

Article

Analysis of the Actual Usage and Emission Reduction Potential of Electric Heavy-Duty Trucks: A Case Study of a Steel Plant

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Abstract: In order to understand the driving characteristics of electric heavy-duty trucks in practical application scenarios and promote their usage to replace diesel trucks, this study analyzed the actual usage of electric and diesel heavy-duty trucks in a steel factory based on vehicle-monitoring data and remote online monitoring data and estimated the emission reduction potential of the application of electric trucks by using a mileage-based method and the greenhouse gas emission model. The results showed that the electric heavy-duty trucks in the steel factory mostly operated for over 14 h, with a vehicle kilometers traveled (VKT) of 50–300 km each day, which could meet most of the demands of the transportation of the steel industry. The average daily energy consumption for most trucks falls within the range of 210–230 kWh/100 km, with higher consumption in winter than in summer, which can save approximately 18–26% in operating costs compared with diesel trucks. It is estimated that the usage of these electric heavy-duty trucks can achieve an annual reduction of 115.8 tons of NO_x emissions, 0.7 tons of PM emissions, and 18,000 tons of CO₂ emissions. To further promote the application of electric heavy-duty trucks in China, several policy suggestions, such as introducing priority road-right policies, promoting vehicle and battery leasing markets, and exempting zero-emission vehicles during heavy pollution days, were proposed.

Keywords: electric heavy-duty trucks; steel industry; travel characteristics; charging characteristics; emission reduction



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1. Introduction

At present, air pollution remains one of the most severe problems in global environmental pollution [1]. The constant increase in the concentration of atmospheric pollutants, such as NO_x, PM, etc., not only poses serious harm to human health [2–4] but also has adverse effects on biodiversity and ecosystems [5–7]. Furthermore, according to the research by the World Meteorological Organization and the Intergovernmental Panel on Climate Change (IPCC) [8], the concentration of greenhouse gases in the atmosphere is constantly rising due to human activities, exacerbating the problem of global climate change. Therefore, the Paris Agreement proposes to keep the increase in global average surface temperature well below 2 °C by the end of this century compared with pre-industrial levels and strive to keep it within 1.5 °C.

Transportation is one of the major sources of atmospheric pollutants and greenhouse gases. According to a public research report by the International Energy Agency (IEA) [9], the global energy-related CO₂ emissions reached 36.3 Gt in 2021, of which approximately 21% were from the transportation sector. According to the China Mobile Source Environmental Management Annual Report (2022) [10], the emissions of NO_x and PM from motor vehicles in China in 2021 stood at 5.821 million tons and 69,000 tons, respectively, accounting for 59.8% and 1.2% of the total emissions of atmospheric pollutants in the country.

Among them, the NO_x and PM emissions from heavy-duty trucks accounted for about 74.3% and 47.8%, respectively. Therefore, controlling the emissions of pollutants and CO₂ from heavy-duty trucks is important to reducing emissions in the transportation sector.

Previous studies showed that an increase in the use of renewable electricity realized a reduction in the emissions of electric vehicles [11,12]. A recent study demonstrated the feasibility of producing green hydrogen that could be used in hydrogen fuel cell vehicles, which would greatly reduce energy consumption and emissions throughout the life cycle chain [13]. Therefore, adopting and promoting zero-emission vehicles (mainly electric vehicles and hydrogen fuel cell vehicles, etc.) to replace traditional fuel vehicles is an important measure to reduce emissions of pollutants and CO₂ [14]. Multiple countries around the world have put forward their development goals for zero-emission vehicles. According to the IEA statistical data [15], from 2010 to 2021, the global ownership of electric cars increased from 10,000 to 16.5 million. An increase of about 46.5% was achieved from 2020 to 2021. China has the highest number of electric vehicles in the world. From 2015 to 2021, the ownership of new energy vehicles in China increased from 420,000 to 7.84 million, with its proportion in vehicle ownership increasing from 0.26% to 2.60%. In particular, the new energy passenger car sales reached 3.3 million in 2021, which is about 15.5% of the total sales of passenger cars in that year. As of 2021, the use of electric vehicles in China had achieved a cumulative CO₂ reduction of 85.6 million tons [16]. Meanwhile, the emissions of pollutants such as PM and NO_x have also been significantly reduced [17,18]. Since 2015, the number of zero-emission commercial vehicles in China has also increased, but the growth rate is relatively slow. In particular, the zero-emission rate of heavy-duty trucks remains at a very low level of only about 0.44%.

Researchers have so far carried out many studies on zero-emission vehicles, such as analyzing the influencing factors of the energy consumption of electric vehicles and their impact degrees [19–30], analyzing and predicting the energy consumption of electric buses [31–33], discussing the feasibility of the electrification of taxis or ride-hailing vehicles [34,35], studying charging behavior and predicting charging demand [36,37], assessing the potential for carbon reduction over the entire life cycle [38], exploring the transition process of traditional cars to electric cars in developing countries [39], etc. However, most studies use model simulation or experimental methods, and a few studies manage to combine the actual driving data of passenger cars on actual roads [21,24,25,28,34–36]. For electric heavy-duty trucks, Afsane Amiri et al. used a bi-objective programming model to study the green vehicle routing problem of electric heavy-duty trucks and traditional trucks [40]; Robert L. et al. evaluated the performance of a Class 5 battery electric urban delivery vehicle, focusing on two standardized driving cycles and employing a steady-state range test on a chassis dynamometer [41]; Mareev et al. used simulation methods to study the life cycle cost of electric trucks and the battery demand in long-distance transportation scenarios [42]; Tong Fan et al. used model simulation methods to study the charging behavior and charging load of electrified long-haul freight trucks [43]; Emir Çabukoglu et al. used survey data and data from an automated performance monitoring system of Swiss truck fleets to analyze the feasibility of replacing diesel trucks with electric heavy-duty trucks [44]; Brennan Borlaug et al. studied the charging demand of electric semi-trailer trucks based on US large-scale vehicle telematics data [37]; Burak Sen et al. used a hybrid life cycle assessment method to analyze and compare the differences in life cycle emissions, costs, and externalities between Class 8 category electric heavy-duty trucks and other alternative fuel trucks [45]; Susumu Sato et al. used a chassis dynamometer to study the energy consumption rates and energy regeneration rates of three types of electric heavy-duty trucks [46]. It can be seen that, due to the limited actual application of electric heavy-duty trucks at present, research on the use of electric heavy-duty trucks in actual application scenarios is rare.

