SEPTEMBER 2023

Real-world use cases for zero-emission trucks

A COMPARISON OF ELECTRIC AND DIESEL TRACTORS IN TANGSHAN, CHINA

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ACKNOWLEDGMENTS

Significant support with coordination and information sharing for this work was provided by external consultants from BIT and VECC-CRAES. The authors thank Lingzhi Jin, Hui He, Hussein Basma, and Yidan Chu (ICCT) for their invaluable comments and inputs on an earlier version of this work. The authors also appreciate Amy Smorodin's generous editorial support for this paper before publication.

Edited by Amy Smorodin

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INTRODUCTION AND METHODOLOGY

Tangshan, a typical medium-sized city 200 km southeast of Beijing in the Jing-Jin-Ji (JJJ) region, is a major center of steel production in China due to its critical geographic location and abundant mineral resources. The city produces 58% of domestic strip steel and 49% of domestic section steel (Yin, 2022). Tangshan has experienced heavy air pollution in recent years; the city was ranked as one of the country's most polluted due to coal burning mills and tailpipe emissions from heavy trucks around production yards (Guo, Wang, He, Li, Meng, Hou, & Yang, 2021).

In 2021, a particulate matter ($PM_{2.5}$) level of 102.7μg/m^3 was detected (Guo, Wang, He, Li, Meng, Hou, & Yang, 2021), which is almost threefold higher than the national ambient air quality standard of 35 μg/m^3 and more than tenfold higher than the 10μg/m^3 limit set by the World Health Organization(Guo, Wang, He, Li, Meng, Hou, & Yang, 2021). Elevated $PM_{2.5}$ concentrations are associated with increased mortality from lung cancer, cardiopulmonary disease, and acute respiratory infections. Given health impacts in Tangshan and the JJJ region, China's State Council promoted actions to address air pollution in Tangshan and its neighboring areas.

Beginning in 2018, a three-year national plan called Blue-sky Defense required Tangshan to restructure its freight system for shipping iron ore by rail as a key part of air pollution campaign in JJJ region (International Energy Agency, 2021). In 2021, Tangshan also engaged in a national EV battery swapping program aimed at promoting the deployment of battery swapping in heavy-duty trucks in local industries (Ministry of Industry and Information Technology, 2021). Tangshan Port, the industrial transport hub of Tangshan, has also been highlighted as an area to transition to greener and cleaner transportation.

The Tangshan bay area's bulk cargo throughput ranks second globally with a volume of 769 million metric tons in 2022 (The People's Government of Hebei Province, 2023). Before the adoption of electric yard tractors, diesel was the dominant technology. According to 2018 data on the port's fleet, 20% complied with China III standards, 30% complied with China IV standards, 40% complied with China V standards, and 10% were powered by compressed natural gas (CNG) (Shao, 2020). Since 2021, Tangshan Port has adopted more than 4,400 battery-swapping electric tractors (Mao, Zhang, Bieker, & Rodríguez, 2023). However, the cost benefit of electric tractors is a concern for fleet operators. An ICCT study of their total cost of ownership (TCO) in China suggests that it will be challenging for typical electric tractors to reach a cost breakeven point with their diesel counterparts before 2027 (Mao, Basma, Ragon, Zhou, & Rodríguez, 2021). Electric tractors that enable battery swapping, however, can reduce costs with financial tools such as leasing and battery-as-a-service.

In recent years, Tangshan has exemplified the success of China's Clean Diesel Action Plan in regard to freight delivery in the most polluting industries. Since 2021, the city has become the largest electric tractor-trailer market in China; about 2,200 electric tractor-trailers have been newly deployed in Tangshan, with an unparalleled 18% of market penetration (Chu & He, 2022).

In this study, we analyze the applicability and economic performance of an electric tractor model manufactured by XCMG (Table 1 and Figure 1). The specific tractor model is designed to accommodate both charging and battery swapping; in this case study, we assume the fleet operator can only access chargers to charge the electric tractors in daily operation. This tractor fleet is used by a steel factory to deliver iron ore and products between the factory and two nearby ports (Tianjin Port and Caofeidian Port), marked as itinerary A and B in Figure 2. A typical route of delivery is as follows: the tractors deliver iron ore from the ports to the factory (their loads are assumed to be full) and travel to the ports with empty trailers. Both itineraries are about 110 km round-trip.

