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Electrifying on-road freight: A case study of drayage trucks in Tianjin, China

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INTRODUCTION

In recent years, China's central government has implemented various initiatives to accelerate the market penetration of new energy heavy-duty trucks (HDTs).[1] One aim has been to expand deployment of new energy HDTs in specific sectors, including at ports and in fleets used for logistics distribution, postal service, sanitation, and engineering. Several provinces and cities, including Hebei, Shandong, and Henan, have promoted new energy HDTs, primarily by providing financial subsidies and preferential road access, and setting a minimum market penetration rate.

Despite growing availability of new energy models, sales of new energy HDTs in China remain concentrated in certain regions, including the Beijing-Tianjin-Hebei region and surrounding areas and the Pearl River Delta.[2] Barriers to more widespread adoption of new energy HDTs include higher upfront purchase costs compared with diesel vehicles, concerns over battery performance, a lack of unified battery standards, and insufficient charging infrastructure.[3] A better understanding of real-world use cases and the total cost of ownership (TCO) of new energy HDTs can help address some of these challenges.

This paper presents both a TCO analysis of drayage trucks at Nanjiang Port and a cost and revenue analysis of charging and battery swapping infrastructure. It evaluates diesel HDTs, charging-based battery electric heavy-duty trucks (BETs), and swap-capable battery electric HDTs (with purchased or leased batteries). The data used in

1 Ministry of Industry and Information of China, 工业和信息化部等八部门关于组织开展公共领域车辆全面电动化先行区试点工作的通知 [Notice on Organizing Pilots for Full Electrification of Vehicles in Public Domains], January 30, 2023, https://www.gov.cn/zhengce/zhengceku/2023-02/03/content_5739955.htm; Lingzhi Jin and Yidan Chu, *Accelerating New Energy Vehicle Uptake in Chinese Cities: Assessment of New Energy Commercial Vehicle Policies* (International Council on Clean Transportation, 2023), https://theicct.org/publication/commercial-nevs-cities-policies-jul23/.

2 CALSTART, Drive to Zero's Zero-Emission Technology Inventory Data Explorer, Version 1.5, accessed November 11, 2024, https://globaldrivetozero.org/zeti-data-explorer/https://globaldrivetozero.org/tools/zeti-data-explorer/; Lingzhi Jin and Shiyue Mao, *Race to Zero: Zero-Emission Bus and Truck Market in China in 2023* (International Council on Clean Transportation, 2024), https://theicct.org/publication/r2z-zero-emission-hdv-china-2023-aug24/.

3 Shiyue Mao et al., *Total Cost of Ownership for Heavy Trucks in China: Battery Electric, Fuel Cell, and Diesel Trucks* (International Council on Clean Transportation, 2021), https://theicct.org/publication/total-cost-of-ownership-for-heavy-trucks-in-china-battery-electric-fuel-cell-and-diesel-trucks/.

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this analysis were collected in 2023 by the China Automotive Technology and Research Center (CATARC) through on-site interviews and a literature review; this paper is based on the report CATARC developed from this research.

USE CASE AT NANJIANG PORT

The Port of Tianjin, located at the western end of Bohai Bay in the Binhai New Area of Tianjin, serves as the maritime gateway for the Beijing-Tianjin-Hebei region and the "Three-North" areas of north, northeast, and northwest China. It is also the main sea outlet for the Xiong'an New Area of Baoding. The port is a crucial intersection for the Belt and Road Initiative, the eastern starting point of the China-Mongolia-Russia Economic Corridor, and a key node in the New Eurasian Land Bridge Economic Corridor. The Port of Tianjin is divided into different port areas, and these include the Beijiang, Dongjiang, and Nanjiang Ports, among others.

According to CATARC's on-site interviews (these are the source of all port-related data in this section), as of 2023, the Port of Tianjin had 144 container shipping routes and maintained trade relations with more than 500 ports in over 180 countries and regions. In the first half of 2023, the Port achieved a cargo throughput of 241 million tons, a year-on-year increase of 2.1%. Container throughput reached 11.353 million twenty-foot equivalent units in the same period, which was 8.0% year-on-year growth.

