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Electrifying on-road freight: Deployment and charging of construction dump trucks in Zhengzhou, China

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INTRODUCTION

Recognizing vehicle electrification as an essential step toward the goal of a "Beautiful China," China's central government has set a target for 45% of all new vehicle sales to be new energy vehicles (NEVs) by 2027 (The Central Committee of the Communist Party of China & China State Council, 2024).[1] To decarbonize transportation and improve air quality, many provinces—including Sichuan, Hebei, Guangdong, Hainan, and Shaanxi—have made efforts to develop their NEV markets and deployed NEV technologies for different use cases, including heavy-duty battery electric trucks (BETs; Mao et al., 2023; Niu et al., 2023, 2024; Niu, 2024).

Henan province has also prioritized vehicle electrification and budgeted ¥200 million in 2021 from its provincial air pollution prevention funds to support transport electrification in the city of Zhengzhou, the capital of Henan province. The electrification efforts in Zhengzhou specifically covered three heavy-duty vehicle types, dump trucks, concrete mixer trucks, and straight trucks, as well as two light-duty types, taxis and urban logistics trucks.[2] By the end of 2022, Zhengzhou had become one of the leading markets for electric dump trucks, with a stock of over 1,400 (Ministry of Ecology and Environment, 2023).

1 In China, NEVs include battery electric vehicles (BEVs), plug-in hybrid vehicles (PHEVs), and fuel-cell electric vehicles (FCEVs).

2 Heavy-duty vehicles are defined as those having a gross vehicle weight equal to or greater than 4.5 tonnes. Light-duty vehicles are defined as those with a gross vehicle weight of less than 4.5 tonnes.

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To better understand the performance of battery electric dump trucks in Zhengzhou, this study analyzes a use case of real-world operations of 15 electric dump trucks used for transporting construction waste in Zhengzhou. The study evaluates the efficiency and cost of BETs compared with diesel models and compares the similarities and differences in the performances of electric dump trucks for the same construction use cases in Henan and Guangdong. All data and information used in this analysis were collected from publicly available sources or by our partner organizations.

POLICY REVIEW

Multiple departments within the Zhengzhou government have jointly introduced a series of policies and incentives to promote the replacement of internal combustion engine (ICE) dump trucks with new energy dump trucks for the transport of construction materials and waste. These policies grant new energy dump trucks certain road privileges, including exemption from travel restrictions and traffic control measures applied to ICE dump trucks during times of heavy pollution (People's Government of Zhengzhou City, 2021). Incentives are also provided by the Zhengzhou government to support the replacement of natural gas dump trucks and for research and design of new energy dump truck models (Zhengzhou Municipal Bureau of Industry and Information Technology, 2021; Zhengzhou Municipal Bureau of Urban Management, 2021). The policy assumes the useful life of natural gas dump trucks used for transport of construction waste is 72 months (6 years). Details of the policies, including the incentives and road privileges provided to new energy dump trucks, are described in Table 1.

Table 1
New energy dump truck promotion policies in Zhengzhou

Policy	Details
Implementation Plan of New Energy Dump Truck Promotion in Zhengzhou[a]	• New energy dump trucks are exempt from traffic restrictions applied to ICE dump trucks, which are prohibited from operating between 6 a.m. and 10 p.m. New energy dump trucks can operate throughout the day, except during peak hours (7 a.m.–9 a.m. and 5 p.m.–7 p.m.), allowing for up to 12 additional operating hours per day compared with ICE dump trucks.[e] • New energy dump trucks are exempt from air pollution control measures applied to ICE dump trucks during times of heavy pollution, allowing for up to 70 more operating days per year than ICE dump trucks.[f] • The use of new energy dump trucks is prioritized in key provincial and municipal projects. • Charging and swapping stations are being promoted along main routes of electric dump trucks.
Incentives of Dump Truck Emission Reduction in Zhengzhou[b]	• An incentive of ¥5000/month is provided for voluntarily scrapping a natural gas dump truck and purchasing a new energy dump truck, with the total incentive based on remaining useful life of the natural gas truck. The remaining useful life is calculated by deducting the number of months the truck has been in use from the total useful life of 72 months.
Incentives of Research and Design of New Energy Special Purpose Commercial Vehicles in Zhengzhou[c]	• An incentive of ¥100,000 per model is provided to the manufacturer for research and design of a new energy dump truck.
The Action Plan on Air Quality Improvement of Henan Province[d]	• By 2025, most dump trucks operating in urban areas will be new energy vehicles.

[a] People's Government of Zhengzhou City (2021)
[b] Zhengzhou Municipal Bureau of Urban Management (2021)
[c] Zhengzhou Municipal Bureau of Industry and Information Technology (2021)
[d] People's Government of Henan Province (2024)
[e] Zhengzhou Municipal Bureau of Ecology and Environment (2021)
[f] Consultant research

TRUCK SPECIFICATIONS AND OPERATION

The following sections detail the operation and performance of the battery electric dump trucks in our study case (Figure 1).

