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ZEBRA

ZERO EMISSION BUS

RAPID-DEPLOYMENT ACCELERATOR

Analysis of Electric Bus Performance Monitoring in Mexico City

METROBÚS

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INTRODUCTION

The transport sector contributes significantly to greenhouse gas (GHG) emissions, which intensify global warming and the emission of criteria pollutants such as nitrogen oxides (NO_x) and particulate matter (PM), which affect air quality and the health of the population. One option for reducing GHG emissions and local environmental pollutants is to upgrade the transport sector with zero-emission fleets. Many cities around the world are making efforts to migrate to electric transport fleets.

Mexico City has set for itself the goal of being carbon neutral by 2050 and, through various programs and actions, has made commitments to reduce emissions from transportation. The current administration (2018-2024) has made progress in electric mobility with the establishment of tangible commitments through instruments such as the CDMX Climate Action Program 2021-2030, the Climate Action Strategy 2021-2050[1], and the Plan to Reduce Emissions from the Mobility Sector[2], which establishes a goal of reducing by 30% emissions of criteria pollutants from mobile sources in 2024. Additionally, Mexico City is a signatory of the C40 Green and Healthy Streets Declaration[3], through which it has committed to ensuring that, starting in 2025, all buses acquired are zero emission.

Public transport fleets have been identified as a vehicle segment with the greatest potential for successful transition to zero-emission technologies in the short term. Generally speaking, they are relatively small fleets, with intensive operation on specific routes, and are regulated by local government agencies, which could facilitate the planning, financing, and introduction of electric fleets, together with their charging infrastructure.

Among the most outstanding actions in electromobility in Mexico City are the commitment to implement 4 lines of Cablebús, of which two are currently operating; the expansion of the Trolleybus network through the acquisition of 500 units (193 of which were acquired between 2019 and 2020); and the integration of a zero-emission Metrobús line, which will operate with electric articulated buses.

1 Ministry of Environment of Mexico City, (n.d.) "LOCAL CLIMATE ACTION STRATEGY 2021-2050 MEXICO CITY CLIMATE ACTION PROGRAM 2021-2030", http://www.data.sedema.cdmx.gob.mx/cambioclimaticocdmx/images/biblioteca_cc/PACCM-y-ELAC_uv.pdf.

2 México City Government, (n.d.) "PLAN TO REDUCE EMISSIONS FROM THE MOBILITY SECTOR IN MEXICO CITY", https://www.jefaturadegobierno.cdmx.gob.mx/storage/app/media/plan-reduccion-de-emisiones.pdf.

3 C40 Cities, "Green & Healthy Streets Accelerator", https://www.c40.org/accelerators/green-healthy-streets/.

ELECTRIC BUSES IN THE METROBÚS SYSTEM

Metrobús, Mexico City's BRT (*Bus Rapid Transit*) system,[4] has begun its transition to electromobility. Since 2020, this transport system, in collaboration with manufacturing companies and the International Council on Clean Transportation (ICCT), has evaluated buses of various types from different manufacturers, using the actual operational characteristics of the system's lines as an evaluation framework.

As a result of the evaluations, in 2021 Metrobús Line 3 incorporated 9 electric articulated buses into its fleet, for which 7 chargers were installed in the enclosure bus depot. During the official presentation of these vehicles, a public commitment was made to replace the remainder of the line's fleet with electric buses, in line with the commitments of the city, so that by 2024 a Metrobús line will be all electric. As a follow-up to these actions, it is expected that in the first quarter of 2023, 51 additional electric articulated buses (60 in total) will be in operation and the installation in the depot of the charging infrastructure necessary to operate the fleet (25 additional chargers) will be completed.

In parallel, after having evaluated electric vehicles from several manufacturers, planning is underway for the acquisition of 19 electric buses for Line 4, and of the charging infrastructure required for their operation. The medium-term plans are to gradually convert the entire Line 4 fleet to electric vehicles.

According to the operating rules established by Metrobús for vehicle replacement, buses operating on the system must be replaced after completing 10 years of operation, with the exception of double-decker buses, for which a period of fifteen years is established. Under this schedule, bus replacements are expected to reach 508 units by 2030[5], representing 65% of the current fleet, which presents a great opportunity to promote the transition toward the electrification of the system.

4 Gobierno de la Ciudad de México, sitio web de Metrobús, https://www.metrobus.cdmx.gob.mx/.

5 Leticia Pineda, Carlos Jimenez, y Oscar Delgado, *Estrategia para el despliegue de flota electrica en el Sistema de Corredores de Transporte Publico de Pasajeros de la Ciudad de México "Metrobús": Líneas 3 y 4* (ICCT: Washington, DC 2022) https://theicct.org/publication/mexico-latam-hdv-zebra-mar22/.

MONITORING OF THE ELECTRIC ARTICULATED BUS

This section analyzes the operational performance of the monitored electric articulated bus, through the analysis of technical and operational data recorded in the monitoring period. The evaluated parameters included distance traveled, energy consumption in absolute and relative terms with respect to distance traveled, speed, energy regeneration through regenerative braking, and periods at idle.

The analysis was complemented by a series of ballast tests, which allowed for more accurate measurements of energy consumption under different and controlled load conditions. The results of these tests are presented and analysed to establish a correlation between energy consumption and the transported load.

The monitored vehicle is an 18 m, high-floor electric articulated bus, with capacity for 160 passengers, model E18-ZK6180BEVG manufactured by the Chinese company Yutong. It has a pack of LFP (lithium iron phosphate) batteries of 564 kWh, two electric motors with a rated capacity of 150/260 kW, and an estimated range of more than 300 km. The main technical characteristics are presented in Table 1. Considering the climatic conditions of Mexico City, the bus is not equipped with air-conditioning or heating systems.

During the evaluation period, the bus operated in Metrobús Line 3, providing service under the same conditions as the internal combustion bus fleet. This allowed project staff to record representative information of the operation, which can also be used in calibrating simulation models to predict energy consumption in other operating scenarios. Line 3 provides service along 20.4 km between Tenayuca, in the northwest, and Pueblo Santa Cruz Atoyac, in the center-south of the city. The main route circulates through Avenida Vallejo and Eje 1 Poniente, a relatively flat route with a maximum slope of 6 degrees, and along which 37 stations and 6 terminals are distributed.

Figure 1. Yutong electric articulated bus model E18-ZK6180BEVG. Photo: Carlos Jiménez.

