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Comparison of mechanical bicycle and e-bike in the public bicycle-sharing system of Cuenca-Ecuador

Comparación de bicicleta mecánica y eléctrica en el sistema de bicicleta pública compartida de Cuenca-Ecuador

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ABSTRACT: The vehicular congestion and the constant increase in the number of vehicles in urban areas represent significant issues due to the negative externalities associated with these phenomena. In this context, Bicycle-sharing systems have emerged as alternatives to mitigate the inconveniences linked to private vehicle use. Therefore, it is imperative to explore new options within shared bicycle systems, such as including e-bikes. The city of Cuenca is located in the Andes Mountain range 2550 meters above sea level, with an approximate population of 650,000 inhabitants, and is considered an intermediate city. Despite having a public bicycle system, it has not achieved the expected acceptance, according to reports from the City's Public Mobility Company. Consequently, in this study, we propose a comparative analysis of perceptions and operational parameters, such as speed and acceleration, between mechanical and e-bikes within the public bicycle system of the city of Cuenca, Ecuador. The results revealed that participants perceive more positive aspects when using e-bikes compared to conventional mechanical bicycles. Elements such as the enjoyment of the journey and the widespread recommendation of these stand out, findings that are supported by the data obtained from the analyzed operational parameters.

RESUMEN: La congestión vehicular y el constante incremento del parque automotor en áreas urbanas representan problemáticas significativas debido a las externalidades negativas asociadas a estos fenómenos. En este contexto, los sistemas de bicicletas compartidas han surgido como alternativas para atenuar los inconvenientes vinculados al uso del vehículo privado. Por ende, resulta imperativo indagar en nuevas opciones dentro de los sistemas de bicicletas compartidas, como la inclusión de bicicletas eléctricas. Cuenca, ubicada en la cordillera de los Andes a 2550 metros sobre el nivel del mar, con una población aproximada de 650,000 habitantes, se considera una ciudad intermedia. A pesar de contar con un sistema de bicicletas públicas, éste no ha alcanzado la aceptación prevista según informes de la Empresa Pública de Movilidad de la Ciudad. Por consiguiente, se planteó en este estudio un análisis comparativo de percepciones y parámetros operativos, como velocidades y aceleraciones, entre bicicletas mecánicas y eléctricas dentro del sistema de bicicletas públicas de la ciudad de Cuenca, Ecuador. Los resultados revelaron que los participantes perciben más aspectos positivos al utilizar la bicicleta eléctrica en comparación con la convencional mecánica. Se destacan elementos como el disfrute del viaje y la recomendación generalizada de la bicicleta eléctrica, lo cual encuentra respaldo en los datos obtenidos de los parámetros operativos analizados.

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1. Introduction

In the last decades, there has been a notable increase in global automotive production, registering, for example, an average annual growth rate of 2.8% between the years

1994 with 49.6 million vehicles, and 2018 with 95.6 million [1]. Simultaneously, this mode of transportation immerses users in a sedentary lifestyle, representing a significant risk factor in the development of non-communicable chronic diseases, accounting for 9% of premature deaths per year worldwide [2]. In terms of emissions, in EU countries, the transportation sector is responsible for over 30% of CO_2 emissions, with 72% attributed to road transport [3]. Similarly, in Latin America, around one-third of CO_2 emissions are generated by the transportation sector as well [4]. It is pertinent to mention that air pollution from fossil fuel combustion caused 8.7 million premature deaths in 2018 [5]. This issue accounted for one in every five deaths worldwide in 2018, with Ecuador attributing 7.2% of its deaths to this cause [6]. Approximately 76% of the pollution in the city of Cuenca is attributed to the automotive fleet [7]. Moreover, the automotive fleet has an annual growth rate of 8 to 10% including 147,484 vehicles [8].

In this context, it is essential to consider that the growth of cities leads to increased energy demands, and for this reason, according to the World Bank, cities are responsible for two-thirds of global energy consumption, generating more than 70% of greenhouse gas emissions [9]. In the case of Ecuador, energy consumption from fossil fuels accounted for 86.9% in 2014 [10]. Therefore, the expansion and growth of urban areas represent a critical point regarding their development amid the current climate crisis. In the case of Cuenca, it is the most densely populated city in Ecuador according to data from the latest census (2010), exhibiting a consistent urbanization pattern compared to other cities in the country. Furthermore, it points towards consolidating a densely populated city with an annual growth rate of 2.15% between 2001 and 2010 [11]. Hence, population growth generates increased mobility demands. In this sense, by 2015, Cuenca faced a 60% degree of oversaturation in 14% of its road capacity [8].

Bicycle-sharing systems have been on the rise in recent decades across Europe, North America, South America, Asia, and Australia [12], with an average annual growth rate of 37% since 2009 [13]. They emerge as a counterpart to the issues stemming from the growth of the automotive fleet, increased demands for fossil fuel-based energy, air pollution, health concerns, sustainable development, and mobility. By August 2022, bike-sharing fleets had achieved around 9 million bikes, reporting around 200,00 electrical devices, which was an increase of almost 73% in 2021 [14].

In Ecuador, some public policies have been implemented to regulate traffic, including projects, public transport plans, intermodal transportation, and active transport modes. For instance, Quito has implemented key mobility initiatives such as "Pico y Placa" (Peak and Plate), a law that bans certain license plate's numbers from cars to drive on certain days, during and specific hour days, the public bicycle system "BiciQuito," the Quito Metro, and an integrated mobility system [15]. On the other hand, Cuenca features the mass transit corridor "Tranvía", an Active Mobility Plan emphasizing an inverted transport hierarchy, and the "Bici Pública" (public bycicle) system [16, 17].