In recent years, the Chinese government has launched several important policies to ensure clean transportation in the steel industry, which have greatly promoted the application of electric heavy-duty trucks, and a large amount of basic data has been

accumulated on the actual use of electric heavy-duty trucks in this application scenario. Based on the actual application data, this study analyzed the daily travel times, charging behavior, traveling characteristics, and energy consumption of electric heavy-duty trucks in a steel factory and estimated the emission reduction potential of the application and promotion of electric trucks to replace diesel trucks in the steel industry using the key parameters obtained from the actual data analysis. This research also serves as a reference for the product optimization of electric heavy-duty truck manufacturing companies in the future. Meanwhile, it can also provide evidence and references for the promotion of electric heavy-duty trucks in other industries.

2. Data and Method

2.1. Electric Heavy-Duty Trucks and Charging/Battery Swap Infrastructures in the Steel Plant

This study uses a steel plant in Hebei Province as an example to analyze the actual usage and emission reduction potential of electric heavy-duty trucks in short-haul operations. The steel plant currently has 300 electric trucks in use, each with a maximum tractive tonnage of 38 tons and priced between USD 100,000 to USD 108,600 (including battery cost). The battery price is about USD 50,000, and the service life is about five years, or 800,000 kWh of discharge.

There are 57 charging piles in use in the plant. Another 32 charging piles and three dual-channel battery swap stations are under construction. The price for a charging pile body is about USD 11,400. Each charging pile can charge up to 80% in about one hour with dual guns, and a full charge takes about one and a half hours. Each charging pile can serve about 16 trucks per day. The construction of a single-channel battery swap station that serves 50 trucks per day costs approximately USD 1.14 million, and a dual-channel station that serves 100 trucks per day costs about USD 2.14 million (neither includes site civil engineering costs). The battery swapping time at the swapping station is about six minutes. Meanwhile, there are 15 charging piles at Caofeidian Port for supplementing the power of electric heavy-duty trucks traveling between the steel plant and the port.

2.2. Vehicle Operation Scenarios

There are two main operation scenarios for the electric heavy-duty trucks in the steel plant.

Scenario I: The main operating route is from the steel plant to surrounding downstream users and train platforms, with a transportation distance of about 10–50 km. The distance between the plant and the train platform is less than 10 km. The goods transported are mainly steel products, by-products, fuels, etc. Charging within the plant can meet the requirements of transportation.

Scenario II: The main transportation route is from the steel plant to ports, including Caofeidian Port and Tianjin Port, with a transportation distance of 60–70 km. It mainly transports sea-shipped scrap steels, fuels, steel products, iron ores, etc. Charging at both the port and the plant is needed.

The diesel heavy-duty trucks are mostly used in the same scenarios as described above, but sometimes they are also used to carry out long-distance transportation according to the actual needs of the plant.

2.3. Data Description and Pre-Processing

This study selected 61 electric heavy-duty trucks and 15 diesel heavy-duty trucks from the steel plant for the analysis of their actual operating characteristics. The basic information about the trucks is shown in Table 1.

The operation data of electric heavy-duty trucks were sourced from the vehicle-monitoring data of the electric vehicle company, while the data on diesel trucks were sourced from remote online monitoring data of heavy-duty vehicles. The main types of data obtained and the statistical methods used are shown in Table 2.

Table 1. Basic information about the diesel and electric heavy-duty trucks in this study.

Indicator	Diesel Heavy-Duty Trucks	Electric Heavy-Duty Trucks
Number of Vehicle	15	61
Curb Weight	9 t	11 t
Maximum Tractive Tonnage	40 t	38 t
Maximum Speed	89 km/h	89 km/h
Vehicle Emission Phase	China VI	/
Battery Type	/	Lithium Iron Phosphate
Battery Capacity	/	282 kWh
Charging Time	/	20–90% ≤1 h
Driving Range	/	About 150 km
Number of Trips	44,530	9953

Table 2. Data collection types and statistical methods for heavy-duty trucks.

No.	Data Type	Statistical Method
1	Daily Travel Times	Count the number of journeys a vehicle makes each day.
2	Single Charging Duration	Count the duration of each charge for the electric heavy-duty truck, setting the interval length to 0.5 h.
3	Daily Charging Duration	Count the daily charging duration for electric heavy-duty trucks and set the interval length at 0.5 h.
4	Daily Charging Times	Count the charging times of electric heavy-duty trucks per day.
5	Actual Charging Rate	Calculated by dividing the change in state of charge (SOC) per charge of electric heavy-duty trucks by charging duration and setting the interval length at 0.1 h^{-1} .
6	Starting/Ending SOC of Charging	Count the distribution of the starting and ending SOC of each charge for electric heavy-duty trucks, with a step length of 10%.
7	Single VKT	Take 15 min of vehicle immobility as the standard for determining the end of a trip and count the VKT for each travel, with an interval length of 5 km.
8	Daily VKT	Count the cumulative daily VKT of the vehicles and set the interval length at 10 km.
9	Daily Travel Duration	Count the cumulative daily travel duration of the vehicles and set the interval length at 0.5 h.
10	Single-Trip Energy Consumption	The calculation method for electric heavy-duty trucks' energy consumption is the consumed SOC \times nominal energy storage \div corresponding travel distance; take 15 min of vehicle immobility as the standard for determining the end of a trip; and set the interval length at 20 kWh/100 km.
11	Daily Energy Consumption	Count the average energy consumption for the daily travel of electric heavy-duty trucks and set the interval length at 20 kWh/100 km.
12	Single-Trip Fuel Consumption	Take 15 min of vehicle immobility as the standard for determining the end of a trip, count the fuel consumption for each trip of diesel heavy-duty trucks, and set the interval length at 5 L/100 km.
13	Daily Fuel Consumption	Count the average fuel consumption for the daily travel of diesel heavy-duty trucks and set the interval length at 5 L/100 km.
14	Average Speed per Trip	Take 15 min of vehicle immobility as the standard for determining the end of a trip, count the average speed for each trip of vehicles, and set the interval length at 10 km/h.

