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# Energy and Cost Comparison of ICE-Rickshaws and E-Rickshaws.

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## Abstract:

Autorickshaw-type vehicles have been consolidated as a highly relevant transportation alternative, especially in regions of South Asia, Africa, and some cities in Latin America. Their impact lies in the fact that they represent an economically accessible option both in terms of acquisition and operation, in addition to offering high versatility due to their compact size, without sacrificing load capacity compared to other means, such as motorcycles. In Colombia, this type of vehicle has been adopted mainly in small, intermediate, or satellite cities, where its use is growing, making it increasingly necessary to analyze the environmental impact they generate. Low and zero-emission technologies are presented as an alternative for the decarbonization of public transportation in different regions of Colombia. However, the transition toward electric motorized rickshaws has been limited by the lack of knowledge about the benefits these vehicles present compared to internal combustion motorized rickshaws. To promote the adoption of electric autorickshaws, it is required to have direct comparisons to quantify performance in terms of energy and emissions.

In the present study, vehicle dynamics models were developed to estimate the energy consumed by electric autorickshaws and internal combustion autorickshaws, and a driving cycle developed for autorickshaws from monitored data in a city in the Colombian Caribbean was used to compare the energy requirements and equivalent emissions of each technology.

This study enables the quantification of the energy benefits that electric vehicles offer compared to traditional vehicles.

Finally, by knowing the energy consumption of electric autorickshaws and internal combustion autorickshaws, the monetary costs of the energy used in the internal combustion motorized rickshaw and in the electric motorized rickshaw were quantified. According to this, the economic benefits of the energy savings presented by electric motorized rickshaws were quantified.

## Keywords:

Electric autorickshaw, Internal combustion autorickshaw, Power consumption, equivalent emissions, energetic performance.

## 1. Introduction

The transport sector is one of the main contributors to global emissions. In 2019, it accounted for 23% of energy-related $CO_2$ emissions worldwide, with roughly 70% of those emissions coming from land transport [1]. Despite efforts by many countries to meet the Sustainable Development Goals and international climate targets, transport-related emissions have continued to rise in recent decades.

Between 2010 and 2019, emissions from the sector increased steadily, driven primarily by road transport and rising mobility demand. However, the average emissions rate was lower than in the previous decade (2000–2009) [2], suggesting that these measures have had some effect in limiting growth. It is therefore essential to continue researching and developing effective emissions reduction strategies in the transport sector to support a sustainable transition aligned with global climate goals.

In Colombia, the transportation sector's behavior reflects the identified global trends. Between 1990 and 2021, emissions from this sector accounted for approximately 13.92% of total national emissions [3], making it a significant source of greenhouse gases in the country. This contribution not only exacerbates climate change and the greenhouse effect but also has direct impacts on public health, especially in densely populated urban areas with heavy traffic. Air pollution from transportation worsens air quality, increases the risk of respiratory and cardiovascular diseases, and undermines overall quality of life, underscoring the need to strengthen mitigation strategies in this sector.

In the context of urban transport, three-wheeled motorized vehicles, or autorickshaws, are a widely used means of mobility in South Asia and have experienced significant growth in Latin America in recent decades. Their popularity stems from the fact that they offer an accessible, low-cost transport alternative, providing greater cargo capacity and comfort than a motorcycle while maintaining relatively similar energy consumption [4].

However, these vehicles can generate significant levels of polluting emissions (such as CO, $CO_2$, and $NO_x$) that are considerably higher than the limits set by emissions standards, especially in traffic conditions characterized by frequent acceleration and deceleration, as well as prolonged idling [5] [6].

In this context, electric autorickshaws have emerged as a promising alternative for reducing the environmental impact of urban transport and decreasing dependence on fossil fuels. This option should be evaluated to quantify the energy and environmental benefits it can offer compared with internal combustion engine vehicles. Some studies have addressed this issue under operating conditions characteristic of South Asian cities [7], but the available evidence for Latin America, where driving patterns, infrastructure, and mobility dynamics are significantly different, remains limited.

Furthermore, many analyses use standardized driving cycles rather than real-world driving conditions. Consequently, there is still limited research comparing the performance of electric and internal combustion three-wheelers under locally generated driving cycles in Latin American cities. The municipality of Soledad, Colombia, is characterized by the rapid growth of this type of transport; however, research on the energy transition of these vehicles remains largely unexplored.

To address this gap, this study evaluates and compares the performance of an electric motorized rickshaw and a conventional internal combustion three-wheeler operating under the same driving cycle generated from real traffic conditions in the municipality of Soledad, Colombia [6]. The analysis focuses on estimating the energy requirements and the equivalent emissions associated with each technology.

By applying a locally derived driving cycle, this research provides a more realistic assessment of the potential environmental and energy benefits of electric three-wheelers in the Latin American context. Additionally, the study quantifies the economic benefits associated with the energy savings achieved by electric motorized rickshaws. The results contribute to a better understanding of the role that electrification of this type of vehicle can play in supporting sustainable urban mobility and reducing emissions in emerging urban transport systems.