The Nanjiang Port area, an essential component of the Port of Tianjin, is itself one of the largest ports in northern China (Figure 1). It mainly handles the transshipment and transportation of bulk cargoes such as coal, iron ore, oil, and liquid chemicals. Nanjiang Port accounts for 50% of the annual ship entries and exits and 20% of the total cargo throughput of the entire Port of Tianjin.

Figure 1
Location of Nanjiang Port

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The Tianjin Port Bulk Cargo Logistics Center (hereafter "the Logistics Center") is an integral part of the Port of Tianjin (Figure 2). It manages entry procedures and serves as a pre-entry area for vehicles entering Tianjin Port to load and unload. The Logistics Center occupies an area of 106,000 sq meters and has four functional zones: parking, paperwork processing, distribution center, and amenities/support services. The facility serves multiple port areas, including Nanjiang Port, Dagukou Port, and Gaoshaling Port, among others.

Figure 2
Tianjin Port Bulk Cargo Logistics Center

Source: CATARC

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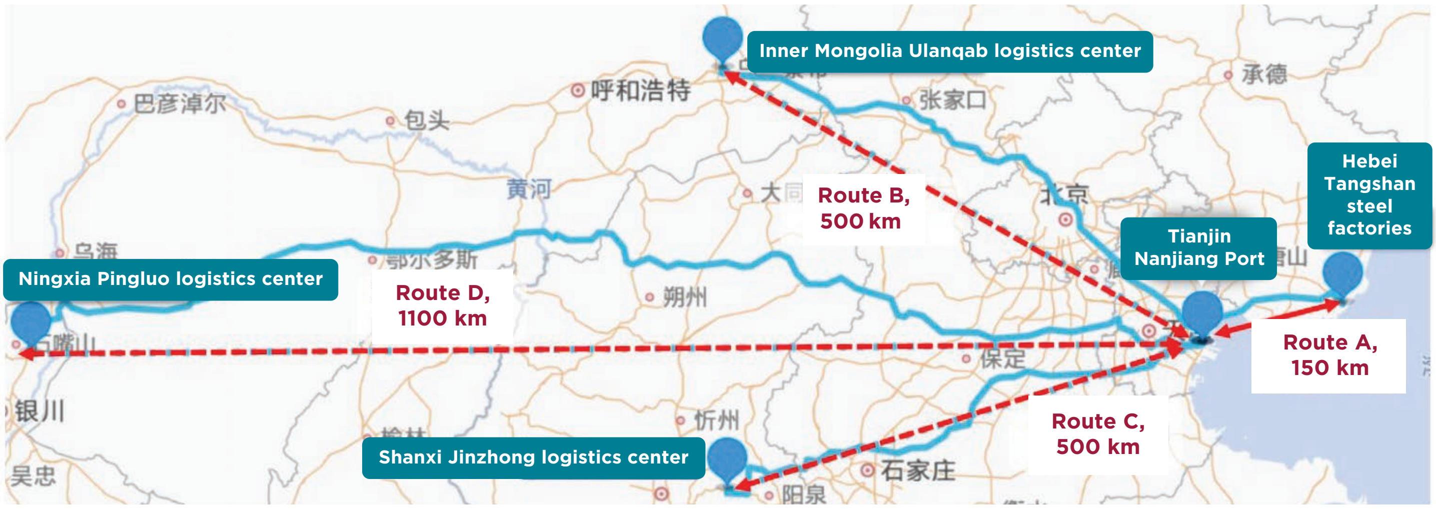
The Logistics Center has 500 parking spaces. Its daily traffic flow averages approximately 3,500 trucks, with the peak period (typically at the end of December each year) seeing over 4,000 trucks per day. The average time that trucks spend waiting in the Logistics Center is about 10 minutes. Most trucks utilizing the Logistics Center are owned by logistics and transportation companies and out of the roughly 1 million annual vehicle trips, about 5% have been replaced by BETs. The primary goods transported include coal, coke, ore, and other bulk commodities. There are four main routes traveled by trucks departing from the Logistics Center, and they lead to Hebei, Shanxi, Inner Mongolia, and Ningxia provinces (Figure 3). Hebei is the most common destination province, and depending on the precise factory to which the truck is going, a one-way trip typically ranges from 120 km to 180 km. This route is the focus of this study.

