WORKING PAPER

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Real-world use cases for zero-emission buses: Effective operations, charging, and maintenance in Chinese cities

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INTRODUCTION

After a decade-long promotional effort by the Chinese government, China has become the largest global market for and producer of electric buses (e-buses). In 2022, approximately 138,000 e-buses were sold in China, the e-bus share of the total on-road bus stock was 64.8%, and e-buses accounted for 97% of new bus sales (Ministry of Transport, 2023). That same year, China exported over 617,000 e-buses; Peru, Egypt, Chile, Vietnam, and Ecuador were the top five destination countries (Chinabuses, 2023). In several cities, such as Shenzhen, Chengdu, and Zhengzhou, e-bus fleets are successfully operating after the phase-down of government e-bus subsidies (Bailey et al., 2023; Yiyang & Fremery, 2022). E-buses' quiet, comfortable, and soot-free operation appeals to both drivers and passengers.

Energy consumption and driving range are critical parameters for the daily operation of e-buses in urban fleets. According to a previous ICCT study, e-bus ranges were 30% shorter, on average, in real-world operations than type-approval values suggest (Mao et al., 2023). In this study, we explore the real-world experiences of local e-bus fleet operators based on public financial information and surveys of 10 fleet operators. This work contributes to improving the understanding of e-buses, the challenges faced by local bus operators, and opportunities to improve performance, and aims to aid policymakers in developing and reviewing regulations and type-approval procedures.

SCOPE

In China, most bus services are provided by public entities such as local governments and state-owned companies. In 2023, we solicited feedback on the performance of

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e-bus fleets from 10 fleet operators in the eight Chinese cities shown in Figure 1. These 10 operators were located in different regions with different climates and owned a total of 9,277 e-buses, with fleet sizes ranging from 20 to 6,316 e-buses (see Table 1). In some cities, including Dalian, Haikou, and Sanya, the surveyed operators only owned a portion of the total e-bus fleet; this study examines the surveyed operators' activity only, and not that of other fleet operators in the cities. Questions in the survey, which focused on the real-world performance of the buses during routine, daily operations, are listed in the Appendix.

Figure 1
Geographical spread of the bus fleets in this study

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Table 1 presents the model specifications of each fleet, which have been anonymized for data protection. In both Zhengzhou and Tianjin, we approached two different fleet operators, denoted as fleet A and fleet B.

Table 1
Specifications of the e-bus models in the surveyed fleets

City and fleets	Fleet size (number)	Battery capacity (kWh)	Body length of e-bus (m)
Zhengzhou fleet A	22	200	8/10.5/12
Zhengzhou fleet B	6,316	95/157/350	8/12
Tangshan	255	140/258	8/10.5
Tianjin fleet A	90	255	10.5
Tianjin fleet B	24	62/161/125/57	7/10.7/8.2/6
Dalian	90	100/132/136	8/10.5/10.7
Harbin	2,111	62/161/125/57	7/10.7/8.2/6
Haikou	55	62	6.4
Neijiang	245	62/175/203	7/8.1/10.5
Sanya	48	300/157/210/315	10.5/8.6/8.5/10.5

In the following sections, we present insights on the daily operation of e-buses, including driving patterns, energy consumption and range, maintenance expenses, and charging strategies. We conclude with a discussion of some policy implications of our findings.