## 2. Methodology

The methodology proposed in this study is structured around four main components (Figure 1). First, the study region and vehicles used are defined, encompassing the location, operation, and routes of the autorickshaws, as well as a characterization of the vehicles themselves. Second, a driving cycle for evaluation is established by characterizing the driving cycle used, which leads to the selection of a characteristic velocity profile. This profile feeds into the third component, an energy model based on the longitudinal dynamics of vehicles, which enables a comparison of energy consumption between combustion and electric three-wheelers. Finally, a cost model is developed, incorporating both energy costs and maintenance costs, allowing for a direct cost comparison between combustion and electric vehicles.

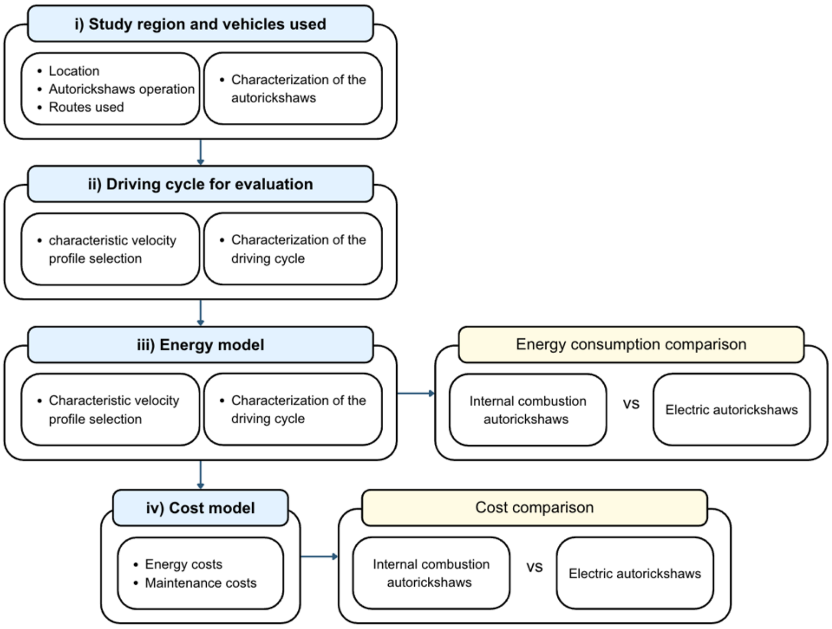

***Figure 1.*** *Study methodology.*

## 2.1 Region and study vehicles

The Colombian Caribbean region is composed of 8 departments and 193 municipalities, accounting for 11.6% of the country's total territory. This region has a predominantly flat topography, characterized by valleys and plains between the central and western mountain ranges, as well as floodplains of various rivers [8]. The region is home to approximately 20% of the country's population, with over 9 million inhabitants. The main populated areas include Barranquilla, Cartagena, Soledad, Valledupar, Santa Marta, and Montería, which together concentrate nearly 40% of the region's population [9] [10].

For the present study, the municipality of Soledad, Atlántico, was selected as the study area. This municipality accounted for 25.2% of the total population of Atlántico in 2025 [11] and covers a total area of 67 km², equivalent to 1.97% of the department's total extension. Geographically, it borders Barranquilla to the north, the municipality of Malambo to the south, Galapa to the west, and the Magdalena River to the east [12], which gives it a strategic location within the metropolitan area, making it a municipality with high vehicular traffic.

In this context, a significant growth in the use of three-wheeled autorickshaw-type vehicles as a passenger transportation mode has been observed, consolidating them as one of the primary urban transport alternatives in the municipality [13] [14]. This relevance within the local transportation system constitutes the main criterion for the selection of Soledad, Atlántico, as the case study. The main characteristics relevant to this study can be found in Table 1.

***Table 1.*** *Characteristics of the municipality.*

| Characteristic name | Measurement unit | Value | Ref |
|---|---|---|---|
| Average ambient temperature | °C | 30 | [15] |
| Altitude above sea level | masl | 31 | [16] |
| Number of inhabitants | Population | 722845 | [11] |

Autorickshaws are three-wheeled motorized vehicles with a simple and lightweight chassis, open sides, a canvas roof, and systems similar to those of a motorcycle [17]. These vehicles are characterized by their low speed and agility for use in confined spaces, which has made them an attractive option for passenger transport in intermediate cities such as Soledad, Atlántico [6].

In the study area, and more broadly across Colombia, the Bajaj Torito RE is the most used autorickshaw for passenger transport. These vehicles are equipped with four-stroke internal combustion engines with typical displacements of 0.2 L and 10 HP of power. Additionally, they lack an engine control unit or other electronic systems that would allow for signal acquisition [18]. Table 2 presents the main characteristics of the internal combustion autorickshaw model selected for this study.

***Table 2.*** *Vehicle Bajaj Torito RE characteristics [19].*

| Category | Parameter | Detail |
|---|---|---|
| Motor | Displacement | 198.88 cc |
| | Power | 10.19 HP a 5,000 rpm |
| | Torque | 17 Nm a 3,500 rpm |
| | Transmission | 4 speeds + reverse |
| Brakes and Tires | Brakes (Front and Rear) | Drum |
| | Front tire | 4.00 – 8, 6PR Tubetype. |
| | Rear tire | 4.00 – 8, 6PR Tubetype. |
| Suspension | Front suspension | Articulated single-arm SKUDO design, coil spring + hydraulic double-acting shock absorber |
| | Rear suspension | Wishbone + compression coil springs + hydraulic double-acting shock absorbers |
| Dimensions | Overall Length | 2,658 mm |
| | Overall Width | 1,300 mm |
| | Overall Height | 1,700 mm |
| Capacity and Weight | Passenger Capacity | 1 driver + 3 passengers |
| | Load Capacity | 310 Kg |
| | Curb Weight | 362 Kg |
| | Gross Weight | 672 Kg |
| Variants | Available Models | Cherokee canopy, Luxury canopy, Torito, Utility canopy |
| | Canopy Colors | White, Red, Blue, Black |