For this study, information on the real-world operation of tractor-trailers was obtained from China's big data open laboratory of the National Big Data Alliance of New Energy Vehicles (NDANEV), which is a conglomerate of research institutes and vehicle manufacturers founded in 2017 (NDANEV, 2021). In total, real-world data from 117 tractor-trailers operating in 2022 are tracked and collected.

Table 1. Specifications of the vehicle model examined in this study.

Vehicle type	Tractor	Fuel type	Battery electric
Length × Width × Height	7470×2550×3750(mm)	Max. speed	84 km/h
Total weight	25,000 kg	Battery chemistry	Lithium iron phosphate
Curb weight	12,500 kg	Engine power	360/489 kw
Max payload	36,370 kg	Driving motor rated power/peak power	240/360 kw
Battery capacity	281 kWh	Model year	2020

Figure 1. The XCMG electric tractor model assessed in this study.

Figure 2. Locations in Tangshan City and the itineraries for cargo delivery in this case study.

COMPARISON OF PERFORMANCE BETWEEN ELECTRIC AND DIESEL TRACTORS

Electric tractor performance must be competitive with the diesel alternatives for fleet operators to transition to cleaner transport. In Tangshan, thanks to a national plan to promote electric trucks in 2021 (Ministry of Industry and Information Technology, 2021), over 5,000 battery swapping electric tractors were procured and deployed (China trucks, 2022; Lu, 2023). The following sections present the daily performance of electric tractors in comparison with diesel counterparts with same itineraries. The operation information of diesel tractors was collected from the fleet operator.

DAILY DRIVING RANGE AND WORKING DURATION

Driving range is an imperative indicator for daily performance. In this case, the daily median driving range for electric tractors is about 140 km, which is 80 km shorter than the median range for diesel tractors (220 km). Diesel tractors are also more competitive for long-haul transport of ranges of more than 450 km (more than four return itineraries) per day, as shown in the left plot of Figure 3.

On the other hand, electric tractors operate for a longer time duration than diesel tractors. On median, electric tractors operate 17 hours per day, 50% longer than diesel counterparts (at 11 hours). The most common working duration is 19 hours per day for electric tractors; 5.2% of diesel tractors can be operated throughout the whole day with a night shift (right plot of Figure 3). It should be noted that reported working durations are tracked by the total available time of connection to NDANEV, excluding charging events. Hence, the working duration of electric tractors is potentially overestimated due to idle time or network connection issues.

While battery technology is rapidly maturing, gaps in performance between electric and diesel trucks are still evident when their technical specifications (e.g., driving range) are compared.

