

Electrifying on-road freight: A case study of 49-ton electric tractor-trailers in the city of Yulin, Shaanxi province

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INTRODUCTION

Deploying new energy vehicles (NEVs) is an essential step for accelerating the transition to more green and sustainable freight transport across industries. In recent years, China has announced implementation plans for ultra-low emission standards targeting three key industries: iron and steel, cement, and coke. These standards include NEV deployment targets for freight transport. (Ministry of Ecology and Environment, 2024a, 2024b, 2019).

Shaanxi is the third largest coal-producing province, responsible for around 17% of China's total raw coal production (Figure 1) (China National Coal Association, 2022). In 2022, Shaanxi reported an annual average $PM_{2.5}$ concentration of $39 \mu\text{g}/\text{m}^3$, which is $10 \mu\text{g}/\text{m}^3$ higher than the national average. (Ministry of Ecology and Environment, 2022) On-road trucks were the predominant mode for coal transport in Shaanxi, accounting for 70.2% of the total coal freight volume (Shaanxi Energy Administration, 2019). In Xi'an, the provincial capital, most trucks are powered by diesel. These diesel trucks are responsible for 90% of particulate matter ($PM_{2.5}$) and 80% of nitrogen oxides (NO_x) in Xi'an (Shi & Guan, 2021).

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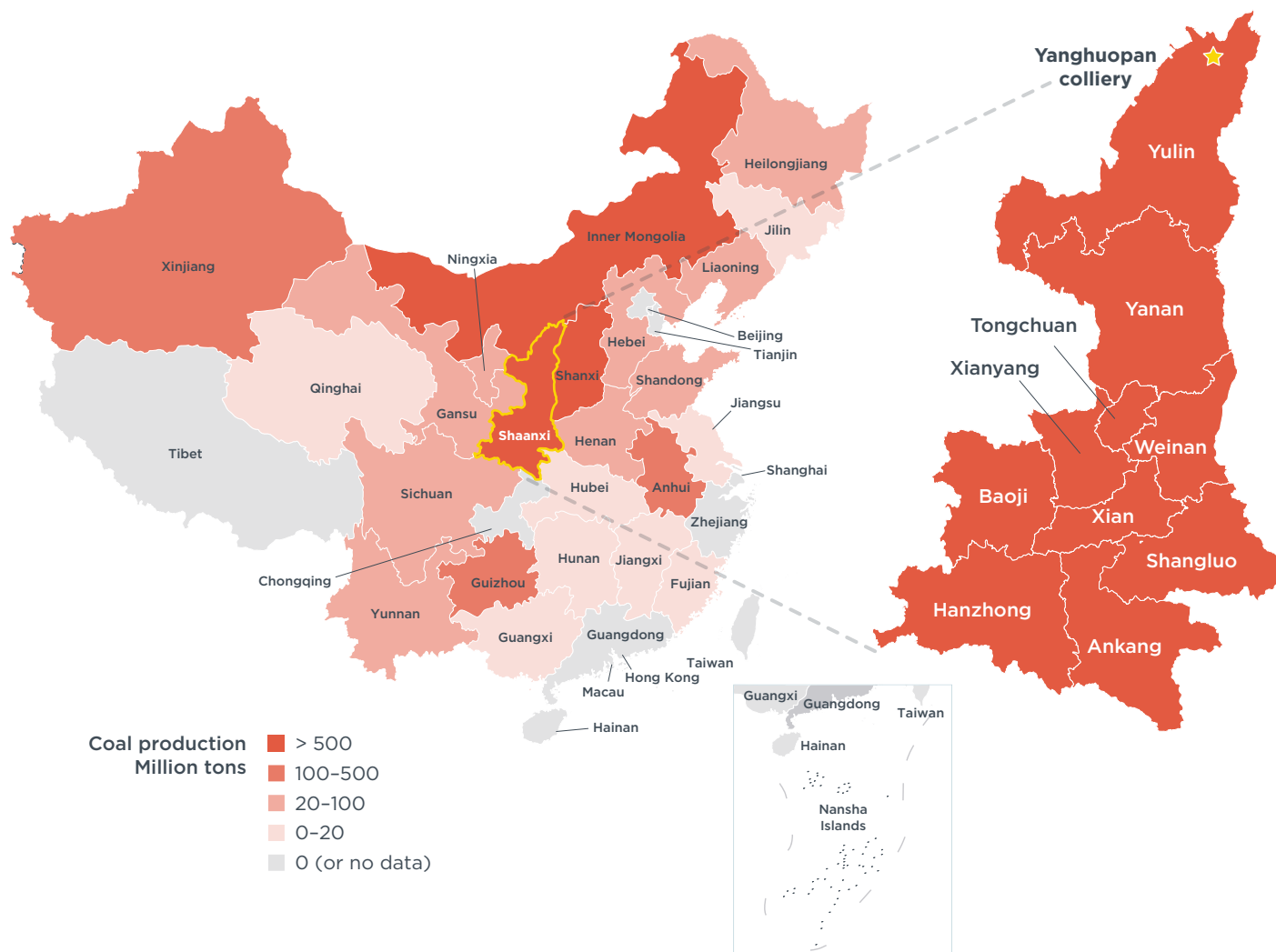
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Figure 1