However, the autorickshaws used for transport in the selected area and other intermediate cities of the Caribbean region emit pollutant gases such as CO and PM2.5, which are associated with cardiorespiratory diseases that accounted for 29% of premature deaths in the city [20]. Despite this, no initiatives have been put forward in the municipality to replace internal combustion vehicles with electric ones. Nevertheless, in another city in the Caribbean region, a pilot program using electric autorickshaws for tourist transport is currently underway, which is expected to drive the adoption of autorickshaw electrification in Soledad [21].

Electric autorickshaws used for passenger transport are characterized by an electric motor with power outputs ranging from 1,000 W to 5,000 W, a maximum speed of 65 km/h, and the use of either lead-acid or lithium-ion batteries for energy storage [22]. For the present study, the Bajaj EV RE E-tech 9.0 electric autorickshaw will be used, whose specifications are listed in Table 3.

***Table 3.*** *Technical specifications Bajaj EV RE E-tech 9.0 [23].*

| Category | Parameter | Detail |
|---|---|---|
| Motor y Battery | Battery Capacity | 8.9 kWh |
| | Maximum Net Power | 4.5 kW |
| | Maximum Net Torque | 36 Nm |
| | Range | 178 km per charge |
| | Maximum Speed | 45 km/h |
| | Transmission | Automatic |
| | Gradeability | 29% |
| Brakes | Braking System | Regenerative braking with detection mechanism |
| | Parking Brake | Yes |
| Dimensions | Overall Length | 2,635 mm |
| | Overall Width | 1,300 mm |
| | Overall Height | 1,700 mm |
| | Wheelbase | 2,274 mm |
| | Ground Clearance | 170 mm |
| Capacity and Weight | Passenger Capacity | 4 persons (including driver) |
| | Kerb Weight | 362 kg |
| | Gross Vehicle Weight (GVW) | 708 kg |

## 2.2 Driving cycle

For the development of this study, a specific driving cycle created for the municipality of Soledad, Atlántico, was selected, built using the micro-trip methodology [6]. This methodology was adopted due to the highly variable and irregular nature of the mobility patterns of autorickshaw-type vehicles, characterized by frequent stops, speed changes, and non-standardized routes. After monitoring six autorickshaws over three months under real operating conditions using the Fuel-Based Micro-Trip (FBMT) methodology, a 1,350-second cycle was generated that reflects the typical driving behavior in this coastal region.

Unlike widely used international driving cycles for the evaluation of emissions and energy efficiency in light vehicles, such as the World Motorcycle Test Cycle (WMTC) [24] or the cycles established by the Economic Commission for Europe (ECE) [25], the selected cycle was constructed taking into account the environmental, geographical, and traffic conditions characteristic of the municipality, as well as the real usage patterns of autorickshaws in the study area. This cycle is shown in Figure 2.

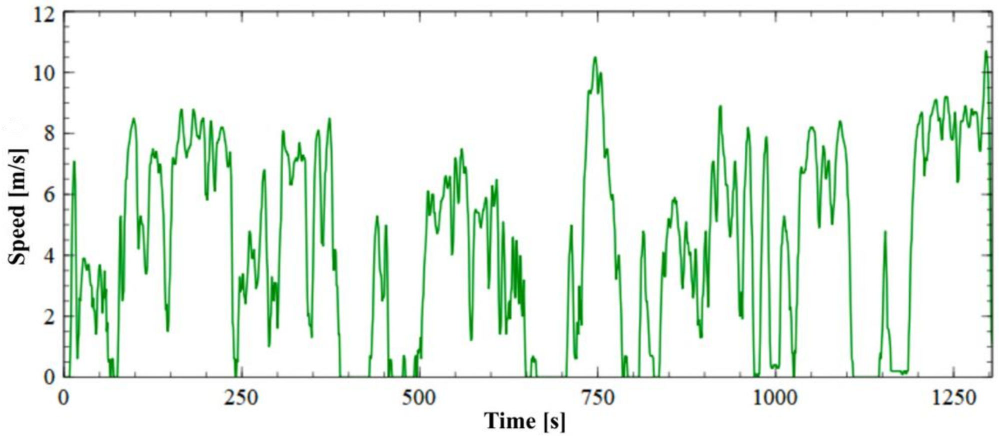

***Figure 2.*** *Soledad Driving cycle [6].*

## 2.3 Energy consumption model

In the present study, a longitudinal vehicle dynamics model was used to estimate the energy consumption of both electric and internal combustion autorickshaws. This model accounts for the external forces opposing motion in order to estimate the energy required for vehicle movement [26]. The forces acting on the vehicle are presented in Figure 3.