OPERATIONS

AVERAGE DRIVING DISTANCE

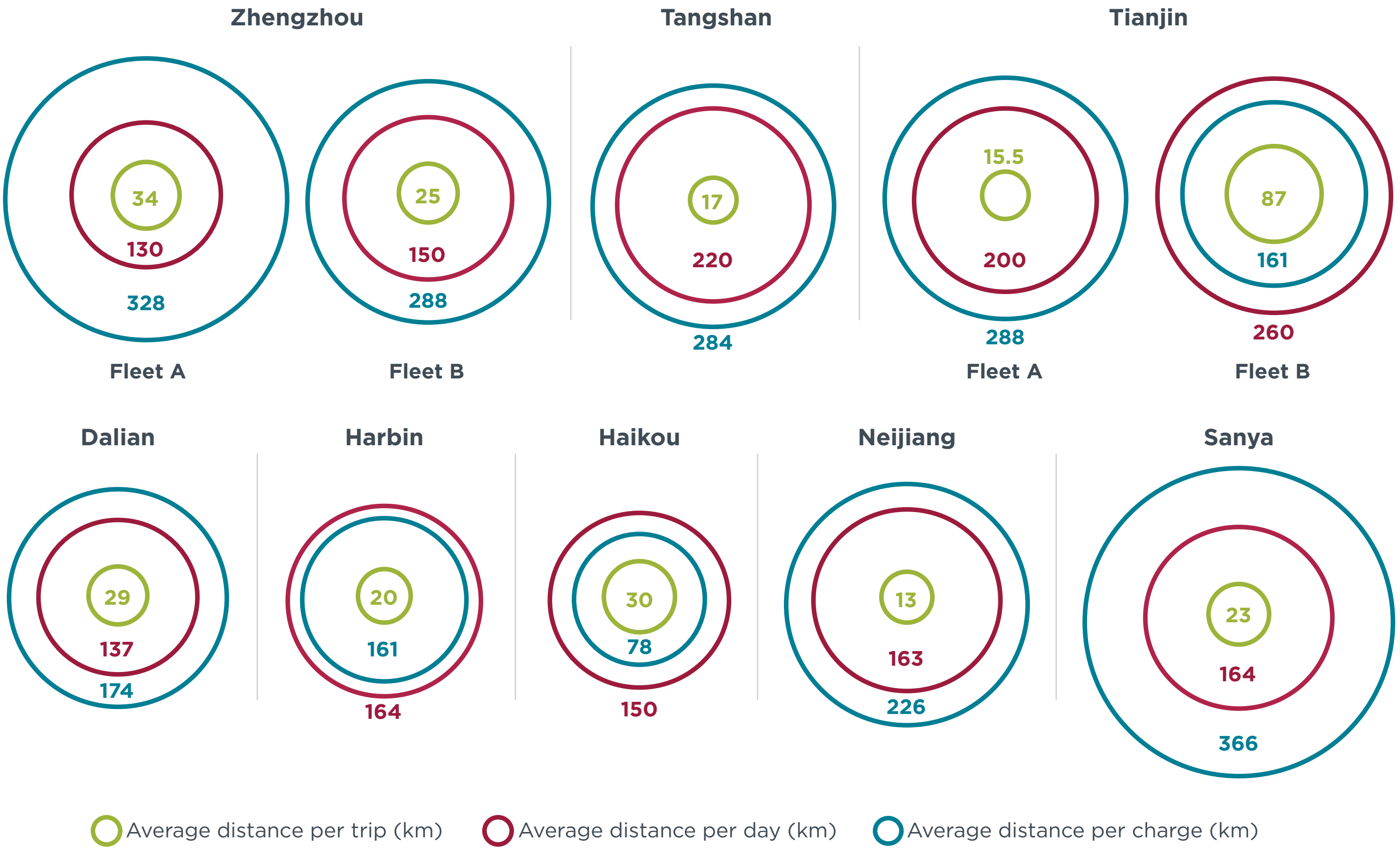
The operators reported their average daily distance and distance per trip in their survey responses, and we obtained information about average distance per charge from the public type-approval information of the e-bus models (Ministry of Industry and Information Technology, 2018). Rapidly improving battery technology has led to greater available e-bus range and durability, such that bus models in recent years have shown longer range with less degradation after use. As shown in Figure 2, the average distance traveled by the surveyed fleets varied from 15 km to 87 km per trip and 130 km to 260 km per day. High variation was due to differences in routes across cities. Fleet B of Tianjin recorded the longest distances per trip (87 km) and per day (260 km).

Regarding the average distance per charge, except for Tianjin fleet B, Harbin, and Haikou, e-bus ranges were theoretically sufficient to support the daily operation of the surveyed fleets in a single charge, because the average distance per charge was longer than the average distance per day.

The operators also reported that under extreme temperature conditions (i.e., a daily average below 0 °C or above 35 °C), real-world energy consumption is up to 20% higher than at mild temperatures of about 20–25 °C (see details in the Appendix). A similar pattern was identified in a previous ICCT report, which found that the energy consumption of e-buses typically increased by 30% to 50% for a comparable range of temperatures (Mao et al., 2023).