Overview of coal production by province and the location of the Yanghuopan colliery in Yulin city



Data source: China National Coal Association (2022)

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In 2019, the government of Shaanxi province published *Launching of the Battle Against Diesel Truck Pollution* to promote NEV uptake in freight transportation (Shaanxi Provincial People’s Government, 2020). The promotion of heavy-duty zero-emission trucks (ZETs) was also highlighted as a critical measure to reduce GHG emissions in Shaanxi’s carbon peaking and carbon neutrality targets and plans (Shaanxi Provincial People’s Government, 2022c, 2022b, 2022a; Shaanxi Provincial Development and Reform Commission, 2021).

Recently, Shaanxi started to deploy heavy-duty battery-electric trucks (BETs) in coal mining activities and is considering using fuel-cell electric trucks (FCETs). Because coal is the raw material for manufacturing coke, it is subject to the same ultra-low emission standard as the coke industry.

To better understand the real-world performance of ZETs, this paper assesses Shaanxi’s heavy-duty ZET market from 2019 to 2022 and the use of ZETs in Yulin’s Yanghuopan colliery. We use first-hand empirical data and information collected from interviews with the colliery fleet owner-operator on the real-world operation and performance of ZETs. We also conduct a total cost of ownership (TCO) analysis to compare the performance of electric trucks with swap-capable batteries to diesel