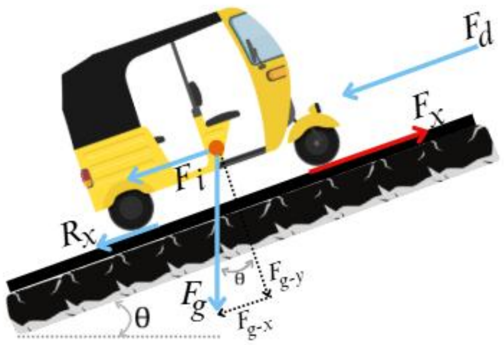

***Figure 3.*** *Diagram of the longitudinal forces acting on the vehicle.*

By analyzing the forces opposing the forward motion of the vehicle, it is found that the force required to move the vehicle can be determined according to equation (1):

$$F_x = F_d + R_x + F_{g-x} + F_i \tag{1}$$

where $F_x$ is the driving force developed by the vehicle, Fi is the force caused by the vehicle's inertia, $F_{g-x}$ is the force caused by the vehicle's weight when the vehicle is on an incline, $R_x$ is the rolling resistance, and $F_d$ is the force caused by the aerodynamic drag of the vehicle. These forces can be estimated according to equations (2)-(6):

$$F_x = F_d + R_x + F_{g-x} + F_i \tag{2}$$

$$F_d = \frac{1}{2}\rho_{air} \cdot A_f \cdot C_d \cdot v^2 \tag{3}$$

$$R_x = f_r \cdot m \cdot g \cdot cos(\theta) \tag{4}$$

$$F_{g-x} = m \cdot g \cdot sin(\theta) \tag{5}$$

$$F_i = m_e \cdot a \tag{6}$$

where $\rho_{air}$ is the density of the air in which the vehicle is operating, $A_f$ is the frontal area of the vehicle, $C_d$ is the aerodynamic drag coefficient, $v$ is the vehicle speed, $f_r$ is the rolling resistance coefficient, $m$ is the total mass of the vehicle, $m_e$ is the equivalent mass composed of the rotational inertia of rotating elements and the vehicle mass, and $a$ is the vehicle acceleration. In the case study, the vehicle inclination was set to 0°, and therefore the forces can be determined according to equations (7) and (8):

$$R_x = f_r \cdot m \cdot g \tag{7}$$

$$F_{g-x} = 0 \tag{8}$$

The inertial force acting on the vehicle integrates the translational inertia force caused by the vehicle's motion and the rotational inertia associated with the rotating elements found in the transmission and differential of the vehicle. To estimate this force, the equivalent mass, $m_e$, is used, which can be calculated according to equation (9) [26]:

$$m_e = m \cdot (1 + 0.04 \cdot N_{TD} + 0.0025 \cdot (N_{TD})^2) \tag{9}$$

where $N_{TD}$ is the transmission ratio of motion from the engine to the wheels. This transmission ratio is determined for each gear of the vehicle. Given that the vehicle acceleration can be either positive or negative, the inertial force may exhibit the same characteristic. The power required by the vehicle is estimated according to equation (10):

$$P_{trac} = \left\{ \frac{v \cdot F_x}{\eta_{trac}} \quad , \quad if\ F_x > 0 \right\} \tag{10}$$

where $\eta_{trac}$is the transmission efficiency of the autorickshaws, which accounts for the mechanical efficiency of both the transmission and the differential. The mechanical efficiency for both internal combustion and electric autorickshaws is set at 95% [26]. The energy consumed to generate the traction power required for vehicle movement depends on the traction power and can be estimated according to equation (11).

$$E_{trac_{inst}} = P_{trac} \cdot t \cdot \frac{1}{3600} \tag{11}$$

The energy consumed for vehicle traction is determined at 1-second time intervals during which the traction force is positive. For time steps where the traction force is negative, the following considerations apply:

- For the internal combustion autorickshaw, energy consumption is assumed to be equal to that of idle operation.
- For the electric autorickshaw, negative traction forces are used for energy regeneration.

The energy consumed by the vehicle on a second-by-second basis can be estimated according to equation (12):

$$E_{cons_i} = \left\{ \begin{matrix} E_{trac_{inst}} & if\ \ F_x > 0 \\ E_n & if\ F_x \leq 0 \end{matrix} \right\} \tag{12}$$

where $\mathrm{E}_{\mathrm{cons}_t}$ is the energy consumed at second $i$ y $E_n$ is the energy consumption when the traction force is equal to zero or negative. In the case of the internal combustion vehicle, $E_n$ is determined according to equation (13):

$$E_n = RPM_{idle} \cdot T_{min} \tag{13}$$

where $RPM_{idle}$ are the vehicle's idle revolutions y $T_{min}$ is the minimum positive torque that can be developed by the motor of the three-wheeler.

On the other hand, electric autorickshaws are equipped with an energy regeneration system that allows the vehicle’s batteries to be recharged by taking advantage of inertia during braking events. For electric autorickshaws, $\mathrm{E}_n$ is determined with equation (14):

$$\mathrm{E}_n = \alpha \cdot v \cdot\ \eta_{regen} \cdot F_x \tag{14}$$

where $\eta_{regen}$ is the combined regeneration efficiency of the vehicle, and $\alpha$ is the regenerative braking factor. The regenerative braking factor depends on the vehicle speed at the moment the brake is applied and can be calculated according to equation (15) [26].

$$\alpha = \left\{ \begin{matrix} 0.5 \cdot \frac{v}{5} & v < 5\left(\frac{m}{s}\right) \\ 0.5 + 0.3 \cdot \frac{v-5}{20} & 5\left(\frac{m}{s}\right) \leq v < 28.33\left(\frac{m}{s}\right) \end{matrix} \right\} \tag{15}$$

The total energy consumed to complete the driving cycle can be estimated according to equation (16):

$$E_{total} = \sum_{i=1}^{s} E_{cons_i} \tag{16}$$

where $s$ is the required time in seconds to complete the driving cycle.