Table 1. Electric articulated bus technical characteristics

PARAMETER	VALUE
Manufacturer	Yutong
Model	ZK6180BEVG
Length * Width * Height (mm)	18,210 * 2,550 * 3,570
Turning radius (m)	23
Vehicle weight (kg)	19,800
Gross vehicle weight (kg)	30,000
Maximum passenger capacity	160
Rated power (kW/rpm)	150/260
Rated torque (N.m/rpm)	1,450/3,200
Batteries	LFP (lithium iron phosphate)
Battery capacity (kWh)	564

BUS MONITORING WITH TELEMATICS EQUIPMENT

By using telematics equipment, it is possible to monitor and record the daily operation of electric vehicles, since they allow the collection, in real time, of operational data (such as GPS coordinates, battery charge status, speed, and distance traveled, among many other variables) that can be transmitted and stored on digital platforms for analysis. This information is relevant for determining the performance of the vehicles, since all operational variables are continuously recorded. Thus, errors or failures in the various electrical systems can be identified, as well as mechanical problems.

Data capture with telematics equipment is done by connecting to the output line of the vehicle's CAN Bus. The CAN system (Controller Area Network) is a centralized protocol through which all the electronic control units (ECUs) of the different sensors and subsystems that make up the vehicles communicate, in such a way that all operational information can be monitored and stored for later analysis.

A telematics company was contracted to provide the equipment, as well as the monitoring and data collection service for a year, which was done by installing a *Canlogger Guard v1.0* device.[6] This was connected non-intrusively to the CAN network of the bus, accessing the information and converting the recorded data to the SAE J-1939 communication protocol for interpretation and analysis.

MONITORING PERIOD

Monitoring was carried out from 23 December 2020 to 19 September 2021, a total of 270 days, or 9 months. For the purposes of this analysis, information on the days on which the bus traveled distances fewer than 50 kilometers (45 days) was excluded as they were considered unrepresentative of daily operation. Fifteen-day data was also excluded due to inconsistencies in the information. In sum, the analysis presented is based on the information of 210 days of operation (78% of the total registered). The monitoring period coincided with the health emergency caused by the SARS-CoV-2 virus pandemic, during which demand on public transport systems was reduced as a result of restrictions and confinement.

6 Didcom, "Didcom Camlogger Guard v.1.0", https://didcom.com.mx/wp-content/uploads/2016/12/CLG-ficha-t%C3%A9cnica.pdf.

MONITORING RESULTS

This section presents the results of the monitoring carried out by telematics equipment of an electric articulated bus deployed in the Metrobús System of Mexico City. Various operational and performance parameters are analyzed, including distance traveled, speed, state of charge (SoC), energy consumption per kilometer, and energy regeneration, among others.

DAILY DISTANCE TRAVELED

During the analyzed period, the average daily distance traveled was 246.7 ± 10.4 km, with a confidence interval of 95%, while the median was 277.7 km. This represents circulation of at least 6 times the longest circuit of the line. The maximum distance covered during a day was 373.2 km (19 June 2021) in which the state of charge decreased 70%; the next highest value was 335 km (3 July 2021).

As seen in Figure 2, showing the daily distance traveled, on 32% of the monitored days the vehicle covered a distance of less than 250 km, on 66.5% of the days it traveled distances of between 250 km and 325 km, and on 1.5% of days it traveled a distance greater than 325 km. The range between 275 km and 300 km accounts for 28.6% of the sample.

Considering the characteristics of the line on which the bus was evaluated, and based on the data on distance traveled, the largest amount of data collected is representative of the regular operation of the bus in service and corresponds to the most demanding operational and environmental conditions present in this service.

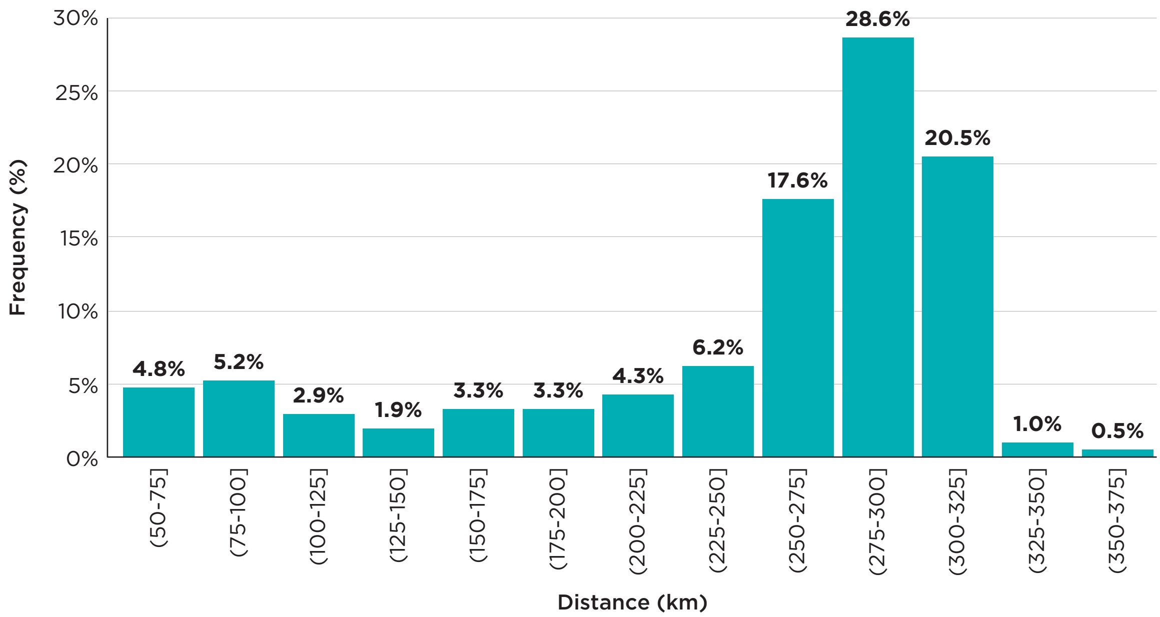

Figure 2. Histogram of daily distance traveled

With regard to the distribution of the daily distances traveled each month, a box diagram is presented in Figure 3, which shows that for 6 months—December of 2020, April of 2021, and June to September 2021—the monthly aggregate average ranges from 200 km to 250 km, while for 4 months—January to March 2021, and May 2021—it ranges from 250 km to 300 km. Regarding the variance of data, during most of the monitored period (7 out of 10 months) the data are found in a range less than 100 km, while during 3 months a variance with amplitude between 150 km and 200 km is observed.

During the final months of the monitoring (between June and September, 2021), the monitored vehicle was used for operator training, prior to the arrival of the additional fleet (9 buses). Driving habits during this process may be associated with the changes in patterns of the variables analyzed, as well as in the increase in the variance of the data recorded during this period.