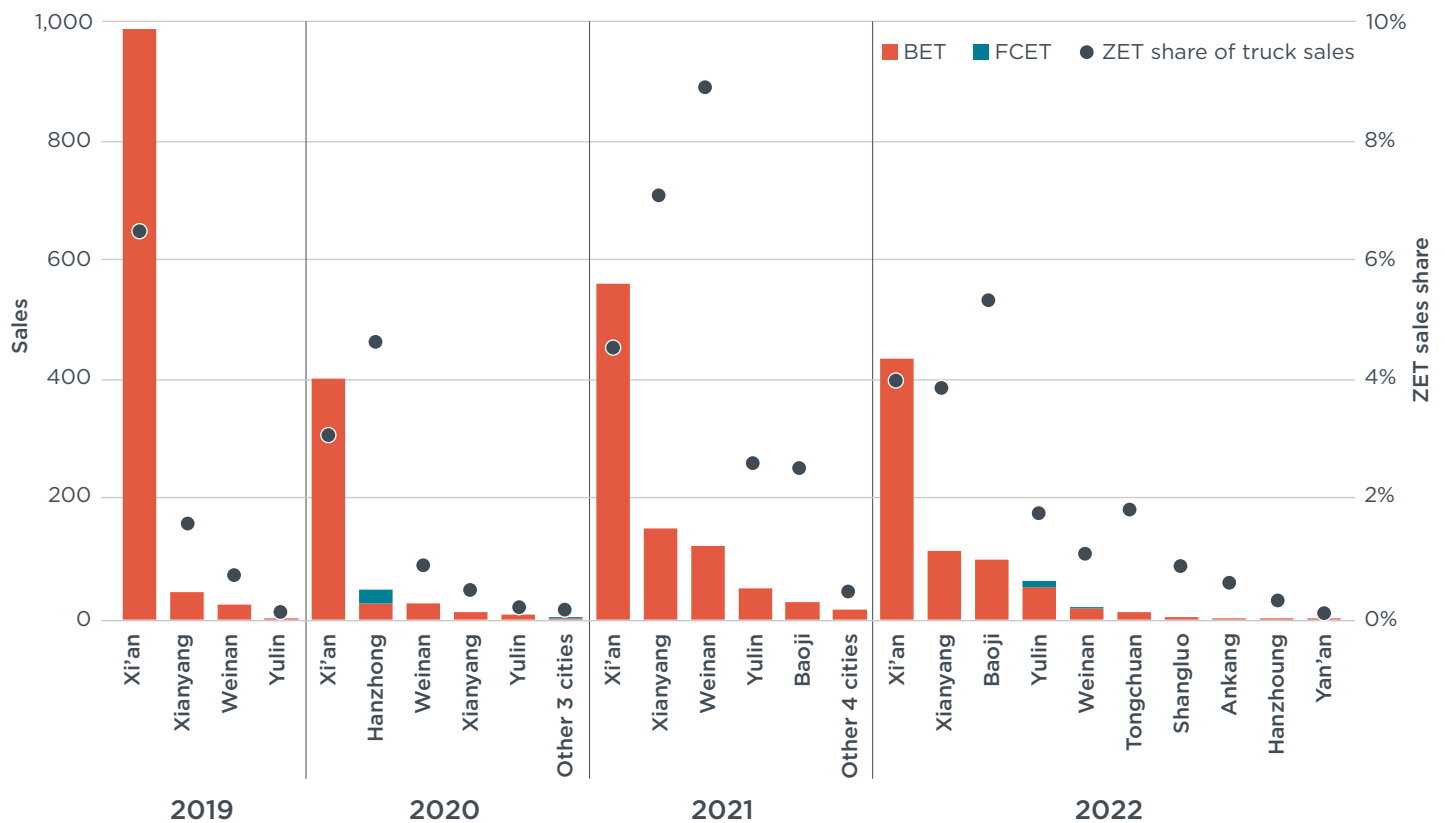
trucks. We also compare the costs of buying a BET with the battery or buying a BET with battery-as-a-service (BaaS).¹

This study is part of a series on real-world use cases of ZETs and is intended to inform the use of battery-electric and fuel-cell electric trucks in other industry sectors.²

HEAVY-DUTY ZET MARKET

The annual sales and sales share of heavy-duty ZETs in Shaanxi (including BETs and FCETs) from 2019 to 2022 are shown in Figure 2. Over the 4 years, 3,241 heavy-duty ZETs were sold, 99% of which were BETs. Approximately 56% of ZET sales occurred in the provincial capital of Xi'an, and the cities of Xianyang, Weinan, and Yulin were responsible for 10%, 8%, and 4% of ZET sales, respectively. In 2022, the provincial ZET sales share was 7%, which was 1% higher than the national average and gave Shaanxi the 11th-highest sales share among all provinces.

Figure 2
Battery electric heavy-duty truck sales and sales shares in Shaanxi cities