## 2.4 Energy cost model

In this study, an energy cost model was implemented in order to assess the economic impact of introducing electric autorickshaws for passenger transport in an intermediate city in the Caribbean region. This model incorporates the average monthly distance traveled by the vehicles, the unit price of energy, and the energy consumption per kilometer traveled. To estimate the annual energy cost of the vehicle, equation (17):

$$CE_i = VKT \cdot E_c \cdot CU_i \tag{17}$$

where $CE$ is the annual energy cost, $i$ is the month of analysis, $VKT$ represents the average monthly kilometers traveled by the autorickshaws, $E_c$ is the energy consumption in [gal/km] for internal combustion vehicles, or [kWh/km] for electric vehicles, $CU$ refers to the energy cost in [COP/kWh] for electric vehicles and [COP/gal] for internal combustion vehicles [26]. According to the type of operation and data published by the Unidad de Planeación Minero Energética (UPME), an average annual distance of 12,500 km/year is assumed for these vehicles [27].

Regarding electricity costs, the price for end users in the country is regulated by the Comisión de Regulación de Energía y Gas (CREG) through Resolution 119 of 2007. This resolution establishes the tariff formula that electricity retailers must apply when charging residential users. The tariff formula used to calculate the cost of electricity is presented in equation (18) [28]:

$$CU_e = G + T + D + C + Pr + R \tag{18}$$

where $G$ represents the cost of energy purchases in the regulated market, published monthly by the local distribution company, $T$ is the transmission cost through the National Transmission System (STN), $D$ is the distribution cost, $C$ is the commercialization cost, regulated by CREG, $Pr$ is the cost associated with generation and transmission losses, and $R$ is the cost of constraints associated with electricity generation and transmission. For the municipality under study, the required values are published by AIR-E, the local distribution company, and historical price data from January 2024 to February 2026 are available [29].

In the case of gasoline, the unit cost is obtained from data published by the Departamento Nacional de Estadística (DANE), which includes records from January 2022 to February 2026. However, for this study, data from January 2024 to February 2026 are used for comparison purposes [30].

The $E_c$ of autorickshaws can be estimated based on the results of the energy model. For electric autorickshaws, energy consumption can be calculated according to equation (19):

$$E_c = \frac{E_{total}}{X_{total}} \tag{19}$$

where $X_{total}$ is the total distance of the driving cycle in km. For internal combustion autorickshaws, energy consumption is calculated according to equation (20):

$$E_c = \frac{E_{total}}{X_{total}} \cdot \frac{3.6}{LHV \cdot \rho_{fuel}} \tag{20}$$

where $LHV$ is the lower heating value of the fuel and $\rho_{fuel}$ is the density of the fuel used. In the case of autorickshaws, low-octane gasoline commercially available in the country, containing a 10% ethanol blend, is considered. Based on this, the lower heating value is taken as 43,141 kJ/kg and the density as 2.8 kg/gal [31][32].

Finally, the future energy cost is estimated by considering variations in energy prices and the country's average consumer price index (CPI) over the past 10 years [33]. The energy cost can be projected according to equation (21):

$$CE_n = CE_{n-1} \cdot \left(1 + \frac{1}{(1+g)^n}\right) \tag{21}$$

where $CE_{i-1}$ is the energy cost from the previous month, $g$ is the sum of the average variation in energy prices, $CPI$ is the average consumer price index over the past 10 years (5.77%), and $n$ is the number of months for which the energy cost is projected [34].

# 3. Results

The driving cycle used for the analysis was developed by Carmona et al. [6] for the municipality of Soledad, Atlántico, based on the monitoring of 306 trips during a data collection campaign of internal combustion autorickshaws operating in passenger transport. The development of the driving cycle was based on fuel consumption, average speed, mean positive acceleration, and the percentage of idle time as key criteria. Table 4 presents the characteristic driving parameters for the municipality of Soledad, Atlántico [6].

***Table 4.*** *Characteristic driving parameters of Soledad, Atlántico.*

| Type | Parameter | Value | Units |
|---|---|---|---|
| Speed | Maximum Speed | 43.20 | km/h |
| | Average Speed | 19.58 | km/h |
| | Speed Standard Deviation | 12.24 | km/h |
| Acceleration | Maximum Positive Acceleration | 2.53 | $m/s^2$ |
| | Maximum Negative Acceleration | -2.98 | $m/s^2$ |
| | Average Positive Acceleration | 0.25 | $m/s^2$ |
| | Average Negative Acceleration | -0.35 | $m/s^2$ |
| Time | Driving Cycle Duration | 1310 | s |
| Distance | Total Driving Cycle Distance | 7.14 | km |

Globally, various driving cycles have been developed for internal combustion autorickshaws. For example, Bagul et al. [7], developed and analyzed driving patterns of autorickshaws operating in Indian cities. In their study, the authors reported an average speed of 8.37 km/h and an idle time of 12.74%. When comparing these results with those obtained for the driving cycle developed for the municipality of Soledad, a difference of 4.12 km/h in average speed and 1.5% in idle time is observed.

