Chinese transport emissions reduction policies: analysis of approaches to promote uptake of new energy construction dump trucks

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Abstract: As China strives to meet its targets for reducing carbon emissions, scrutiny needs to reach new areas. The phenomenal levels of construction in recent years have been accompanied by an increase in the use of heavy-duty dump trucks to remove waste materials. Adoption of new energy construction dump trucks, i.e., dump trucks that use alternative power sources, such as electric batteries and hydrogen fuel cells, has the potential to reduce greenhouse gas emissions and air pollutants. A range of approaches has been used by different cities to incentivize adoption. This study examines their effectiveness through both an analysis of city policies promoting the uptake of new energy dump trucks and mixed method investigation of factors influencing the intentions of target consumers in the case study city in central China. Findings indicate that financial subsidies are the most powerful incentive in market-based promotion policies. The target consumers' purchase willingness is shown to be weak. It is argued that market-based incentive policies have a significant role for promoting the dissemination of low-carbon technologies with the target consumers, but are not strongly effective. The main problems are technical anxiety and high prices. Therefore, although market-based promotion policies are important, policies should be more inclined to support front-end technologies, such as related personnel training and equipment support.

Keywords: new energy construction dump truck; low-carbon technologies diffusion; promotion policy, construction, China

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1. Introduction

Due to the unique threat of global warming to human beings, the world is paying increasing attention to climate change (Ranney and Velautham, 2021). In this context, China has committed to dual carbon goals, including achieving peak carbon by 2030, and the carbon neutrality by 2060[1] (Huo et al., 2022). According to the data from the *"2022 Urban Zero Carbon Traffic White Paper"*, the transportation sector's carbon emissions accounted for 10% of China's whole carbon emission structure. Therefore, the national government needs to address the carbon emissions of the transportation sector to meet its climate goals (Alataş¸2022; Guo et al., 2022; Xue et al., 2023).

The rapid development of China's society and economy, including the acceleration of urbanization, has been accompanied by construction and demolition projects producing a huge amount of solid waste (Zhang et al., 2021). The demand for construction dump trucks. has also increased correspondingly (Lu et al., 2021). The dump truck is the main model of urban muck, construction, and mineral transportation (Pavlenko et al, 2022). The construction dump truck is a large dump truck specially used to transport waste sands and stones from construction sites. In China, most construction dump trucks are 3-axle dump trucks or 4-axle dump trucks (Shenzhen Transportation Commission, 2018). The exhaust emission of heavy trucks including construction dump trucks is one of the main contributors to urban traffic carbon emissions (Breuer et al., 2021).

Heavy-duty diesel trucks have resulted in exhaust emissions and energy consumption problems and cannot meet the requirements of environmental sustainability (McCaffery et al., 2021; He et al., 2022; Xu et al., 2023). According to *China Mobile Source Environmental Management Annual Report (2021*), heavy-duty trucks accounted for less than 5% of China's vehicle ownership in 2020, but their emissions of carbon monoxide, hydrocarbons, nitrogen oxides and particulate matter accounted for 11.4 %, 15.9 %, 75.4 %, and 52.1 % of total vehicle emissions of the country respectively. The high emissions of heavy trucks not only contribute to global warming, but also affect human health (Ramirez-Ibarra and Saphores, 2023). A new energy vehicle is a type of low-carbon product with a low energy consumption, low

[1] Carbon peak is the historical inflection point of carbon dioxide emissions from increasing to decreasing, which means that at a certain point in time, carbon dioxide emissions no longer increase and reach the peak, and then gradually fall back. Carbon neutrality refers to the total amount of carbon dioxide or greenhouse gas emissions directly or indirectly generated by a country, enterprise, product, activity or individual within a certain period of time, through afforestation, energy saving and emission reduction, etc. , to offset the carbon dioxide or greenhouse gas generated by itself. Emissions, to achieve positive and negative offset, to achieve relatively "zero emissions."

pollution and low emission during the operation process (Xin et al., 2022; Luo and Mabrouk, 2022).

Academics have examined the carbon emissions of new energy trucks. Although the batteries used in electric trucks emit carbon during production (Lai et al., 2022), the life cycle carbon footprint of electric power systems is lower than diesel power systems (Chen and Lam, 2022). Yeow et al. (2022) compared the life cycle greenhouse gas emissions of diesel, battery electric and hydrogen fuel cell trucks in Singapore, including the vehicle and fuel production, operation and end-of-life stage. Their results show that the greenhouse gas emissions of battery electric trucks and hydrogen fuel cell trucks are 11% and 23~30% lower than conventional diesel trucks. Therefore, replacing diesel trucks with new energy trucks, such as electric trucks and hydrogen fuel trucks, can reduce these environmental and health problems (Lao et al., 2021; Liu et al., 2021). In 2020, new energy heavy-duty vehicles accounted for 1% of the EU's new registrations and less than 3% of the global market. China was by far the largest market with more than 99% of the cumulative global stock of new energy heavy-duty vehicles by 2021 (International Council on Clean Transportation et al, 2021). Therefore, this study selected a city in central China as a case study to explore the promotion prospects of new energy construction dump trucks.

Electrification of heavy-duty trucks is critical for achieving sustainability and carbon neutrality in road freight (Zhang et al., 2022). This has prompted the government to shift to new energy solutions in China. A series of policies for electrification of heavy trucks have been issued at the national level, such as the "*Notice on the Promotion and Implementation of Financial Subsidy Policies for New Energy Vehicles in 2022"* and "*Notice on the Printing and Distribution of the Development Plan for the New Energy Vehicle Industry (2021-2035)"*. In addition, a number of local governments have adopted the promotion policies for applying new energy construction dump trucks, such as the "*Implementation Plan for the Promotion and Use of Pure Electric construction dump trucks in Shenzhen*" and "*Special rule for New Energy construction dump truck (Trial) in Zhengzhou*". However, due to the purchase costs and technical anxiety, caused by changes in the driving style (Yan and Zhao, 2022), there is a policy debate as to whether or not to promote the application of new energy construction dump trucks to transport construction and demolition waste in the regional levels. Given that, nationally, only five cities by 2022, such as Shenzhen and Zhengzhou, introduced systematic promotion policies for new energy construction dump trucks. Therefore, it is meaningful to investigate their policy effect, and identify influential factors and possible solutions.

This research views new energy construction dump trucks as a type of low carbon technology product that is subject to diffusion. Previous studies on promoting low-carbon technologies or products ~~are~~ analysed. Then, the policy experience and effects of the promotion policies of new energy construction dump trucks in various regions of China are explored. In addition, a Chinese region without new energy construction dump trucks promotion policies was selected as a case study. Through focus groups, semi-structured interviews and a questionnaire survey, the local willingness to apply new energy construction dump trucks was investigated and analyzed. Finally, influential factors and solutions are proposed. International new energy heavy truck manufacturers can potentially get suggestions from the market to improve relevant technologies of new energy construction dump trucks from this study. Western scholars and policy makers can also receive promotion suggestions for new energy heavy trucks from this article.