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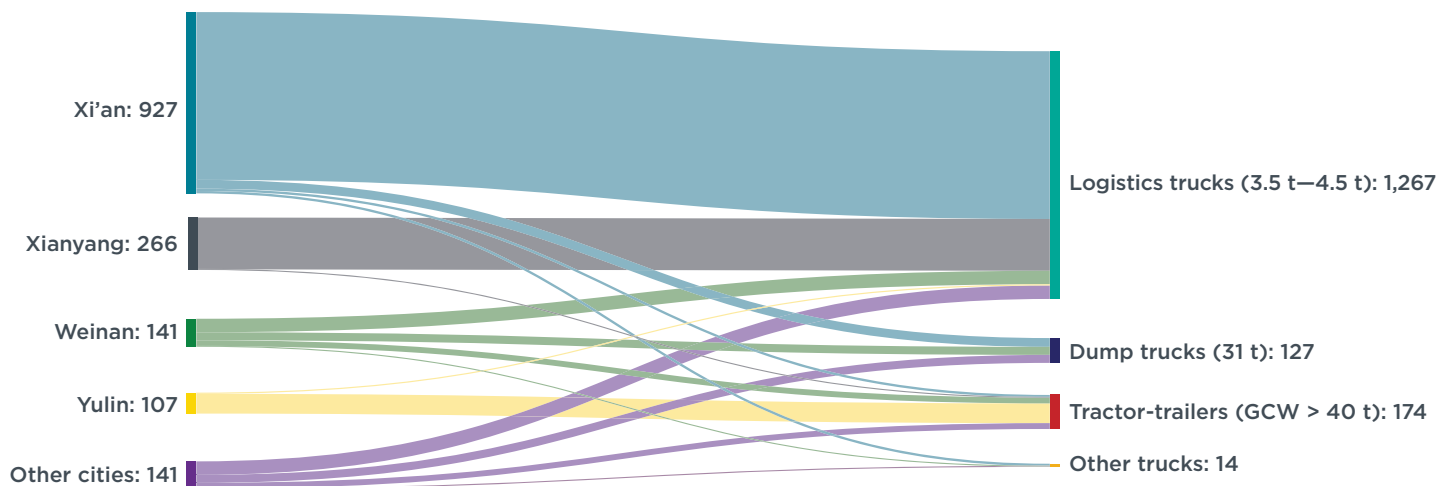
While the overall adoption of ZETs in Shaanxi province remains in its early stages, there have been notable successes. Figure 3 shows BET sales distribution by city and truck type. Xi'an led in terms of total sales, but most sales were logistics trucks in the light segment for gross vehicle weight. Yulin, which accounted for 64% of coal production in Shaanxi (Shaanxi Daily, 2023), dominated in sales of battery-electric tractor-trailers.

¹ Under BaaS mode, fleet owners buy BETs without the battery and rent the battery instead. Rental fees are paid in various formats, such as during refueling. Alternatively, fleet owners can choose to buy the entire BET with the battery.

² See Mao et al. (2023), Niu et al. (2023), and Niu et al. (2024).

Sales in Yulin of battery-electric tractor-trailers with a gross combination weight of over 40 tons increased from zero units in 2021 to 101 units in 2022. Not shown in the figure, Yulin also deployed 10 new fuel-cell electric tractor-trailers in 2022. Shaanxi Province has set an ambitious target of deploying over 5,000 heavy-duty FECTs by 2024 (Shaanxi Provincial Development and Reform Commission, 2022).

Figure 3
Battery electric truck sales by city and truck type, 2021-2022



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These developments highlight the evolving landscape of the ZET market in Shaanxi province and its broader implications for sustainable transportation in China. While the market is still in its early stages, increasing sales and penetration rates can be observed, especially for heavy-duty tractor-trailers.

REAL-WORLD USE CASE OF ZETS IN YULIN

To better understand the real-world use of zero-emission tractor-trailers in Yulin, in May 2023 we conducted a field investigation at the Yanghuopan colliery in Yulin. (See Figure 4). The colliery, which produces 6 million tons of coal annually, was the first to use BETs for coal freight. There are two primary freight routes: a 4 km delivery to a power plant on a nearby hill and a 50 km delivery to freight stations.

The colliery purchased 50 swap-capable electric tractor-trailers in 2021, opting for a battery-as-a-service (BaaS) contract with Geely, which installed two battery-

swapping stations. There are also 18 diesel tractor-trailers in operation. According to our interviews, 10 FCETs acquired in 2022 in Yulin have not formally been put into operation in the colliery, but the government is preparing to test their use.

