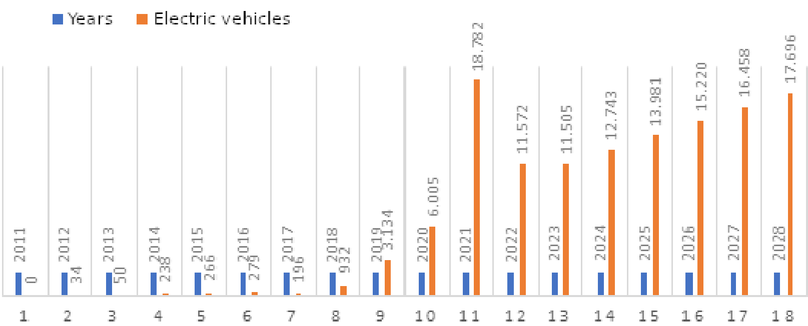

Figure 4: Projected EV sales per year

4. RESULTS

4.1. Budgetary Considerations for Charging Infrastructure

The increasing adoption of electric vehicles (EVs) in Colombia necessitates the expansion and modernization of charging infrastructure. Various types of charging systems can be implemented in different locations to meet the growing demand. Some common locations for charging systems include:

- Residential areas (garages or yards)
- Public parking lots (shopping centers, stadiums, airports)
- Service stations
- Workplaces
- Private facilities
- Public roads

As EV sales continue to rise in the country, it is crucial to upgrade and expand charging infrastructure, which includes modernizing the electrical power system and incorporating renewable energy sources. According to the National Association of Sustainable Mobility (ANDEMOS), EV sales have significantly increased since 2020. This growth has been observed across various vehicle categories, such as cargo vehicles, public transportation, and private electric and hybrid vehicles.

However, several barriers hinder the widespread adoption of EV technology, inclu- ding financial constraints, job instability, credit history, interest in purchasing EVs, charging systems and spaces, conventional grid normalization, and high costs of electric vehicles. This paper aims to present short-, medium-, and long-term scenarios that could address these challenges and facilitate the growth of the EV market in Colombia.

4.2. Resulting Scenarios

4.2.1. Scenario 1: Electric Vehicle Saturation and Energy Solvency

As electric vehicles (EVs) become more prevalent, there will be a significant demand for charging devices and energy solvency. According to ANDEMOS indicators, the Colombian EV market has grown substantially, with more than 18,000 EVs sold nationwide across various brands and classes in 2021 alone. The growth in EV sales has been driven by factors such as government policies (tax incentives, exemptions, subsidies), charging infrastructure concerns, EV costs, and model availability.

In this scenario, pollutant emissions are projected to decrease by 20% by 2030, benefiting the environment, society, and culture in Colombia. As EV sales continue to grow, major automakers like Tesla are producing more affordable electric and hybrid vehicles. As EV ownership increases, charging stations become more commonplace, thanks to various campaigns, partnerships, and government support programs.

With the first EV charging station installed in 2015, Colombia has since invested in more extensive charging infrastructure, with over 45 charging stations in operation by 2023, capable of serving over 11,505 vehicles. The public transportation sector is also transitioning towards clean and sustainable mobility, with more than 1,061 zero-emission buses in operation by 2021.

As the fleet of electric buses expands, there is an increased demand for EV charging systems, necessitating upgrades to existing electrical infrastructure such as transformers, substations (GIS), and transmission lines.

4.2.2. Scenario 2: Gradual Shift towards Electric Vehicles as Population Grows

According to the data, the population of Zipaquirá, the case study location, is expected to grow significantly over the next five years compared to other municipalities in Colom- bia. The number of inhabitants in Zipaquirá in 2023 is estimated to be 14,485. The demand for EVs in the region is still low; however, it is expected that the penetration of electric vehicles will cover more than 70% of the national territory by 2050.

As the population grows and the demand for transportation increases, there will likely be a corresponding increase in the number of combustion vehicles on the roads. This presents a challenge for policymakers and stakeholders in the transportation sector, as it could lead to increased air pollution and associated negative environmental impacts. To address this challenge, it is crucial to promote the adoption of electric vehicles and develop supporting infrastructure, ensuring that the transition to cleaner and more sustainable transportation is as smooth and efficient as possible.

4.2.3. Scenario 3: Independent Installation Based on Studies and Budgets

The decision to purchase an electric vehicle currently depends on various factors such as vehicle brand, autonomy, charging location and space, charging convenience, connector compatibility, time to charge batteries, battery maintenance, and the availability of qualified personnel for maintenance and specialized mechanical workshops. Different charging system connector prototypes should provide safety and reliability, be designed according to Colombian standardized voltages, include protection systems to prevent accidents, and be easy to use for the general population.

To enable the independent installation of charging stations based on studies and budgets, a comprehensive and detailed analysis must be conducted. This analysis should take into account the specific requirements of each location, the types of vehicles to be charged, the capacity of the local electric grid, and the available budget for such installations. Collaboration between local governments, private sector companies, and public institutions is essential to facilitate the development and implementation of appropriate charging infrastructure.