Similarly, Gajanayake et al. [35], developed a representative driving cycle for motorcycles and motorized tricycles in the Colombo Metropolitan Area, Sri Lanka, using a microtrip-based methodology to model the characteristic stop-and-go behavior of urban traffic. The resulting cycle, with a total duration of 1215 seconds, showed an average speed of 13.93 km/h and an idle time percentage of 12.75%. Additionally, the study reported average acceleration and deceleration values of 0.33 $m/s^2$ and $-0.36$ $m/s^2$, respectively. According to the authors, these results suggest that the low average speed is directly linked to the high levels of traffic congestion characteristic of this metropolitan area.

Likewise, Biona y Culaba [36] proposed a driving cycle for tricycles in Metro Manila, Philippines, using a methodology based on Markov theory to capture the stochastic nature of traffic. Their study produced a test cycle with a duration of 240 seconds and an average speed of 14.15 km/h; however, the fraction of idle time was not reported.

Orpilla et al. [37] developed representative driving cycles for two-stroke and four-stroke tricycles in Tuguegarao City, Philippines, using a microtrip-based approach. For the four-stroke vehicle cycle, an average speed of 13.28 km/h and an idle time percentage of 28.84% were reported.

Table 5 shows that the driving cycle developed for the municipality of Soledad, Atlántico, presents characteristic parameters comparable to those reported in the mentioned studies.

***Table 5.*** *Driving cycle comparison.*

| Driving cycle | Average speed (km/h) | Idle time (%) |
|---|---|---|
| Bagul et al [7] | 8.37 | 12.74% |
| Gajanayake et al [35] | 13.93 | 12.75% |
| Biona y culaba [36] | 14.15 | - |
| Orpilla et al. [37] | 13.28 | 28.84% |
| Carmona et al [6] | 12.49 | 13.2% |

# 4. Energy consumption model

An estimation of energy consumption was carried out for the internal combustion autorickshaw, considering the characteristics of the vehicles operating in the study region. The results for internal combustion autorickshaws are presented in Table 6.

***Table 6.*** *Estimation of energy consumption for the internal combustion autorickshaw.*

| Name | Variable | Unit | Value |
|---|---|---|---|
| Energy consumption | E | kWh | 2.04 |
| Fuel consumed | F | L | 0.23 |
| Fuel consumption | FC | L/100km | 3.22 |
| Fuel economy | FE | km/L | 31.01 |
| Energy consumption | EC | kWh/100km | 28.60 |

When comparing the estimation obtained from the energy consumption model with data reported in the literature under similar conditions, the fuel consumption for the internal combustion autorickshaw is estimated at 3.22 L/100 km, representing a difference of 1.26% with respect to the results reported by Carmona et. al [6], who conducted a measurement campaign of fuel consumption for autorickshaws in the municipality of Soledad, Atlántico, obtaining an average value of 3.18 L/100 km under local operating conditions. On the other hand, Asghar et. al [38], performed simulations to determine the fuel economy of autorickshaw-type vehicles under different operating conditions, reporting values between 27 and 33 km/L.

For the electric autorickshaw, energy consumption was estimated under the same climatic and operational conditions as those considered for the internal combustion vehicle. The results of this estimation are presented in Table 7.

***Table 7.*** *Estimation of energy consumption for the electric autorickshaw.*

| Name | Variable | Unit | Value |
|---|---|---|---|
| Energy consumption | E | kWh | 0.57 |
| Fuel equivalent | $F_e$ | $L_e$ | 0.06 |
| Equivalent fuel consumption | $FC_e$ | $L_e$/100km | 0.89 |
| Equivalent fuel economy | $FE_e$ | km/$L_e$ | 111.7 |
| Energy consumption | EC | kWh/100km | 7.93 |

The estimated energy consumption of the electric autorickshaw was 0.57 kWh, representing a 79.1% reduction compared to the internal combustion autorickshaw, which exhibited an energy consumption of 2.04 kWh. This difference is associated with the higher energy efficiency of electric motors compared to internal combustion engines. Figure 4 presents the instantaneous energy consumption estimated for both autorickshaws.