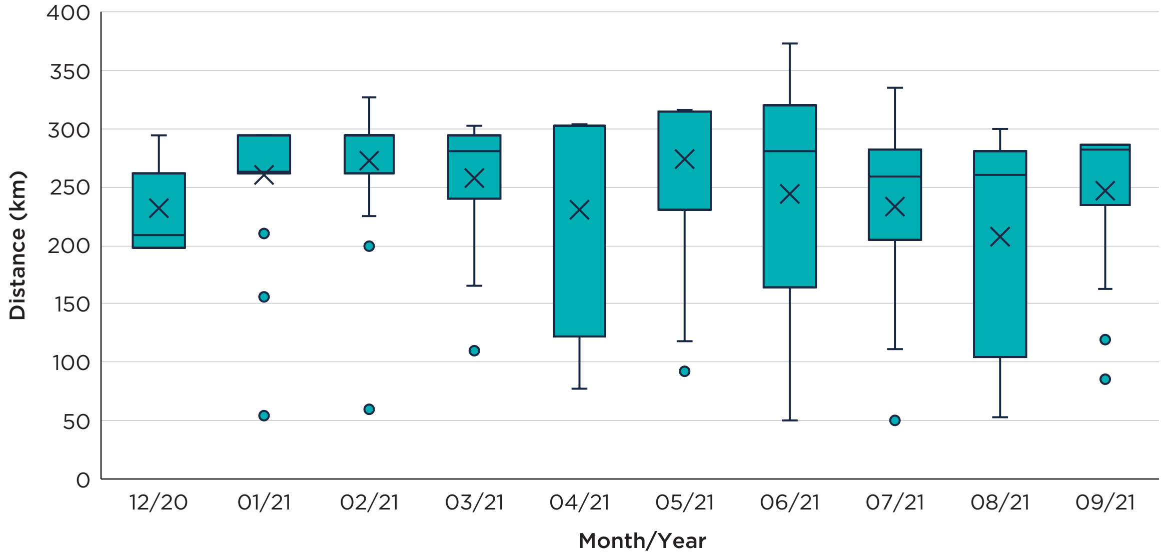

Figure 3. Box diagram of average daily distance traveled

NET ENERGY CONSUMPTION

The observed energy consumption depends on the technical characteristics of the vehicle and the operational parameters. Technical characteristics include: battery capacity, engine power, and vehicle weight, among others; while operational parameters include distance traveled, speed, passenger load transported, use of accessories, route characteristics, and driving style, among others.

Power consumption can be determined by variation in the state of charge (SoC) and by the total capacity of the battery pack, which permits calculation of the net energy consumed. In this analysis, an absolute battery capacity of 563.83 kWh was considered to determine the net energy consumed from the differences in the state of charge recorded during each day.

Batteries gradually degrade, or lose capacity; to determine net energy consumed over time, it is necessary to relate data on energy consumed to recharging energy data, or to periodically monitor the real capacity of the batteries.

During the evaluation period, the average difference between the initial and final state of charge, ΔSoC, was 44.1 ± 1.9% which, assuming 100% of the health status of the battery (current capacity equal to initial capacity), corresponds to an energy consumption of approximately 250.3 ± 10.6 kWh, with a 95% confidence interval. The median was 49.6%, equivalent to 280.8 kWh. The smallest difference in the analyzed period was 8.8% (49.6 kWh), while the largest was 70% (394.7 kWh).

Figure 4, a box diagram depicting the difference between the initial and final state of charge, ΔSoC, shows that the average value is between 40% and 50% discharge. The distribution of values is of the order of 10% in most of the months evaluated (7 out of 10 months), while in the remaining 3 months variances ranged between 30% and 40% of discharge. These coincide with the months with the greatest distribution in daily distance traveled presented in figure 3.

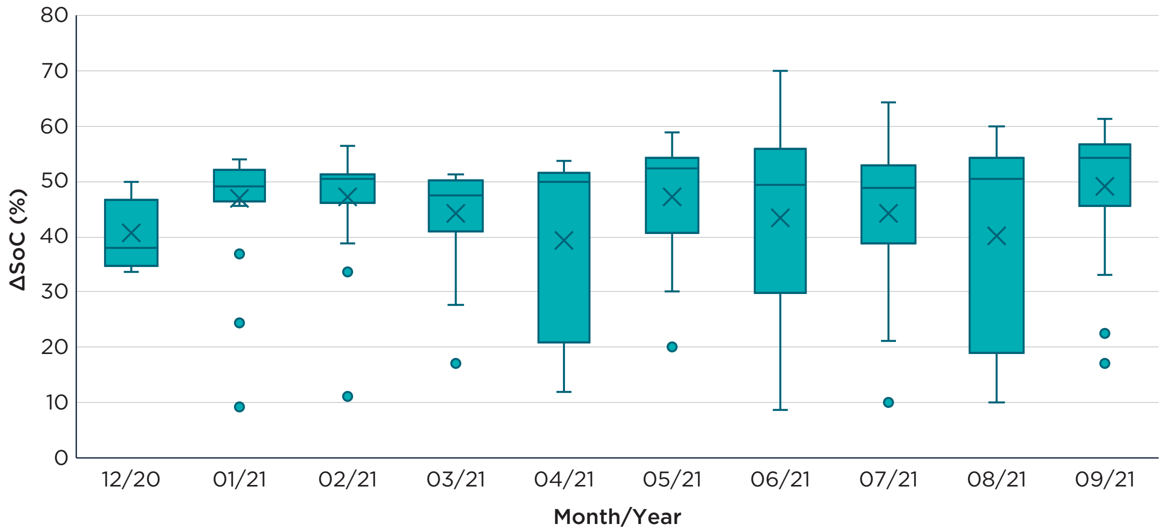

Figure 4. Box diagram of energy consumption (ΔSoC)

RELATION BETWEEN ENERGY CONSUMPTION AND DISTANCE TRAVELED

Plotting energy consumption (kWh) against daily distance traveled (km), Figure 5, we find a directly proportional correlation that can be adjusted by a linear regression, whose slope is positive and which could be interpreted as a first approximation to the average energy consumption per kilometer traveled. For the data analyzed in the monitoring period, the slope is 0.9989 kWh/km; even when the data are more distributed over distances greater than 200 km the determination coefficient (R^2) acquires a value of 0.9554.