2.4. Analysis Methods of Emission Reduction Potential

2.4.1. Calculation of Atmospheric Pollutant Emissions

In this study, “emissions” only refers to exhaust emissions, while the non-exhaust (e.g., brake and tire wear) emissions and life cycle emissions of the vehicles, or emissions from electricity production, are not considered. The main pollutants emitted by diesel trucks are NO_x and PM, which are the main evaluation indicators for assessing the pollutant emission reduction in this study

We used a mileage-based method [47] to calculate the NO_x and PM emissions from the diesel heavy-duty trucks.

$$E_i = P \times BEF_i \times \gamma_i \times VKT \times 10^{-6} \quad (1)$$

where E_i is the emissions of the i -th pollutant (NO_x and PM) from the diesel heavy-duty trucks in tons per year; P is the number of diesel heavy-duty trucks; BEF_i is the benchmark emission factor of the i -th pollutant from diesel heavy-duty trucks in g/km; VKT is the average annual mileage of diesel heavy-duty trucks in km, which is sourced from the operation data in this study; and γ_i is the average speed correction factor of the i -th pollutant. BEF_i and γ_i are sourced from the Technical Guidelines for Compiling Atmospheric Pollutant Emission Inventory of Road Motor Vehicles (Trial), published by the Ministry of Ecology and Environment [47], and the average speed used for the determination of γ_i is sourced from the operation data in this study. The emission factors for electric vehicles were set to 0.

2.4.2. Calculation of CO₂ Emissions

The greenhouse gas emission model for the automotive industry was derived from the 2006 Guidelines for National Greenhouse Gas Inventories published by the Intergovernmental Panel on Climate Change (IPCC) [48]. These guidelines classify greenhouse gas emissions from automobiles due to fuel combustion as energy combustion emissions. The calculation method [48] for CO₂ (only considering the emissions caused by fuel combustion during vehicle operation and not considering the life cycle emissions of the vehicles or emissions from electricity production) is as follows:

$$E_{CO_2} = P \times EF_{CO_2} \times VKT \times 10^{-6} \quad (2)$$

$$EF_{CO_2} = FC \times \rho \times NCV \times CC \times CE \times \frac{44}{12} \times 10^{-2} \quad (3)$$

where E_{CO_2} is the emissions of CO₂ from the diesel heavy-duty trucks in tons per year; EF_{CO_2} is the emission factor of CO₂ from diesel heavy-duty trucks in g/km; FC is the fuel consumption in L/100 km, which is sourced from the operation data in this study; ρ is the density of the diesel in kg/L; NCV is the net calorific value in tJ/Gg; CC is the carbon content per unit calorific value; and CE is the combustion efficiency value. The following data were taken from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The NCV value is 43.0 tJ/Gg, the CC value is 20.2 kgC/GJ, and the CE value is 100%.

3. Results and Discussion

3.1. Charging Behavior of Electric Heavy-Duty Trucks

3.1.1. Daily Travel Times and Charging Duration/SOC

The daily travel times of these electric heavy-duty trucks are shown in Figure 1a. The results show that the majority of these electric heavy-duty trucks in the steel plant travel three to five times a day, accounting for 54.7% of all travels. The percentage of vehicle trips that travel once a day makes up approximately 2.1%, and the cases that travel more than eight times a day account for approximately 12.3%. This indicates that the electric heavy-duty trucks generally travel multiple times a day.

The distribution of the charging duration of electric heavy-duty trucks for each charge and each day is shown in Figure 1b. The results indicate that most vehicles require 0.5–1.5 h for each charge, accounting for 77.6%, with the charging duration of most vehicles being between 0.5 and 1 h, which accounts for 47.2%. The majority of the vehicles have a cumulative daily charging duration of more than 1.5 h, with durations exceeding 3 h accounting for 21.8%. This reveals that the vehicles charge multiple times a day, and the majority of individual charging durations are concentrated between 0.5 and 1 h.