Figure 2

Average range per trip, per day, and per charge



Note: Values per trip and per day were reported by fleet operators and distance per charge was calculated based on survey results of real-world energy consumption and battery size.

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The operational profile of the Haikou fleet showcases the concept of battery right-sizing, or installing a smaller battery and relying on more frequent charging to meet travel demands. In Haikou, with an average daily range of 150 km, the average e-range per charge was 78 km, which allowed the buses to operate on schedule with limited capacity redundancy between charges. A previous ICCT study showed that it can be more cost effective to reduce the size of the battery in an electric vehicle and charge more frequently, which can lower the vehicle purchase price, energy consumption, and total cost of ownership (Poupinha & Dornoff, 2024).

MAINTENANCE COSTS

There was considerable variation in maintenance costs, excluding staff expenses, among the surveyed fleets (see Table 2). For example, maintenance expenses in Tianjin were ¥73,000 per year and ¥58,765 per year for fleets A and B, respectively, while e-bus operators in Neijiang and Dalian reported paying about ¥1,000 per year for maintenance. Maintenance intervals also varied widely from fleet to fleet: Zhengzhou fleet B was scheduled for checks every 1,000 km, while the Dalian and Neijiang fleets were maintained every 30,000 km. According to the survey results, maintenance expenses were affected by fleet size, the body size of the e-buses procured, and the schedule of maintenance checks. (Survey data were not sufficiently granular to identify a function between daily operation and total costs for maintenance.)

Table 2
Bus size and maintenance cost for each fleet

Fleets	Body length of e-buses			Interval of maintenance	Maintenance cost per bus (¥ per year)
	6–8 m	8–10 m	> 10 m		
Zhengzhou fleet A		●	●	1 month	21,827
Zhengzhou fleet B		●	●	1,000 km	19,163
Tianjin fleet A			●	10 days	73,000
Tianjin fleet B	●	●	●	15 days	58,765
Tangshan		●	●	1 month	13,383
Dalian		●	●	30,000 km	1,000
Harbin	●	●	●	6 months	2,389
Haikou	●			1,000 km	14,235
Neijiang	●	●	●	35,000 km	1,190
Sanya		●	●	9,000 km	3,346

BATTERY REPLACEMENT

Due to their chemical properties, batteries degrade over time and through use, and they eventually require replacement. In this study, the operators who stated that they had replaced e-bus batteries generally reported having done so between the third and seventh year of operation (Table 3). Citing funding challenges, 7 out of 10 fleet operators reported that they tolerated greater battery degradation and delayed battery replacements, which typically cost 30%–50% of the purchase cost for replacement.

Table 3
Battery replacement by fleet

Fleets	Battery replaced?	Number and share of e-buses with battery replaced	Years of driving before replacement	Degradation level of battery when replaced
Zhengzhou fleet A	No	—	—	—
Zhengzhou fleet B	No reply	—	—	—
Tianjin fleet A	No	—	—	—
Tianjin fleet B	Yes	1 out of 24 (4.1%)	6 years	17%
Tangshan	No	—	—	—
Dalian	Yes	50 out of 90 (55.6%)	7 years	40%
Harbin	Yes	No reply	6 years	17%
Haikou	Yes	4 out of 55 (7.2%)	3 years	15%
Neijiang	Yes	No reply	6 years	26%
Sanya	No reply	—	—	—

CHARGING STRATEGY

This survey found that besides the depot charging infrastructure available to the operators, fleets in Dalian and Haikou have access to public charging facilities that support long-distance travel. Several operators also adopted a strategy of “charging whenever possible," which is a conservative approach of charging whenever the e-buses return to the yard. The selection of charging strategy is made after weighing several factors, such as fleet size, distance per trip and per day, access to charging facilities, and electricity price by time each day. Table 4 reviews the charging characteristics and strategies employed by each fleet.