2. Literature review

The analysis of ways to promote the use of new energy construction dump trucks can be summarized from the perspective of policy analysis, the influencing factors of low-carbon product diffusion, and consumers' willingness to purchase new energy vehicles.

2.1 Policy Analysis

The term policy analysis describes the scientific assessment of the impact of past public policies and the prediction of future potential policy outcomes (Manski, 2018). Policy analysis plays an important role in defining and outlining goals of a proposed policy and in identifying similarities and differences in expected outcomes with competing alternative policies (Simon, 2023). In light of a broad agreement, government authorities have played a key role in achieving sustainable growth through adopting a range of policy instruments (Ziesmer et al., 2023; Chien et al., 2023; Safdar et al., 2022). Policy instruments are a set of intervention tools that the government tries to ensure support and influence socio-economic and innovative development, such as public procurement, subsidies, tax incentives, and training (Rothwell and Zegveld, 1985). Michael Howlett and M. Ramesh (1995) divided the policy tools into voluntary policy tools (family and community, voluntary organizations, private market), mixed policy tools (information and exhortation, subsidies, property auctions, taxes and royalties) and mandatory policy tools (regulation, utilities, direct provision) based on the level of goods and services provided by the government. As there is a lack of analysis and classification of the promotion policy of new energy construction dump trucks, the policy classification of previous scholars can be used for a reference in this study.

2.2 The Diffusion of Low Carbon Products or Technologies

This section summarizes articles on the factors influencing the diffusion of low-carbon products or technologies in recent years. Examples cover cleaner energy facilities, electric vehicles, and green-manufacturing technologies. Influential factors refer to factors identified by the authors of those studies that promote or hinder the diffusion of low carbon products or technologies.

Previous scholars have conducted substantial research on the influential factors affecting the diffusion of low-carbon products or technologies from the perspective of producers, markets, and public policies. These factors are summarized in Table 1.

Table 1 Factors Affecting the Diffusion of Low Carbon Products or Technologies

	Categories	Influential factors	Object	References
Producer's perspective	Technical capability	Low-carbon technological innovation capacity (+)	Battery electric vehicles	(Yuan and Li, 2021; Li et al., 2021)
		Technology maturity (+)	Green technologies	(Zeng et al., 2020)
	Enterprise's profits	Production costs of low-carbon products (-)	Cleaner fuel	(Guo and Zhu, 2021)
		The long-term benefits (+)	Green-manufacturing technologies	(Kong et al., 2016)
Consumer perspective	-	Demand and preference for low-carbon products (+)	Electric vehicles; wind energy	(Zwarteveen et al., 2021; Chakraborty et al., 2022)
Public policy perspective	Economic tools	low-carbon product subsidies (+)	Low-carbon products	(Yang et al., 2022)
		Environmental taxes (+)	Low-carbon technologies; green transport and mitigation technologies	(Fan et al., 2022; Khurshid et al., 2023)
		Investment in low-carbon activities (+)	New energy vehicles	(Zhao et al., 2022)
		Public procurement for low-carbon products (+)	Low-carbon technologies	(Fan et al., 2022)
		Encourage green finance to join (+)	Cleaner fuel	(Kong et al., 2016)
	Use-based incentives	Special rights (+). e.g. preferential parking price for new energy vehicles	Wind energy	(Chakraborty et al.,2022)
		Establishment of infrastructure(+). e.g. large-scale power stations	fuel cell heavy-duty trucks; zero emission heavy-duty trucks	(Küffner, 2022; Giuliano, 2021)

Note: In the "Influential factors " column, (+) indicates the positive impact on technology diffusion promotion, and (-) indicates the negative impact.

Issues relevant from a "producer's perspective" in table 1 include "technical capability", "enterprise's profits", and "marketing". Technical capability mainly refers to the technical R&D ability of production enterprises, which can improve the attraction of products to promote their diffusion (e.g., by material substitution to reduce cost or increasing energy efficiency) (Yuan and Li, 2021; Li et al., 2021). "Enterprise's profits" refer to the large profit space of enterprises would promote the diffusion of low-carbon technologies or products (Guo and Zhu, 2021; Kong et al., 2016). From the above table, the R&D of manufacturing technology can promote the diffusion of low-carbon technologies and products. Further R&D by manufacturers may also increase the uptake of new energy construction dump trucks in the future. However, it is still necessary to explore which type of technology enhancement is the most required.

"Public policy perspective" includes economic tools and use-based incentives. "Economic tools include" some reward and punishment methods, such as subsidies and taxes, which wound promote the diffusion of low-carbon technologies or products (Yang et al., 2022; Fan et al., 2022; Khurshid et al., 2023). Use-based incentives refer to the increase of special rights and facilities for the use of low-carbon technologies or products, such as preferential parking prices for new energy vehicles, and the construction of charging pile infrastructure (Zhao et al., 2022; Fan et al., 2022). Regarding the perspective of enterprises' profits, companies often emphasize that low-carbon alternatives involve higher costs or lower profits than traditional alternatives (Kuik et al., 2022) which requires the participation of government policies to promote diffusion (Kong et al., 2016) by financial support or mandating the purchase. New energy construction dump trucks may also face the same problem, needing the support of government policies.

Market perspective is mainly the market demand, i.e., issues that encourage uses to adopt the low-carbon technologies or products (Zwarteveen et al., 2021; Chakraborty et al., 2022). The demand for products is an important factor affecting product diffusion (Zwarteveen et al.,2021; Chakraborty et al.,2022). The promotion of new energy construction dump trucks also needs to consider market demand. It is necessary to explore the purchase willingness of target customers.

2.3 Purchase willingness of new energy vehicles

Purchase willingness is the probability that a consumer will buy a product or service. A range of scholars have studied factors affecting the purchase willingness of new energy vehicles through the market investigation, and summarized the factors into three main aspects: consumers, products and promotion policies (Tian et al., 2021).

With regard to the consumer perspective, previous researchers have investigated the impact of environmental awareness and consumer preference on the purchase willingness of new energy vehicles. Research by Okada et al. (2019) and Wang et al. (2022) shows that raising consumers' environmental awareness leads to increased purchase willingness for new energy vehicles and improving education level can improve consumers' environmental awareness. The research of Xiong and Qin (2020) shows that consumers' preference for new energy vehicles is primarily affected by the convenience dimension, technical dimension, economic dimension, road use rights, and driving range.