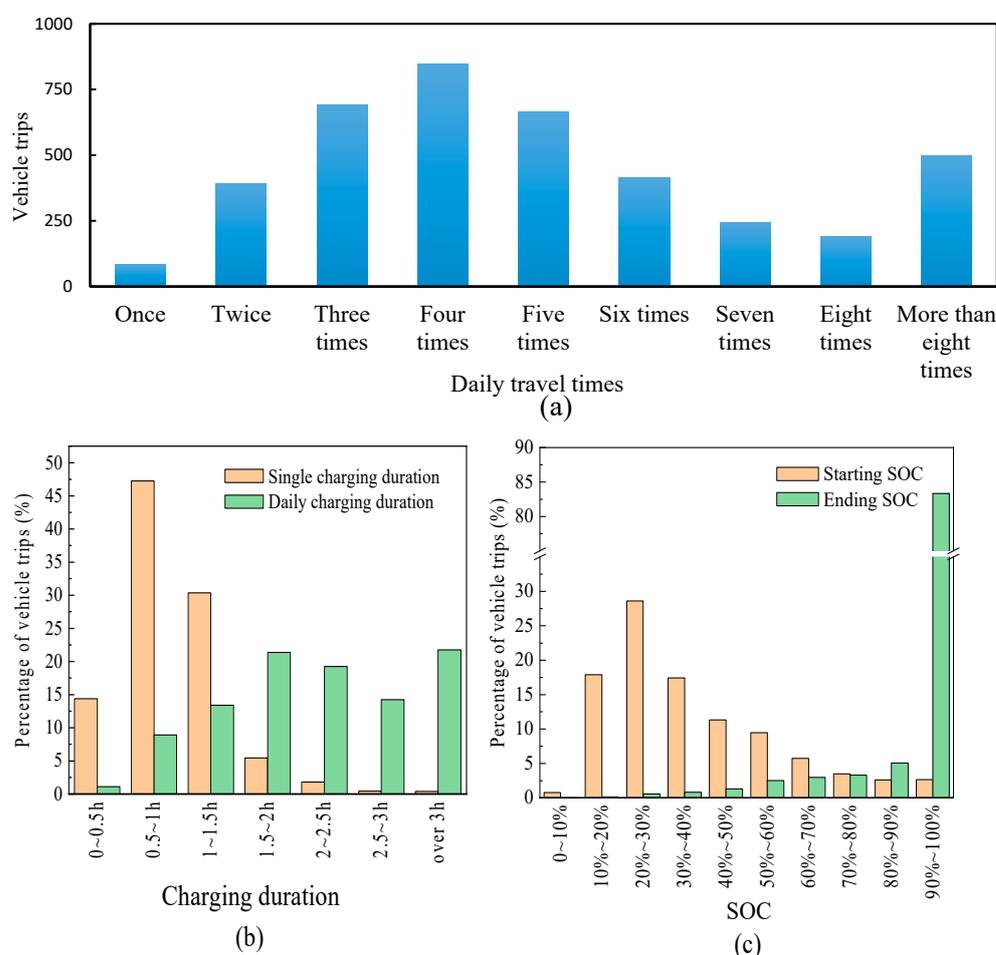


Figure 1. Overview of traveling and charging: (a) distribution of daily travel times, (b) distribution of charging duration, and (c) distribution of starting and ending SOC of charging.

By analyzing the starting and ending SOC of each vehicle's charge, a distribution graph is produced, as shown in Figure 1c. The results show that the initial SOC of the charging process is relatively evenly distributed, with the majority between 10% and 40%, accounting for 63.9%. The final SOC of the charging process is significantly concentrated at 90–100%, accounting for 83.3%. The low SOC at the beginning of charging indicates that users exhibit a low anxiety level about charging and that the charging duration and travel range can basically meet their needs.

3.1.2. Charging Times and Charging Rates

The distribution of the daily charging times and the actual charging rate of each charge for electric heavy-duty trucks are shown in Figure 2. The results show that the majority of vehicles charge two to three times a day, accounting for 68.8% of all charges, and only approximately 5.0% of the vehicles charge more than four times a day. The actual charging rates are concentrated between 0.5 and 0.8 h^{-1} , accounting for 63.3%, and only 3.1% of the vehicles have a charging rate lower than 0.3 h^{-1} . This shows that most of the vehicles

adopted fast charging (or directive current charging), which can charge more electricity compared to alternating current charging, so that the trucks can travel for a longer time in one day and derive higher economic benefits.

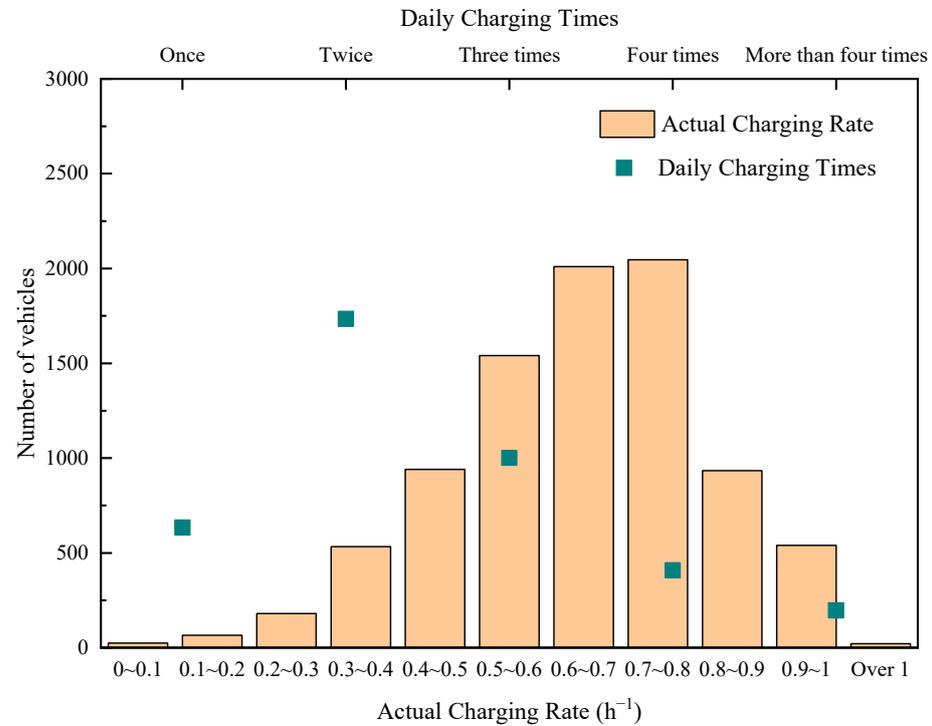


Figure 2. Distribution of charging times and charging rates.

3.1.3. Starting Times for Charging

The distribution of the starting times for each charge of vehicles is shown in Figure 3. The results show that the starting times for charging are widely distributed, with peaks appearing around 11 am and 6 pm, corresponding to lunchtime and dinnertime, respectively. The number of vehicle trips that start charging at night is relatively large, which generally coincides with the regular working/resting hours of workers.