Table 4
Details of fleet charging strategies

Fleets	Charging types		Power of the chargers	Charging strategy
	Depot charging	Public charging		
Zhengzhou fleet A	●		62 kW DC	Overnight
Zhengzhou fleet B	●		120 kW DC	Charging whenever possible
Tianjin fleet A	●		300 kW DC	Overnight
Tianjin fleet B	●		300 kW DC	Charging whenever possible
Tangshan	●		120 kW DC	Overnight
Dalian	●	●	120 kW DC	Overnight
Harbin	●		60 kW DC	Overnight
Haikou	●	●	60 kW DC	Charging whenever possible
Neijiang	●		120 kW DC	Overnight
Sanya	●		120/160/200 kW DC	Charging whenever possible

Figure 3 illustrates the charging power and charging duration applied by the surveyed fleets. Most fleets employed a charging power of 120 kW, which is a cost-effective choice for most operators. While most e-buses of early model years can support up to 187.5 kW or 250 kW charging (see Table 5), it may not be economical for fleets to use the maximum capacity of chargers due to high electricity costs (Dongchedi, 2023; Youjia, 2023). Tianjin fleets reported the highest average charging power, 300 kW, with which e-buses can be fully charged in less than 1.5 hours. On the other hand, due to relatively low charging power, the Zhengzhou fleet A operator reported needing more than 3 hours to fully charge some buses from empty to full capacity.

Figure 3

Charging power and average charging duration of e-bus fleets in different cities

Note: Each dot represents one bus model of the respective fleet.

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Table 5

Standards for direct current (DC) charging

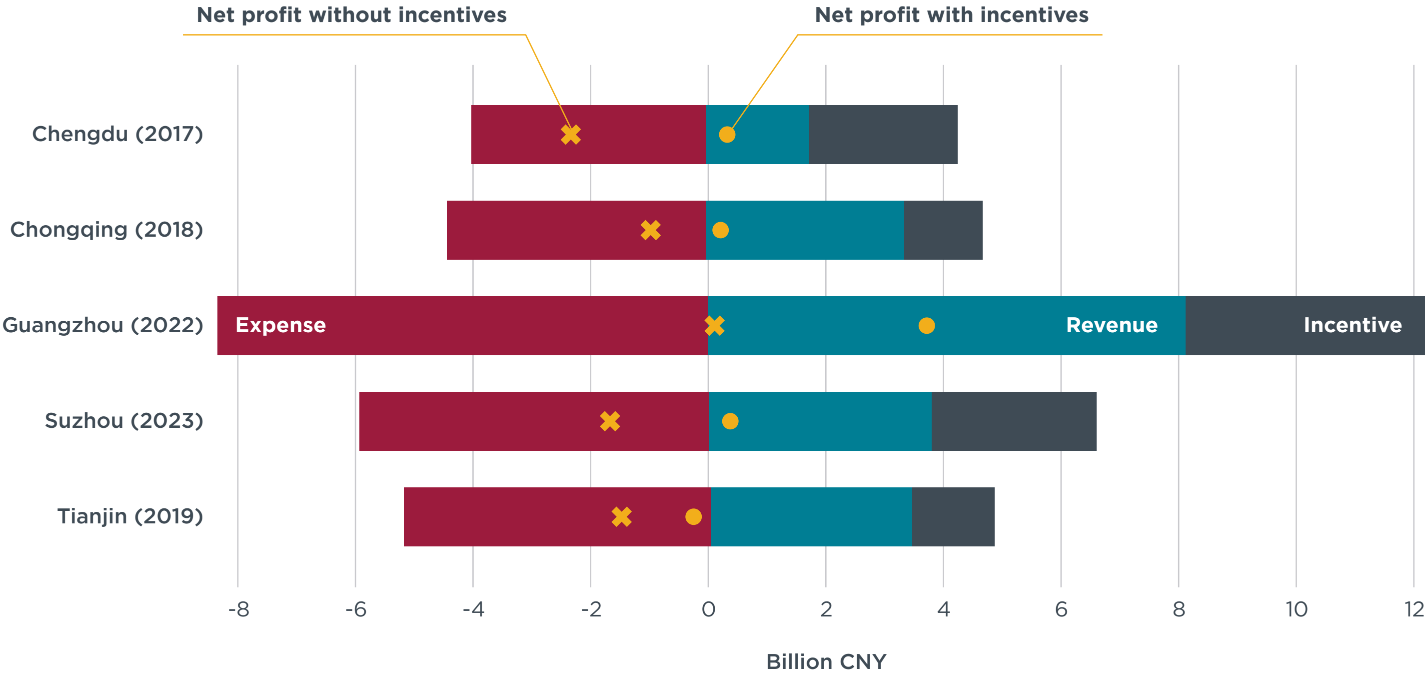
Standard	Rated voltage (V)	Rated current (A)	Max rated power (kW)
GB/T 20234.3-2011	750	125/250	187.5
GB/T 20234.3-2015	750/1,000	80/125/200/250	250
GB/T 20234.3-2023	750/1,000/1,500	Passive cooling: 10/16/25/32/50/80/125/250/300 Active cooling: 200/250/300/400/500/600/800	450 (passive cooling); 1,200 (active cooling)