Figure 1
A battery electric dump truck in Zhengzhou

All 15 trucks in the fleet studied are battery electric dump trucks manufactured by Yutong with a gross vehicle weight of 31 tonnes. The trucks are equipped with a 422-kWh battery. Table 2 details the specifications of this battery electric dump truck model and the top-selling diesel counterpart model in Zhengzhou.

Table 2

Specifications of dump trucks for construction waste used in this study

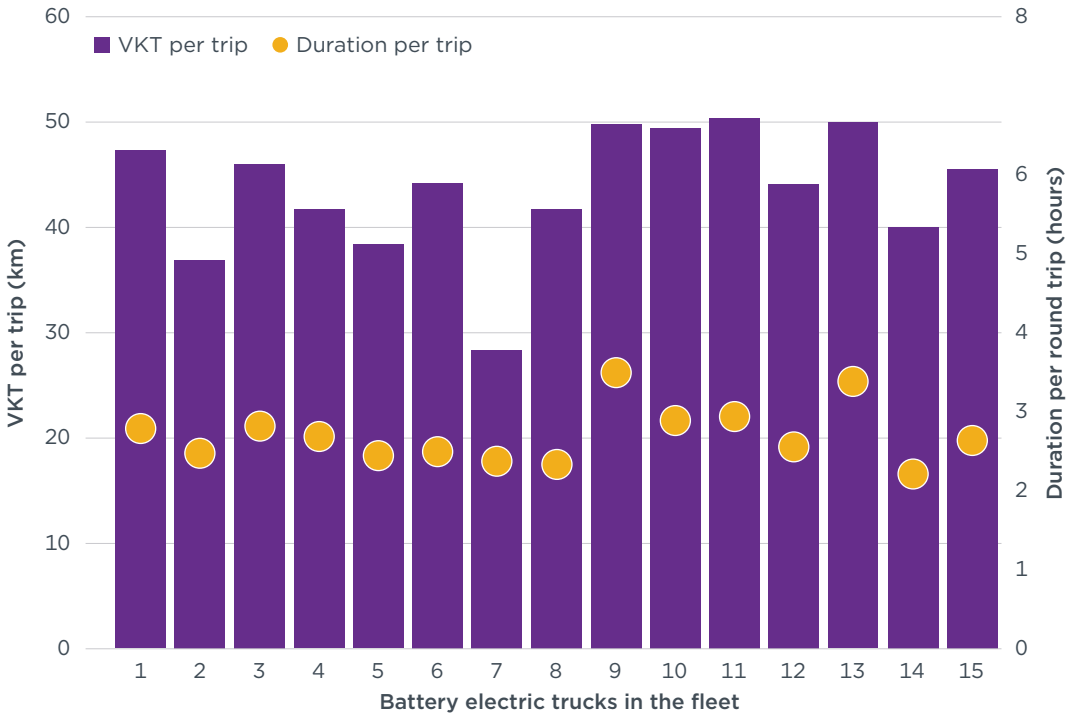
Specification	Battery electric dump truck	Diesel dump truck
Vehicle model	ZKH3310P6BEV	SX3319XD426
OEM	YUTONG	SHACMAN
Gross vehicle weight (t)	31	31
Payload capacity (t)	12.87	15.37
Vehicle size (mm)	Length: 9,730 Width: 2,550 Height: 3,520	Length: 10,950 Width: 2,550 Height: 3,500
Wheelbase (mm)	1,950 + 3,050 + 1,350	1,950 + 4,025 + 1,400
Engine power (kW)	Rated: 280 Peak: 430	Peak: 405
Engine torque (N·m)	Rated: 1,400 Peak: 2,800	Peak: 2,550
Engine displacement (L)		12.54
Energy storage	422 kWh battery	400 L diesel tank
Certified range (km)	325[a]	978[b]

[a] This certified battery electric dump truck range is derived from the constant speed certification at 40 km/hour.
[b] This model's fuel consumption is 40.9 L/100 km. The certified range of the diesel dump truck is calculated by dividing the volume of the diesel tank by the certified diesel consumption, which is 400 L / (40.9 L/100 km) = 978 km.

In this use case, the electric dump trucks transport waste from construction sites to waste disposal sites, operating without fixed routes. Figure 2 details the average vehicle-kilometers traveled (VKT) and driving duration of each round trip for each of the 15 electric dump trucks. The average VKT per round trip for this fleet is 43.6 km, and the average driving duration is 2 hr 40 min, with an average speed of 15.37 km/h.

Figure 2

Vehicle-kilometers traveled and operating duration per trip for each truck



The BETs in this fleet undertake 3 to 5 round trips daily, with an average operation duration of 9 hours and an average daily VKT of 143 km. With an average energy consumption of 148 kWh/100 km, each truck charges 1 to 2 times per day, spending an average of 2 hours charging each day. The fleet has no depot charging station, so the trucks recharge using public chargers with power ranging from 50 kW to 250 kW. Figure 3 demonstrates the daily operation and charging pattern of this fleet.