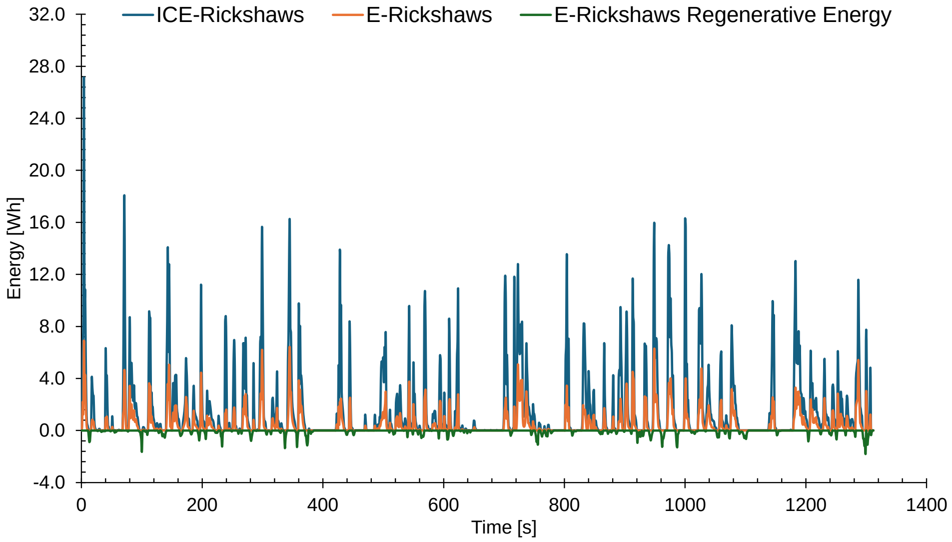

***Figure 4.*** *Instantaneous energy consumption of autorickshaws.*

As shown in Figure 4, the internal combustion autorickshaw exhibits energy consumption peaks exceeding 20 Wh per second. In contrast, the electric autorickshaw presents a maximum peak of 6.9 Wh, which is 74.5% lower than that of the internal combustion vehicle. Additionally, the electric autorickshaw incorporates regenerative braking, allowing instantaneous energy recovery of up to 1.78 Wh. The cumulative energy consumption of both autorickshaws is presented in Figure 5.

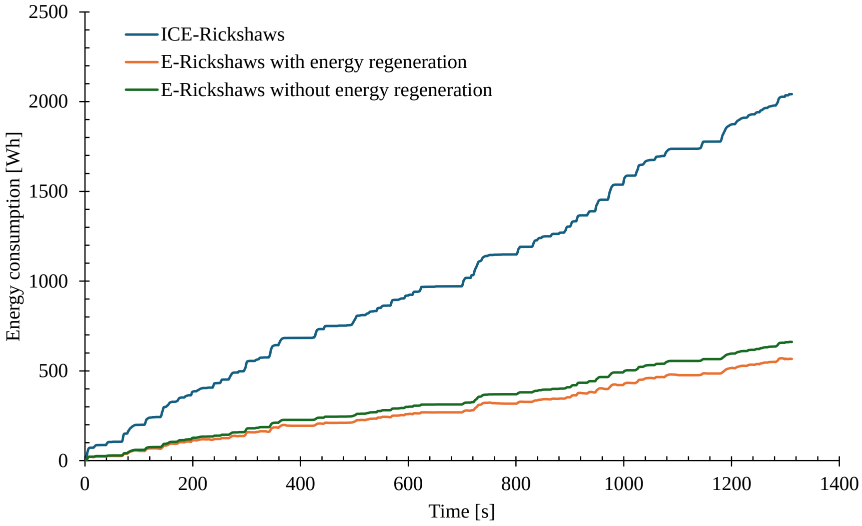

***Figure 5.*** *Cumulative energy consumption of autorickshaws.*

As observed in Figure 5, the energy consumption of the internal combustion autorickshaw is approximately twice that of the electric autorickshaw. Therefore, the implementation of electric autorickshaws offers clear advantages in reducing energy consumption in the transport sector within the study area. Furthermore, the inclusion of regenerative braking results in an energy reduction of 94.2 Wh during the driving cycle, corresponding to a 14.2% decrease in total energy consumption. Although this reduction is not as significant as the difference observed between vehicle types, the results confirm that energy recovery during deceleration phases contributes positively to the overall efficiency of the system.

## 5. Costs

In the study region, the unit cost of electricity is higher than that of gasoline used by autorickshaws. However, the unit cost of electricity has experienced reductions of up to 38%, with the lowest value recorded in February 2026 at 749.9 COP/kWh and the highest in March 2024 at 1211.3 COP/kWh. Figure 6 presents the variation in the unit cost of energy over the period from January 2024 to February 2026 [30][29].

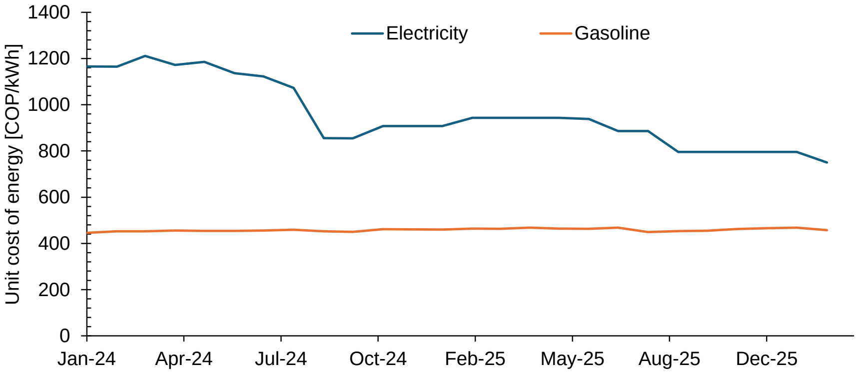

***Figure 6.*** *Unit cost of energy.*

The reduction in the unit cost of electricity is associated with measures adopted by the national government aimed at lowering electricity prices across the country. The cost model estimates the economic impact associated with the energy consumption of electric and internal combustion autorickshaws under representative operating conditions in an intermediate city in the Caribbean region. Based on an annual distance of 12,500 km, equivalent to an average monthly distance of 1,042 km, energy costs were calculated considering both the energy consumption of each technology and the temporal variation in energy prices. The monthly energy costs for electric and internal combustion autorickshaws are presented in Figure 7.