FINANCING OF E-BUS FLEETS AND THEIR OPERATION

Figure 4 illustrates the reported revenues, expenses, and received incentives of a selection of e-bus fleets in recent years based on public finance documents. The incentives in this figure refer to funds provided by the central government to reduce ticket fares. Separately, in 2024, the government announced that it would provide up to ¥80,000 for vehicle replacement and ¥42,000 for battery replacement for e-bus models over 8 years of age (Ministry of Transport & Ministry of Finance, 2024). As discussed below, this initiative could help to address funding challenges identified by some e-bus operators.

Figure 4

Revenue (blue bars), central government incentives (black bars), expenses (red bars), and net profits (yellow dots and crosses) for local fleets in several cities of China



Sources: China Bond Rating Co. Ltd (2022), Tang et al. (2019), and Zhang et al. (2023).

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DISCUSSION AND POLICY RECOMMENDATIONS

Our survey of 10 local e-bus fleet operators in eight cities in China found a wide range of average daily driving distances (between 130 km and 260 km per day), energy consumption (80–120 kWh/100km), annual maintenance costs (¥1,000–¥73,000), and approaches to charging and battery replacement. We also found that extreme temperatures of greater than 35 °C or less than 0 °C can introduce up to a 20% difference in energy consumption compared with mild temperatures around 25 °C.

Depot charging is a necessity for e-bus fleets, and overnight charging was the most popular charging strategy adopted by operators. At the same time, some operators adopted a more flexible charging strategy of charging whenever possible, so that e-buses were always ready to operate. This strategy was employed despite the higher costs of electricity during the day.

Our survey also identified certain operational issues faced by fleet operators. Regarding maintenance and battery replacement, for instance, a majority of surveyed fleet operators reported that it was expensive to replace batteries after several years of use.

This analysis supports the following policy considerations:

Funding challenges related to battery replacement could present further opportunities for government engagement. As China's e-bus market has matured, bus owners have increasingly looked to replace e-bus batteries after several years in operation—though some surveyed operators reported tolerating greater battery degradation before replacement due to funding challenges. If addressing such concerns is of interest to the government, policymakers could consider various options to increase support for battery replacement, including targeted financial support or tax waivers. As noted above, Chinese authorities recently announced subsidies of ¥80,000 for vehicle replacement and ¥42,000 for battery replacement for e-buses over 8 years in age (National Development and Reform Commission & Ministry of Finance, 2024). This policy is expected to help ease the funding challenges associated with e-bus battery replacement.

Warranty requirements could be reviewed and updated. The most recent official battery warranty requirement, which mandated coverage for 5 years or up to 200,000 km, was enacted in 2015 (Ministry of Finance, 2015). This requirement reflected the battery technology at that time and could be reviewed in light of technology advancements, such as evolving battery chemistry and higher energy density, which have greatly extended the average lifetime range and durability of e-buses. In some of our surveyed cities, for instance, e-buses can reach 200,000 km in 3 years. Updates of warranty requirements to reflect the development of battery technology on durability could support more regular battery replacement by e-bus operators.

Technical assistance could help e-bus fleets operate more sustainably and efficiently. Local authorities and associations could launch campaigns to improve drivers' understanding of e-buses and encourage better driving practices. For instance, improved charging and scheduling practices can extend the real-world ranges of e-buses (Lin et al., 2019). Other than overnight charging, fleet operators could be aided to adopt more flexible and localized charging schedules to make best use of route schedules and daily fluctuations in electricity price. Moreover, drivers can be trained to better exploit the benefits and understand the limitations of regenerative braking, which converts the kinetic energy produced during braking into electricity to power the vehicle. Also, authorities and technical agencies can help support fleet operators to right-size the batteries of their e-buses, which can decrease the cost of operation.