Figure 3

Main routes traveled by trucks from the Tianjin Port Bulk Cargo Logistics Center and their approximate distance



Source: CATARC

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The most common brands of diesel HDTs operating at the Logistics Center are FAW Jiefang, Sinotruk China National Heavy Duty Truck Group, Dongfeng, and JAC. For BETs, the most common brands are SANY Heavy Industry and XCMG, and SANY Heavy Industry's most popular model is the EV-490 tractor-trailer. For our TCO analysis, we selected reference models with matching 6x4 axle configurations, the SANY Heavy Industry EV-490 for BETs (Table 1) and a comparable 6x4 diesel tractor-trailer for conventional HDTs.

Table 1

Technical specifications of the EV-490

Specification	Value
Axle configuration	6x4
Wheelbase (mm)	3,800+1,350
Length (m)	7.46
Width (m)	2.545
Height (m)	3.66
Gross vehicle weight (tonnes)	25
Number of tires	10
Fuel type	Battery electric
Nominal range (km)	170
Motor	
Peak power (kW)	360
Rated power (kW)	250
Battery	
Brand	Eve Energy
Type	Lithium iron phosphate
Capacity (kWh)	282.64
Rated voltage (V)	24
Charging method	1C dual-gun direct current fast charging

TOTAL COST OF OWNERSHIP ANALYSIS

This section summarizes key input data from CATARC's research and site visits and presents a TCO analysis for four types of drayage trucks at Nanjiang Port: diesel trucks, battery electric trucks, and two types of swap-capable battery electric trucks (SCBETs), one with a purchased battery (referred to simply as SCBET) and one using a leased battery under a Battery-as-a-Service model (referred to as SCBET-BaaS).[4] We assume an ownership period of 5 years.

CAPITAL EXPENDITURES

The capital expenditures mainly consist of vehicle price, battery cost (if not included in the vehicle price), and vehicle purchase tax. Data for vehicle prices are sourced from Autohome, a leading website for automobile buyers in China.[5] Based on these data, it is assumed that the purchase cost of a swap-capable tractor-trailer without the battery is approximately equivalent to that of a diesel tractor-trailer, while the price of a swap-capable one that includes the battery is higher.

According to the evaluation results presented in the *Energy-Saving and New Energy Vehicle Technology Roadmap 2.0*, truck residual values decrease significantly over the first 5 years of operation, with new energy vehicles generally experiencing a faster decline.[6] Considering that battery life and performance naturally degrade with use, and based on findings from the second-hand truck market, CATARC estimated the residual value rates after 5 years to be 30% for diesel trucks, 15% for BETs (charging-based), and 20% for swap-capable BETs (with either a purchased or leased battery). The breakdown of capital expenditures for each type of truck is summarized in Table 2.

Table 2

Capital expenditures for each type of truck in this study

	Diesel	BET	SCBET	SCBET-BaaS
Vehicle retail price	¥360,000	¥720,000	¥360,000	¥360,000
Battery purchase cost	—	—	¥366,000	—
Purchase tax	¥36,000	—	—	—
Residual value	¥108,000	¥108,000	¥145,200	¥72,000

Note: Only the BET's vehicle retail price includes the cost of the battery, while the cost of batteries for the two types of SCBETs is captured in other costs.