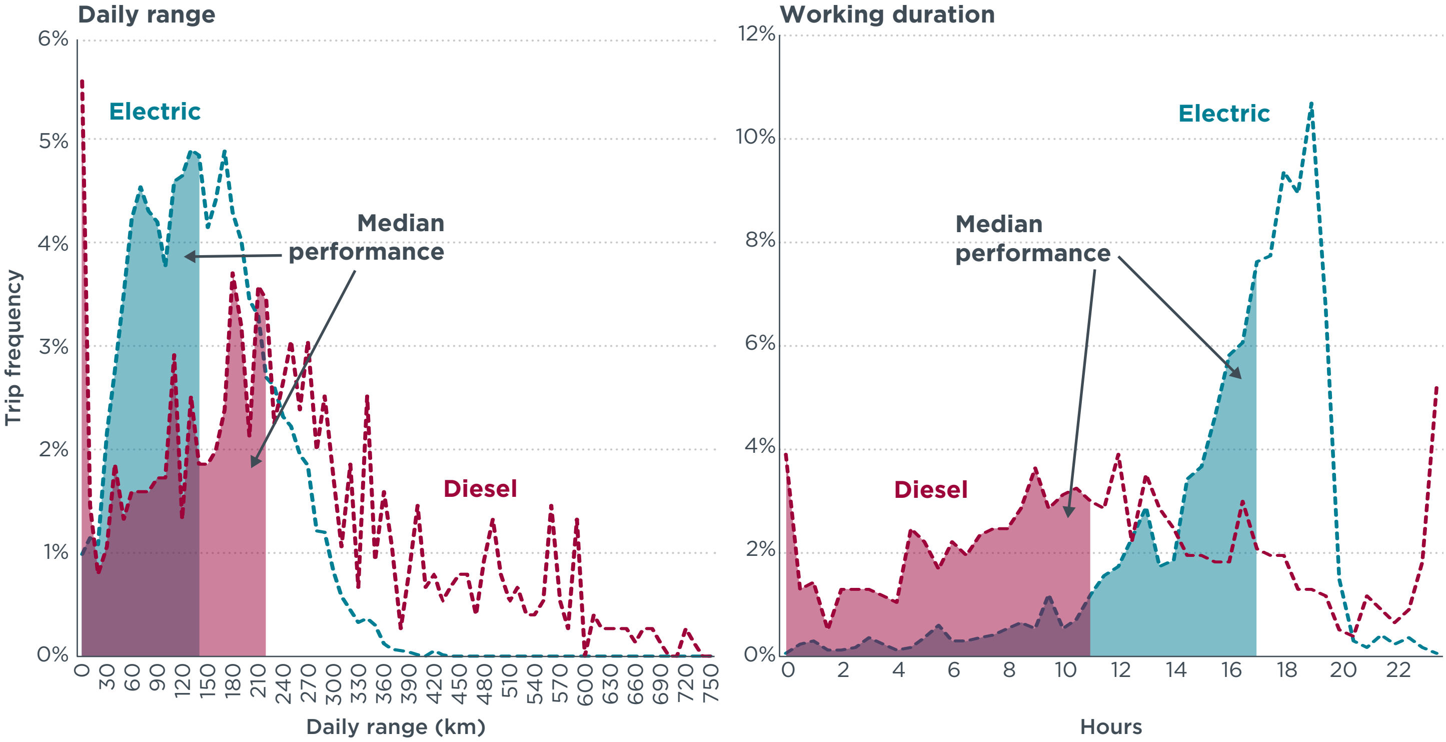

Figure 3. Activity patterns of daily driving range (left, binned by 10km) and working duration (right) for electric and diesel tractors. The solid bands represent median performance.

CHARGING PATTERN OF ELECTRIC TRACTORS

Charging is imperative for electric tractors. As shown in Figure 4, 55% of electric tractors require more than 2 hours of charging time to be fully charged, and two to three charging events per day are common. Longer charging durations and more frequent charging activities can ultimately attribute to low charging rates provided by charging facilities. On average, this study showed a charging rate[1] of 0.7C. This indicates that 1 hour is required for an electric tractor to be fully charged from a 30% of state-of-charge. The charging rate in Tangshan is faster than 85% of heavy-duty vehicle fleets around China, according to an earlier ICCT study (Mao, Zhang, Rodríguez, Wang, & Hao, 2023).

Battery swapping technology can be used to decrease overall fleet charging time, In practice, a truck may take up to 2 minutes to be reloaded with a new battery, reducing total charging duration by more than 95% (Sany Group, 2022). This means that electric trucks can travel for more hours per day during operations. Nevertheless, this case study assumes the fleet operator does not have access to on-site battery swapping stations.