Figure 3
Daily operation and charging pattern of the fleet

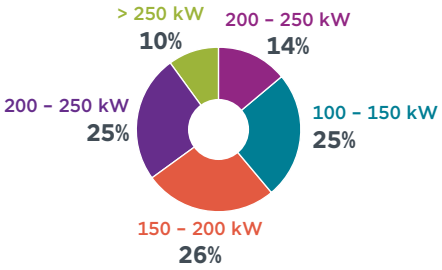
Daily VKT	95 km ~ 170 km	Daily charging time	1 hr 30 min ~ 2 hr 20 min Average: 2 hours
Daily trips	3 ~ 5 round trips	Daily charging frequency	27% of the trucks charge once per day 73% of the trucks charge twice per day
Energy consumption	148 kWh/ 100 km	Distribution of charging sessions	

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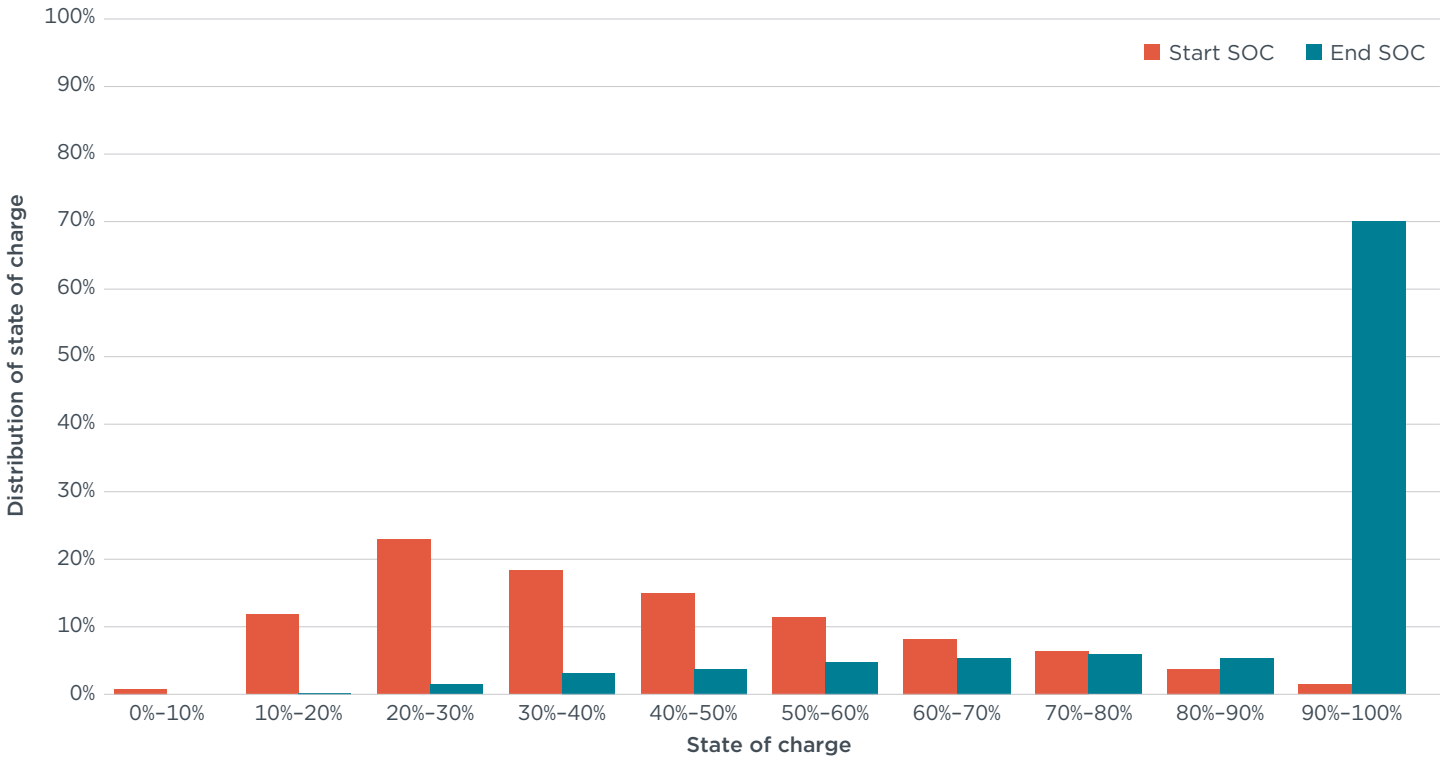
Figure 4 shows the distribution of the state of charge (SOC) at the start and end of charging sessions. The most common SOC at the start of charging ranges between 20% and 30%; 54% of the time, the SOC at the start of charging sessions is below 40%. According to our interviews with the fleet owner and drivers, this is primarily due to the lack of depot charging stations, so trucks are charged when a charger is available. At the end of 70% of the charging sessions, the SOC is between 90% and 100%.