Figure 4
Yanghuopan colliery and battery electric trucks in operation






Photos by Tialin Niu

REAL-WORLD PERFORMANCE

We collected information on the real-world performance of diesel trucks and ZETs operating in the Yanghuopan colliery from interviews with the fleet owner-operator. Table 1 shows the technical specifications of the current in-use diesel trucks and BETs, as well as the FCETs that could potentially be used for coal freight. The retail price of the trucks varies greatly between powertrain types, ranging from ¥300,000 for the diesel truck and ¥1,500,000 for the FCET. The price of the BET with the battery installed is

¥806,000, compared to ¥436,000 for a swap-capable BET. The maximum payload of BETs and FCETs with the same trailers are both 2.63 t less than diesel trucks.

Table 1
Technical specifications of diesel and battery electric trucks in use at the Yanghuopan colliery and the best-selling fuel-cell electric truck in Shaanxi with the same capacity

Powertrain	Diesel	Battery electric	Fuel-cell electric
			
Vehicle model	CA4256P2K15T1E5A80	HN4253H36C8BEV	SX4257MJ4XFCEV
Manufacturer	FAW	Geely	SXQC
Brand	TianV	CAMC	Xuandeyi
Gross combination weight	48,800 kg	48,870 kg	48,870 kg
Traction mass^a	40,000 kg	37,370 kg	37,370 kg
Engine power	276 kW	Rated: 250 kW Maximum: 360 kW	Rated: 220 kW Maximum: 410 kW
Engine torque	2,060 N·m	Rated: 1,600 N·m Maximum: 2,800 N·m	Rated: 1,300 N·m Maximum: 2,800 N·m
Engine displacement	11.6 L	-	-
Energy storage	Diesel tank, 600 L	Battery, 282 kWh	Battery, 120 kWh & 49.4 kg of H ₂ ^b
Certified range	1,500 km	170 km	95 km (without H ₂ system) 650 km (with H ₂ system)
Retail price of tractor in 2023	¥300,000	With battery: ¥806,000 Without battery: ¥436,000	¥1,500,000

Photos: Diesel and battery-electric trucks by Tianlin Niu; FCET by CATARC

^a Traction mass is the sum of the trailer and the total payload.

^b Hydrogen storage is estimated from the vehicle's use of thirteen 165 L 350 bar tanks.

The operational information for the different truck uses in the colliery is presented in Table 2. In the first use case, the trucks travel 7.5 km (round trip) to deliver coal to a power plant located on a small hill. These trips occur as often as 30 times per day. In the second case, trucks travel 95 km (round trip) to deliver coal to a freight station. These trips run, at most, 6 times per day. The trucks are randomly assigned to each

route, making it difficult to quantify their real-world activity. For this study, we assume that a truck will be used for only one use case, will be fully loaded from the colliery to the destination, and will return empty.

Table 2

Summary of truck use cases

Use case	Power plant case	Freight station case
Description	From colliery to power plant	Delivery to the freight rail station or other coal consumers
Distance per round trip	7.5 km	95 km
Trips per day	25-30	4-6
Annual activity	68,000 km	180,000 km
Max service life	8 years	6 years
Carriage fees	~ ¥0.8/tkm	¥0.4/tkm
Full payload	<ul style="list-style-type: none"> • Diesel truck: 16 t • BET: 13 t 	<ul style="list-style-type: none"> • Diesel truck: 16 t • BET: 13 t
Real-world energy consumption	<ul style="list-style-type: none"> • Diesel truck: Empty: 17 L/100 km Full load: 48 L/100 km • BET: Empty: 120 kWh/100 km Full load: 250 kWh/100 km 	<ul style="list-style-type: none"> • Diesel truck: Empty: 16 L/100 km Full load: 42 L/100 km • BET: Empty: 115 kWh/100 km Full load: 210 kWh/100 km

The real-world costs of the in-use diesel trucks and BETs, broken down by capital expenditures and operating expenses, are listed in Table 3. Currently, only diesel trucks are subject to a purchase tax and an ownership tax; BETs are exempt from these taxes. All BETs in the colliery use battery swapping for refueling. A fixed grid electricity price of ¥0.6 per kWh, a battery-swapping station service fee of ¥0.2 per kWh, and a battery rental fee of ¥0.6 per kWh are charged, totaling ¥1.4/kWh.

