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An Assessment Framework to Prioritize Truck Electrification Scenarios in China

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Executive Summary

The transition to new energy trucks (NETs) in China represents a critical component of the nation's strong ambition to reduce carbon emissions, enhance air quality, and meet sustainability goals in the transportation sector. Early electric truck adoption in cities doesn't just bring direct benefits; it also has a powerful ripple effect that can influence the entire ecosystem. Hence, the study described an assessment framework to prioritize truck electrification in varying regions. The assessment consists of four dimensions associated with truck electrification. An initial analysis using this framework was conducted for two selected heavy-duty truck (HDT) electrification scenarios in China at provincial level. Scenario 1 is mining site transport and Scenario 2 is logistics trunk transport. Relevant indicators for each dimension were chosen and data were collected accordingly. The final results were presented in a heatmap form, showing electrification prioritization for each scenario.

Keywords: Electric Vehicles, Heavy Duty Electric Vehicle & Buses, Policy & Promotion

1 Introduction

China announced the goal to achieve carbon peak by 2030 and by carbon neutral in 2060 for the first time. To realize the great ambition, China issued a comprehensive plan to promote the achievement of these goals [1]. Transport is identified as one of the important sectors for decarbonization, and the approach includes the promotion of energy efficient and fuel-alternative vehicles. China began its journey in new energy vehicles (NEVs) development since 2013 through various incentives for vehicle manufacture and infrastructure construction. In the Roadmap 1.0 for Green and Low Carbon Development of the Automobile Industry, China set the target to have NEVs accounting for 45.0% of total new vehicle sales by 2025 and 60.0% by 2030 [2].

1.1 Truck electrification potential in China

Compared to the progress made for passenger vehicle and bus electrification, truck electrification is still lagging despite of being a significant source of air pollutants in China and a major fuel consumer in the transportation sector. By 2024 October, penetration rate of domestic NEV retail has already reached 52.9% [3]. However, the penetration of light-duty trucks (LDT), mid-duty trucks (MDTs) and heavy-duty trucks (HDTs) only reached 6.2%, 2.9%, 5.6% respectively in 2023 [4]. Table 1 shows the vehicle composition and respective emissions for 4 major air pollutants in China. Despite counting only 11.2% of total vehicle ownership, trucks are responsible for 28.6%, 23.5%, 84.4%, 91.2% for the total emissions in CO, HC, NO_x

and PM where NO_x and PM are mainly contributed by HDTs.

Table 1: 2022 Vehicle composition and respective emission comparison [5],[6]

	Ownership (in 10,000)	CO (in 10,000 tons)	HC (in 10,000 tons)	NO_x (in 10,000 tons)	PM (in 10,000 tons)
Passenger vehicles	25717.6	669.0	172.0	515.9	5
Goods vehicles	3238.9	191.4	40.5	435.4	4.6

The slow take-up of trucks in the early period could be associated with fewer policy tools, high costs, limited vehicle models and lack of adequate infrastructure. With more dedicated policies and incentives on truck electrification, available truck models serving different needs, deployment of high-power charging stations and battery swapping stations, Chinese government managed to gradually shift its vehicle-electrification efforts to trucks in recent years. The national policies are orienting the development direction, focusing on technological innovation and moving away from inclusive subsidy mechanisms. From 2016 to 2019, the minimum battery energy density of NEV eligible for national financial subsidy technical standards increase from 90 kWh/kg to 125 kWh/kg [7],[8]. From 2019 to 2020, the maximum energy consumption per unit payload mass (E_{kg}) of battery electric truck (BET) decrease from 0.30 Wh/km·kg [8] to 0.29 Wh/km·kg [9] to be eligible for subsidies. Local policies such as the right of way for new energy trucks (NETs) aim to improve economic benefits via enlarging operation zones and running longer durations. One of the critical barriers for truck electrification is that they have too diverse applications, and the driving forces and execution of electrification differ significantly from region to region. Taking HDT electrification for example, new energy heavy-duty truck (NEHDT) is mostly seen for short-haul and medium-haul operation with average mileage concentrating within 240 km. The application scenarios primarily focus on resource-based cities with industry such as ports, mining, and steel. These application scenarios feature limited driving ranges, fixed routes, and schedules, facilitating the rapid adoption of NEHDT [10]. Driven by a combination of environmental urgency, policy ambition, technological advancement, and economic incentives, truck electrification in China sees great potential.