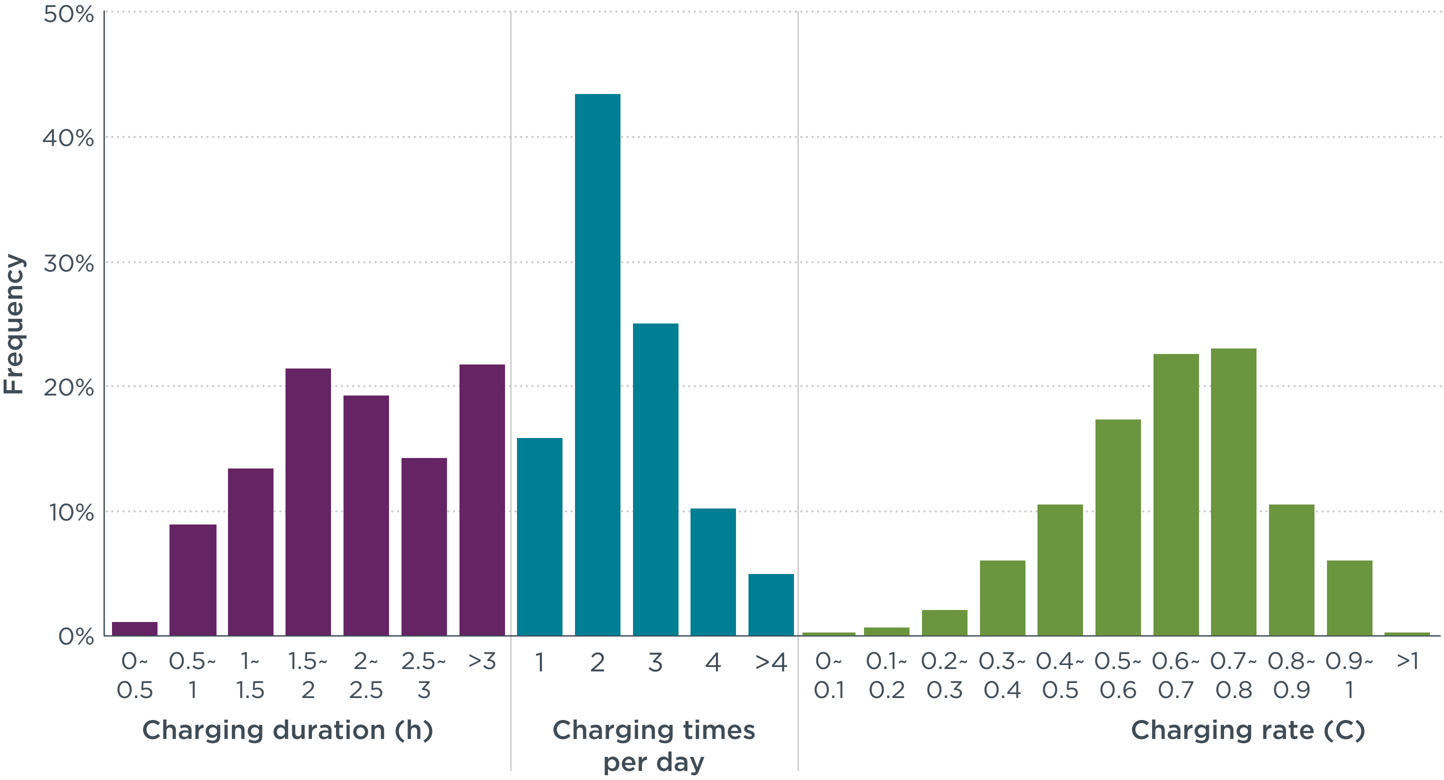

Figure 4. Charging pattern of electric tractors in this study.

ECONOMIC COMPARISON

This section presents an economic comparison between electric and diesel tractors, which is calculated based on first-hand information collected from the fleet operator (Table 2). This study applies a simulation model of TCO developed in an earlier ICCT study of China, with several customized inputs (Mao, Basma, Ragon, Zhou, & Rodríguez, 2021). This analysis accounts for the declining financial subsidy for electric tractors and updated eligibility requirements (Mao, Zhang, Bieker, & Rodríguez, 2023). In this case study, factories can receive a total subsidy of ¥49,500. We also account for

1 A technical indicator to measure how fast an electric tractor can be fully charged from empty. In math, charging rate can be denoted as the reciprocal of charging duration in hours.

the 10% purchase tax levied on the procurement of conventional vehicles (Mao, Basma, Ragon, Zhou, & Rodríguez, 2021).

The real-world energy or fuel consumption while in-use for both technologies was also collected. Due to a heavy workload and complex operating conditions, the fleet operator reported that electric and diesel tractors consumed an average of 230kWh/100km and 61L/100km, respectively. Diesel prices are highly volatile and fluctuate within a range of ¥5.0/L–¥9.0/L, according to historical data (Eastmoney.com, 2023). In this study, ¥7.5/L is assumed to be the average price over a five-year period. Electricity prices are comparatively stable with minor fluctuations occurring during different periods of the day. According to the fleet operator surveyed, power rates are ¥1.00/KWh. Working activity information, such as vehicle-kilometers traveled and maintenance expenses, were also collected from the operator and applied over the five-year period. We also use the residual curve developed in the TCO model to determine the final recyclable values after 5 years. For electric tractors, the residual values of batteries and chassis are measured separately. After 5 years, the residual value of electric tractors and diesel tractors are 27% of their original price (Mao, Basma, Ragon, Zhou, & Rodríguez, 2021). Monetary value declines over time, so a 10% of discounted rate is also applied to conservatively calculate the net value of future expenses.