For the product perspective, scholars have studied the impact of price and performance on the purchase willingness of new energy vehicles. Till et al. (2018) believe that the purchase price has a significant impact on the purchase willingness of new energy vehicles. Sun et al. (2023) used an empirical analysis to confirm that consumers' willingness to purchase new energy vehicles is affected by energy prices. Rotaris et al. (2021) insist that purchase price and driving range play a crucial role in consumers' purchase decisions, while charging time is not statistically significant.

Regarding the policy perspective, researchers have found that financial incentives, infrastructure development policies, and policy privileges have an important impact on the purchase willingness of new energy vehicles (Wang et al. 2017; Hu et al., 2023). Yang and Chen (2023) also argue that financial incentives and license plate restrictions on the traditional fuel vehicles affect the diffusion of new energy vehicles in large cities in China.

At present, there is no research specifically on the purchase willingness of new energy construction dump trucks, only research into alternative fuel freight vehicles, light-duty trucks and household cars (Zhang et al., 2019; Zhou et al., 2019; Tian et al., 2021; Lin and Shi, 2022). The purchase willingness of new energy household cars is higher than that of new energy trucks. The survey of Tian et al. (2021) showed that 75.12% of respondents consider buying new energy household cars and Zhang et al.

(2023) found that 90.14% of residents are willing to buy new energy vehicles in the future. Yan and Zhao's (2022) research shows that only 13.89% of truck drivers or related professionals are willing to buy new energy heavy trucks. The main reasons for the weak willingness to buy new energy trucks compared to household cars are price and technical anxiety such as cruising range and battery replacement.

In order to promote the use of new energy construction dump trucks, it is necessary to conduct policy analysis to understand the implementation effect of the promoted areas. At the same time, to understand the specific factors affecting the promotion of new energy construction dump trucks, it is necessary to explore the purchase willingness and concerns of potential consumers. The research on the purchase willingness of new energy construction dump trucks in this study is a supplement to the literature in the field of new energy heavy trucks as well as technology diffusion.

3. Methodology

There are two parts of the study – the review of city level policies and the primary data collection with potential customers for the technology. This study adopted a mixed qualitative and quantitative analysis method. The research process is shown in Figure 1.

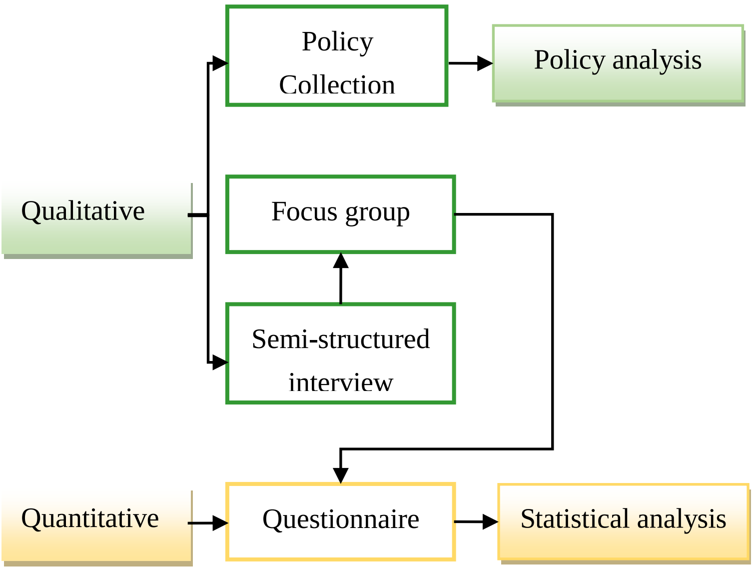

Fig.1 Research process

Comparative policy analysis is a systematic study of policies in different geographical and political regions such as cities or nation-states. By conducting this research, researchers compare and analyze the results and effects of adopting specific policy tools, which are the means by which the government achieves its policy goals (Wang et al., 2022). The core of policy tool theory is the classification (Chai et al.,2020). In this research, through on-line searching, we retrieved regional policies regarding promoting new energy construction dump trucks. Then, the relevant policy tools and their effectiveness were analyzed.

In order to gauge the response of truck users, a case study city was selected. The research area is selected in a metropolitan city in central China (which has participated on condition of anonymity), which plays an important role in finance, management, culture and transportation and has the advantages of fast communication. A focus group is a group session that facilitate focused communication among research participants (Gellman and Turner, 2013). It is an effective method for exploring and attaining a deeper understanding of views in a group (Myrnes-Hansen and Skeiseid, 2022). Under the assistance of the local muck association, this study adopted the focus group method to collect construction dump truck drivers' and representatives' of construction dump truck companies views and willingness to purchase new energy construction dump trucks in the stud area, where the drivers are potential customers of new energy construction dump trucks. In addition, the focus group was adopted to collect the opinions of staff from the urban administration department, which is responsible for the supervision of local environmental sanitation, transporting construction and demolition waste. Details of the focus group interviews are listed in table 2. Each focus group interview involved about 20 people, assisted by the local muck association organization.

Semi-structured interview refers to an informal interview conducted according to a broad outline of the interview. Its advantage lies in the interviewers' flexibly making necessary adjustments according to the actual situation of interviews and getting more abundant and deeper answers (Dolczewski, 2022). In this research, through interviews with battery R&D experts, they evaluated the applicability of current heavy truck batteries and expressed their opinions.

The questionnaire survey is an important method used in psychology and other social science research to collect data through a series of questions to measure people's behavior and attitude (McLafferty, 2016). There are a number of advantages for this approach compared to other approaches such as interviews: greater efficiency in data collection if responses are needed from a large number of individuals, faster data processing and reduced research costs (Pitura, 2023). The questionnaire design of this study followed the design principles of clear, relevant, meaningful and unambiguous questions for eliciting the desired information from selected respondents. An electronic questionnaire was sent to the Wechat group [2] of construction dump truck drivers, who were potential customers of new energy muck trucks and could anonymously participate in the online questionnaire survey. We got in touch with the local muck association, they helped us to distribute the questionnaire quick response code in the group.

[2] Wechat is one of the most popular messaging apps in the Asia, especially in China, and Wechat group is a platform for multi-person chat and communication launched by Tencent, which can quickly send voice messages, videos, pictures and text through the network.