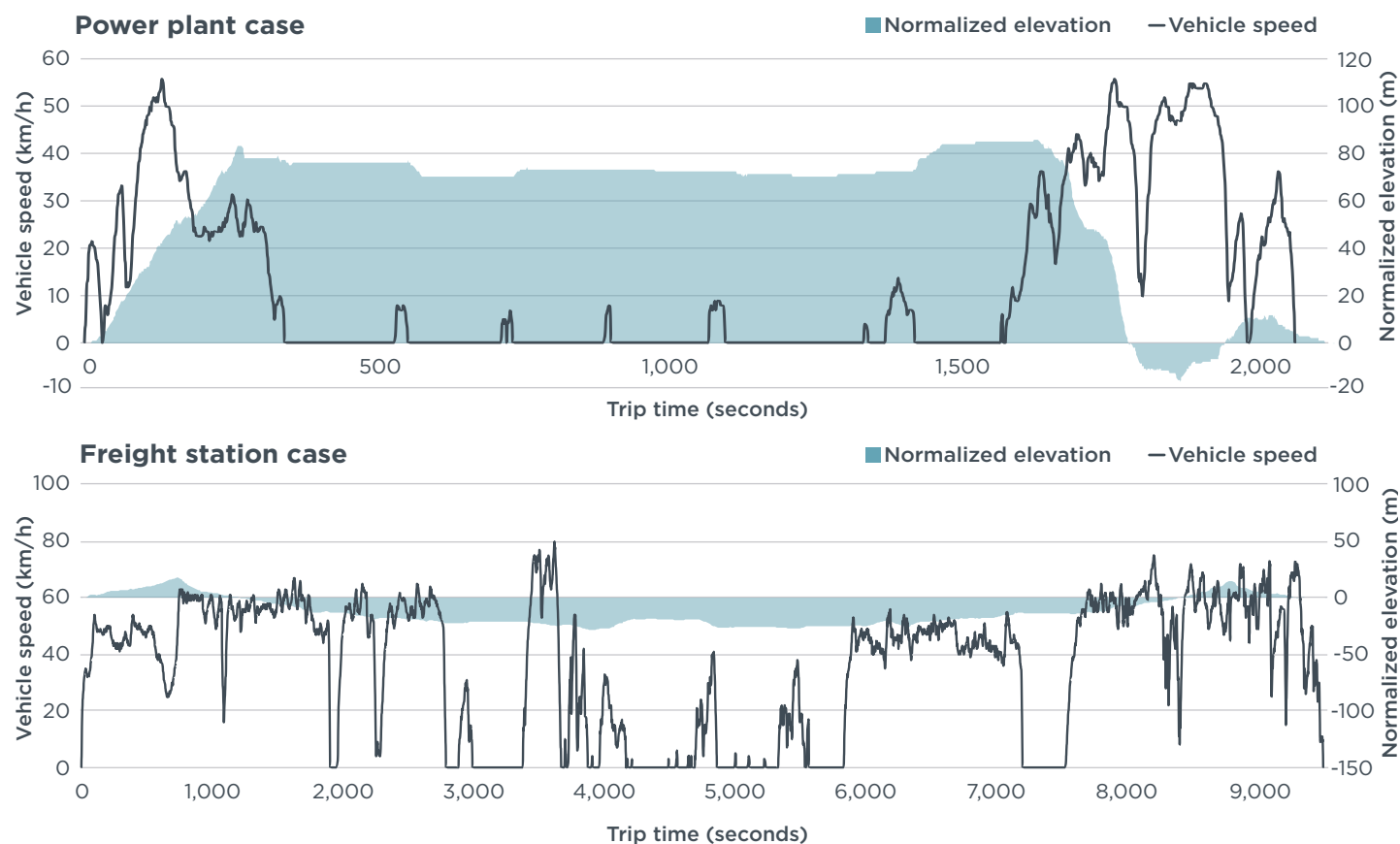
Table 3

Real-world cost of in-use diesel trucks and BETs at the colliery, 2023

Year 2023	Diesel trucks	BET-BaaS	BET
Capital expenditures			
Retail price	¥300,000	¥436,000	¥800,000
Purchase tax	10% of the retail price	Exempt	Exempt
Down payment	30%	30%	30%
Loan term	3 years	3 years	3 years
Interest rate	10%	10%	10%
Residual value	¥100,000	¥125,000	¥200,000
Operating expenses			
Average refueling cost	¥8.4/L	¥1.4/kWh	¥0.8/kWh
Ownership tax	¥60 per ton of curb mass per year	Exempt	Exempt
Maintenance cost	¥0.30/km	¥0.22/km	¥0.22/km
Insurance	¥24,000/year	¥40,000/year	¥62,000/year
Staff salary and other	¥200,000/year	¥200,000/year	¥200,000/year

We used an independent device to collect additional information on the trips, including vehicle speed and altitude profiles, which are shown in Figure 5. In the power plant case, the plant is about 80 m above the colliery, and the truck experiences idling time when dropping off coal at the plant. In the freight station case, the route includes highways where the truck's speed is over 40 km/h, and the elevation is somewhat consistent.

Figure 5
Operation cycle sample for power plant case and freight station case



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We recognized from our interview that the fleet owner was aware of the lower energy costs of ZETs. However, the key challenge is that the use of ZETs generates less revenue because carrying the battery results in a lower payload.