Cuenca´s Bicycle-sharing systems started operations in April 2019, offering 240 public bicycles and 20 stations for the citizens of Cuenca [18]. This shared public bicycle system is equipped with smart stations strategically distributed across the city. Access to bicycles requires prior registration in the service system and operates through membership modalities tailored to each user's needs. Furthermore, it includes regulations for system usage, service desks, and an online mode for service provision [17]. In this same context, shared bicycle systems have design characteristics that entail complexity concerning their adoption, which may lead to non-acceptance or failure to meet proposed goals. Consequently, exploring the limitations of these systems, both conventional and electric cycling-related, becomes imperative.

2. Literature review

In this section, some relevant and recent studies around the world are reported, which exhibit the success of e-bike systems and their advantages with respect to traditional mechanical ones. In 2017, the number of e-bikes used in the northwestern region of the Netherlands was higher than that of conventional mobility: the users showed tolerance for longer trips, the chance to use detours for more enjoyable routes, and savings in time. [19].

Similarly, in 2020, at the University of Liege in Belgium, a city characterized by hilly terrain, a study aimed to identify and assess transportation using mechanical and e-bikes. The results indicated that most individuals traveling more than 4 km, and almost all those covering more than 8 km, stopped thinking of the elevation changes as a challenge and did not experience insecurity while using the electric device. Also, users felt they made 4 times less effort and saved time. [20].

Correspondingly, the first national survey on the profile of urban cyclists in Ecuador that took place in 2018, addressing the use, attitudes, and issues related to conventional bicycles as a mode of transportation in Ecuadorian cities, found that some of the reasons preventing people from using bicycles include: lack of respect from drivers, crime, comfort, long distances, societal status associated with bicycles, absence of bike lanes and infrastructure, weather conditions, inclines and topography, sluggishness as a mode of transportation, and fear of accidents [21]. It is noteworthy that, in the city of Cuenca, a quarter of trips made through the "Bici Pública Cuenca" system occur solely from low-lying areas to higher elevations [22].

The Citizens' Oversight Committee of Cuenca suggests revising the "Bici Pública Cuenca" project, expressing concern about the gap between registered and active users. This indicates a lack of a gradual user acquisition strategy. Additionally, they state that 75% of the stations are not connected to bike lanes and that most system beneficiaries do not reside within the designated project areas. Therefore, they propose combining it with another public transportation mode [23]. Hence, it is evident that these mechanical and electric-assist mobility modes present contrasts. Electric cycling, among its advantages, offers energy efficiency, use of renewable energies [20], compliance with the recommended exercise intensity by health experts to reduce the risk of severe diseases [24], higher speed, the ability to cover long distances, reduced physical effort, and ease of mobility on inclines [25]. Therefore, they are perceived as more attractive than the barriers posed by conventional bicycles. Additionally, it is demonstrated that functionality and convenience components are important factors in the intention to adopt a shared bicycle system [26].

3. Methodology and materials

According to the objective of this study, for the development of the methodology and its requirements, a review of the state of the art at both global and local levels was carried out. Subsequently, based on literature criteria and researchers' insights, decisions were made within the local context of the research. Following this, a specific population sample was selected, as well as a specific route, including the development of the survey, organization of the routes, definition of materials and data collection instruments to be used, and pilot tests. Finally, the round-trip journeys were conducted with each type of bicycle. Data collection underwent GPS data gathering for each outbound and inbound movement, and the survey was administered at each corresponding arrival point. Subsequently, the information enters a filtering process, so that data analysis allows conclusions and recommendations to be drawn.

Some of the criteria for comparing electric versus mechanical bikes include average travel times and percentages between both groups for several questions about a user's perception when using a kind of bike.

3.1 Sample

Determining the sample size is based on finite population sampling; in turn, the finite population is related to the average number of trips made during a month in the bicycle-sharing system. The calculation of the sample size comes from the following formula 1. [27]:

$$n = \frac{Z^2NPQ}{(N-1)E^2 + Z^2PQ} \quad (1)$$

Where:
n= sample size sought.
Z= statistical parameter, approximately 1.96 for a 95% confidence interval.
N= population size.
E= maximum accepted estimation error (recommendation: 5%).
P= probability of occurrence of the studied event (success).
Q= (1-P) = probability that the event studied does not occur.

Nevertheless, a larger sample size is to be used, since it may offer greater assurance in the estimates [27]. In terms of the sample composition, we aim to stratify it to ensure gender equity. However, we do not specify a predetermined age range for the sample. The surveys were carried out one time per user, after a minimum number of trips were made, to find out about their perception when using an electrical or mechanical device.

3.2 Route

The route selection considered variables in the incidence of cyclists in the urban environment [28], the infrastructure of the bikeways corresponding to the bike sharing system, housing density, land use diversity, number of intersections, road hierarchy, positive and negative slopes in the bikeway, in addition to the different interconnections with the city's public transport systems. This route has starting and arrival points, which represent points of interest of great affluence of people [29]. In addition, the route should not represent a distance greater than 5 km for reasons of slowness before motorized means of transport [30]. Finally, the route should represent a time within the regulations of the system, be located around the estimate of the average travel time of the local population, since this criterion focuses on the system, as an alternative for daily commuting, and could be taken as a reference for route validation the average travel times made by testing the outbound and return routes, with the condition that these values are within the margins listed above. If the predefined requirements are not met, the entire route selection procedure must be repeated.

3.3 Survey

For this step, questions are selected about the research objectives but also extracted from related research; it should be noted that some of the questions may be based on information relevant to the local environment or situation. The questionnaire will also have as few questions as possible, according to the literature. A questionnaire can be of 30 questions and should be able to be administered within 30 minutes [31]. Following this recommendation, the survey should take around 15 minutes with a maximum limit of 20 questions. Regarding the questions, they were written in a clear, caring language, avoiding jargon or language inappropriate to the educational, economic, and social conditions of the participants. They should not induce in any way towards any answer, they should be easy to interpret, the questions should be, as far as possible, simple and understanding, socio-demographic questions relevant to the researcher should be available. And they should be ordered from the easiest to the most difficult with examples if necessary [31].

Questions with graded responses using a Likert scale are to be used, with a recommendation of 5 options, and responses related to numerical values should be used to facilitate the information, processing. As a final requirement, a statement of anonymity should be included.