Table 2 Focus group, Semi-structured interview and Questionnaire details

	Object	Date	Major topics
Focus group	Group 1: managers of construction dump truck enterprises	Dec-21	New energy construction dump truck driving mileage New energy construction dump truck suitable for driving temperature New energy construction dump truck waterproof performance New energy construction dump truck price
	Group 2: construction dump truck drivers (⩾2 year construction dump truck driving experience)	Mar-22	Annual muck production Number of fuel construction dump trucks The purchase willingness of new energy construction dump truck
	Group 3: construction dump truck drivers (⩾2 year construction dump truck driving experience)	Apr-22	New energy construction dump truck price New energy construction dump truck endurance Industry downturn
	Group 4: Administration department staffs	May-22	Subsidies for new energy construction dump trucks
Semi-structured interview	Battery R&D expert 1 (⩾5 year construction dump truck driving experience)	Jan 5-22	Comparison of lithium iron phosphate battery and hydrogen Fuel Cell Battery weight reduction possibilities in the next few years
	Battery R&D expert 2 (⩾5 year construction dump truck driving experience)	Jan 6-22	Working feasibility of heavy truck battery in severe cold environment Waterproof performance of heavy truck battery
Questionnaire	construction dump truck drivers (⩾2year construction dump truck driving experience)	Apr-22	Current situation of the much transportation The situation of fuel musk trucks in use purchase willingness of new energy construction dump trucks Potential purchase willingness under incentive policies

4. Research Findings

4.1 Policy analysis results

Exploring appropriate policy tools by establishing pilot regions and promoting them to the whole country is a method frequently used by the Chinese government (Liu et al. 2022). Because of the different levels of economic development and regional characteristics, the promotion strategies of new energy construction dump trucks in various cities are also different. By the early 2022, only five cities had systematically declared a policy strategy to implement new energy construction dump trucks. Drawing upon policy experiences of typical cities in China, the policy tools were summarized in the Table 3.

Subsidies for applying the new energy technology: This refers to the financial subsidy for the application of new energy construction dump trucks based on its actual mileage of transporting construction and demolition waste. A new energy construction dump truck in the Chinese market is around 1 million RMB[3] while the traditional fuel construction dump truck is only about 500,000 RMB. For example, the

[3] Truck sales websites, such as https://www.360che.com/

transportation routes and distances travelled for all new energy construction dump trucks were traced by the monitoring platform in Shenzhen. The subsidy standard for each new energy construction dump truck is 3.56 RMB/km (SDRC et al., 2021). Shenzhen's subsidy for the purchase and application of each new energy construction dump truck could reach up to 800,000 RMB, about 80 % of the purchase price (SDRC et al., 2021). The subsidy for each new energy construction dump truck in Zhengzhou was about 300,000 RMB, which is 30% of the original price (ZCAB et al., 2021).

Subsides for eliminating fossil fuel construction dump trucks: This means that the government issues financial subsidies as a compensation for the elimination of fossil fuel construction dump trucks. For example, in Shenzhen, the elimination of a fossil fuel construction dump truck by the owner will be subsidized up to 108,000 RMB (STC, 2018). The elimination here refers to the self-disposal of traditional construction dump trucks by scrapping and transferring.

Green procurement: This policy is to encourage state-owned enterprises such as the local urban development enterprises, bus enterprises and transportation investment enterprises to purchase new energy construction dump trucks.

Table 3 New energy construction dump trucks promotion policies of typical cities in China

Policy tool	City				
	Shenzhen	Zhengzhou	Guangzhou	Changsha	Shijiazhuang
Subsidies for applying the new energy	√	√			
Subsides for eliminating fuel construction dump trucks	√	√			
Green procurement			√	√	√
Reduced driving limit	√	√	√	√	√
Encourage municipal engineering priority use	√	√	√	√	√
Infrastructure development	√	√	√	√	√
Optimize the vehicle registration process	√	√	√	√	√

Note: The statistical data above were from the promotion policy documents of each province (STC, 2018; STB et al., 2019; ZCAB et al., 2021; GOZPG, 2021; GCACLEB, 2020; GOCPG, 2020; SMPGO, 2021).

As shown in table 3, two cities primarily introduced financial subsidies for new energy construction dump truck promotion, while the other three cities adopted green procurement strategy. Besides the two different modes, other policy tools are summarized as follows:

Reduced driving limit: In order to effectively reduce vehicle exhaust pollution and promote air quality improvement, the government restricts the driving of a range of high-emission vehicles, such as construction dump trucks, during rush hours or in heavily polluted weather (XHPEO, 2019). The new energy construction dump truck is not subject to air-quality restrictions and can work out normally.

Encourage municipal engineering priority use: For example, in Shenzhen and Zhengzhou, local policy encourages municipal construction sites to give a priority to the use of new energy construction dump trucks, and the requirement is even listed in the bidding documents for urban planning projects.

Infrastructure development: This refers to the planning of building charging piles, power stations and other supporting facilities to accommodate the application of new energy construction dump trucks in a near future.

Optimize the vehicle registration process: In order to effectively promote the sanitation and safety of muck transportation, each regional government implements a transportation approval system for muck transport enterprises [4] in China. The examination and approval of the construction dump truck enterprises is processed by multiple government departments. For example, the Transportation Bureau is in charge of the approval process of road transportation license, and the Urban Administration Bureau has the responsibility to authorize construction waste disposal permits and construction waste transportation permits. In the case of the cities promoting new energy construction dump trucks mentioned in Table 3, local government departments have been objective to shorten the number of approval days to ensure the instant operation of the new energy construction dump trucks.

Compared with the promotion policies of new energy household cars, such as financial incentives and convenience measures (CATARC et al., 2015; Liu et al., 2021; Liu et al., 2022), the promotion policies of new energy construction dump trucks relies more on government support in terms of reducing driving limit and encouraging municipal engineering priority use. The possible reason is that the new energy construction dump trucks as a type of product with low-carbon technologies have a greater market resistance.

The effects of the promotion policies adopted in the pilot cities mentioned in the table 3 can be reflected from the number of new energy construction dump trucks finally purchased by the local area. By the middle of 2022, according to news reports, except for cities of Guangzhou and Qingdao, which promoted and applied hydrogen fuel cells, all other cities mentioned in figure 3 introduced pure electric construction dump trucks.

Summarized in Figure 2, cities with strong financial subsidies for new energy construction dump truck promotion, especially in Shenzhen, delivered the largest number of new energy construction dump trucks, whilst cities with a green procurement mode, such as in Shijiazhuang, Guangzhou and other cities, fewer new energy construction dump trucks were introduced finally.

[4] As projects of dumping construction and demolition waste are only contracted to enterprises instead of to individuals in China, construction dump truck transportation enterprises provided platforms for drivers who purchased construction dump trucks to join in the form of investment or affiliate (Ministry of housing and urban-rural development, 2005).