OPERATIONAL EXPENSES

The operational expenses presented in this section reflect first-hand empirical evidence collected via on-site interviews by CATARC (in 2023, recall). Drayage trucks at the Nanjiang Port primarily handle dry bulk cargo. The average one-way transport distance is between 120 km and 180 km, and daily mileage is 400 km; with 330 working days per year, this corresponds to 660,000 km over a 5-year period.[7]

4 In a BaaS model, fleet owners purchase the BET without a battery for a lower upfront cost and then pay a battery rental fee every time a battery is swapped.

5 汽车之家 [Autohome], https://www.autohome.com.cn/.

6 China Society of Automotive Engineers, 节能与新能源汽车技术路线图2.0正式发布 [Energy-Saving and New Energy Vehicle Technology Roadmap 2.0 Officially Launched], press release, October 27, 2020, https://www.sae-china.org/news/society/202010/3957.html.

7 For simplicity and to allow for a fair comparison, the daily mileage and annual operating days for each technology were assumed to be the same. However, in real-world scenarios, charging times for BETs can vary, and diesel trucks may not have the same road access privileges as new energy trucks, which could increase operating costs.

For energy costs, the recent average electricity price was ¥1.4/kWh. A 6x4 battery-electric tractor-trailer equipped with a 282 kWh battery has a typical nominal range of 170 km to 190 km. Based on this range, the estimated average energy consumption is approximately 1.5 kWh/km. For the diesel truck, we use the recent average retail price for diesel in Tianjin of ¥7.5/L and a fuel consumption rate of approximately 40 L/100 km. Diesel exhaust fluid (DEF) is estimated to be 5% of the volumetric diesel fuel consumption at a price of ¥4/L. The fee to lease the battery is assumed to be a fixed ¥5,000 per month.

Regarding labor costs, we account for staff wages by assuming that trucks operate with three shifts per day. New energy trucks generally have lower maintenance costs than diesel trucks. However, due to battery degradation, the maintenance costs for BETs are slightly higher than for swap-capable BETs. The details of operating expenses for each type of truck are shown in Table 3.

Table 3
Operating expenses for each type of truck in this study (refueling infrastructure costs not included)

	Diesel	BET	SCBET	SCBET-BaaS
Average refueling cost	¥7.5/L	¥1.4/kWh	¥1.4/kWh	¥1.4/kWh
Energy consumption	0.4 L/km	1.5 kWh/km	1.5 kWh/km	1.5 kWh/km
DEF consumption	0.02 L/km	—	—	—
DEF price	¥4/L	—	—	—
Battery lease	—	—	—	¥60,000/year
Maintenance cost	¥10,000/year	¥6,000/year	¥5,000/year	¥5,000/year
Staff salary	¥300,000/year	¥300,000/year	¥300,000/year	¥300,000/year