Innovative financial tools and business models could be applied to make e-buses more affordable to fleet operators. For instance, policymakers could consider a financial leasing program, whereby a lessor covers the upfront cost of the vehicle; in turn, fleet operators make regular payments to the lessor over time until the full cost is paid. Authorities could also play a role in demand aggregation, which has been employed in some Latin American countries and can strengthen operators' negotiation position with dealers and manufacturers. Such measures can help drive down capital expenses for fleet operators and accelerate the adoption of e-buses.

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APPENDIX. THE QUESTIONNAIRE DISTRIBUTED TO LOCAL E-BUS FLEET OPERATORS

Questions on fleet size and bus specs:

1. How many battery electric buses do you operate?
2. What is the bus manufacturer and model?
3. What is the battery nominal capacity in kWh?
4. What is the main type of bus service?
    a. City bus
    b. Bus Rapid Transit (BRT)
    c. Intercity bus
    d. Regional bus
    e. Shuttle bus
    f. Other (*please specify*)
5. What is the average age of the bus fleet?

Questions on fleet operation:

1. What is the average distance for a typical trip?
2. What's the average distance per day or per year?
3. What is the typical trip frequency?
4. What is the average bus speed?
5. What is the average dead kilometers per bus per day (*if any*)?

Questions on charging technology and strategy:

1. Where do you charge the buses?
    a. Depot
    b. Dedicated charging stations along the bus line,
    c. Public fast-charging stations
    d. Other (*please specify*)
2. When do you usually charge?
    a. Overnight
    b. During the day
3. What type of chargers are installed at your depot?
    a. AC 11 kW
    b. AC 22 kW
    c. DC 50 kW
    d. DC 150 kW
    e. DC 300 kW
    f. Other (*please specify*)
4. How many chargers are there in a typical depot?
5. What is the ratio of buses to chargers?
6. Do you face any grid-power restrictions during charging?
7. What type of chargers do you use at the dedicated charging stations along the bus line?
    a. DC 50 kW
    b. DC 150 kW
    c. DC 300 kW

   d. Not applicable
   e. Other (*please specify*)
8. What type of chargers do you use at the public fast-charging stations?
   a. DC 50 kW
   b. DC 150 kW
   c. DC 300 kW
   d. Not applicable
   e. Others (*please specify*)

Questions on maintenance and availability:

1. How frequent is your scheduled maintenance?
   a. Weekly basis (*please specify after how many weeks*)
   b. Monthly basis (*please specify after how many months*)
   c. Kilometer basis (*please specify after how many months*)
2. How much does an electric bus cost in maintenance per month (*CNY/month*)?
3. How much does an electric bus cost in maintenance per km (*CNY/km*)?
4. Does the electric bus charging affect their availability for operation?
   a. Yes
   b. No
5. What is the buses' availability rate (*for example, 90% of the time the electric buses are available for operation*)?
6. Did you replace the bus battery due to performance degradation?
7. After how many years of operation did you have to replace the battery?
8. After how many driven kilometers did you have to replace the battery?
9. What was the battery state of health upon replacement (*for example, after 20% capacity degradation*)?
10. Did the e-bus maintenance staff get any training?
   a. Yes
   b. No

Questions on energy efficiency:

1. What is the average energy consumption of the buses in kWh/km?
2. Is this in line with what is declared by your bus manufacturer?
   a. Higher (*please specify after by how much, for example, + 20%*)
   b. Lower (*please specify after by how much, for example, - 20%*)
   c. Aligned
3. Do you observe a significant increase in bus energy consumption during hot or cold weather conditions?
   d. Yes
   e. No
4. How much does the bus energy efficiency increase during cold weather conditions (*for example, +20% at -10 °C relative to normal weather conditions*)?
5. How much does the bus energy efficiency increase during hot weather conditions (*for example, +20% at 40 °C relative to normal weather conditions*)?
6. Does this affect your electric bus fleet scheduling?
   a. Yes
   b. No

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