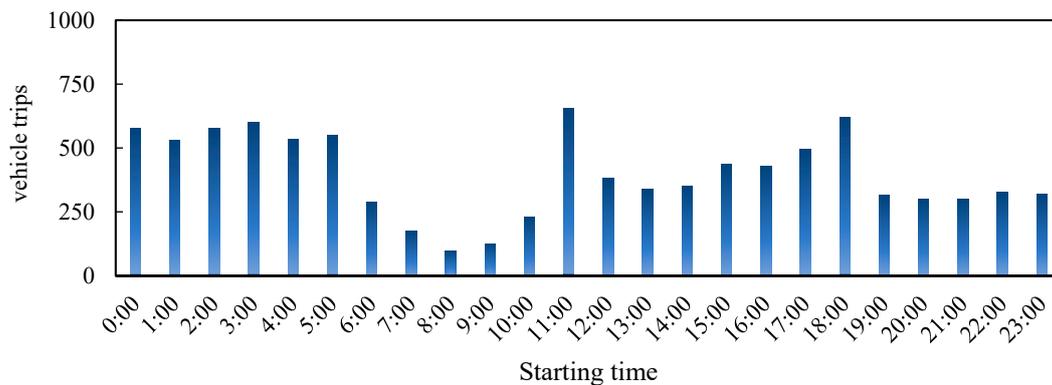


Figure 3. Distribution of charging start times.

3.2. Comparison of Operating Characteristics between Electric Heavy-Duty Trucks and Diesel Heavy-Duty Trucks

3.2.1. VKT

The single VKT and average daily VKT of the electric heavy-duty trucks and diesel heavy-duty trucks in the steel plant are analyzed, as shown in Figure 4. The results show that the most common single VKT for both the electric and diesel heavy-duty trucks is less than 10 km, and the number of trips decreases significantly with an increase in single VKT. On the one hand, this is due to the shorter single VKT of these vehicles in the actual operation scenarios, and on the other hand, this study uses a standard of no vehicle displacement for 15 min to determine the end of a trip, which may cause data deviation due to traffic jams and other situations, leading to a smaller recorded single VKT. The analysis of the average daily mileage shows that the distribution of average daily mileage for electric heavy-duty trucks is relatively even, with two peaks at 60–80 km and 170–220 km, and fewer cases under 50 km or above 300 km, accounting for only 5.6% and 7.3%, respectively. The peak mileage matches the transport radius and daily travel times of the two transport scenarios obtained by field research, reflecting the transport characteristics of 3–5 long-distance transports (60–70 km) and 8–10 short-distance transports (as low as 10 km) per day. The peak of the distribution of daily VKT for diesel heavy-duty trucks appears at the level of over 350 km (accounting for about 24.0%), and the maximum daily VKT reaches 730 km, indicating that some trips that the diesel trucks operated are long-distance transportation, together with the speed distribution shown in Section 3.2.3. Electric trucks cannot easily be used on these long-distance trips under the current level of technology and infrastructure construction. However, from the comparison of the VKTs of the two kinds of vehicles, it is inferred that the electric trucks can carry out about 76.0% of the trips made by the diesel trucks at the plant.

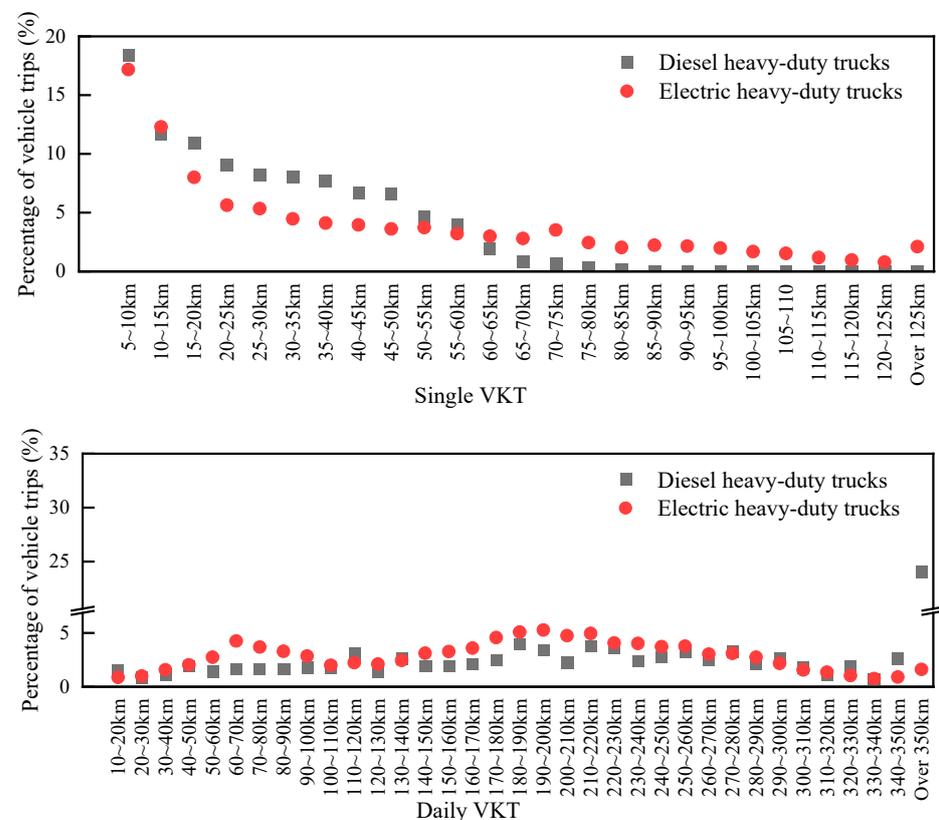


Figure 4. Comparison of mileage.

3.2.2. Driving Time

This study analyzed the average daily driving time, as shown in Figure 5. It can be seen that the average daily driving time for electric heavy-duty trucks is mostly concentrated at 19.5 h or more, accounting for about 11.7%, and the number of trips increases significantly with the increase in operating time. Combined with the VKT, it can be seen that the overall operation state of the electric heavy-duty trucks in the steel plant features short single VKTs, frequent daily travels, and long daily driving times. Similarly to the electric heavy-duty trucks, the maximum daily driving time for diesel heavy-duty trucks is also above 19.5 h, accounting for about 13.3%. It was also found that 78.7% of the electric trucks traveled more than 14 h every day, which is much higher than the proportion of diesel trucks (35.9%). This indicates that more electric vehicles operated for extended periods of time every day than the diesel trucks, and the most likely reason for this is the lower operating cost, as shown in Section 3.2.4.