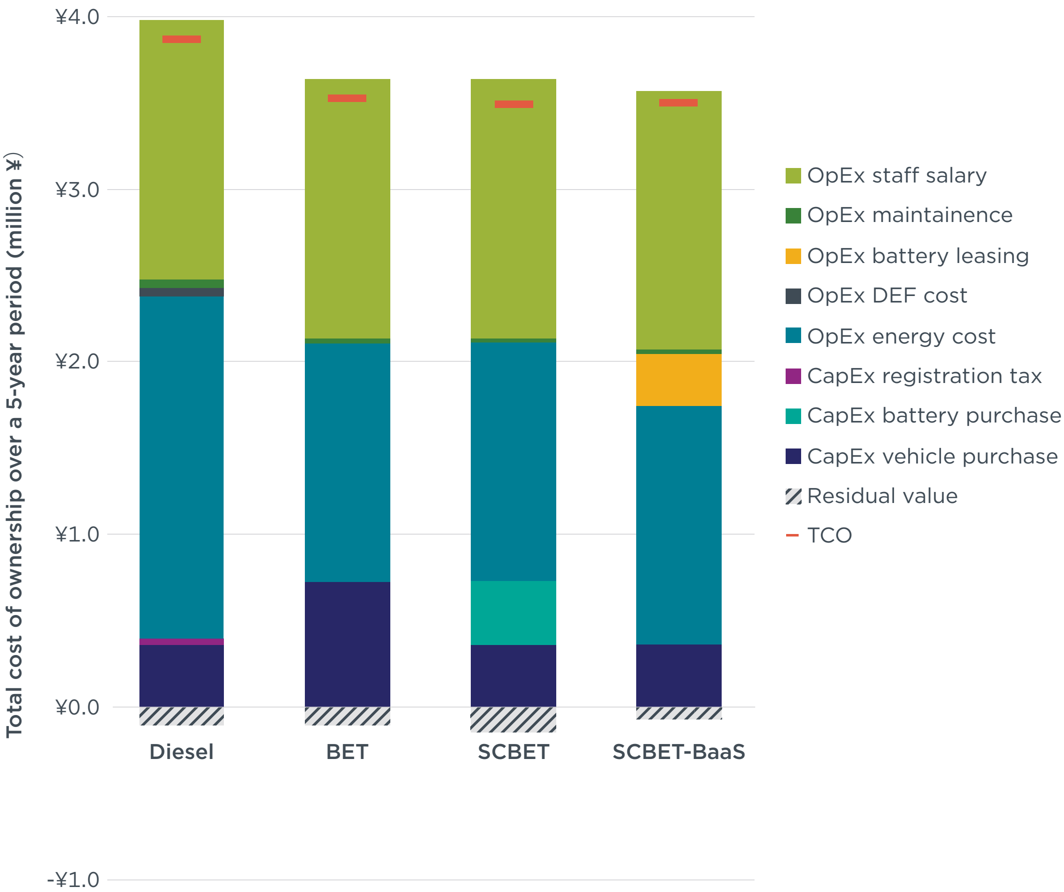
RESULTS AND DISCUSSION

Figure 4 presents the 5-year TCO for each of the four types of drayage trucks at Nanjiang Port. Results show that charging-based BETs can reduce costs by 9% compared with diesel trucks. SCBETs, whether with purchased or leased batteries, show a 10% cost reduction compared with diesel trucks.

SCBETs with leased batteries have the lowest upfront capital expenditures. This reflects both the absence of battery cost at the time of purchase (which spreads battery expenses out over time by incorporating them into operating expenses) and the exemption of these vehicles from vehicle purchase tax. BETs and SCBETs with purchased batteries have lower operating expenses than diesel and SCBET-BaaS counterparts, primarily due to the cost of diesel and battery leasing fees.

Figure 4

Total cost of ownership of drayage trucks at Nanjiang Port over a 5-year period



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COST AND REVENUE ANALYSIS OF CHARGING AND BATTERY-SWAPPING INFRASTRUCTURE