3.4 Organization of the routes

Participants were scheduled according to their time availability; therefore, a means of real-time registration must be used to avoid the crossing of reservations of electric and public bicycles and the loan of cell phones or other devices. These reservations included a date, time of use, name of the person in charge, the element to be reserved, considering the recharging time of the e-bikes and, as time constraints, the schedule defined by the bike sharing system. Additionally, participants will be informed that they must communicate with each other in advance for time changes and their respective deliveries and receptions of e-bikes, cell phones or other accessories.

Pilot tests were carried out for the survey, the use of the applications, the route, and the guides; they served to provide feedback, reduce difficulties, detect unforeseen events, and finally led to its implementation. There were no previous tours of the participants with the bicycles in order to avoid inferring the information to be obtained.

3.5 Bicycles

Conventional bicycles are to be provided by the authors based on the loan regulations of the shared system and prior training of the participants; the e-bikes will also be provided by the researchers after training. As an additional criterion, the electric bikes to be provided must comply with the current legal regulations of the country.

3.6 Data collection instruments

The survey and GPS data collection are developed through the use of freely available applications. The choice may be inferred by their application in other studies or according to the opinion of the researchers. In addition, based on available resources, participants may be offered cell phones, tablets, iPads, specialized instruments for GPS data collection or another available device. It is necessary to highlight that within the characteristics of the GPS application, it must allow the entry of several records, a sampling frequency of at least 1Hz, options in terms of units of measurement (distance, time, longitude and latitude), including data export in different formats (CSV, KLM); additionally, the survey instrument must be simple, easy to manipulate, its database offers the export of surveys in various formats (XLS, CSV). As points in common, they must be available indistinctly to the installed versions of the operating systems and must indispensably work offline. The scheduling of bicycles or any other implement uses the online mode of a shared Excel document.
Furthermore, the following software was required:
Microsoft Excel for data manipulation: according to the information export formats available for mobile applications, "R Studio" for data analysis: due to its free use, first level, availability of import formats, tools, and potential in the development of statistical programming.

For the treatment of outlier data, a mix of known methods was used, including boxes and whiskers (Tuckey rule), as the standard deviation with center at the median or its mean, with their respective values of extension of valid data range. The comparisons were developed using the selected software, and, in the same way, methods are to be used to compare the collected parameters, such as the "Mann-Whitney U-test" to check whether there is equality between 2 distributions.

3.7 Guides and training

The guides contain a cover page, the topic, general and specific objectives, with orderly development, simple language, short instructions, supported by images that contribute to the fulfillment of the objectives, besides multimedia content. Instructions are required for the survey, use of the applications, recommendations at the time of cycling, use of the e-bikes, and an oral or written guide to the use of the public bicycle system based on its regulations. The trainings were conducted in person, previously agreed upon, with the guides, information collection instruments, and bicycles present, so that the different doubts of the participants could be solved. It is important to mention that preferences for one of these modalities should not be encouraged during the process.

4. Results

4.1 Sample size

The sample was established according to the average number of trips in the period April-December 2019 prior to the pandemic, with a confidence level of 95%, margin of error of 5%, and P and Q values of 50%, which yielded a sample size of 345 trips. Nevertheless, a total sample of 448 trips was collected, of which 39% correspond to women and 61% to men. The age of the participants was limited to those over 15 years of age due to membership acquisition and to participants under 55 years of age, selecting an economically active population. In addition, students from the "Universidad del Azuay" collaborated in the search for participants. The number of surveys differs from the number of completed trips because trips that did not accurately record the data were excluded.

4.2 Route

The analysis routes were defined from the bicycle stations located at the: Universidad del Azuay (UDA) and the ¨La Merced¨ Cycle-station, according to the proposed methodology, establishing route 1 from UDA-La Merced as indicated in Figure 1 and route 2 back La Merced-UDA indicated in Figure 2, with estimated distances of 4.331 km and 4.099 km, respectively.

It is necessary to mention that the routes have positive and negative slopes and flat route spaces, located between the so-called terrace of the historic center of Cuenca with heights from 2,560 to 2,520 meters above sea level and the terrace of the lower part of the city with heights from 2,500 to 2,560 meters above sea level; this can be evidenced in the profile topography of Figures 3 and 4. On the other hand, the time to cover the routes estimated by pilot tests is 24 minutes, which is within the range of use of the bicycle-sharing system of 30 minutes and, at the same time, within the time interval of 0-30 minutes of 65.66% of the people moving within the city of Cuenca [32].

4.3 Survey

The total sample consisted of 624 surveys, answered using the KoBoCollect mobile application. The questions were divided into three sections: demographic, estimating parameters and information, and perception.