TOTAL COST OF OWNERSHIP AND PROFIT

Figure 6 provides an overview of the current TCO, revenue, and resulting profit of diesel and battery-electric trucks in the colliery, assuming the trucks are used for only one of the use cases. The total cost of ownership assumes trucks are in operation for 8 years in the power plant case and 6 years in the freight station case. To understand the benefits of buying swap-capable BETs (marked as BET-BaaS), we also estimate the results for fleet owners who buy BETs with a battery (indicated as BET).

Figure 6

Total truck cost of ownership, revenue, and profit by use case

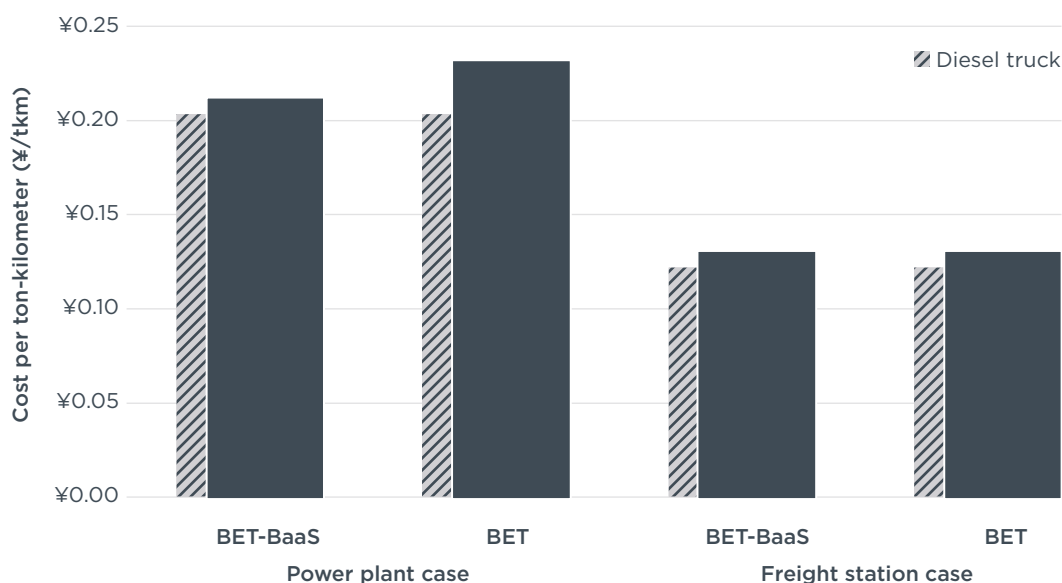


The results of the TCO analysis indicate:

- » The BETs in the Yanghuopan colliery fleet, which are charged via battery swapping, have a lower TCO compared diesel trucks.
- » In the power plant case, using a BET with battery swapping results in a 5% lower TCO than using a diesel truck, while the TCO of using a BET with upfront battery purchase is 2% higher.
- » For the freight station case, using a BET with or without BaaS will have a TCO of about 8% lower than using a diesel truck.
- » Buying BETs and using BaaS can result in lower upfront purchase costs. According to our interviews, a lower purchase cost has more influence on an owner's purchase decision, even if they pay more in energy costs.