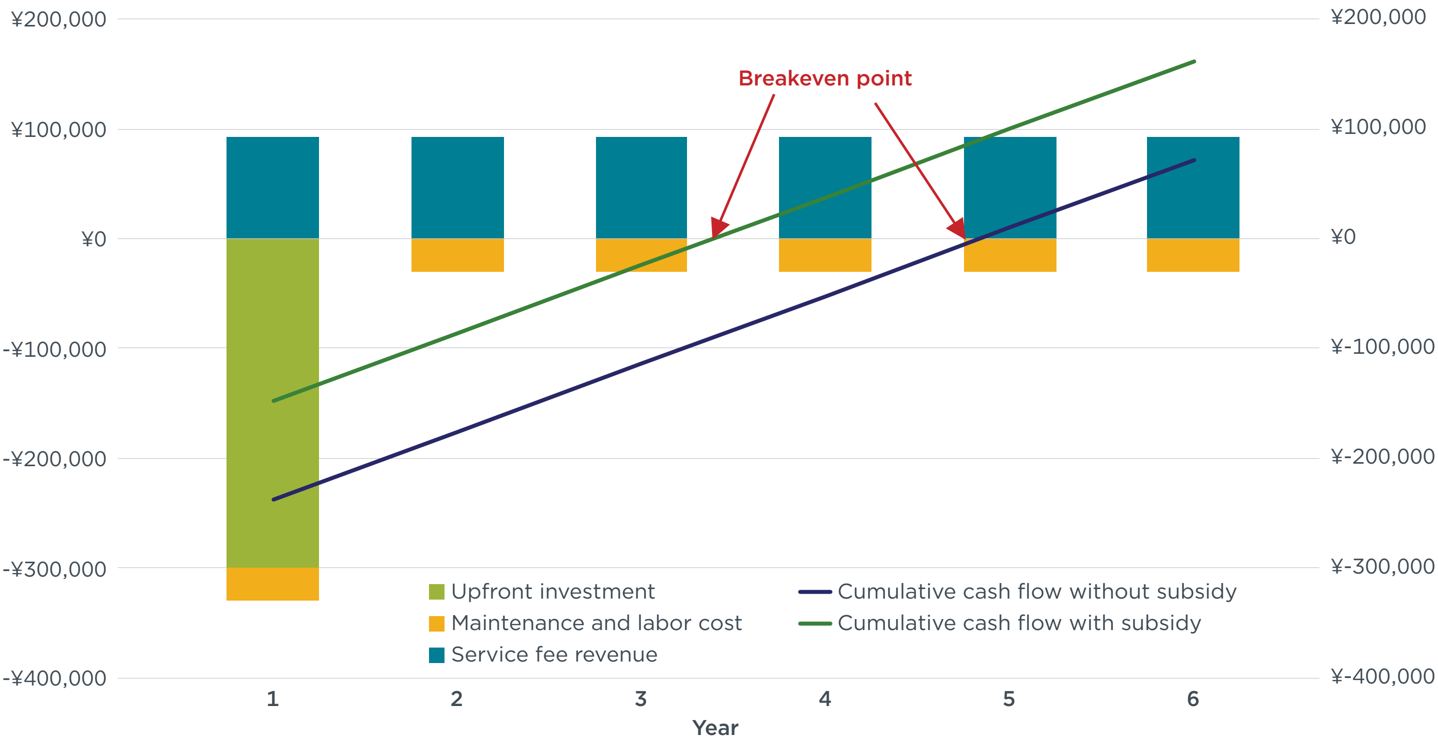
According to data gathered by CATARC, the upfront construction costs for HDT charging stations mainly include the cost of the charging station itself, site preparation (such as hardening), low-voltage power lines, and power distribution infrastructure. Taking a 300 kW charging station as an example, the total construction cost is about ¥300,000 (Table 4). One-time subsidies for the construction of a single charging station vary by region but generally fall between ¥200 and ¥300/kW. Assuming a subsidy rate of ¥300/kW, a single charging station can receive a total subsidy of ¥90,000, and that would bring the net construction cost down to about ¥210,000.

The revenue generated by charging stations is determined by the service fee charged per kWh of electricity and the station's utilization rate, defined as the percentage of time the station is in use. In this analysis, the TCO was calculated based on a charging service fee of ¥0.5/kW and an average station utilization rate of 35%. Annual equipment maintenance and labor costs are collectively estimated to be 10% of the upfront investment. Without subsidies, the payback period for the construction of the charging station is estimated to be 4.8 years. This is shortened to 3.4 years with subsidies (Figure 5).

Table 4
Estimated costs and revenues of a charging station for battery electric HDTs

Item	Value
Upfront investment	¥300,000
Utilization rate	35%
Theoretical maximum electricity charged	525,600 kWh/year
Revenue from service fee	¥0.5/kWh
Annual revenue from service fee	¥91,980
Annual equipment maintenance and labor cost	¥30,000
Annual net cash flow	¥61,980

Figure 5
Cash flow and breakeven point for an HDT charging station



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Note: Bars show revenue and expenses, with revenue on the positive y-axis and expenses on the negative y-axis.