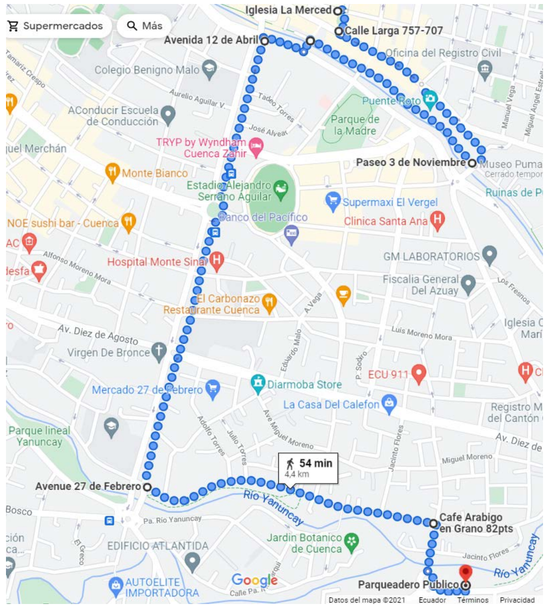

Figure 1 Route 1: UDA-La Merced

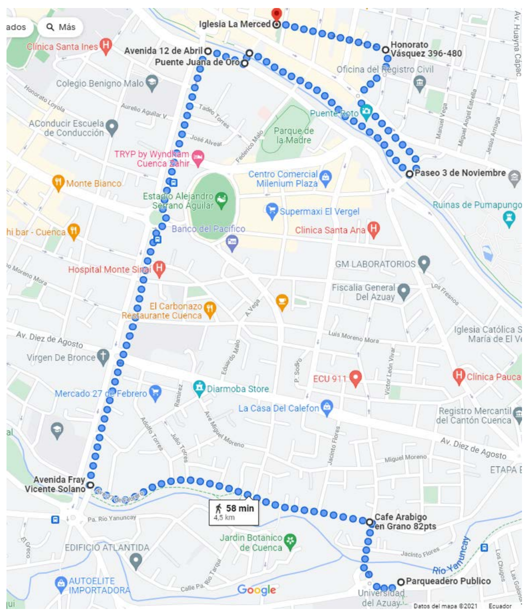

Figure 2 Route 2: La Merced-UDA

Figure 3 Altitudes in Route 1: UDA-La Merced

Sociodemographics

The majority of the participants were male, with a total of 398 males (63.81%) and 226 females (36.19%). The

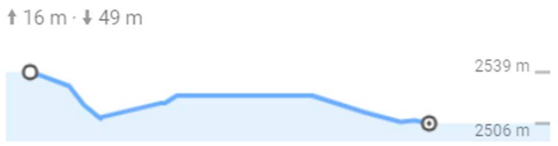

Figure 4 Altitudes in Route 2: La Merced -UDA.

Table 1 Travel time on each route per bicycle type

Bicycle type	Estimated average time (min) Route 1	Estimated average time (min) Route 2
Ebike	19.72	17.19
Mechanic	25.75	22.32
Percentage difference	23.41%	22.98%

mean age of the participants was 27.33 years, and its median was 24 years, which indicates that the working age corresponds to young people between 20 and 30 years old. Additionally, the information of the surnames and names of the participants was collected to reference the data in terms of filtering and to establish the number of tours given to each student; previously, they were informed that their data would be kept anonymous and would only be used for research purposes.

Operating parameters

The survey was conducted during the period from 03/27/2021 to 07/24/2021, with 10.48% of rainfall during the total trips. It presents 50.96% of the surveys for e-bike rides and 49.04% for public bicycles, i.e., almost an equal sampling of both modes of transport was achieved. "La Merced" had 50.8% of the respondents as their endpoint and 49.2% as the other route, demonstrating an almost balanced sample in terms of outbound and return routes; in turn, this information was used for the debugging of CSV files. "The arrival time" was another element that was collected as data; this was used as additional information for data cleaning with respect to the last hours recorded in the CSV files of the "GPS Logger" application.

In the case of the perception of travel time on the routes, the participants were asked to enter the time to cover the route; the results can be seen in Table 1, where it can be observed that the average time perceived by the participants for route 1 on the e-bike is 23.41% less time, compared to the public one, and for route 2, the e-bike is 22.98% less time.

Perception questions

This section consisted of 5 perception questions with ratings from 1 to 5 on a Likert scale, requested at the end of each trip using the respective means of transportation, either e-bike or mechanical bicycle of the public bicycle system. The first question asked about people's perception of safety, where 67.82% feel totally safe using the e-bike and 32.17% with the mechanical bicycle, 42.25% feel safe using the e-bike, and 57.74% feel safe using mechanical bike. There are 36% of respondents who feel undecided in this section about the e-bike, and 64% feeling undecided about the mechanical bicycle. On the other hand, 12.5% of respondents felt unsafe with the e-bike and 87.5% with the mechanical bicycle. Finally, of the responses received in the case of total insecurity, only 2 of the participants responded to the e-bike. All the above-mentioned correspond to Route 1, as shown in Figure 5. For Route 2, in terms of safety, the percentage of those who responded with a rating of totally safe was 68.59% using the e-bike and 31.4% with the mechanical bicycle In comparison,43.88% felt safe with the e-bike, and 56.11% did so with the mechanical bicycle.

On the other hand, 33.33% of the respondents who answered this question feel undecided about the e-bike, and 66.66% about the mechanical bicycle. However, 25% of the respondents were unsure about using the e-bike and 87.5% were unsure about using the mechanical bicycle. Finally, one person felt totally insecure while using the mechanical bicycle, as shown in Figure 5.

The second analysis is related to the perception of fatigue felt by the participants during the trip. When asked about not being tired, 77.3% responded in favor of the e-bike, while 22.68% responded in favor of the mechanical bicycle; concerning being slightly tired, 48.31% perceived it on the e-bike and 51.68% felt it using the mechanical bicycle; on the other hand, as for tired participants, 20.89% belonged to the e-bike and 79.1% to the mechanical bicycle; then, with respect to quite tired, 22.58% responded to the e-bike and 77.42% to the mechanical bicycle. In last place, the participants who consider themselves totally tired correspond to 11 people, of which 27.27% responded to the e-bike against 72.73% of those who responded mechanical bicycle, this regarding Route 1 on the basis of Figure 6. Regarding Route 2, for the same analysis mentioned above, in the same way for the e-bike corresponds to 76.42% for not tired, 46.36% for slightly tired, 20.37% for tired, 0% for quite tired, and 60% for totally tired. On the other hand, for the mechanical bicycle, 23.58% were not tired, 53.63% were slightly tired, 79.63% were tired, 100% were quite tired and 40% were totally tired corresponded to each evaluation, as shown in Figure 6.