Figure 4

Distribution of the state of charge at the start and at the end of each charging session



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For this study, we further analyze seasonal operation data, defining June 1, 2022, to August 31, 2022, as summer and November 1, 2022, to January 31, 2023, as winter. Figure 5 and Figure 6 display the average energy consumption and VKT for the 15 BETs in winter and summer. The seasonal difference is evident in Figure 5, with winter energy consumption rising from 0.41% to 18.27%. On average, the fleet's energy consumption is 8.7% higher in winter than in summer, indicating a greater energy requirement for heating than for cooling. As shown in Figure 6, most trucks, except for Truck 15, travel longer distances in summer, with the fleet-average summer VKT 40% higher than in winter. This demonstrates more active construction operations and a higher demand for transport of construction waste during summer.

Because the electric dump trucks in this study do not have access to depot charging, the trucks must travel from their operational routes to charging stations. However, this mileage could not be identified from existing data.

Figure 5

Average energy consumption for each of the 15 electric dump trucks in summer and winter

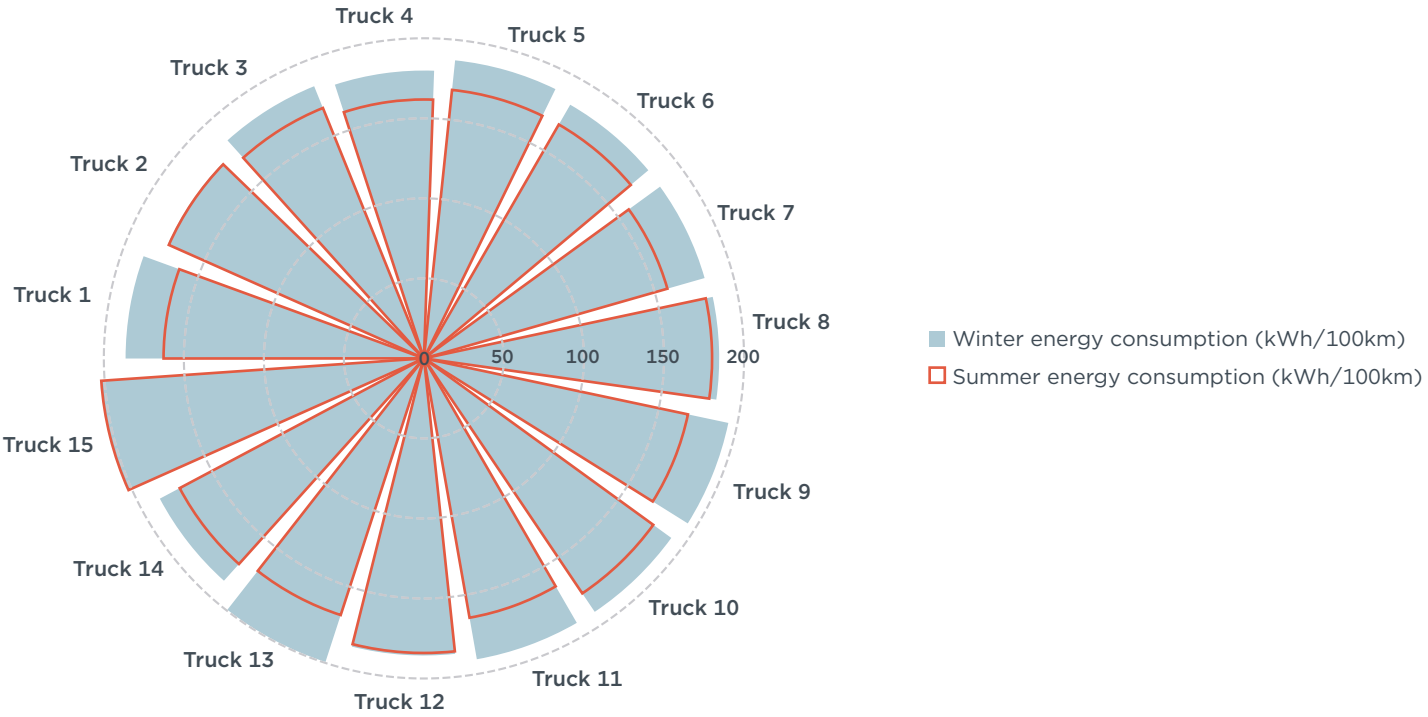

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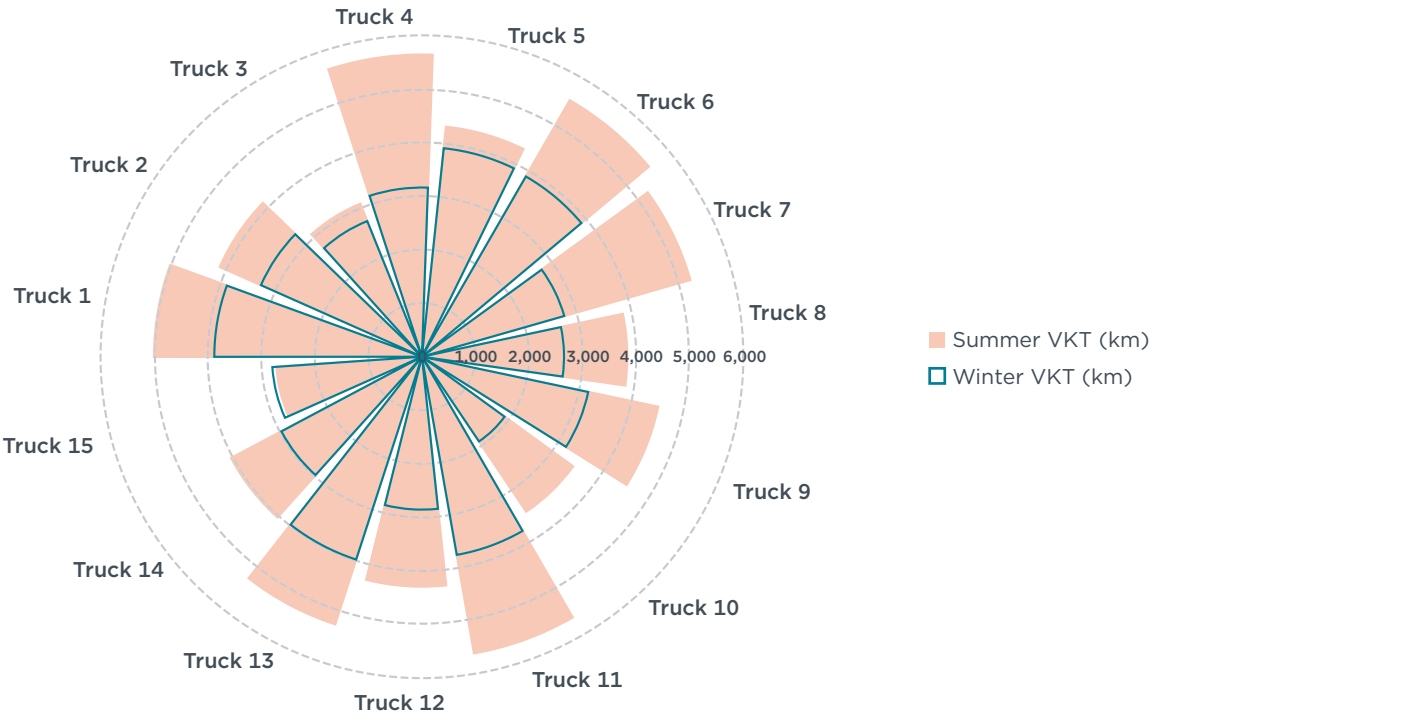
Figure 6

Total vehicle-kilometers traveled for each of the 15 electric dump trucks in summer and winter



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TOTAL COST OF OWNERSHIP ANALYSIS

This section examines the lifetime total cost of ownership (TCO) of battery electric dump trucks and diesel dump trucks used for the transport of construction waste in Henan. The analysis employed the ICCT's Analyzer of Zero-emission Transportation Energy and Costs (AZTEC) model; the methodology of this model is detailed in an earlier ICCT report (Alvarez et al., 2022; Nui et al., 2023).