Additionally, educational and training programs should be implemented to develop a skilled workforce capable of designing, installing, and maintaining electric vehicle charging infrastructure. This would not only create job opportunities but also ensure the efficient and sustainable operation of charging stations across the country.

In this scenario, the government and private companies should work together to provide incentives and subsidies for the installation of charging infrastructure, making it more accessible and affordable for a broader range of users. This collaboration would also ensure that the necessary resources are available to address potential challenges and barriers to widespread electric vehicle adoption, ultimately contributing to a cleaner and more sustainable transportation system in Colombia.

5. DISCUSSION

In this study, we examined the growth and development of electric vehicle (EV) adoption in Colombia and the associated challenges in infrastructure and energy management. We outlined three scenarios, highlighting the possible outcomes that could arise from varying levels of EV penetration and the importance of strategic planning to accommodate the growth of electric mobility in the country.

In Scenario 1, we discussed the potential saturation of EVs in the market, leading to a strain on the existing charging infrastructure and energy supply. The rapid growth of EV adoption in Colombia indicates the need for a comprehensive strategy to address the increasing energy demands and infrastructure requirements. Ensuring that the energy sector keeps pace with the growing EV market will be essential in maintaining the reliability and resilience of the electricity grid, as well as providing a seamless transition to cleaner transportation modes for the Colombian population.

In Scenario 2, we examined the consequences of an increasing population and the corresponding growth in combustion vehicles. The associated rise in air pollution and environmental degradation could pose significant challenges for policymakers and stakeholders in the transportation sector. To mitigate these negative impacts, it is crucial to promote the adoption of EVs and develop supporting infrastructure, facilitating a smooth and efficient transition to cleaner and more sustainable transportation.

Scenario 3 highlighted the current uncertainty surrounding EV adoption and the various factors that could affect consumers' decisions to purchase an electric vehicle. These factors include the availability of charging infrastructure, the compatibility of charging connectors, the efficiency of charging systems, and the expertise required for EV maintenance. Addressing these concerns will be essential in fostering greater consumer confidence in EV technology and increasing the adoption rates of electric vehicles in Colombia.

Given the rapid growth of the EV market and the potential benefits of electric mobility in terms of environmental sustainability and improved air quality, it is crucial for Colombia to develop a strategic plan that addresses the challenges presented in these scenarios. This plan should include the expansion and modernization of charging infrastructure, the development of regulatory frameworks for EV adoption and charging systems, the promotion of EV technology through financial incentives and public aware- ness campaigns, and the creation of training programs for EV maintenance and servicing professionals.

The successful integration of electric vehicles into Colombia's transportation system will require concerted efforts from all stakeholders, including the government, the energy sector, vehicle manufacturers, and consumers. By anticipating and addressing the potential challenges outlined in these scenarios, Colombia can ensure a smooth transition to electric mobility, significantly reducing its carbon footprint and fostering a more sustainable future for its citizens.

6. CONCLUSION

The country has not achieved high levels of deployment in installing charging systems for electric vehicles (EVs) by 2023 in terms of infrastructure and EV sales. This article aims to provide an overview of the growing demand for electric vehicles in a short time and illustrate the infrastructure needs through different scenarios.

Our findings demonstrate that a stand-alone charging system for electric vehicles is feasible in residential areas of Zipaquirá, Cundinamarca, but only at strategic locations, as an indiscriminate increase in charging points may lead to a significant increase in energy costs for users. Data-driven techniques, such as linear regression, have proven to be valuable tools for identifying the relationship between population growth and EV adoption, assisting consumers in making informed decisions regarding electric transportation purchases.

Electric vehicles offer several potential benefits, including lower environmental impact, reduced noise levels, fewer engine components, and lower operating and maintenance costs. However, their limited range and the current scarcity of charging infrastruc- ture may cause uncertainty among potential buyers. The evolution of EVs has encoura- ged universities and research groups to employ linear regression methods to assess the range and viability of this technology.

Domestic charging stations, such as Celsia, are expanding across Colombian households, with Enel X covering the capital territory. However, the outcomes obtained in each scenario reveal that technological growth in Colombia remains uneven. Certain areas, such as Zipaquirá, do not project the necessary energy infrastructure to support initiatives aimed at reducing CO2 emissions. This has led to a lack of interest in adopting cleaner vehicle technologies in the region.

Fostering a more widespread and equitable adoption of electric vehicles in Colombia requires a concerted effort from all stakeholders, including the government, energy sector, vehicle manufacturers, and consumers. By addressing the existing infrastructure gap and promoting cleaner transportation technologies, the country can transition to a more sustainable and environmentally friendly future.

ACKNOWLEDGEMENT

This work was supported by the Universidad Distrital Francisco José de Caldas, in part through CIDC, and partly by the Facultad Tecnológica. The views expressed in this paper are not necessarily endorsed by Universidad Distrital. The authors thank the research group ARMOS for the evaluation carried out on prototypes of ideas and strategies.

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