The third inquiry has to do with the mood of the participants before the tour. Concerning Route 1, 60.93% of the participants mentioned that they were totally encouraged by the use of the e-bike and 30.07% for the mechanical one, followed by 40.78% for the electric one and 59.22% for the mechanical one, on the other hand, 42.85% of

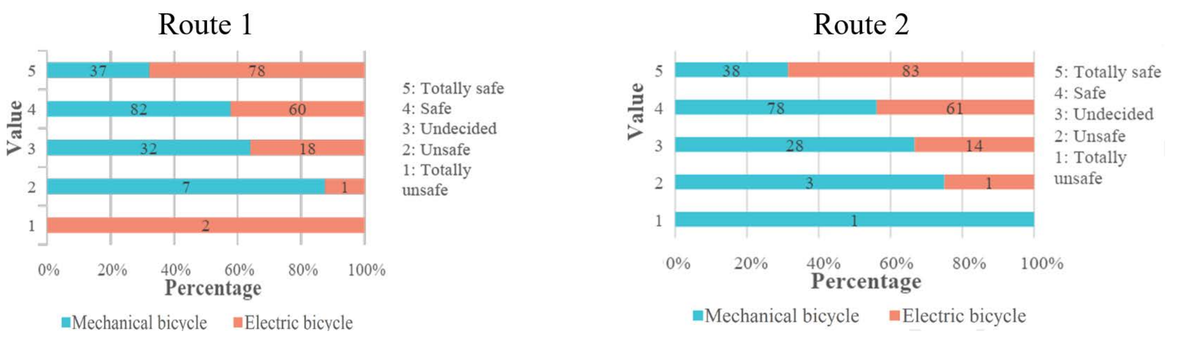

Figure 5 How safe did I feel on the ride?

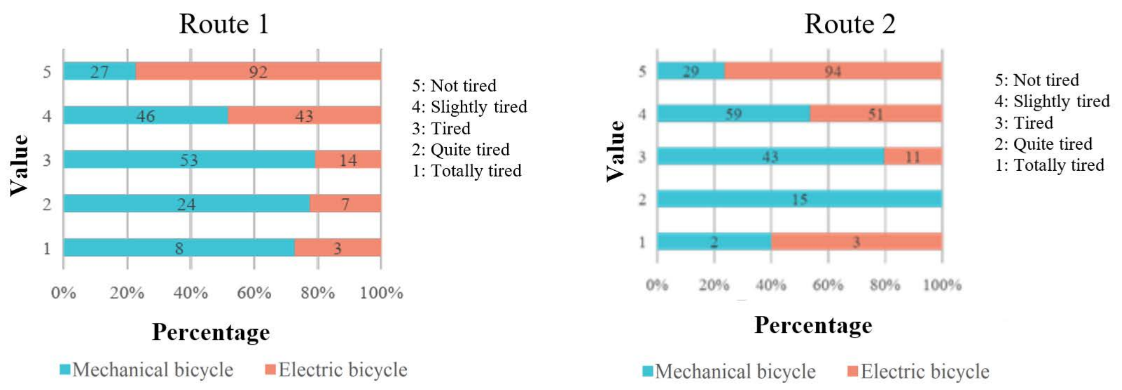

Figure 6 How tired did I feel on the ride?

the participants in the e-bike felt discouraged against 57.14% for the mechanical bike. On the other hand, 42.85% of participants in the e-bike felt, against 57.14% in the mechanical one, then there was one person who felt discouraged by each mode of transport, as shown in Figure 7; however, there were 38.89% of people who felt normal before the e-bike and 61.11% who perceived it in the same way before the mechanical bicycle. Likewise, in Route 2, the mood before the trips for the electric and mechanical bicycle are respectively: totally encouraged 67.1% and 32.89%, encouraged 37.86% and 62.14%, normal 37.5% and 62.5%, discouraged 30% and 70%. Finally, 2 people were totally discouraged before the mechanical bicycle, as can be seen in Figure 7.

The fourth question is related to the previous question, referring to the mood of the participants after the rides. Corresponding to Route 1 in Figure 8, the percentages of people who selected each evaluation for the electric and mechanical s are: totally encouraged 66.67% and 33.33%, followed by encouraged with 43.01% and 56.99%, normal at 26% and 74%, then discouraged 23.52% and 76.47%. Finally, 4 people felt totally discouraged before the mechanical bicycle. For Route 2, according to question 4, for the electric and mechanical bicycles, respectively, the results show: totally encouraged 67.88% and 32.12%, encouraged 49.55% and 50.44%, normal 22.22% and 77.78%, then 9 people felt discouraged together with 3 people totally discouraged after using the mechanical bicycle, as shown in Figure 8.

The perception of enjoyment at the end of the routes was defined in the fifth question. For the first part of Route 1, the following responses were obtained respectively for the electric and mechanical bicycle, with the following percentage of people who responded to each validation: 64.84% and 35.15% enjoyed it very much, 36.11% and 63.89% simply enjoyed it, 25% and 75% were undecided, 6 people did not enjoy it and only 2 people did not enjoy it at all, the latter referring to the e-bike, as shown in Figure 9. For the second part, Route 2, in the same way, the following perceptions were received regarding the use of the electric and mechanical bicycles, respectively: 64.84% and 35.15% enjoyed it very much, only 44.23% and 55.76% enjoyed it, 17.24% and 82.75% were undecided, 8 people did not enjoy it, and only one person did not enjoy it at all their ride on the mechanical bicycle, as shown in Figure 9.

The consideration about "recommending or not" of the modality used after the tours was given by the sixth question, respectively, for the electric or mechanical bicycle was as follows: people would definitely recommend it 67.86% and 32.14%, would recommend it 36.22% and 63. On the other hand, 33.33% and 66.66% were undecided;

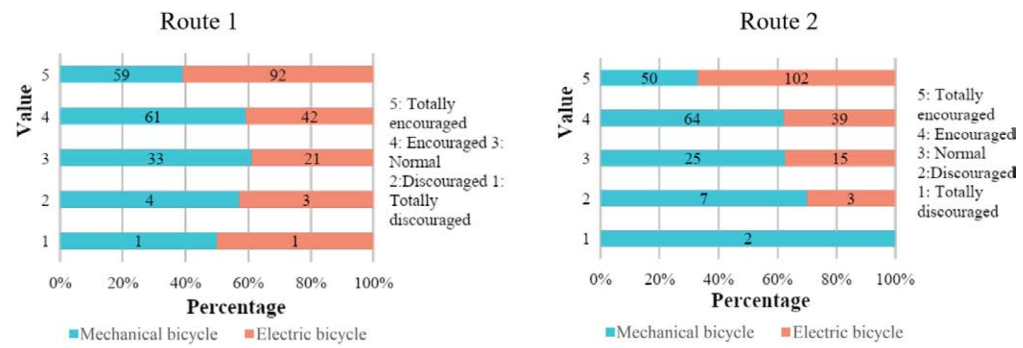

Figure 7 How well do I feel before the ride?