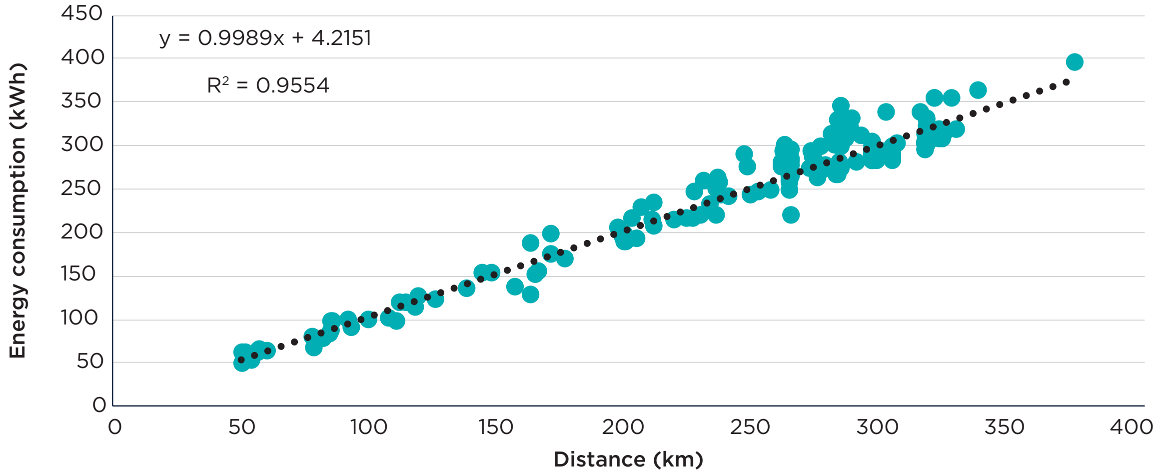

Figure 5. Relation of energy consumption to daily distance traveled

ENERGY CONSUMPTION PER KILOMETER TRAVELLED

The average energy consumption per kilometer traveled during the monitoring period is 0.92 ± 0.0068 kWh/km, with a 95% confidence interval. The median has a value of 0.90 kWh/km. The range for the evaluated data ranges from a minimum of 0.82 kWh/km to a maximum of 1.14 kWh/km.

The histogram of Figure 6 shows that 6% of the data analyzed have an energy consumption per kilometer traveled of less than 0.86 kWh/km, 40% shows consumption between 0.86 and 0.90 kWh/km, another 49% is grouped in values between 0.9 and 1.0 kWh/km, and the remaining 5% is consumption of greater than 1.0 kWh/km.

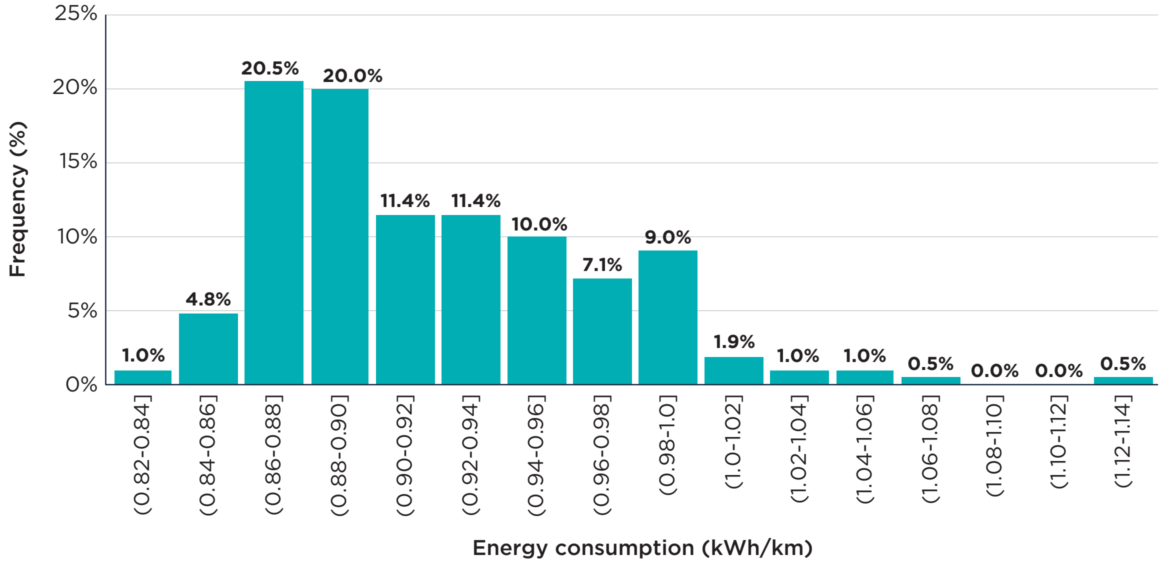

Figure 6. Histogram of energy consumption per kilometer traveled

Figure 7 shows that energy consumption per kilometer traveled remained between 0.90 and 0.95 during the first 2 months of the evaluation period. In the following 4 months, from February to May, consumption per kilometer was lower, remaining below 0.90 kWh/km, with very low distribution in the data and, in the period from June to September, energy consumption per kilometer traveled gradually increased to 0.98 kWh/km. In addition to increasing consumption, this period shows the greatest spread of data, with amplitudes greater than 0.05 kWh/km.