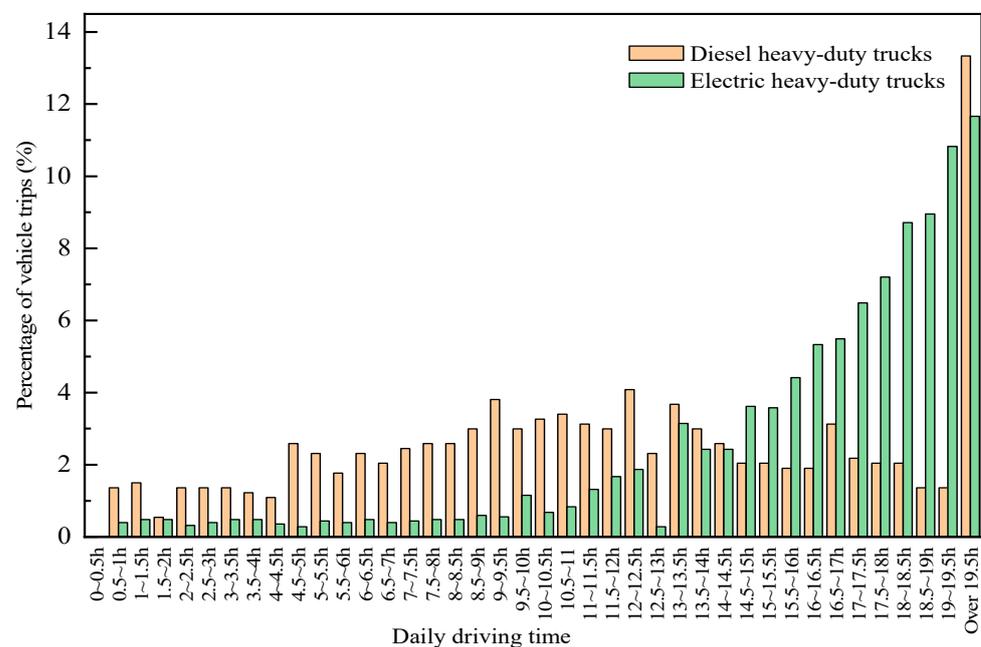


Figure 5. Comparison of daily driving times.

3.2.3. Speed Distribution

The average driving speed during a single trip for electric heavy-duty trucks and diesel heavy-duty trucks was analyzed, as shown in Figure 6. Due to the inclusion of short-term parking (within 15 min), the calculated average speeds are relatively low. However, overall, it can be seen that both types of vehicles in the steel plant generally operate at a low speed. Due to the higher pollutant emission factors under low-speed operation conditions for the diesel trucks, it is more effective to use electric vehicles to replace the diesel vehicles in these short-distance transport scenarios. However, it can also be seen that the average driving speed of electric heavy-duty trucks is relatively lower than that of diesel heavy-duty trucks. According to this study, the average speed of 98.5% of the vehicle trips by electric heavy-duty trucks is concentrated within 30 km/h, while the average speed of 44.4% of the vehicle trips by diesel trucks is above 30 km/h. Given the distribution characteristics of driving VKT, this is mainly due to the fact that the electric heavy-duty trucks are mostly used in short-distance transport and have greater start–stop times, while some trips in the diesel trucks represent long-distance transportation with lower start–stop times and faster average speeds.

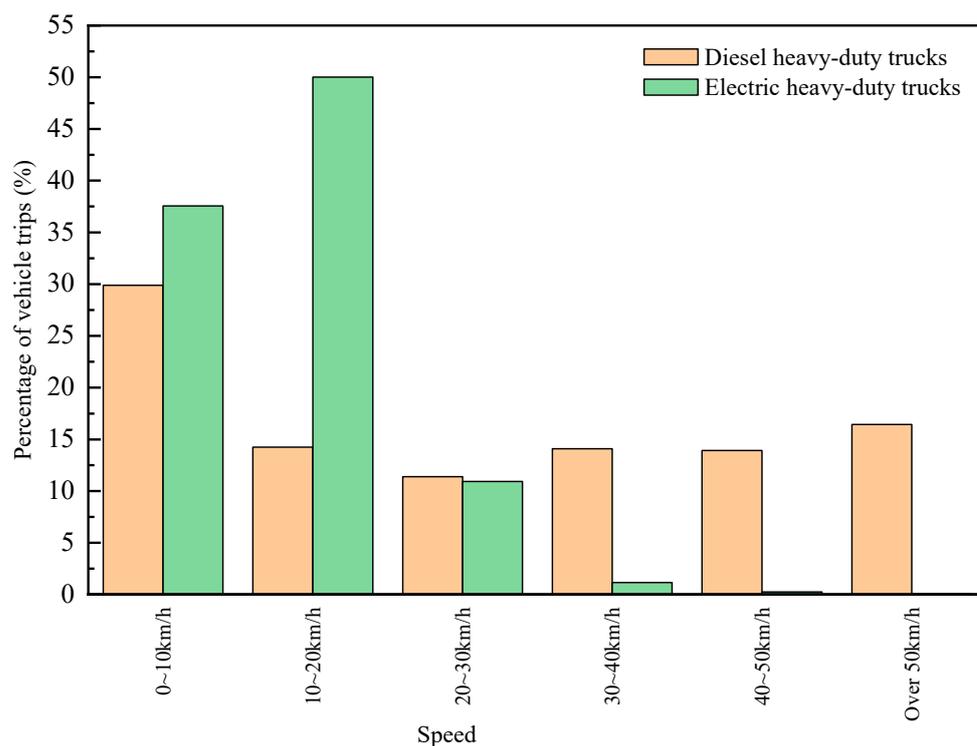


Figure 6. Speed distribution.