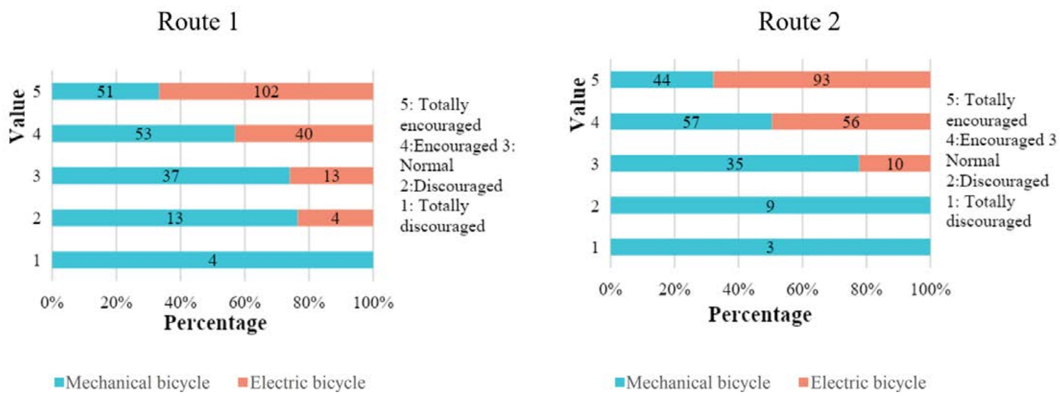

Figure 8 How well did I feel after the ride?

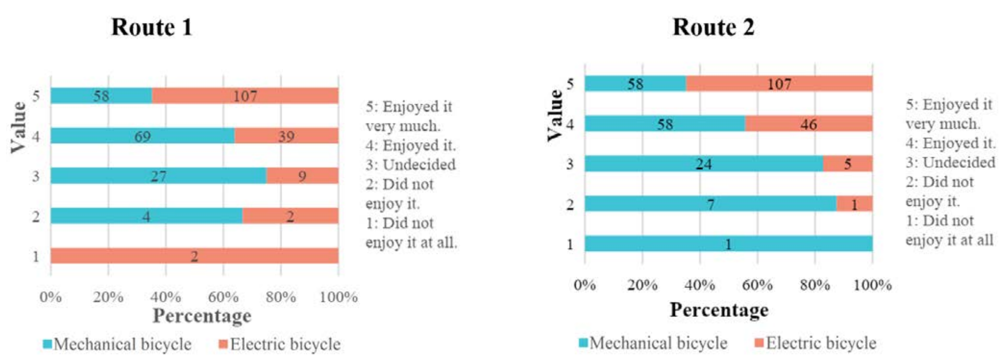

Figure 9 How much did you enjoy the ride?

however, 45.45% and 54.54% of people would not recommend it; for Route 1, there were no people who would definitely not recommend the use of any of these means of transportation, as shown in Figure 10. Similarly, for Route 2 towards the electric or mechanical bicycle, 67.65% of people using the e-bike and 32.35% who used the mechanical bicycle would definitely recommend this form of transportation, as well as 42.06% and 57.94% would recommend it, and 31.58% and 68.42% of people using the e-bike and 32.35% using the mechanical bicycle would definitely recommend it. 58% and 68.42% of participants were undecided; on the other hand, participants who would not recommend each of their forms of transportation consisted of 25.57% and 71.42%, similar to Route 1 had no people who would definitely not recommend their mode of transportation, as denoted in Figure 10.

Finally, the participants were asked about their perception of riding compared to the vehicular traffic around them. In Route 1, according to Figure 11, the participants who did it by electric or mechanical bicycle and who selected each valuation, the following percentages correspond to them respectively: 70% and 30% of the participants perceived

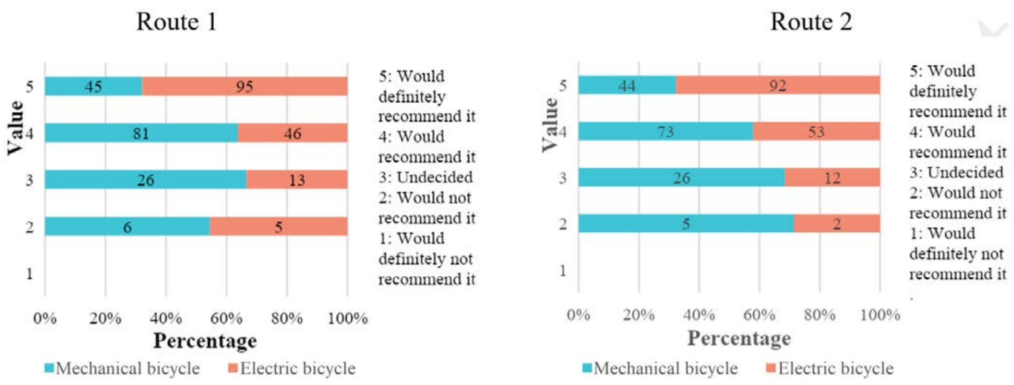

Figure 10 After the ride, how much would you recommend using of bicycles as a transportation mode?

that they were going much faster, 47.29% and 52.71% felt faster; however 35. 38% and 64.61% of the people responded to a valuation of equally fast; on the other hand, 15 people considered that they transited slower, and 1 person valued that they went much slower; these last two valuations only belonged to the mechanical bicycle, as can be observed in Figure 11. Similarly, Route 2 had the following results: 65.41% and 34.58% felt much faster, 42.74% and 57.26% felt faster, 44% and 56% perceived that they were going as fast, then 7 people felt they were going slower, and no person felt that they were going much slower during this route as shown in Figure 11.