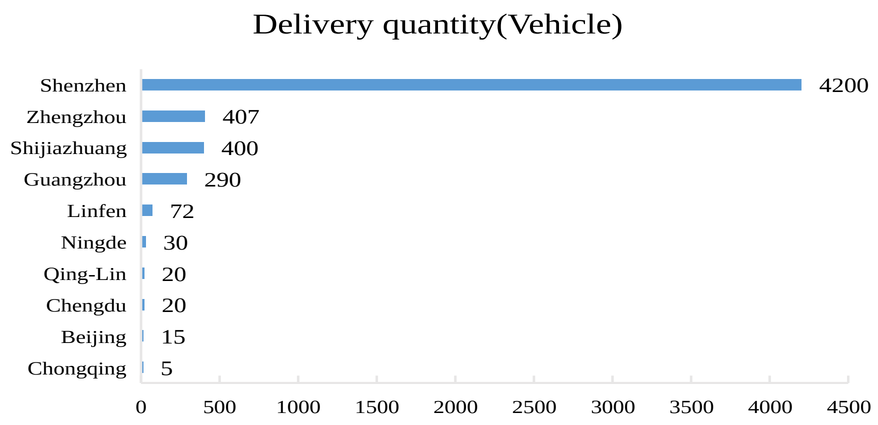

Fig. 2 Cities and their quantity of new energy construction dump trucks by May 2022 (refer to Shenzhen Transportation Bureau, 2019; Peoplezf.cn, 2021; Commercial Vehicle News Network, 2022; Peoplezf.cn, 2021; China Transportation News Network, 2022; Hebei News Network, 2021; North Star Hydrogen Energy Network, 2021; Shanxi Daily , 2022; Trams Resources, 2020; Qingdao Daily, 2021; Chengdu Transportation Investment Group, 2021)

Thus, financial subsidy is a powerful measure to promote the application of new energy construction dump trucks. Due to the high purchase price, the application of new energy musk trucks has a huge market resistance and strongly relied on the support from subsidies.

To clarify specific factors affecting the application of new energy construction dump trucks, an in-depth research is necessary to be conducted to identify specific factors affecting construction dump trucks' decision to apply new energy models.

4.2 Willingness to purchase new energy construction dump trucks

In the case study area, no new energy construction dump truck promotion policy has been introduced and only traditional diesel construction dump trucks are used locally. Qualitative data collected from the focus group approach shows the concerns of local construction dump truck drivers, construction dump truck enterprise representatives and managers about new energy garbage trucks, including the expensive purchase price, excessive weight and concerns for reliability.

"Fuel construction dump truck sells about 0.45 million RMB. The new energy one will cost us 1 million RMB, and is too expensive. "

——Construction dump truck driver 1 from focus group 2

"I think it's too expensive and I can't afford to buy it unless the government subsidises"

——Construction dump truck enterprise representative 1 from focus group 1

"When the temperature is low, the battery life of cars will drop. Will this be the same problem for the new energy construction dump trucks?"

——Construction dump truck driver 3 from focus group 3

In addition, interviewed battery experts acknowledged the decline in battery performance at low temperatures.

"It (the battery of a heavy-duty truck) cannot adapt to the severe winter."

——Battery R&D expert 1 from semi-structured interview

"At-40 ° C, the mileage will be reduced by about 40 %."

——Battery R&D expert 2 from semi-structured interview

Also, under a great financial pressure, and it is hard to largely subsidize the promotion of new energy construction dump trucks.

"Due to the impact of COVID-19, fiscal expenditure is large and the urban revenue is small. Even if there is a subsidy, the amount cannot be large."

——Urban administration department staff 1 from semi-structured interviews

Based on the above findings, factors affecting the promoting of new energy construction dump trucks were summarized. Then, a questionnaire was designed to collect widespread opinions on the willingness to purchase new energy construction dump trucks and detailed influential factors from the perspective of the current situation of the construction dump truck drivers, the situation of fuel musk trucks in use, the purchase willingness of new energy construction dump trucks, and their potential purchase willingness under incentive policies.

4. 3 Statistical analysis results

Through the electronic questionnaire survey, a total of 133 valid questionnaires were collected. The respondents of this questionnaire are drivers who have purchased traditional construction dump trucks, and they are potential buyers of new energy construction dump trucks.

4. 3. 1 Current situation of the construction dump truck drivers

The demographic characteristics of construction dump truck drivers are shown in **Table 4**.

Table 4 Details of construction dump truck drivers in the studied area (*N*=133)

Variable		Percent (%)	n
Age	≤20 years old	0.00	0
	21~30 years old	9.02	12
	31~40 years old	48.87	65
	41~50 years old	34.59	46
	≥51 years old	7.52	10
Monthly Income	2,000~4,000 RMB	9.02	12
	4,000~6,000 RMB	13.53	18
	6,000~8,000 RMB	37.59	50
	8,000~10,000 RMB	33.83	45
	≥10,000 RMB	6.02	8
Educational background	Junior high school and below	43.6	58
	Technical secondary school	28.6	38
	Senior high school	18	24
	Junior college	19	12

Bachelor degree or above	0.8	1

The survey shows that the majority of construction dump truck drivers are middle income, and middle-aged group, and therefore are cautious consumers who would not easily purchase expensive new products. In addition, limited education may affect drivers' environmental awareness and thus their attitude towards new energy construction dump trucks.

In recent years, the impact of COVID-19 on the muck transportation industry has been significant. A large quantity of local construction projects were postponed, and therefore, the workloads of the construction dump truck industry decreased in 2020 (Figure 3). These would inevitably affect the drivers' income and their willingness to replace with new energy construction dump trucks.

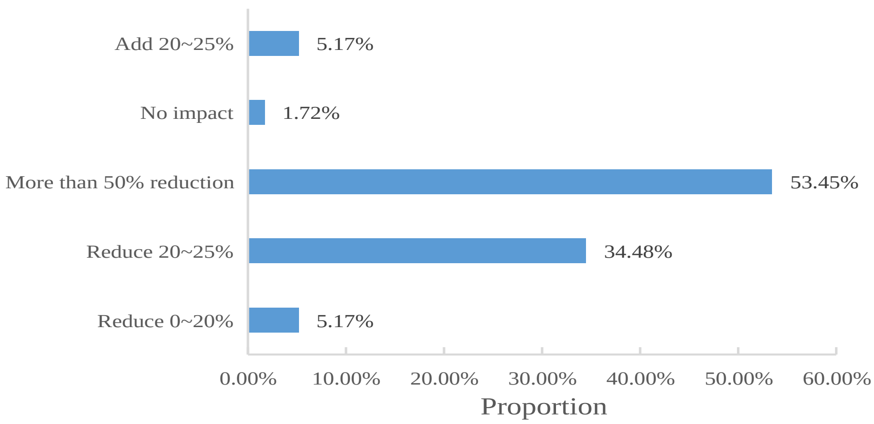

Fig.3 The change of muck transport volume before COVID-19

4. 3. 2 The situation of fuel musk trucks in use

The survey shows that the construction dump trucks used in this central China area are all fuel construction dump trucks, with an average purchase price of 0.5 million RMB; 71% of the vehicles were manufactured after 2017. According to the “compulsory scrapping standards for motor vehicles” issued by the Ministry of Commerce of China in August 2012, the scrapping period of construction dump truck is 15 years.