3.2.4. Energy Consumption

This study analyzed the energy/fuel consumption of the trucks, as shown in Figure 7. It can be seen that the energy consumption for a single trip of the electric heavy-duty truck is mostly concentrated between 210 and 230 kWh/100 km, accounting for 17.1%, and the daily average energy consumption is also mostly concentrated in this range, while the distribution of the energy consumption for a single trip is basically consistent with the distribution for each day. For the diesel heavy-duty trucks, the fuel consumption for a single trip is mostly concentrated between 25 and 30 L/100 km (accounting for 13.9%), and the daily average fuel consumption is also mostly concentrated in this range. Calculated with an electricity cost of USD 0.093/kWh and a fuel cost of USD 0.96/L, the use of electric heavy-duty trucks can save about 18–26% of operating costs per 100 km, which is about USD 4.5–7.4.

Of the 61 electric heavy-duty trucks, 8 were operated in mid-July, 2021, and these can be used for an analysis of energy consumption differences between winter and summer. In this study, the operating data of the eight electric heavy-duty trucks from July to August were selected to characterize their summer behavior, and the operating data from December to January were used to characterize their winter behavior. Using the daily driving energy consumption per 100 km as an index, the energy consumption distribution in winter and summer was obtained, as shown in Figure 8.

It can be seen that the daily operating energy consumption in summer is concentrated between 140 and 170 kWh/100 km, while in winter, it is concentrated between 190 and 230 kWh/100 km. It can be concluded that the energy consumption of these vehicles in winter is higher than in summer, and the increase rate is about 35–36%. This is mainly due to the lower environmental temperature in winter, the use of air conditioning, and the decrease in battery efficiency, which is consistent with the conclusions of relevant research by Rastani [49], Yuksel [50], Yi [51], etc. This difference also shows that the electric vehicles need to carry out more charging activities in the winter to ensure the factory's transportation needs. However, it can be calculated that the driving range in winter can still reach 100–120 km when fully charged, so the electric trucks can also meet the short-distance transportation needs of the factory in winter. On the other hand, with the development of

battery technology, the energy consumption difference between summer and winter has been reduced to below 10% in recent years, which is shown in another study on the electric heavy-duty trucks used for concrete transportation. Therefore, the impact of future winters on the energy consumption of electric heavy-duty trucks will be even smaller.

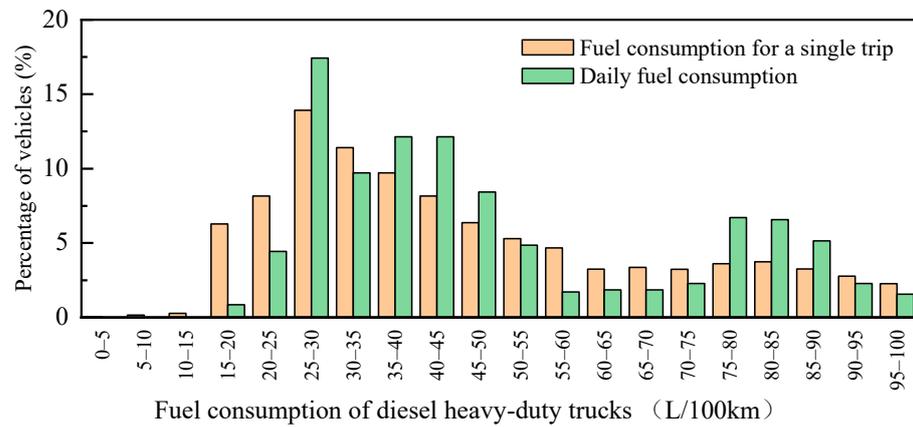
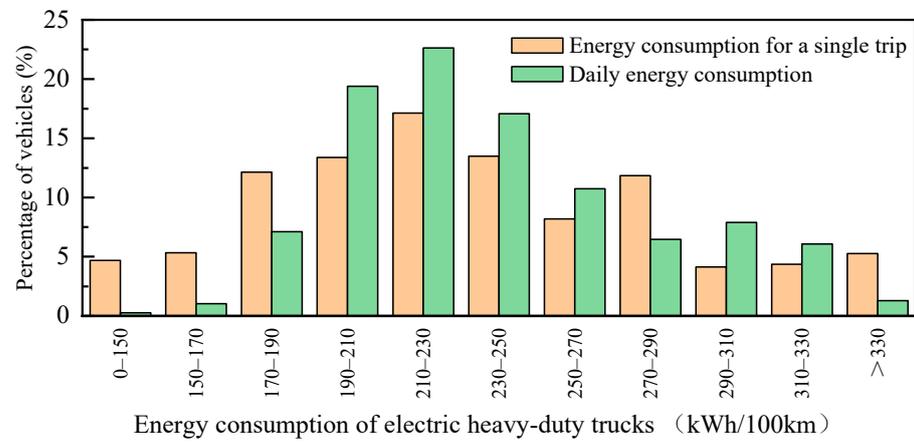


Figure 7. Energy consumption comparison.

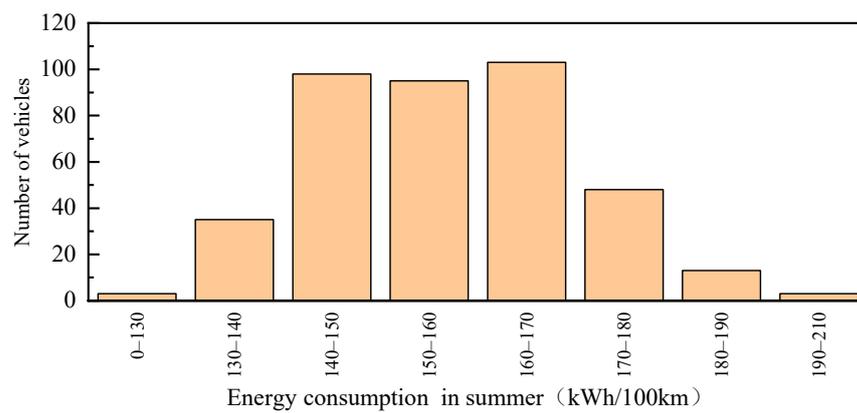


Figure 8. Cont.