Charging facilities are additional expenses associated with electric tractors. In this case, the steel factory deploys 57 chargers costing ¥80,000 each, according to the fleet operator surveyed. Installation of a power distribution system across the entire yard to service the chargers adds an additional cost of ¥6.5 million. Although the Infrastructure is a one-time investment, it increases the overhead expenditure during the life cycle of electric tractors.

Based on these factors, the economic comparison is favorable for electric tractors. In this case, the purchase and operational cost of electric tractors is approximately 35% less than their diesel counterparts. Despite higher upfront costs and initial infrastructure investment, electric tractors have lower energy costs and maintenance expenditures during the five-year lifecycle. Economies of scale can drive down the TCO of electric tractor fleets even further by lowering the infrastructure investment per tractor. This also increases the competitiveness of electric models over diesel tractors from the perspective of fleet operators.

Table 2. Five-year economic comparison of electric and diesel tractors (breakdown cost for each tractor).

Phase	Items	Electric costs (¥)	Diesel costs (¥)	Comments
Procurement	Purchase costs	720,000	300,000	Source: survey
	Financial subsidy	49,500	0	Source: Mao, Zhang, Bieker, et al. (2023)
	Purchase tax	0	30,000	10% of applicable purchase tax to diesel tractors only
	Charging facilities set-up	36,867	0	¥80,000 per charger, 57 chargers in use; ¥6.5 million for power distribution system; 300 tractors in the fleet
In-use	Energy expenses	480,355	1,305,436	Electric: VKT of 255,000 km, energy consumption of 230 kWh/100km, electricity fee as ¥1.00 per kWh. Source: survey Diesel: VKT of 330,000 km, fuel consumption of 64.4 L/100km, fuel cost as an average of ¥7.5/L. Source: survey
	Maintenance expenditure	81,902	122,853	Source: survey
Disposal and resale	Residual net value	194,400	81,000	Source: Mao et al. (2021)
Total		**1,075,224**	**1,677,289**	

A COMPREHENSIVE COMPARISON BETWEEN ELECTRIC AND DIESEL TRACTORS

The evaluation of performance between electric and diesel tractors is shown in Figure 5. The chart illustrates key performance dimensions such as daily range, working duration, and cost efficiency. The performance of diesel tractors has been benchmarked as 100% (red dashed line), while electric tractors are represented by the blue line.

In this case study, electric tractors were found to operate more hours per day than diesel tractors but traveled a shorter daily range due to the more conservative schedules adopted by the fleet operator. Electric tractors are shown to be cost competitive with diesel in this case. Regarding cost efficiency of delivery, defined as tonne*km/CNY, electric tractors have a 10% premium over diesel tractors through the five-year life cycle.