The survey also collected drivers' satisfaction with the performances of current fuel construction dump truck, including "driving horsepower", "fuel consumption per 100 km", "noise", and "loadable muck weight". Using the Likert five-level scale, "strongly unsatisfactory" was 1 point, "unsatisfactory" was 2 points, "neutral" was 3 points, "satisfactory" was 4 points and "strongly satisfactory" was 5 points.

Table 5 Satisfaction with the performance of the existing fuel musk trucks

Driver' s attitude		Strongly unsatisfactory	Unsatisfactory	Neutral	Satisfactory	Strongly satisfactory	Average score
Performance	Driving horsepower	3. 76%	9. 02%	8. 27%	57. 14%	21. 8%	3. 84
	Fuel consumption per 100 km	11. 28%	22. 56%	18. 05%	37. 59%	10. 53%	3. 14
	Noise	8. 27%	16. 54%	16. 54%	43. 61%	15. 04%	3. 41
	Loadable muck weight	10. 53%	6. 77%	21. 8%	46. 62%	14. 29%	3. 47
Average percentage		8. 46%	13. 72%	16. 17%	46. 24%	15. 41%	3. 46

The average score for the four performances of the fuel musk truck is larger than 3 points, shows that construction dump truck drivers were relatively satisfied with the condition of the existing fuel construction dump truck, especially with the "driving horsepower", which is key to construction dump trucks when working in construction sites with mud and steep slopes. The lowest score was given to "fuel consumption per 100 km", which shows that fuel consumption was indeed a problem of the existing fuel construction dump trucks, but overall, its satisfaction was greater than unsatisfactory.

Generally, the relative satisfaction with existing fuel musk trucks potentially reduced drivers' willingness to purchase new energy musk trucks in recent years.

4. 2. 3 purchase willingness of new energy construction dump trucks

In this study, the expectation of construction dump truck drivers to replace the existing fuel construction dump trucks was investigated from the perspective of the expected replacement time of construction dump trucks and the type of power expected to be replaced.

According to **Figure 4**, accumulatively, 73.68% of construction dump truck drivers had no intention to replace construction dump trucks in a near future (within 4 years).

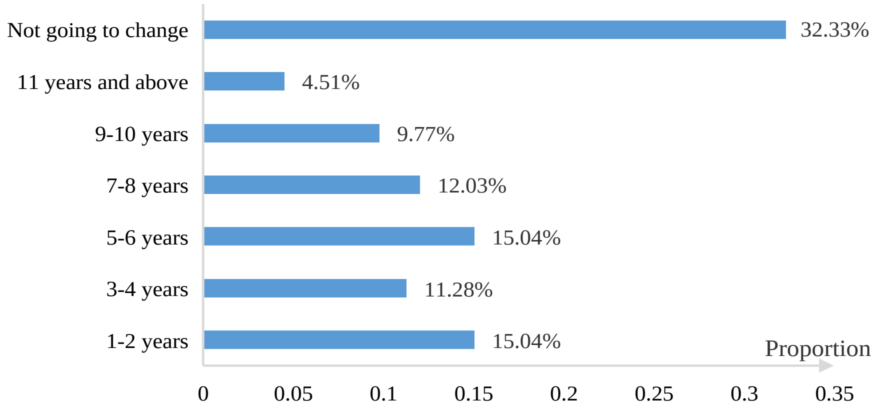

Fig.4 Expected replacement time of the construction dump trucks

Figure 5 shows that even if there is a demand for construction dump trucks, drivers prefer fuel-based construction dump trucks, followed by fuel-electric hybrid vehicles, then new energy construction dump trucks, and finally natural gas. This also reflected the weak willingness of construction dump truck drivers to buy new energy construction dump trucks.

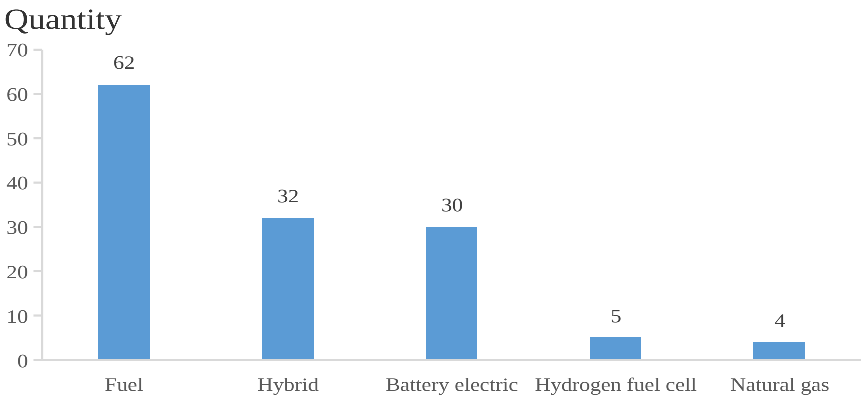

Fig.5 What type of power do you plan for your next construction dump truck?

Only 4% of drivers expressed their willingness to buy new energy construction dump truck (**Figure 6)**. The price of a single new energy construction dump truck is as high as 1 million RMB. If there is no financial subsidy, drivers' intention to buy a new energy construction dump truck is extremely low.

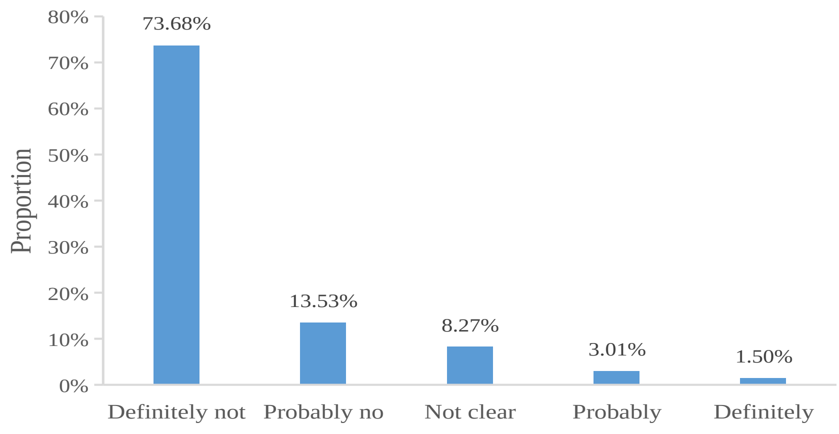

Fig.6 How likely are you to purchase a new energy dump truck without a subsidy?