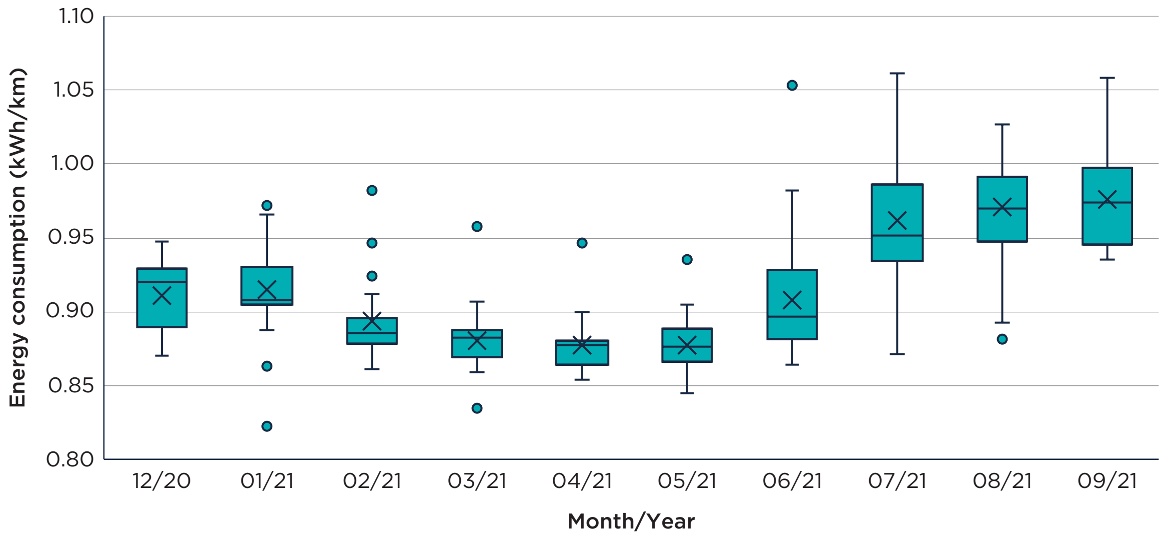

Figure 7. Box diagram of energy consumption per kilometer traveled

AVERAGE DAILY SPEED

The average daily speed of the bus ranged between 10 and 16 km/h during the test period, with an average value of 13.81 ± 0.32 km/h, with a confidence interval of 95% and a median value of 14.65 km/h. This is the average speed of the entire daily operation and considers the idling periods of the vehicle (V~0), which are discussed below. The line on which the bus operated during monitoring ran mainly within a confined lane for BRT service, stopping at traffic light crossings and stations distributed at a distance of approximately 500 m along the line.

As seen in the box diagram for this operating parameter, during the first two months of monitoring, speeds between 12 and 14 km/h were recorded. For 4 months, between February and May, the average daily speed remained around 15 km/h, with little variance in the data, and from June onward speeds were lower and variance in the data was higher.

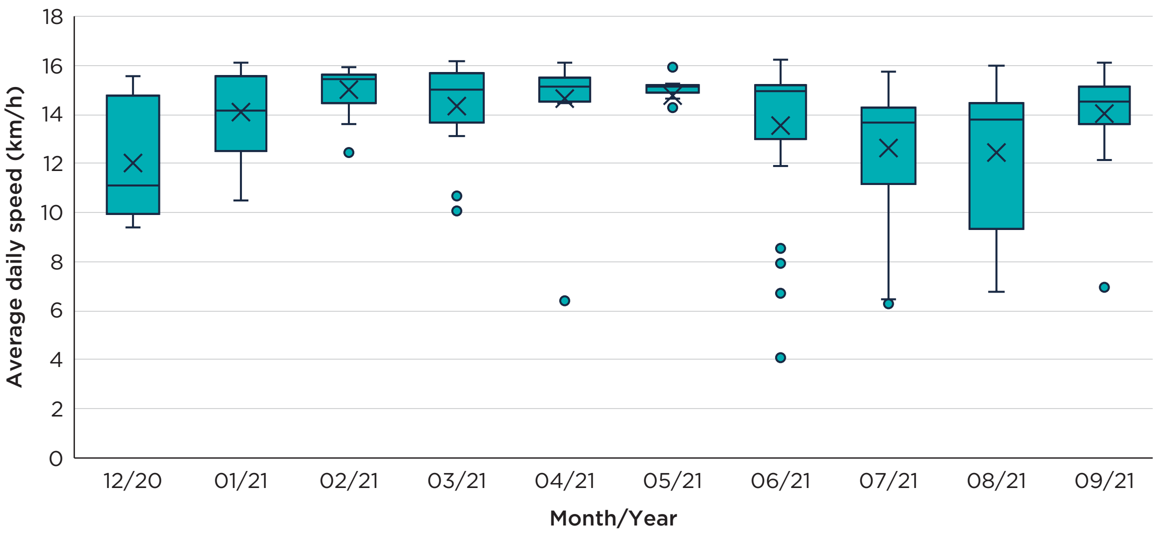

Figure 8. Box diagram of average daily speed

ENERGY REGENERATION

Electric vehicles have an energy regeneration system through braking, known as regenerative braking. During this process the engine changes its mode of operation to function as an energy generator, which is used to charge the batteries. The amount of energy regenerated depends on how the vehicle is operated and the characteristics of the route on which it is operated, due to the frequency of acceleration and braking situations, as well as the technical characteristics of the regenerative system. The energy regenerated through this process during the monitoring period ranged from 15.9% to 26.1% of the total energy consumed. The mean regeneration was 22.4 ± 0.21%, with a 95% confidence interval, and the median was 22.5%.

The histogram for this parameter, Figure 9, shows that for 33.3% of the data analyzed, the regeneration was between 22% and 23%, for 18.1% it ranged between 21% and 22%, and for 17.6% it ranged from 23% to 24%. In sum, between 21% and 24% of regeneration is found in 69% of the sample. On the other hand, 6.2% presented regeneration of less than 20% and only 5.3% of the analyzed data presented regeneration of greater than 25%.

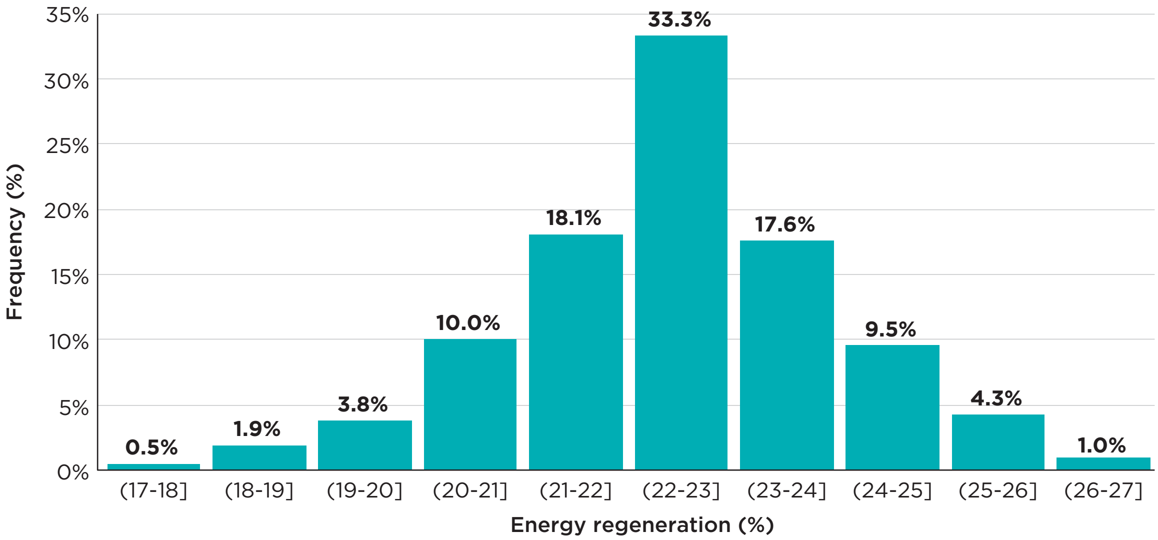

Figure 9. Histogram of energy regeneration

The box diagram for regenerated energy, presented in Figure 10, shows that during the first five months of the evaluation the regeneration gradually decreases from 23% to 21%, maintaining its performance with little variance. From May to September, regeneration gradually increases, exceeding 23% of regenerated energy during the final 3 months. During the last five months of monitoring, data variance is greater, with August being the month with the greatest variance, almost 4 percentage points.