The following sections evaluate the capital expenditures, operation expenses, and other expenses over a 6-year lifetime with detailed breakdowns, including purchase costs, energy costs, maintenance, insurance, and tax. An annual discount rate of 10% is applied to all costs.

CAPITAL EXPENDITURES

The purchase price for a battery electric dump truck, after subsidies provided by the Zhengzhou government, is ¥930,000, with an additional cost of ¥50,000 for a 3-year payment installment plan, including interest and other financial costs. The retail price for a diesel dump truck is ¥450,000, with an additional cost of ¥24,200 for a 3-year payment installment plan, including interest and other financial costs. A 10% purchase tax is also required for diesel trucks, from which electric dump trucks are exempt (Ministry of Industry and Information Technology, 2021).

OPERATIONAL EXPENSES

Annual activity, energy consumption, refueling cost, maintenance cost, ownership tax, and insurance fees jointly determine the operational expense. Table 3 summarizes the average annual activity, energy consumption, and payload in this use case. The Implementation Plan of New Energy Dump Truck Promotion in Zhengzhou grants electric dump trucks road privileges, including exemption from ICE dump truck travel restrictions and traffic control measures during times of heavy pollution (People's Government of Zhengzhou City, 2021). Consequently, this paper assumes these privileges result in diesel trucks traveling approximately 20% fewer kilometers annually compared with the battery electric trucks.[3] Specifically, the battery electric trucks travel 30,000 km annually, while the diesel trucks travel 24,000 km.