Table 2 The Time Medians

Bicycle type	time (min) Route 1	time (min) Route 2
Electric	17.88	16.55
Mechanical	22.72	18.73
Percentage difference	21.3%	11.64%

Table 3 Speed Medians

Bicycle	Speed – Median (m/s) Route 1	Speed – Median (m/s) Route 2
Electric	16.2	16.88
Mechanical	12.58	13.88
Percentage difference	22.35%	17.77%

4.4 Data processing

The total information collected by the GPS Logger application consisted of 851 CSV and 804 KML format files, which were then processed by filtering by box and whisker diagram in Excel according to their distribution, adding the following criteria ere also added to purge the files: incomplete, not corresponding to their path names, duplicates, saved with incorrect name formats, with erroneous information corresponding to the path between their KML and CSV and impossible to match their author; finally a set of 448 valid CSV files were determined for the analysis. On the other hand, due to the data distributions, for the parametric comparisons between the e-bike and the public bicycle, the Mann-Whitney U test was used to establish if there is a difference between these parameters; additionally, when processing the data, the speeds equal to zero were eliminated, that is, the moments when the bicycles were at rest during the routes, and only the positive accelerations were taken into account for the processing of the acceleration.

Time

The time parameters were represented by their medians, using the minute as the reference unit for representation. The medians for each route, along with their respective modalities, can be observed in Table 2.

Speed

The reference for speeds was solely based on medians. Due to the shape of the distributions, as mentioned earlier, only outliers and speeds at zero were excluded. The results can be seen in Table 3, and a comparison image in Figure 12.

Acceleration

The medians of the collected acceleration data can be observed in Table 4, and a comparison image in Figure 13. Only positive accelerations were considered, indicating the starts during transit, as decelerations may represent braking, cessation of acceleration, or involve some positive slope. Accelerations of zero were also omitted. It is important to note that acceleration was calculated based on speed.

Mann-Whitney U Tests

The following values were obtained using R software among the different distributions shown below in Table 5

A significance level of 0.05 was considered, meaning that

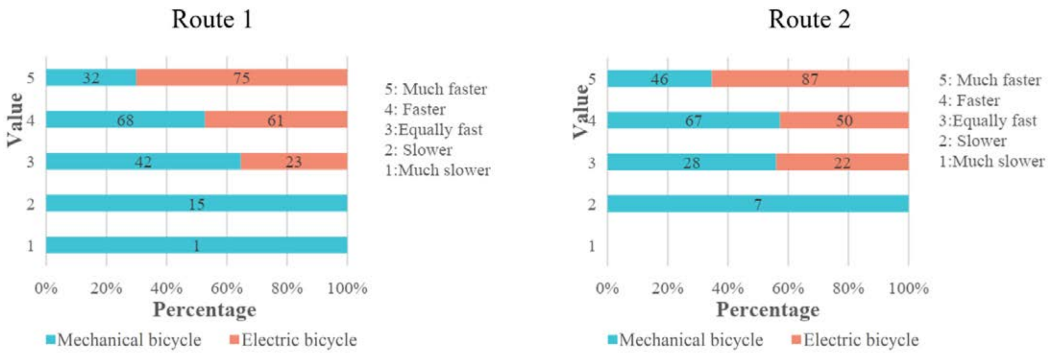

Figure 11 How fast did I go compared to the vehicular transit flow on the ride?

Table 4 Acceleration Medians

Bicycle	Acceleration – Median (m/s^2) Route 1	Acceleration – Median (m/s^2) Route 2
Electric	0.5458	0.5572
Mechanical	0.3922	0.4247
Percentage difference	28.14%	23.78%

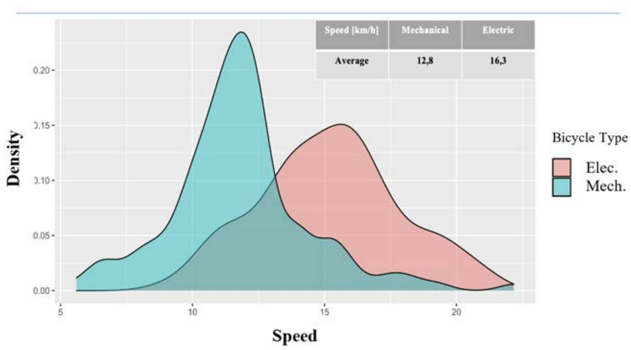

Figure 12 Comparison of average speed in both routes

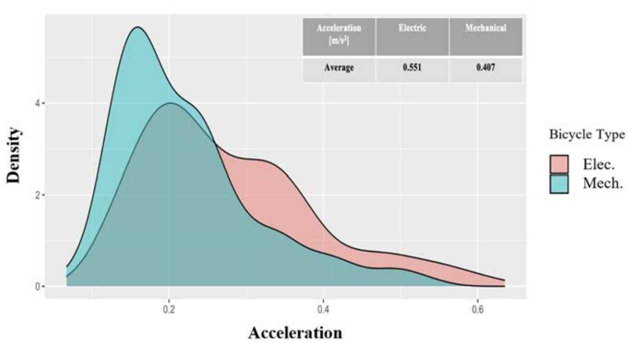

Figure 13 Comparison of average acceleration in both routes

to conclude, there is a statistically significant difference between the medians, $p \leq 0.05$.