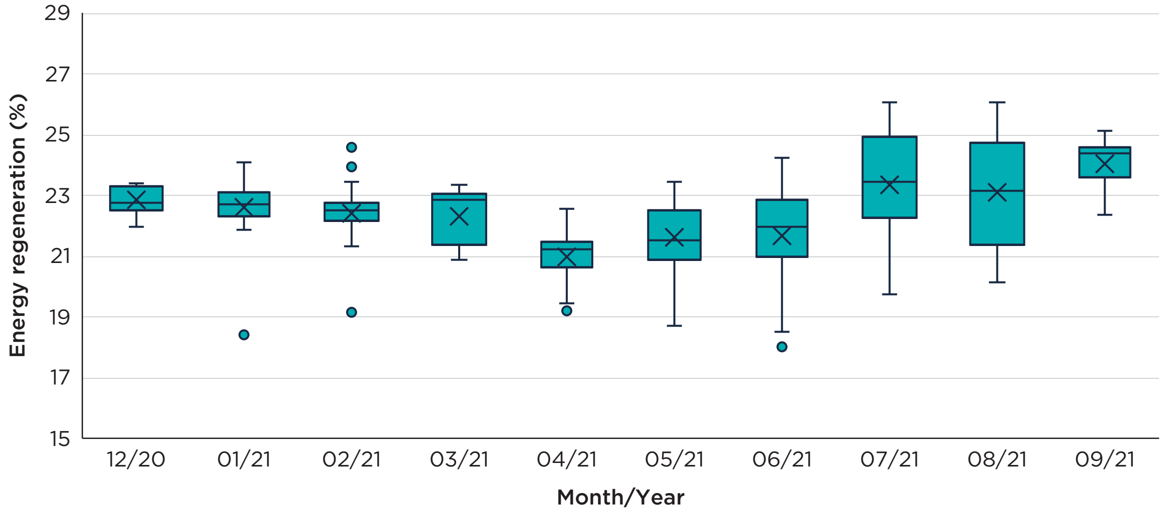

Figure 10. Box diagram of energy regeneration

IDLING TIME

Idling is the mode during which the vehicle is turned on and operating, but is stopped. During this time, the systems and accessories consume energy, but the vehicle is not moving. From an operational perspective, it is important to reduce the periods in this mode; however, they are unavoidable: they correspond to the intervals of passenger boarding and disembarking, as well as waiting times at traffic lights and terminals.

During the monitoring period, idling periods averaged 97.35 ± 10.8 s/km, with a 95% confidence interval and a median of 70.34 s/km. The minimum value during all monitoring was 37.99 s/km and the maximum was 710.21 s/km. As the box diagram for this parameter shows, this maximum value must be regarded critically, since it is inconsistent with the overall behavior recorded throughout the analyzed period. The range in which this parameter varies throughout the monitored period remains between 50 and 200 s/km.

The box diagram for idling time is presented in Figure 11, where it is observed that for 7 months the monthly average was less than 100 s/km, in 5 of which the data are concentrated in ranges of very low variance. For 3 months, the average was greater than 100 s/km, and the data show greater variance, of more than 50 s/km.

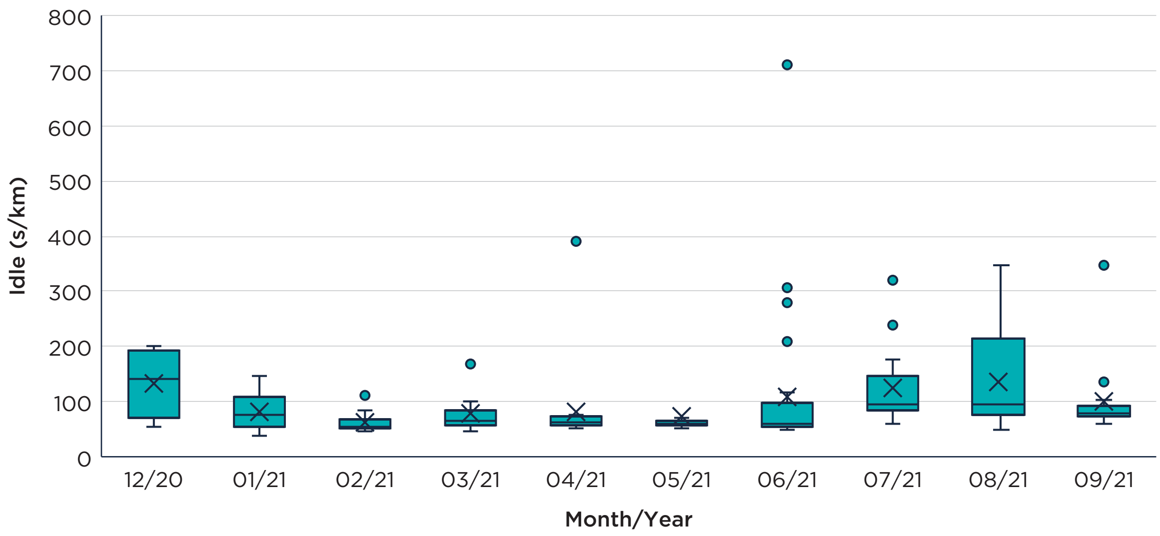

Figure 11. Box diagram of idling time

If we consider that an operational workday lasts between 18 and 21 hours, during which buses circulate on average 246.7 km, the idle time ratio indicates that, on average, for each kilometer traveled the bus is stopped 97.35 seconds, which means 24,016 seconds a day. This is equivalent to 6.67 hours a day, which represents between 32% and 37% of the daily operating time.

Table 2 presents statistical variables including median, average with confidence interval of 95%, minimum value, and maximum value, recorded for the technical and operational parameters previously discussed.