For the construction of an HDT battery-swapping station, upfront costs include the battery-swapping equipment, batteries, and power lines and other grid infrastructure (Table 5). For one battery swapping station, the upfront investment for equipment is estimated to be ¥3 million. A single station typically requires seven spare batteries and 40 onboard batteries for trucks in use. At an average cost of ¥360,000 per battery of 300 kWh, the total investment is ¥2.52 million for the spare batteries and ¥14.4 million for the onboard batteries. With 50 daily swaps and 350 days of uptime, the annual battery-swapping capacity is estimated at 5.25 million kWh. The investment for power lines and other grid infrastructure such as power supply and distribution equipment, site-specific upgrades like cabling, and grid integration components is estimated to be ¥2.35 million, based on industry averages gathered by CATARC.

Labor and equipment maintenance costs are estimated to cost ¥130,000 annually. Revenue is primarily generated from battery rentals and service fees. The total annual revenue from battery rentals is estimated to be ¥2.4 million. A battery rental service fee of ¥0.3/kWh, with 350 working days per year, leads to an annual service fee income of ¥1.575 million. Without subsidies, the payback period for the investment is 5.8 years, and this is reduced to 5.6 years with a one-time government construction subsidy of ¥500,000 (Figure 6).

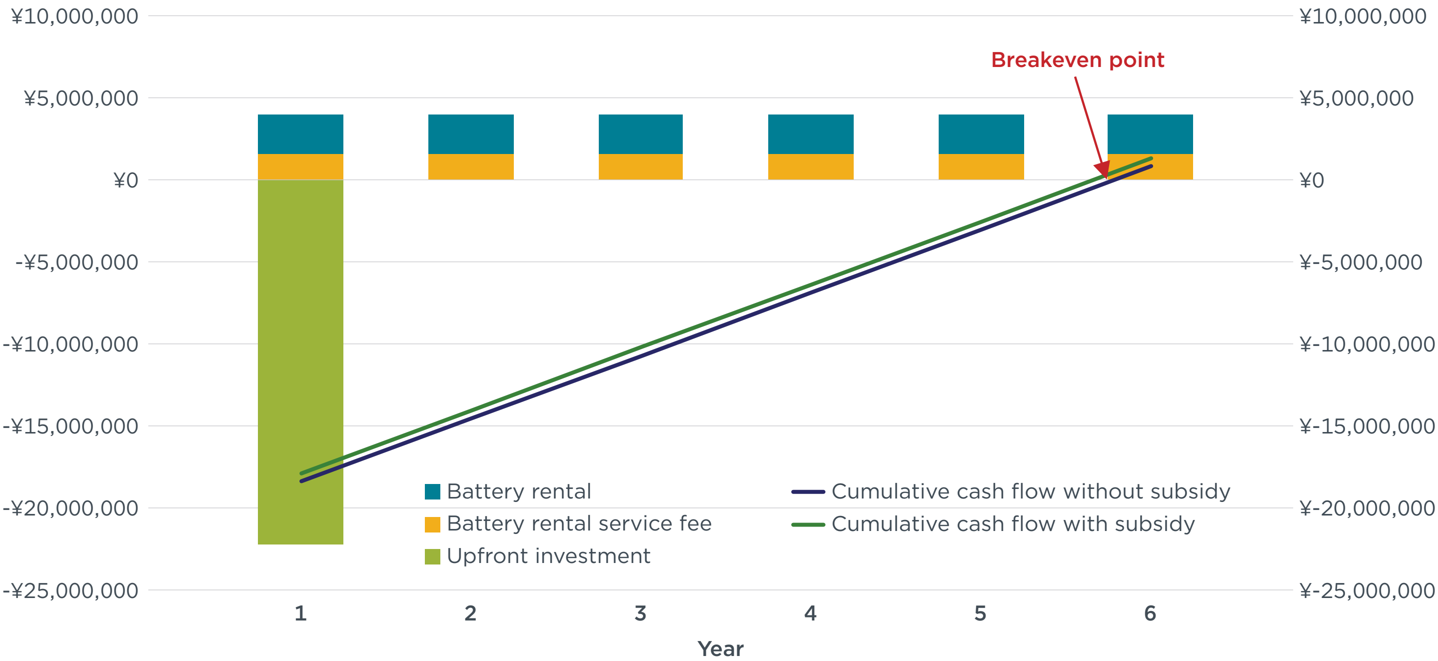
Table 5

Estimated costs and revenues of a battery-swapping station for HDTs

Item	Value
Capital expenditures	
Battery-swapping equipment	¥3,000,000
Power lines and grid upgrade	¥2,350,000
Spare batteries	¥2,520,000
Onboard batteries	¥14,400,000
Revenue and operating expenses	
Revenue from battery rental (40 batteries)	¥2,400,000/year
Revenue from battery rental service fee	¥0.3/kWh
Daily battery swaps	50 times/day
Annual uptime	350 days/year
Annual battery-swapping capacity	5,250,000 kWh
Annual revenue from battery rental service fee	¥1,575,000
Annual equipment maintenance and labor cost	¥130,000
Annual net cash flow	¥3,845,000

Figure 6

Cash flow and breakeven point for a heavy-duty truck battery swapping station



Note: Bars show revenue and expenses, with revenue on the positive y-axis and expenses on the negative y-axis.

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CONCLUSIONS AND GLOBAL POLICY EXPERIENCES

This study evaluated battery electric drayage trucks at Nanjiang Port in Tianjin and estimated that over a 5-year ownership period, the TCO of these BETs is 9% lower than their diesel counterparts, and the TCO of swap-capable BETs (whether the batteries are leased or purchased) is 10% lower than diesel trucks. Leasing batteries for swap-capable BETs helps alleviate the upfront cost burden.