This survey of target customers for new energy construction dump trucks found that 83 % of the concerns were technical anxiety, such as “limited battery life”, “insufficient climbing horsepower”, “not suitable for cold weather”, “short endurance mileage”, “long charging time” and “incomplete charging infrastructures”, and only 17 % concerns were from “high prices” (**Figure 7**). The applicability of battery technology rather than prices is key to the promotion of new energy construction dump trucks. This potentially reflects that relying solely on the government’s financial subsidies was not a solution. The driver’s willingness to purchase new energy construction dump trucks can be effectively improved with the improvement of technologies such as the battery efficiency and infrastructure development.

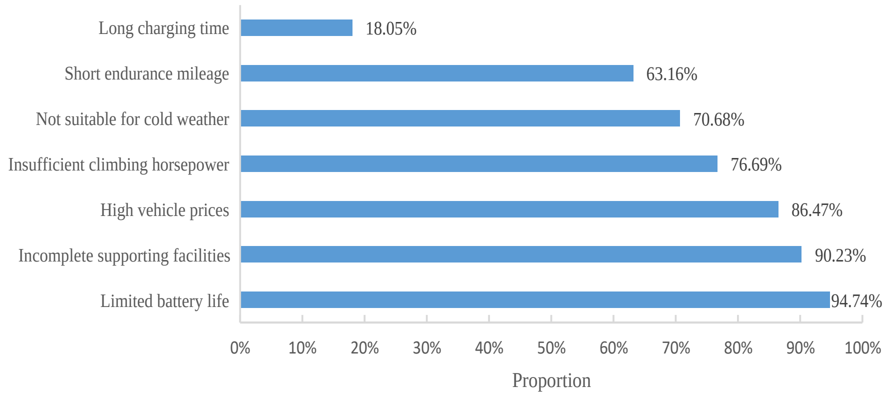

Fig.7 Responses to ‘what are the disadvantages of new energy construction dump trucks?

4. 2. 4 Potential purchase willingness under incentive policies

, Questions were formulated in response to the policy promotion tools in typical cities in China. Construction dump truck drivers' feedback towards incentive policies such as “①financial subsidies”, “②more driving routes”, “③more driving time”, “④optimize the vehicle registration” and “⑤encourage municipal engineering priority use”, are summarized as follows (**Table 6**). Using the Likert five-level scale, "strongly unwilling" was 1 point, "unwilling" was 2 points, "neutral" was 3 points, "willing" was 4 points and "strongly willing" was 5 points.

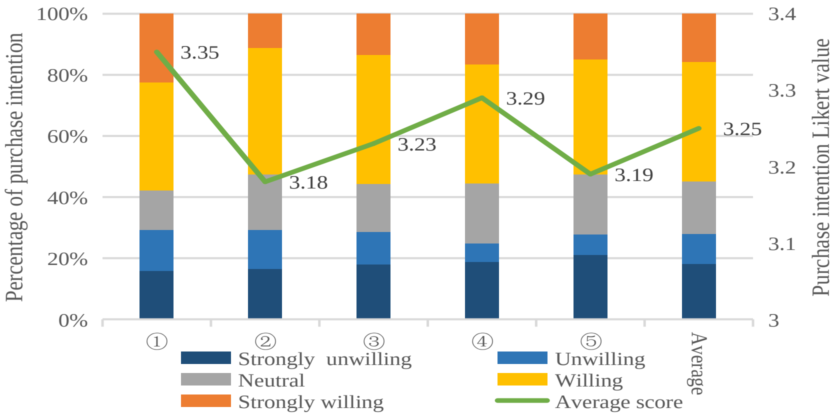

Fig.8 Drivers' willingness to purchase new energy construction dump trucks under policy incentives

The data in the table 6 shows that once the incentive policies are introduced, the average willingness of construction dump truck drivers to purchase new energy construction dump trucks is greater than 3 points, indicating that the above policy measures have a certain incentive effect on the purchase of new energy construction dump trucks. However, the highest score is 3.35 of the financial subsidy, which is between "neutral" and "willing", indicating that the target consumer is not very strong even with financial subsidies. This is consistent with the finding in Figure 8, besides price, there are technical concerns. Market-based support policies, such as providing purchase subsidies, arranging more driving routes or time, optimizing the vehicle registration process and encouraging municipal engineering priority use, may not be ideal, and policy support may be more feasible to shift to upgrading product technology.

5. Discussion

5.1 Policy analysis of promoting new energy construction dump truck

Comparing the existent policy tools of new energy construction dump trucks (see table 3) with that of general low-carbon technologies (refer to table 1), promoting new energy construction dump trucks relies on the market-based promotion work, which focuses more on stimulating the purchase and application of products rather than the R&D of the products. The introduction of new energy construction dump trucks in a city often comes from the strong support of the local government. Drawing upon strategies adopted in table 1, to promote the market of new energy construction dump trucks, local governments can take measures to encourage financial institutions to participate. On the one hand, financial institutions can invest in new energy construction dump truck manufacturers to reduce production costs. On the other hand, financial institutions can provide buyers with flexible loan methods.

Compared to new energy household cars, new energy construction dump trucks are expensive but the quantity demand is limited due to the exhaustible quantity of generated construction waste, so it is possible to introduce subsidies for the whole new energy construction dump trucks in operation without an excessive burden to the local government in a normal economic environment. Shenzhen provided a high subsidy for the promotion of new energy construction dump trucks before 2020 and the effect is remarkable as discussed in section 4.1. However, given the post COVID-19 economic condition, it still brings too much burden for the local government to largely subsidize the purchase cost of new energy construction dump trucks.

It seems that the introduction of support policies, such as reducing driving limit and optimizing the vehicle registration process of new energy construction dump trucks, can foster the market of new energy construction dump truck without financial burden of the local government.

5.2 Analysis of purchase willingness for new energy construction dump trucks

Previous scholars have studied the purchase willingness of new energy vehicles mainly from three perspectives: consumers, products and promotion policies (Tian et al., 2021). The results of this study show that consumers' willingness to purchase new energy construction dump trucks is weak. The main obstacles are the high purchase cost of new energy construction dump trucks, the satisfaction with existing traditional construction dump trucks, and concerns about the maturity of new technologies. Yan and Zhao (2022) also found that consumers are not willing to buy heavy-duty hydrogen fuel cell trucks primarily due to the purchase price. However, further analysis indicates that once incentive policies, especially financial subsidies are introduced, the purchase willingness for new energy construction dump trucks will significantly increase. Therefore, it is argued that the government can introduce technology-push policies to promote the development of technologies such as the lightweight, the cold resistance and the endurance mileage of batteries for heavy-duty vehicles, encouraging new energy construction dump truck manufacturers to upgrade their products to reduce production costs and attract consumers. Once the improved quality attracted consumers' attention, the market acceptance will naturally increase.