Table 3
Summary of fleet operations

	Battery electric truck	Diesel truck
Fleet average annual VKT	30,000	24,000
Useful life	6 years	6 years
Payload capacity (t)	12.67	15.37
Load rate	50% of trips fully loaded, 50% empty	50% of trips fully loaded, 50% empty
Average energy consumption	148 kWh/100 km	40.9 L/100 km

In this study, the average refueling cost is ¥0.6 per kWh for BETs and ¥7.5 per liter for diesel trucks. Maintenance costs vary by powertrain type and VKT, with BETs costing

3 The consultant research found that BETs—which benefit from exemptions on ICE dump truck travel restrictions and heavy pollution traffic control measures—can have around 12 additional working hours per day and approximately 70 more working days per year compared with diesel trucks. However, current data is insufficient to determine the real-world additional operating time of BETs compared to diesel vehicles. Therefore, considering that 70 days is approximately 20% of a 365-day year, this paper assumes that the VKT for diesel dump trucks is 20% lower than the VKT for electric trucks.

¥0.22/km and the diesel trucks costing ¥0.33/km. The annual ownership tax for the diesel trucks is ¥84 per tonne of curb weight; BETs are exempt from this tax (People's Government of Henan Province, 2012). According to the fleet owner interviewed for this study, the average annual insurance is ¥45,000 for BETs and ¥23,000 for diesel trucks.

RESIDUAL VALUE

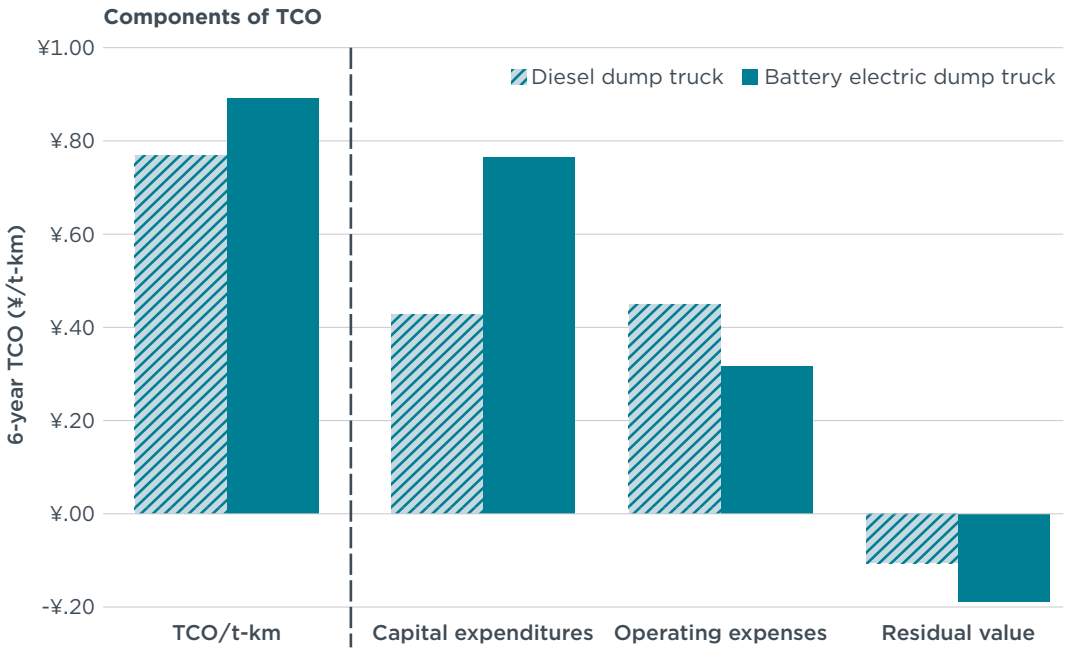
The average useful life of a dump truck in this use case is 6 years (Zhengzhou Municipal Bureau of Urban Management, 2021). A report by China Automotive Technology and Research Center shows the annual depreciation rate is 8% for diesel trucks and 12% for battery electric and fuel-cell electric trucks (Zhao et al., 2022]). Based on this depreciation rate and our interviews with the fleet owner and drivers, we assume the residual value is about ¥200,000 for diesel trucks and ¥372,000 for BETs.

RESULTS AND DISCUSSION

The 6-year lifetime TCO is ¥1,032,205 for a battery electric dump truck and ¥851,195 for a diesel dump truck. Due to road privileges and the weight of the battery, the VKT and payload capacity of BETs differ from those of diesel dump trucks. Therefore, this section analyzes the TCO per tonne-kilometer (t-km), which is the cost of transporting 1 tonne of payload a distance of 1 kilometer, to compare the economic performance.

Figure 7 presents the lifetime TCO/t-km analysis results for BETs and diesel trucks in this use case. The lifetime TCO per tonne-kilometer for electric dump trucks is ¥0.89, 16% higher than the TCO of ¥0.77 for diesel dump trucks. The increase is primarily due to the high purchase and insurance costs of the BETs. However, lower energy costs and exemptions from purchase and ownership taxes for BETs help to reduce the TCO gap between electric and diesel trucks.