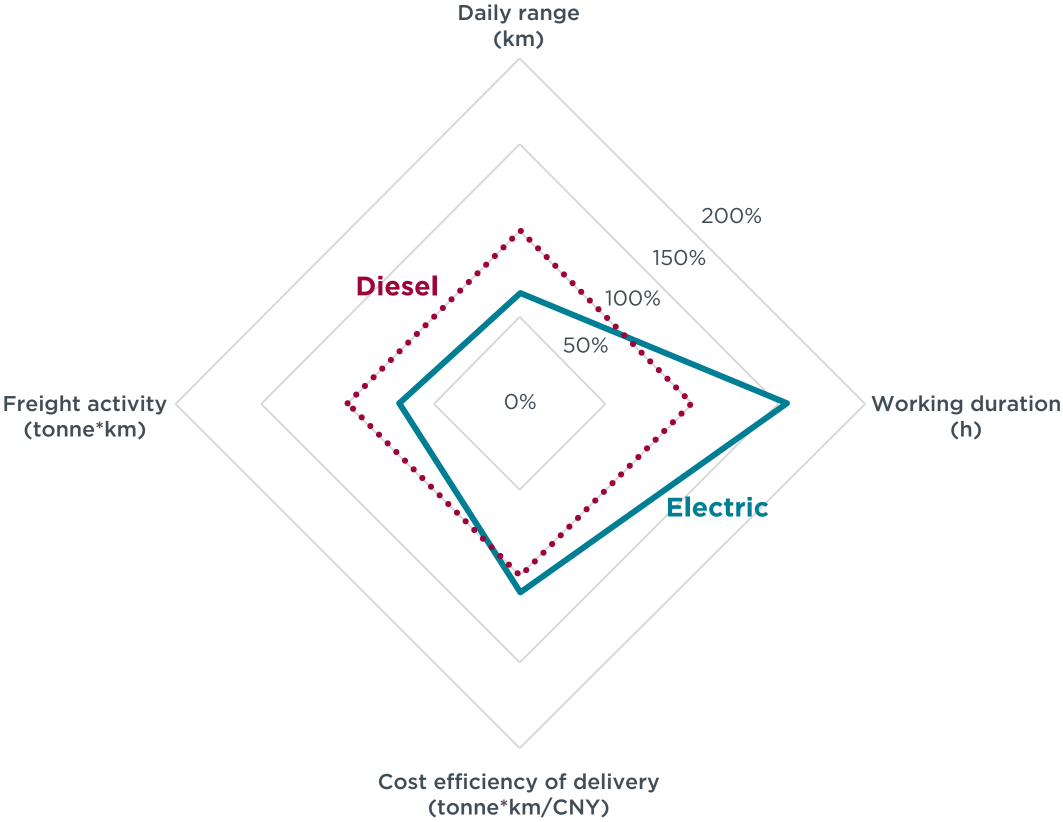

Figure 5. Performance evaluation of electric tractors, and their competitiveness to diesel tractors.

KEY INSIGHTS AND RECOMMENDATIONS

This study identifies several working patterns of electric tractors relative to diesel tractors. Our findings suggest that additional policies could help to promote further adoption of electric tractors:

1. **Electric tractors have begun to show economic benefits over diesel tractors in Tangshan due to lower operating costs. To assist with upfront purchase costs, local governments could consider providing financial incentives to replace the discontinued national subsidy scheme.** This study finds that the electric tractor fleet is becoming competitive with the diesel fleet from the perspective of cost efficiency. However, as the national subsidy scheme was discontinued at the end of 2022, the upfront costs of electric tractors for operators will increase. Local governments could consider providing financial incentives to help offset the phase-out of the national scheme.
2. **Governments could provide incentives for the construction and operation of battery swapping stations such as financial subsidies, the waiver or discount of land lease contracts, and other mechanisms. In addition, governments could encourage innovative business models such as battery-as-a-service, public-private partnerships, or financial leasing to lower the barrier to adopting electric tractor fleets.** Infrastructure can be a bottleneck for the deployment of electric tractors, especially for battery swapping models. Governments can encourage new business models regarding infrastructure setup and operation. In China, battery swapping technology is prevailing due to faster recharging speeds and grid-friendly charging patterns. But infrastructure, particularly battery swapping stations, can be a bottleneck for fleet operators to fully leverage the advantage of battery swapping technology. In this study, the operator had no access to battery swapping stations; electric tractors could only charge by cable.
3. **Local authorities could aggregate the demand and supply of electric tractors to decrease their upfront price with bulk sales**. Upfront spending can be a barrier for fleet operators in procuring electric tractors. To reduce upfront costs, local authorities could compile orders and negotiate with manufacturers for bulk procurement. This strategy could provide certainty to electric tractor manufacturers, while supporting the establishment of regional maintenance services. In this study, we identified that the upfront price of electric tractors is responsible for about 70% of the total cost during the five-year lifecycle, and the economic advantage of electric tractors is still not decisively competitive with diesel tractors. Demand aggregation could be an additional support to make electric tractors more cost-effective in the Tangshan Bay area.
4. **Local authorities could launch public awareness campaigns or trainings for drivers to help them better understand electric tractors and their differences from diesel tractors**. The fleet operator in this study was hesitant to assign tasks to electric tractors. The charging patterns revealed in this case study reflect concerns regarding the performance of electric tractors. While fleet operators will understandably adopt a conservative operational strategy, specific trainings regarding driving maneuvering and energy-saving techniques are needed for drivers to better understand the characteristics of electric tractors and their variance from diesel tractors.

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