BETs also present challenges for the owners in the use cases, as illustrated in Figure 7. Because BETs sacrifice payload to carry the battery, the total tons carried per kilometer will be lower than diesel trucks over the same lifetime. As a result, the total revenue and total profit from using diesel trucks in both cases will be higher than from using BETs. In terms of TCO per ton-kilometer, the cost for diesel trucks is ¥0.20/tkm in the power plant case and ¥0.12/tkm in the freight station case. The cost of BETs using BaaS is 5% higher in the power plant case (¥0.21/tkm) and 8% higher in the freight station case (¥0.13/tkm). Further, a BET purchased with the battery will cost 15% (¥0.23/tkm) more in the power plant case and 8% (¥0.13/tkm) more in the freight station case.

Figure 7
Total cost per ton-kilometer for battery electric trucks compared with diesel trucks



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It's important to note that the cost per ton-kilometer of BETs is currently close to that of diesel trucks. If improvements are implemented that enable ZETs to carry the same load as diesel trucks or operate longer, ZETs can reach the same ton-kilometer cost and revenue as diesel trucks. Because BETs have lower TCO than diesel trucks, there is the potential for up to 12% higher profits for using BETs in all modes and use cases.

Currently, BETs are performing the same routes as diesel trucks in Yulin's colliery, but with a lower total cost of ownership. This real-world use case of electric trucks in

Yulin demonstrates the potential for widespread adoption of zero-emission trucking solutions in coal transport and in other industries.

CONCLUSIONS AND OUTLOOK

In line with Shaanxi's goals to promote electrification of coal freight transport, this paper examined the state of the heavy-duty ZET market in Shaanxi and presented an analysis of real-world use cases of swap-capable BETs at the Yanghuopan colliery in Yulin city.

We found that 58% of sales in 2021 and 2022 of new electric tractor-trailers with a gross combination weight of over 40t in Shaanxi province were in Yulin, as were all 10 fuel-cell tractor-trailer sales. The policy measures implemented in Yulin for promoting the application of ZETs in coal freight likely contributed to the high sales.

The analysis of real-world ZET use cases in Yanghuopan colliery in Yulin showed that the current swap-capable trucks have similar performance as diesel trucks, and have already achieved TCO parity with diesel trucks. The use of BETs with battery swapping reduces upfront costs by shifting some of the capital expenditures to operating fees for battery swapping, which may make it easier for buyers to choose BETs. The key challenge with using ZETs is lower revenue and profit resulting from the weight of the battery reducing the available payload.

Drawing on these findings, we suggest exploring the following to help integrate environmentally friendly zero-emission technologies into the coal and coke industry in Shaanxi province, as well as into other industries traditionally associated with high emissions:

Consider innovative financing and business approaches, such as BaaS and others, to promote new energy trucks. Applicable financing and business approaches should be investigated on a case-by-case basis. In Yulin, the fleet owner puts higher consideration on the purchase cost and down payment rather than the additional battery rental fee during refueling. In some cases, the reduction of upfront costs with BaaS is more than the increased costs during operation. Promoting innovative financing and business approaches could increase a buyer's willingness to purchase a ZET.

Additional allowances for payload could be considered to promote the economic performances of ZETs. The weight of the battery and hydrogen tank reduced the total payload available for goods transport, leading to lower net revenue and higher cost per ton-kilometer for ZETs. Policymakers can consider innovative approaches to support ZETs carrying the same payload as diesel trucks. For example, authorities could issue permits for certain goods that would allow ZETs to carry more than the rated payload, or they could design a specific method for certifying the gross vehicle weight of ZETs.

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