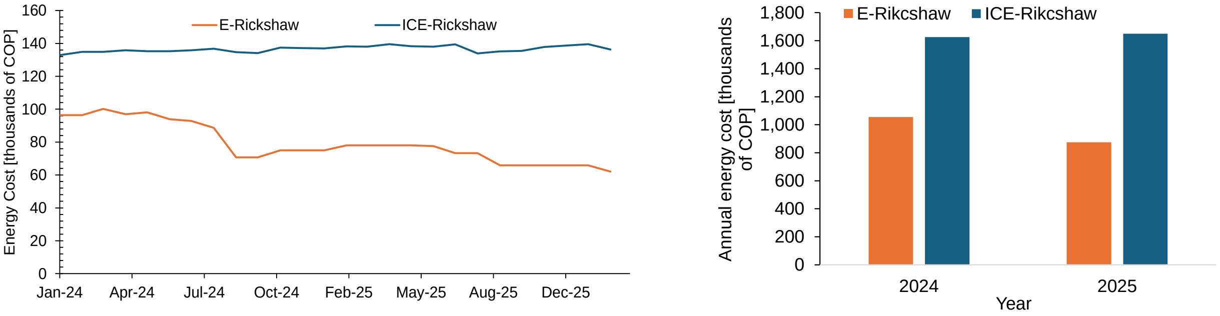

***Figure 7.*** *Energy Cost.*

The energy cost for the electric autorickshaw in 2024 was estimated at COP $1,054,874, while for 2025 it was estimated at COP $874,502, representing a 17.1% reduction in energy costs for electric autorickshaws. In contrast, energy costs for internal combustion autorickshaws increased by 2% between 2024 and 2025.

When comparing electric autorickshaws with internal combustion ones, it is observed that the monthly energy cost for electric autorickshaws was between 27% and 54% lower, with savings ranging from COP $36,000 to COP $74,000. Consequently, annual savings between COP $570,000 and COP $923,000 were estimated for electric autorickshaws compared to the currently used internal combustion vehicles. Therefore, electric autorickshaws are economically attractive from an energy cost perspective, offering clear advantages over internal combustion alternatives.

Regarding cost projections, the model enabled the estimation of future energy expenditures by considering both historical price trends and the consumer price index (CPI). The projected energy costs for electric and internal combustion autorickshaws are presented in Figure 8.

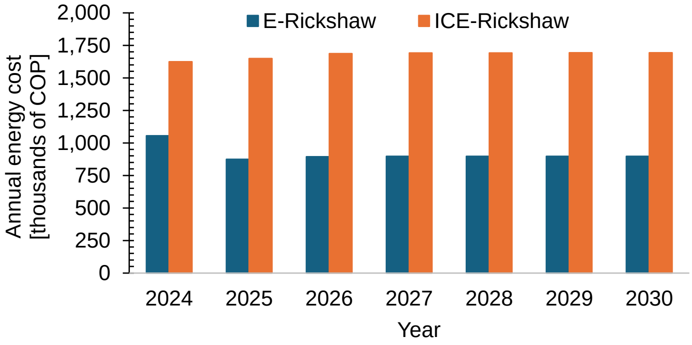

***Figure 8.*** *Projected energy costs for electric and internal combustion autorickshaws.*

For a projection period spanning from 2026 to 2030, the annual energy cost for the electric autorickshaw was projected at COP $897,078 for the year 2030, while for the internal combustion vehicle it was estimated at COP $1,691,880. These results indicate that the electric autorickshaw exhibits lower energy costs throughout the entire analysis period.

## 6. Conclusions

This study developed a methodology to estimate energy consumption and the associated energy costs of electric and internal combustion autorickshaws. The proposed approach combines a longitudinal vehicle dynamics model with a driving cycle developed for an intermediate city in the Colombian Caribbean region to estimate the energy consumption of both electric and internal combustion autorickshaws.

The results show that electric autorickshaws achieve a 79.1% reduction in energy consumption compared to internal combustion autorickshaws. This reduction is primarily due to the higher energy efficiency of electric motors and other components of the electric powertrain relative to the internal combustion engines used in conventional autorickshaws. This significant reduction in energy consumption suggests that electric autorickshaws are energetically viable for performing passenger transport activities currently carried out by internal combustion vehicles.

Additionally, the analysis of energy costs associated with electric and internal combustion autorickshaws over the period from 2024 to 2030 shows that electric vehicles provide cost savings due to their lower energy consumption. The projected energy cost for internal combustion autorickshaws in 2030 is estimated to be approximately 1.8 times higher than that of electric autorickshaws. Considering both the reduction in energy consumption and associated costs, electric autorickshaws are expected to experience increased adoption in the coming years, contributing to the energy transition in transportation systems in cities along the Colombian Caribbean coast.

It is important to note that the present study estimated energy consumption without considering variations in road grade, and vehicle speeds were based on measurements from a previous study. Furthermore, energy cost projections were conducted considering only average variations in energy prices. However, these values may be affected by external factors such as El Niño phenomena or fuel supply shortages at the national level.

Future work will focus on developing estimations and comparing them with field measurements in autorickshaws operating in cities with steeper road gradients than those found in municipalities along the Colombian Caribbean coast. Additionally, future studies will incorporate variations in transported mass for cargo autorickshaws operating in different cities across the country.

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