Table 2. Statistical parameters per day of operation of the analyzed variables

Parameter	Units	Median	Average	Minimum	Maximum
Daily distance traveled	km	277.7	246.7 ± 10.4	50.1	373.2
ΔSoC per day of operation	%	49.6	44.1 ± 1.9	8.8	70.0
Daily net energy consumption	kWh	280.8	250.3 ± 10.6	49.6	394.7
Energy consumption per kilometer	kWh/km	0.90	0.92 ± 0.0068	0.82	1.14
Average daily speed	km/h	14.65	13.81 ± 0.32	4.06	16.26
Energy regeneration per day	%	22.5	22.4 ± 0.21	15.9	26.1
Idling time	s/km	70.34	97.35 ± 10.8	37.99	710.21

BALLAST TESTING

Due to the importance and influence of the transported load on energy consumption, during March 2022 a series of tests with controlled load was carried out, as a complement to the monitoring period, in order to generate a correlation between energy consumption and the load transported since no load records were available during the monitoring period.

A test protocol was generated and, based on information collected between December 2020 and September 2021, the operational parameters and load scenarios were established. Prior to the execution of the tests with controlled load, a pre-inspection was undertaken to verify that the vehicle was in suitable conditions for the development of the ballasting tests. During this process, the suspension, tires, powertrain, and electrical systems were verified, no failures were detected through pre-inspection in any of the systems.

Additionally, the operating company, assisted by the manufacturer, carried out a procedure to determine the State of Health (SoH) of the battery pack. With this procedure it was determined that, after a year and a half of operation (~75,000 km), the state of health of the batteries was 90% of its original capacity. The consistency of the cells was good and the diminishment of the SoH fit the degradation curve expected by the manufacturer.

According to the developed protocol, the test was carried out for five different load scenarios, which are presented in Table 3. Due to variations in the weight of the material used to simulate the cargo of the passengers (sacks of sand and drums filled with water), there were differences between the nominal load and the real load. The same table presents the aggregate load in each scenario, as well as its correlation with the actual cargo transported and with the equivalent number of passengers for each scenario, taking into account an average of 63.75 kg per passenger.

Table 3. Nominal load and actual load scenarios for testing

Nominal load (%)	Total weight (kg)	Load (kg)	Percentage of load capacity (%)	Equivalent passengers
0	17,660	0	0	0
25	21,120	3,460	34.3	54
50	23,260	5,600	54.9	87
75	25,960	8,300	81.3	130
100	28,340	10,680	104.9	167

The total weight (kg) column in Table 3 corresponds to the weight of the empty vehicle plus the added load for each scenario, while the Load column lists the weight added to the vehicle for each scenario. Thus, according to the measurement, the empty vehicle has a weight of 17,660 kg. For the first scenario, a load of 3460 kg was added, equivalent to carrying 54 passengers, reaching a total weight of 21,120 kg. Additional weight continued to be added, up to a load of 10,680 kg, equivalent to carrying 167 passengers, which brought the total weight of the bus to 28,340 kg.

During the development of the tests, in addition to monitoring by telematics equipment, some operational parameters were manually recorded, such as the time and odometer reading. Similarly, the state of charge on board was recorded at the beginning of each driving cycle and at the end of each day. A summary of these records is presented in Table 4.

Table 4. Ballasting test daily operation summary

Nominal load (%)	Date	Distance (km)	SoC_i (%)	SoC_f (%)	ΔSoC
0	21 March 22	319.96	98	44	54
25	19 March22	278.16	99	48	51
50	18 March 22	316.36	99	36	63
75	17 March 22	242.02	99	49	50
100	16 March 22	321.61	100	26	74

From the differences in the state of charge, and considering the verified state of health of the batteries prior to testing (90%) as well as their corrected capacity (507.45 kWh), the energy consumption vs. distance traveled curves were generated and are presented in Figure 12. As expected, the greater the load transported, the greater the energy required to travel the same distance.

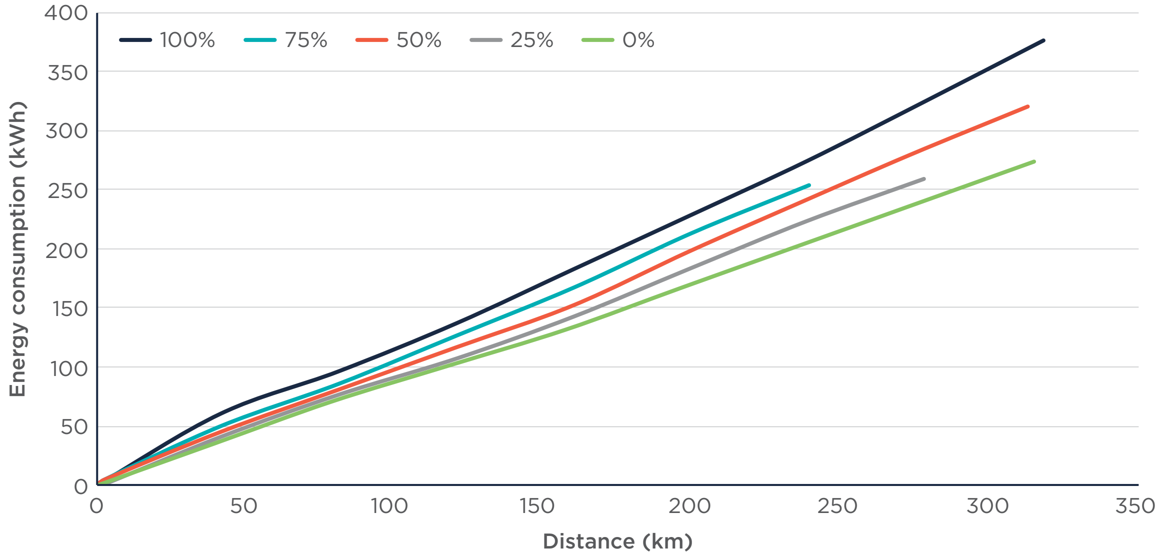

Figure 12. Energy consumption (kWh) vs distance for each load scenario

From the recorded values and the data monitored by telematics, the energy consumption per kilometer traveled for each load scenario was determined. These are shown in Table 5, as well as in Figure 13.