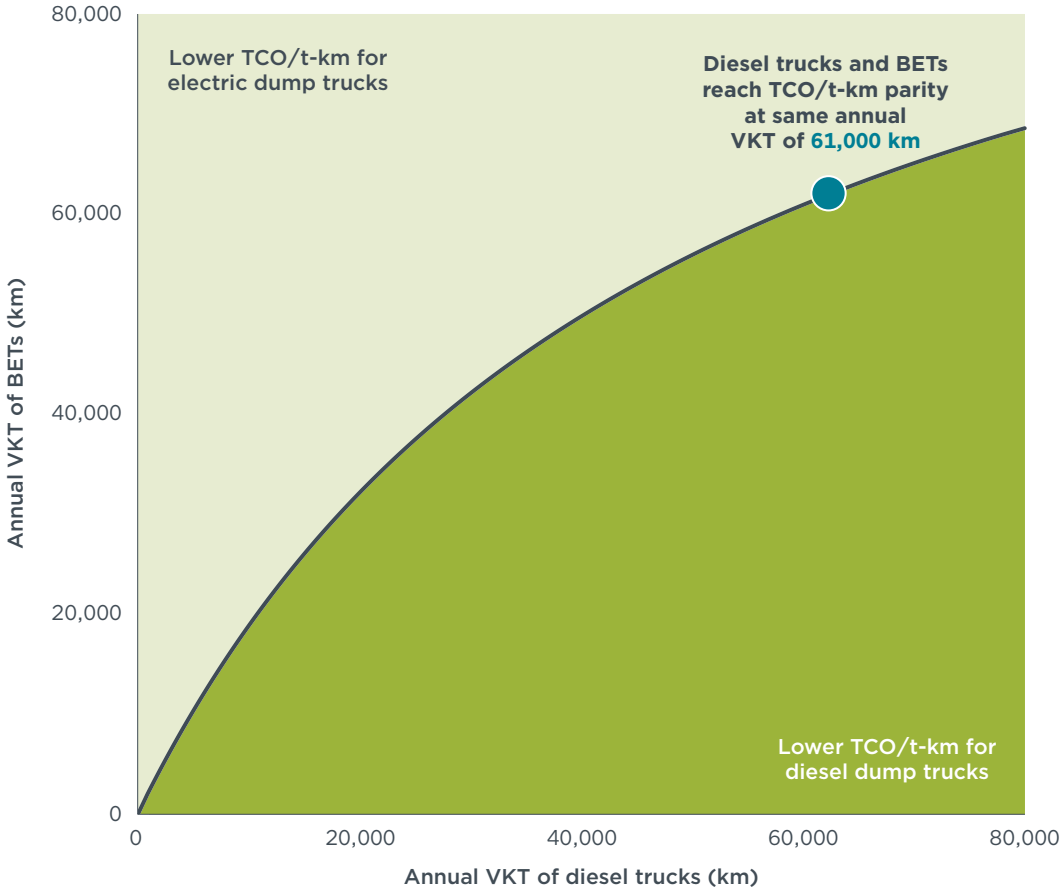
Figure 7
6-year total cost of ownership of battery electric and diesel dump trucks in Henan per tonne-kilometer



Higher capital expenditures and reduced payload capacity result in a higher TCO/t-km for BETs than diesel trucks. However, the main advantage of BETs is their lower energy cost, which indicates that they must travel longer distances to be economically competitive in terms of TCO/t-km. Figure 8 shows that BETs and diesel trucks reach cost parity at an annual VKT of approximately 61,000 km. Beyond this threshold, BETs outperform diesel trucks in terms of TCO/t-km due to their reduced energy costs. In this use case, road privileges for BETs and traffic restrictions on diesel dump trucks can enhance the economic performance of BETs by allowing the trucks longer hours of operation.

Figure 8

Annual vehicle-kilometers traveled for battery electric and diesel dump trucks to reach total cost of ownership parity per tonne-kilometer