In recent years, national and local governments have successively issued relevant policies to promote the R&D of new energy battery industry, for instance, *Action Plan for Promoting the Development of Automobile Power Battery Industry (2017), Three-year Action Plan for the Development of New Energy Battery Industry of Kunming city (2022-2024).*With these policies, the new energy construction dump truck battery production technology will potentially have a breakthrough in future.

5.3 Factors affecting the promotion of low-carbon technologies

The R&D of low-carbon technologies making the products more attractive to the market will promote the diffusion of technologies (Yuan and Li, 2021; Li et al., 2021; Zeng et al., 2020). Low-carbon technologies can use a market research to understand the needs of target customers to clarify which aspects of technologies need to be upgraded and improved. In this study, through the investigation of target consumers, it is found that the technical defects of new energy muck trucks necessary to be improved are battery life, climbing horsepower, battery cold resistance, endurance mileage, and charging time (figure 8).

Policies are crucial to the promotion of low-carbon products, but it is necessary to distinguish between front-end and market-based differences. The front-end policy here refers to the R&D-related policies that promote product improvement and upgrading, and the market-based policy refers to the policies that promote product purchase. Regarding the role of policy promotion, a number of cities in China have promoted new energy muck trucks through subsidies and other supported policies, such as reduced driving limit, optimize the vehicle registration process and encourage municipal engineering priority use, with a limited effect.

This study conducted a survey of policy incentives for target consumers in the studied area, and found that the average purchase willingness was limited and the main reason is that the technical applicability of the new energy construction dump trucks still not meets the expectations of the target consumers.

Perhaps the support of government policies should focus on the improvement of front-end technologies, such as strengthening the training of relevant technical talents, and supporting the R&D of technical equipment and key technologies. A number of Chinese cities recently issued policies fostering front-end technologies. For example, *Guangzhou Hydrogen Energy Industry Development Plan (2019-2030)* involves the introduction of high-end talents and technologies in the field of hydrogen energy and the cultivation of leading enterprises in the field of hydrogen energy.

Previous studies suggest that consumer demand is one of the important reasons affecting the diffusion of low-carbon products or technologies (Zwarteveen et al.,2021; Chakraborty et al.,2022). This study found that the demand for new energy construction dump trucks is very low by exploring the change demand of target consumers (figure 5, figure 6).

6. Conclusion

This study adopted a policy analysis and case study method to investigate the promotion situation of new energy construction dump trucks in China. The findings show that financial subsidies have played a key role in promoting the diffusion of new energy construction dump trucks in the national market. Additionally, this paper studied the purchasing intention and influencing factors of new energy construction dump truck consumers in a city in the central China through qualitative and quantitative methods. In general, local consumers had a weak purchase willingness for new energy construction dump trucks due to their limited technical applicability. We therefore argue that policy support on purchase subsidies should shift to the cultivation and support of relevant talents and battery innovation.

The promotion of low-carbon technologies can use market research to clarify the specific needs of potential customers, which helps to upgrade technology and promote low-carbon technologies. For the diffusion promotion policy of low-carbon products, market-based policy support is important but should be more inclined to front-end investment such as relevant personnel training and equipment support. This study is helpful for policy makers to formulate long-term effective promotion policies, and also provides suggestions for international producers to design and manufacture new energy construction dump trucks.

The purchase willingness of new energy construction dump trucks is the result of a variety of influential factors. The relationships between influential factors are complicated, and they can have mutual influences, some of which are unidirectional and some of which are mutually influential. It is difficult to express the relationships clearly using only basic statistical analysis. Therefore, we will seek a statistical path analysis method to explore the causal structure between the influential factors of the purchase willingness of new energy construction dump trucks.

Author contributions

Ning Lan: Data collection, analysis, investigation, and original draft writing. **Qiaozhi Wang:** Research design, investigation, data analysis, writing, reviewing and editing. **Pauline Deutz**: reviewing and editing. All authors were implicated in the final manuscript preparation and approved the final manuscript. Each author agrees to be personally accountable for the author's own contributions.

Declaration of Competing Interest

None.

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Appendix A. List of questionnaires

Table A.1

Personnel background related and other questions

Item in questionnaire	Options					
What is your age ?	18-20 years old	21-30 years old	31-40 years old	41-50 years old	Over 51 years old		
What is your average monthly income ?	2,000~4,000RMB	4,000~6,000RMB	6,000~8,000RMB	8,000~10,000 RMB	More than 10,000 RMB		
What is your educational background?	Junior high school and below	Technical secondary school	Senior high school	Junior college	Bachelor degree or above		
Has the COVID-19 affected the workload of your muck transportation?	Reduce 0~20%	Reduce 20~25%	More than 50% reduction	No impact	Add 0~20%	Add 20~25%	More than 50 % increase
When are you going to change ?	1-2 years	3-4 years	5-6 years	7-8 years	9-10 years	11 years and above	Not going to change
If you want to change the construction dump truck, what power type do you want to change ?	Fuel	Hybrid	Battery electric	Hydrogen fuel cell	Natural gas		
What disadvantages do you mind most about electric construction dump trucks ?	Limited battery life	Incomplete supporting facilities	High vehicle prices	Insufficient climbing horsepower	Not suitable for cold weather	Short endurance mileage	Long charging time

Table A.2
Questions that can be analyzed based on Likert scales

Item in questionnaire	Score				
	1	2	3	4	5
Are you satisfied with the climbing horsepower of the construction dump truck currently in use ?	a	b	c	d	e
Are you satisfied with the fuel consumption per 100 kilometers of the construction dump truck currently in use ?	a	b	c	d	e
Are you satisfied with the noise of the construction dump truck currently in use ?	a	b	c	d	e
Are you satisfied with the amount of muck that can be loaded on the construction dump truck currently in use ?	a	b	c	d	e
If there is no construction dump truck purchase subsidy, will you buy it ?	a	b	c	d	e
If the government has a truck purchase subsidy, would you like to switch to an new energy construction dump truck ?	a	b	c	d	e
If the government allows more road sections for new energy construction dump trucks, would you prefer to switch to electric construction dump trucks ?	a	b	c	d	e
If the government allows to increase the operation time of new energy construction dump truck, would you like to change to electric construction dump truck ?	a	b	c	d	e
If the government simplifies the process when registering new energy construction dump trucks, are you willing to switch to electric construction dump trucks ?	a	b	c	d	e
If the government encourages municipal engineering to give priority to the use of new energy construction dump trucks, are you willing to switch to electric construction dump trucks ?	a	b	c	d	e

Note:The scale consists of a set of statements. Each statement has five answers : ‘ very dissatisfied or very unwilling ’, ’ dissatisfied or unwilling ’, ’ neutral ’, ’ satisfied or willing ’, ’ very satisfied or very willing ’, which are recorded as 1,2,3,4,5 points respectively.

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