Table 5. Energy consumption measured for each load scenario

Nominal load (%)	Percentage of load capacity (%)	Gross vehicular weight (kg)	Energy consumption (kWh/km)
0	0	17,660	0.92
25	34.3	21,120	1.01
50	54.9	23,260	1.10
75	81.3	25,960	1.15
100	104.9	28,340	1.23

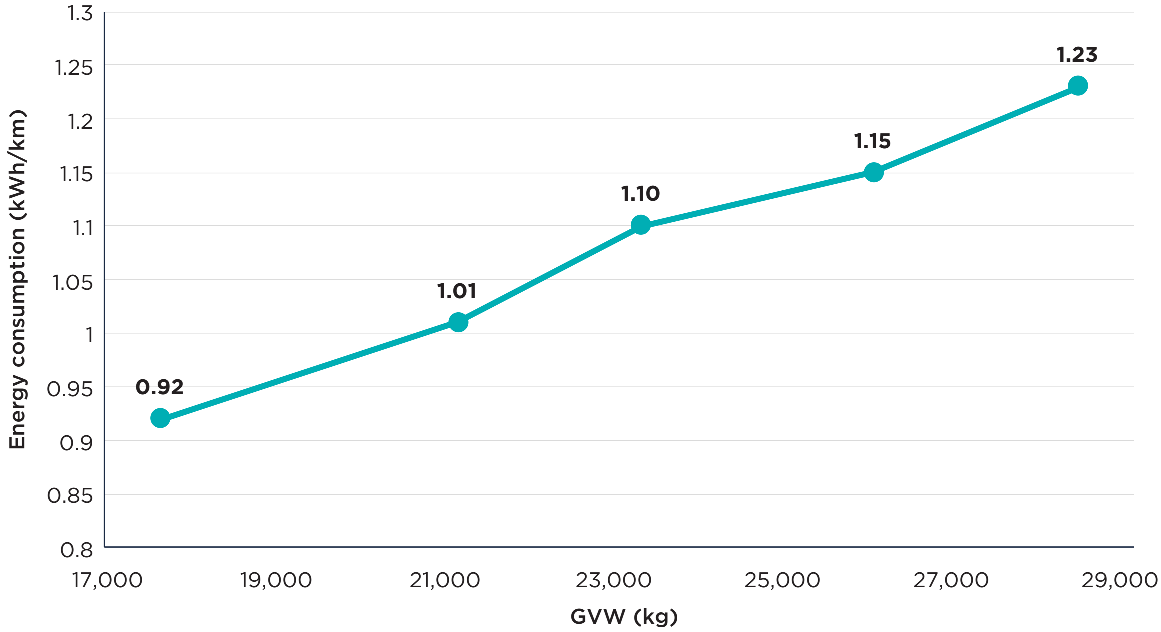

Figure 13. Measured energy consumption for each load scenario

As can be seen, the consumption values calculated from the data recorded with known loads are higher than those registered during the monitoring period. Consumption of up to 1.23 kWh/km was reached with full load, against a maximum recorded in the monitoring period of 1.14 kWh/km. Considering that the test environment was supervised and controlled, we estimate that the consumption obtained through this process is more representative of the actual operation of the vehicle, whose energy performance ranges between 0.92 and 1.23 kWh/km.

Considering the results obtained for energy consumption and the equivalence of passengers transported in each scenario, we find that consumption increases by 0.092 kWh/km for every 50 additional equivalent passengers transported.

RECHARGE SYSTEM INFORMATION

During the ballast testing period, access was obtained, through the operating company, to a summary of the information recorded through the charging system platform, which gives us data on the energy supplied from the charger and the charging periods. This information is presented in Table 6.

Data on energy supplied and the recorded periods of charging reveal that the average charging speed is approximately 2 kW/min, a value consistent with four of the five observations. Note the duration of the last loading period, which is much higher than the rest. This may be because at the end of the tests, the bus was not going to continue operating and, although it could have finished charging earlier, it was not until that time that it was disconnected from the charger.

Table 6. Operator recharge information

Date	Charged energy (kWh)	Charge starting time	Charge end time	Charging elapsed time	Charging speed (kW/min)
16 March 22	368.59	2:33	5:37	3:04	2.00
17 March 22	258.24	0:00	2:10	2:10	1.98
18 March 22	324.43	2:11	4:54	2:43	1.99
19 March 22	267.31	23:28	1:43	2:11	2.04
21 March 22	282.30	1:53	6:31	4:38	1.01

In Table 7 the energy consumed is compared, using the analysis carried out with telematics data, against the energy supplied by the charger to reach the full load. In all records there is a difference between 1.5% and 3.3%, with more energy fed than consumed. This could be related to the efficiency of the energy transfer between the charger and the batteries; however, more information and data is required to draw conclusions regarding these values. Because of inconsistencies in the registry, the value for the full load scenario is not presented.

Table 7. Comparison of energy consumption and energy powered by the charger

Nominal load (%)	Bus energy consumption (kWh)	Energy supplied by charger (kWh)	Difference
0	274	282.3	3.03%
25	258.8	267.31	3.29%
50	319.7	324.43	1.48%
75	253.7	258.24	1.79%

CONCLUSIONS

To meet its decarbonization goal, Mexico City has begun the transition to electromobility. Among many actions, a commitment has been established that, by 2024, a Metrobús line will be zero emission. As of 2020, Metrobús, with the support of international technical assistance from various initiatives and organizations, and from investors and manufacturers, has carried out different pilot tests in real operating conditions. The objective is to know and gain experience with the new technologies of battery-electric buses and to be able to evaluate their performance, as well as to become familiar with their daily operation.

This report analyzes the performance and energy consumption of an electric articulated bus over a 10-month period. Making use of telematics equipment, the daily operation of the bus was monitored, recording a large number of technical and operational parameters that allow us to characterize the operational performance of the vehicle.

As can be seen throughout the specific analysis for each of the variables evaluated, the bus met the operating requirements, traveling between 250 km and 325 km for two-thirds of the monitoring period. For 99% of this period, the energy intake per kilometer travelled remained in a range of 0.86 to 1.0 kWh/km. Similarly, the energy regenerated by the braking system remained in a range of between 21% and 24%, equivalent to approximately 130 kWh per day.

Operational parameters directly influence the performance of electric vehicles, i.e. speed, idle time and braking mode, as well as driving mode and driving cycle. Therefore, there are opportunities to improve the energy performance of electric buses, through operator training, as well as through optimization of routes and services.

Through the evaluation with controlled loads, the differences in consumption per kilometer were determined for different scenarios, which covered and exceeded the capacity of the transported load without incurring any risk, according to the manufacturer's specifications. According to the analysis, the consumption of the unladen vehicle was 0.92 kWh/km, while when evaluated at 105% of the maximum capacity, the consumption amounted to 1.23 kWh/km, which suggests that, during the monitoring period, occupancy of the vehicle was low, consistent with the confinement period due to the SARS-CoV-2 health emergency. For this reason, it is recommended that the consumption values resulting from the test with controlled loads be used as a reference.

Finally, the analysis of energy consumed by the bus and supplied by the chargers showed differences of between -2% and 3.3%. However, a more in-depth analysis with a larger sample is recommended, as five data values are not sufficient to obtain valid representative information.

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