5. Discussion

Current mobility systems are not sustainable; priority has been given to planning cities around the private automobile [33]. In some cities of Ecuador, such as Quito and Cuenca, efficient, non-motorized and sustainable alternative solutions have been promoted, such as the so-called Bicycle-sharing systems. In the city of Cuenca, the inquiry about the change from a totally mechanical mode to an assisted mode, through the comparison of perceptions using a survey, has obtained that 1.16 people feel safer with respect to the use of the e-bike than with the mechanical one for Route 1 and likewise 1. 25 for Route 2. This information is similarly related to the study of the University of Liege in Belgium, , through a survey concerning insecurity, it has been determined that this is 1.29 times less mentioned; we can possibly argue that these data are not higher because in Ecuador, 59% of cyclists believe that their neighborhood is safe to transit and 52% of cyclists believe that cycling is dangerous according to the 1st National Survey of Urban Cyclists [21]. Regarding fatigue, it was found that 3.4 more people felt less tired on the e-bike than on the mechanical bicycle for Route 1, and 3.24 more people felt it for Route 2, similar to the 4 times less mentioned in the study of Liege; this may be due to the similarity of both cities in terms of their particular topographic characteristics and emphasizes the importance of the slopes for the presence of cyclists in the city of Cuenca [29]. On the other hand, the relationship of each of these means concerning traffic determined that 1.36 more people perceived going faster through traffic with e-bike than with conventional bicycle for Route 1 and 1.21 for Route 2, which is almost analogous to the result obtained from the University of Liège of 1.3 times [20].

Table 5 Mann-Whitney U Tests

Collected Parameters	P-value Route 1 Electric and Mechanical Bicycles	P-value Route 2 lectric and Mechanical Bicycles
Time	1.087e-13	1.318e-08
Speed	2.65e-15	1.87e-12
Acceleration	4.17e-09	2.908e-06

The present study makes an inference, in turn, on the perspective of the mood of the people in terms of before and after the experimentation of a mode of transport, where positive percentages towards the e-bike of 5.63% for Route 1 and 5.37% for Route 2 were evidenced, which does not occur with the mechanical bicycle within this context with a decrease of 13.33% for Route 1 and 12.87% in Route 2. These positive results of the e-bike, according to a study from the northwest of the Netherlands, are due to not investing large amounts of time in transportation, and not arriving tired or sweaty[19]; on the other hand, the negative percentages of the conventional bicycle in the same plane is the speed for which it is selected as a means of transportation over another, corresponding to 23% in its speed to consider it as an alternative, likewise 19% of cyclists only like it or do it for pleasure, i.e., this percentage enjoys it [21].

The position of people who would definitely recommend the e-bike is 2.1 more people than for mechanical bicycle after traveling Route 1; for Route 2, it is 2.1, which is very significant, and implies a greater probability in the intentionality of traveling by bicycle, that is, there is a presence of positive attitudes as indicated by the study for the modal shift towards cycling in the case of Mexico City [34]. The analysis of the collected parameters for time, speed, and acceleration distinctly highlights the superior performance of the e-bike compared to the mechanical bicycle as a means of transportation. As detailed in Tables 2, 3, and 4 of the manuscript, the e-bike demonstrated enhanced efficiency on two distinct routes.

Specifically, for Route 1, the e-bike showed improvements of 21.3% in time, 22.35% in speed, and 28.14% in acceleration. The statistical analysis provided in Table [5], further substantiates these findings, confirming the e-bike's efficacy in performance, thereby making it a significantly more efficient option within urban mobility frameworks. The results in speed are notably lower compared to the reductions of up to 49% observed in mechanical bicycles, as reported in the study "Evaluation of the electric bicycle as an alternative mobility in the city of Cuenca, Ecuador." [35], such differences may be due to the profiles of the participants in the data collection, the characteristics of electric and conventional bicycles, and the routes and conditions under which they are developed, which in our case consisted of a shared bicycle system. Finally, regarding the parameters between the electric and mechanical bicycle, it can be assured that there is a contrast between the distributions of both means; that is, there is a difference between the parameters of time, speed, and acceleration, due to the Mann-Whitney U tests.

6. Conclusions

The study on electric and mechanical bicycles in Cuenca's public bicycle system reveals significant insights. Firstly, participants experience a heightened sense of security, comfort, and enjoyment while using e-bikes compared to those in the Bicycle-sharing system. These conventional bikes, with their restrictive gear settings and heavier build, do not match the personal bike experience.

E-bikes within the public system present a clear advantage by not having speed limitations or legal constraints like those in Ecuador. This allows for superior performance data in terms of speed and acceleration, which is not only faster but also more efficient, cutting down travel times considerably. While greater acceleration in e-bikes initially poses a challenge, it can eventually enhance safety, particularly at intersections. The use of e-bikes is also associated with reduced fatigue. This is crucial in cities like Cuenca, where the terrain is irregular, making e-bikes a strategic choice for improving urban mobility. Furthermore, e-bikes maintain higher levels of user motivation post-usage compared to mechanical bikes, which see a significant drop. This suggests that e-bikes might encourage a shift in transport modalities if people are exposed to and can experience their benefits first-hand.

Moreover, the data suggests a general perception of moving faster relative to traffic, regardless of the type of bike used. However, within the bike-sharing context, e-bikes are distinctly preferred over mechanical bikes, as evidenced by their higher recommendation rates. Finally, the statistical analysis of time, speed, and acceleration parameters between the two types of bikes shows that e-bikes offer a competitive edge within the shared system, especially considering Cuenca's topographic challenges. While e-bikes provide greater acceleration, this feature requires some acclimatization to manage effectively, ensuring both safety and a positive user experience.

Declaration of competing interest

We declare that we have no significant competing interests, including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

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Author contributions

J. A. Romero-González and B. M. Coello-Salcedo: Were in charge of the information gathering process, validation of the instruments, training of the participants and writing the article. I. A. Mendoza-Vázquez and M. F. Coello-Salcedo: Were in charge of the conception of the methodological protocol and data processing, and also contributed to the writing of the article.

Data availability statement

The authors verify that the data substantiating the results of this study can be found in the article and/or its supplementary materials. The data of the study cand be found here: https://github.com/ivanmendozav/research.git

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