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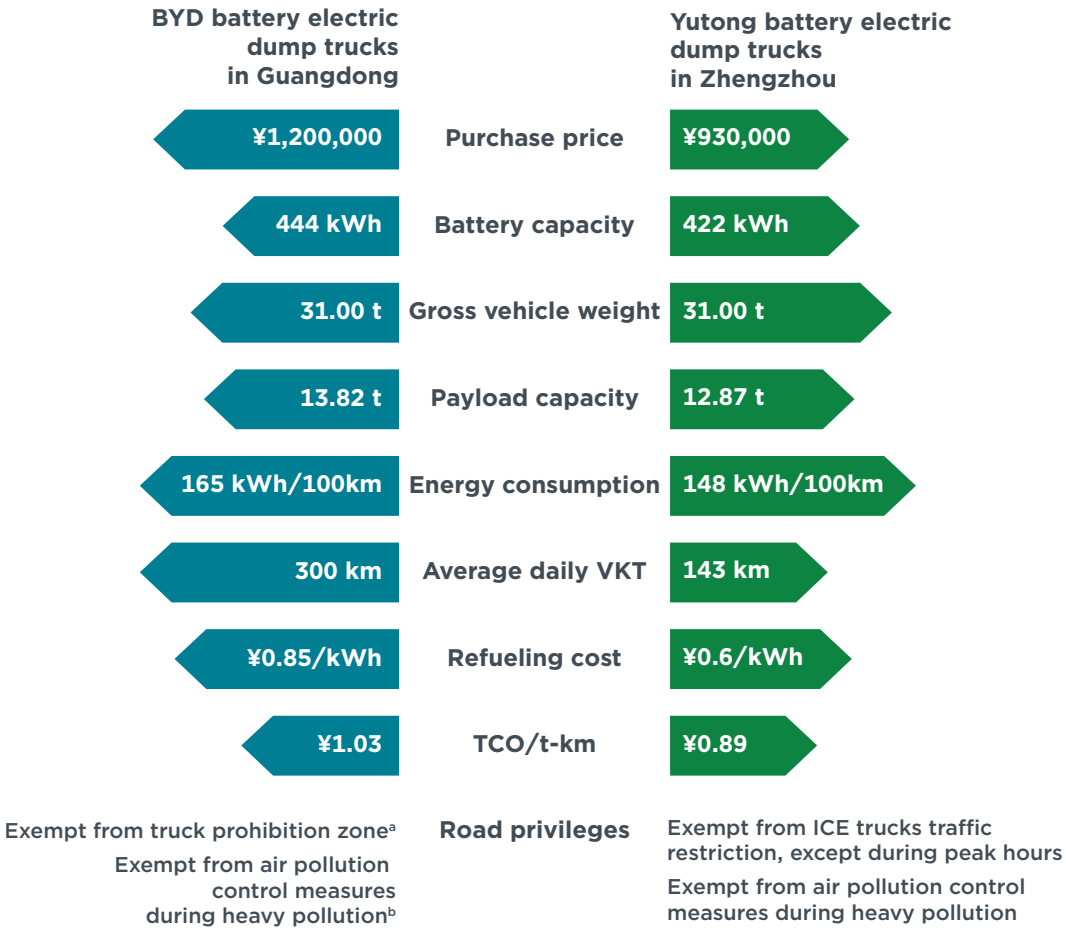
GUANGDONG BATTERY ELECTRIC DUMP TRUCK COMPARISON

A previous ICCT paper assessed the real-world application of BETs transporting construction materials and waste in Guangdong province, a use case similar to this study (Niu et al., 2023). This section compares and analyzes these two use cases, including the vehicle specifications, operation, and TCO. The comparison is detailed in Figure 9.

Although the use cases are similar, the BETs are made by different manufacturers with different retail prices; the BETs in the Guangdong study were made by BYD and the BETs in Zhengzhou were made by Yutong. Both trucks have a gross vehicle weight

of 31 tonnes, but the payload of the Guangdong truck is 1.15 tonnes higher. The most significant variation lies in the average daily VKT: Trucks in Guangdong travel more than twice the distance than those in Henan, which may be attributed to greater construction activity in Guangdong. These factors collectively contribute to the difference in TCO between the two cases.

Figure 9
Comparison of battery electric dump trucks in Guangdong and Zhengzhou



[a] Guangzhou Municipal Bureau of Urban Management (2020)
[b] Guangzhou Municipal Bureau of Ecology and Environment (2021)

CONCLUSION

Zhengzhou has prioritized the promotion of NEVs to mitigate air pollutants and greenhouse gas emissions from traditional ICE vehicles, with the aim of improving air quality. Multiple departments within the Zhengzhou government have introduced policies and incentives to promote the replacement of traditional ICE dump trucks with new energy dump trucks for transport of construction waste, resulting in the wide adoption of battery electric dump trucks.

This paper examined the performance and TCO of battery electric dump trucks for the transport of construction waste. We found that the 6-year TCO per tonne-kilometer for electric dump trucks is ¥0.89, 16% higher than the TCO of ¥0.77 for diesel dump trucks. While BETs have a higher retail price compared with diesel trucks, the lower energy cost narrows the TCO gap with diesel trucks. However, electric dump trucks can

achieve TCO parity and outperform diesel trucks when used to travel longer distances, as they benefit from road privileges and from traffic restrictions on diesel trucks.

Drawing on these findings, we make the following observations regarding the promotion of electric dump trucks in Zhengzhou:

Financial incentives for electric dump trucks can help close the TCO gap with diesel dump trucks. According to our analysis, the capital expenditure for electric dump trucks is 80% higher than comparable diesel trucks due to their higher retail price. Financial incentives such as purchase subsidies and tax exemptions may increase fleet owners' willingness to purchase electric dump trucks. Keeping such incentives could be considered until the electric trucks reach TCO parity with diesel.

Road privileges granted to electric dump trucks can increase the cost-competitiveness with diesel trucks. Total VKT is critical in achieving TCO parity between electric and diesel dump trucks. Implementing traffic restrictions for diesel dump trucks in urban areas could allow electric dump trucks to increase their VKT, thereby enhancing their cost competitiveness in terms of TCO per tonne-kilometer. Additionally, these policies would help to improve urban air quality.

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