Drayage trucks typically spend around 10 minutes at the Logistics Center waiting to complete entry procedures or to queue for port access. With current technology, battery swapping takes approximately 3–10 minutes, which is comparable to the refueling time for diesel trucks. In contrast, fast charging takes about 1–2 hours to fully charge a battery.

Global experiences show that the following policy options may help accelerate the electrification of drayage trucks:

1. **A low- or zero-emission freight demonstration zone.** This is a designated area that promotes the use of zero-emission or near-zero-emission freight operations to achieve low or zero emissions during the transportation of goods. In developing a low- or zero-emission freight demonstration zone at a port, officials could initially focus on short- and medium-haul applications and then gradually expand to other segments. Action plans could be developed that define clear targets for the adoption of electric trucks, and this could serve as a model to be replicated and scaled in other zones in other areas.
2. **Phased and differentiated financial incentives.** Upfront costs are still a considerable share of the total TCO of new energy HDTs. Financial support can help address the upfront cost gap between diesel and new energy HDTs. Usage-phase incentives can also be strengthened through measures such as reduced road tolls and special road access privileges for new energy HDTs. These incentives can be gradually adjusted as market conditions mature.
3. **Expanded charging infrastructure.** Building a multi-level charging network that includes slow charging, (ultra-)fast charging, and battery-swapping stations would help spur drayage truck electrification. This may involve developing new regulations and guidelines on land use, technical specifications, and management models to address land availability and grid infrastructure needs. As an example of recent efforts to expand charging infrastructure, in October 2023, the Logistics Center at the Tianjin Port and State Grid Electric Vehicle Service (Tianjin) signed the Tianjin Port Heavy-duty Truck Charging Cooperation Agreement, under which 300 kW charging stations will be built. Once completed, this project will be the largest public charging station for new energy HDTs in Tianjin, capable of charging 35 trucks simultaneously.
4. **Improved charging infrastructure standards to enhance operational efficiency.** As charging infrastructure grows, standardizing charging interfaces will be crucial for enhancing interoperability. In the case of battery-swapping stations, for instance, a lack of compatibility between battery packs from different brands and technologies will pose a challenge for users, as each station may use a different battery-swapping method. Developing standards for battery-swapping packs, vehicle interfaces, swapping equipment, battery-swapping station construction, and operations management could thus be part of an effective policy mix to accelerate standardized, efficient, and user-friendly electric vehicle infrastructure.

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