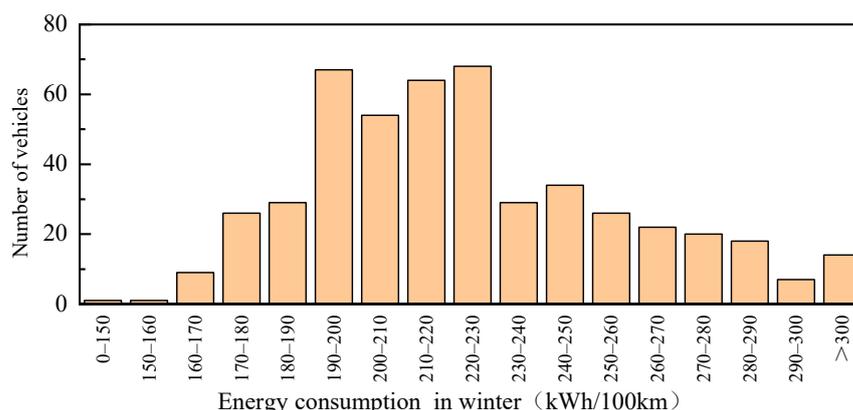


Figure 8. Energy consumption in summer and winter.

3.3. Environmental and Economic Benefit Analysis

The steel plant has used 300 electric heavy-duty trucks, which is equivalent to reducing the use of an equal number of traditional diesel heavy-duty trucks, thus achieving a reduction in pollutants and CO₂, as well as energy costs.

The pollution benchmark emission factor is calculated based on the emission factor of China V diesel heavy-duty trucks (some heavy-duty China IV and older trucks are actually still in use in China, so the actual emission reduction is slightly higher than the calculated value in this study). Some parameters, including the average speed, the annual mileage of heavy-duty trucks, and the fuel consumption, are sourced from the operation data of the trucks in this study.

Currently, the steel industry in China employs about 2.13 million heavy-duty trucks, making it a significant industry in relation to the use of heavy-duty vehicle transportation. With the continuous maturation of electric heavy-duty truck technology, combined with the promotion effect of related policy support, it is expected that the proportion of electric heavy-duty trucks applied in the steel industry will rapidly increase in the future. Based on the assumption that 76% (according to the analysis in Section 3.2.1) of the vehicles in the steel industry will be replaced with electric heavy-duty trucks in the future, the emission reduction benefits and economic benefits derived from energy cost savings were estimated, and the results are shown in Table 3.

Table 3. Environmental and economic benefits of replacing diesel heavy-duty trucks with electric heavy-duty trucks in the steel industry.

Indicator	Unit	The Steel Plant	The Steel Industry in China
Replacement Quantity	vehicle	300	1,618,800
Annual Mileage	km	73,000	73,000
Average Speed Correction Factor of NO _x and PM	/	1.12	1.12
NO _x Emission Factor	g/km	5.288	5.288
NO _x Emission Reduction	tons	115.8	624,838.9
PM Emission Factor	g/km	0.034	0.034
PM Emission Reduction	tons	0.7	3970.6
CO ₂ Emission Factor	kg/km	0.224	0.224
CO ₂ Emission Reduction	10,000 tons	1.8	9705.9
Energy Cost Saving	million USD	1.0–1.6	5318–8745

4. Policy Recommendation

The clean transportation requirements of the policies of ultra-low emissions and performance-based classifications in China have effectively promoted the application of electric heavy-duty trucks in the steel industry. However, due to current mileage limitations

and the higher purchase cost of electric heavy-duty trucks, combined with the shortage in the construction of charging and battery swapping facilities, the wide use of electric heavy-duty trucks is still challenging. Given the significant role of electric heavy-duty trucks in pollution reduction and carbon mitigation, the following policy recommendations are proposed to accelerate their application and promotion. Firstly, strengthen fiscal and taxation incentive policies for electric heavy-duty trucks and their charging and battery swapping facilities. Introduce priority road-right policies, such as unrestricted access for zero-emission trucks, exemption from highway tolls, etc. Secondly, promote the vehicle leasing and battery leasing markets to alleviate the cost pressure of purchasing electric heavy-duty trucks. Thirdly, develop targeted policies to promote electric heavy-duty trucks based on the characteristics and needs of different application scenarios. For example, provide preferential policies for clean transportation companies during heavy pollution days according to the performance-based classification system of key industries, exempt zero-emission vehicles from low-emission zones, and allow zero-emission vehicles to use bus lanes.

5. Conclusions

This study analyzed the actual usage of the electric and diesel heavy-duty trucks in a steel plant in Hebei Province, China. In addition, the emission reduction resulting from replacing the diesel trucks with electric trucks in the steel industry was estimated. Overall, the electric heavy-duty trucks exhibit an operating state of short VKTs, frequent daily trips, and long daily driving times, which fits the short-distance characteristics and transportation needs of the steel industry. Most electric heavy-duty trucks operate for more than 14 h per day, meeting the industry's needs for long operating hours. The average daily energy consumption of electric heavy-duty trucks is mostly between 210 and 230 kWh/100 km, with higher consumption in winter than in summer. Based on the current electricity and fuel costs, electric trucks can save about USD 4.5–7.4 per 100 km compared to diesel trucks. The use of 300 electric heavy-duty trucks can reduce NO_x emissions by 115.8 tons, PM emissions by 0.7 tons, and CO₂ emissions by 18,000 tons annually. If 76% of the diesel heavy-duty vehicles used in steel plants in China are replaced by electric vehicles, 624,838.9 tons of NO_x emissions, 3970.6 tons of PM emissions, and 9705.9 tons of CO₂ emissions can be reduced.

The analysis is based on the actual operation data of electric heavy-duty trucks in use. This is conducive to understanding the actual application effects of electric heavy-duty trucks in typical scenarios, which is of great significance for the subsequent development of electric heavy-duty trucks and their promotion in other industries.

Although electric heavy-duty trucks can play a significant role in pollution reduction and carbon mitigation, it is still challenging to widely promote them due to technical and cost constraints. In the future, policy preferences should be set out in terms of technology research and development, use cost, and convenience in order to promote electric heavy-duty trucks and enable them to play a more critical role in the clean transportation of goods in typical industries.

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