1.2 Study objective

Strategic truck electrification deployments are more likely to succeed, providing advantages to first movers and driving further adoption [11]. This study aims to develop a multi-criteria assessment methodology to prioritize truck electrification scenarios in different provinces in China, to inform policy and investment development, as well as to provide a better understanding of the capabilities of electric trucks. The paper is organized as follows: Section 2 offers a comprehensive literature review on the evaluation methods on truck electrification feasibility. Section 3 elaborates on the methodologies utilized in this study, including the framework model and indicators explained. Section 4 details the analysis process of framework by applying it to selected truck electrification scenarios. Section 5 summarizes the significant findings of the research, highlighting the implications for the advancement of truck electrifications and recommendations for future study.

2 Literature review

Research in truck electrification assessment is an emerging field. The literature in this field includes diverse approaches. Forrest et al. quantified the technical feasibility for MDT and HDT electrification in California by estimating the travel demands of in-state medium-duty and heavy-duty sectors [12]. Similarly, two studies [13],[14] examined HDT decarbonization feasibility in the scenario of battery electric vehicle (BEVs) and fuel cell electric vehicles (FCEVs) respectively for countrywide freight applications in Switzerland using real data from the entire Swiss truck fleet. Other than estimating travel demand, other key parameters include energy consumption, vehicle configuration, activity data (e.g. truck trip telemetry), charging infrastructure availability and considerations of adverse conditions in vehicle performance etc. are used for technical feasibility assessment as well. Alonso-Villar et al. developed the technical assessment by considering the impact of extreme weather conditions on electric truck performance [15]. Total cost ownership (TCO) is another common indicator to evaluate truck electrification from an economic perspective in many studies. Y. Feng and Z. Dong developed a quantitative method on electrified powertrain design and selection for light-duty logistics trucks considering TCO [16]. In [17], TCO of mid-duty diesel trucks and mid-duty electric trucks (MDET) are calculated for use case in Toronto Canada, suggesting different drive cycles, operating temperatures and payloads could affect lifetime TCO, making MDET less feasible.

Some studies show different potential of deploying NET considering the locations through comparative analysis. A break-even analysis was conducted for certain Latin-American countries to economically compare diesel and electric trucks. The study suggests that Chile and Uruguay are the first countries to break even in most segments as TCO heavily depends on electricity and fuel price variation which are different crossing countries. A report from NACFE and RMI identified and prioritized high-potential regions to electrify trucks in the United States with a three-part framework [11]. With a heatmap crated, favorable states for truck electrification are found across the countries.

While previous literatures addressed a number of truck electrification feasibility questions, there lacks comprehensive multi-dimensional evaluation for different truck scenarios. Besides, most studies are based on European and American cases, ignoring geographical limitations and regional differences in China for freight demand disparities. To fill the gaps in the literature, this study develops a multi-facet framework to evaluate NET adoption priority. It is novel in the following way: (1) address truck electrification feasibility by differentiating application scenarios for different regions in China; (2) provide a framework to evaluate truck electrification priority from multiple dimensions, specific to China condition. This study also presents an initial analysis using this framework for selected truck electrification scenarios.

3 Methodology and materials

The framework consists of four dimensions which aims to determine high priority regions of China for truck electrification, shown in Figure 1. Possible indicators are listed in the box for each dimension as an example.

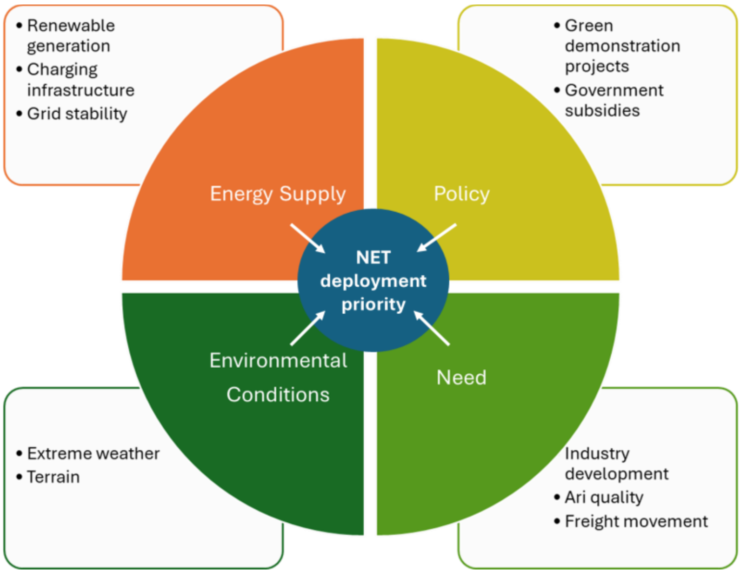

Figure 1: Framework to prioritize NET development in China

Energy Supply China's push toward truck electrification is influenced by its energy supply dynamics, including electricity generation, grid stability, renewable energy integration and charging infrastructure etc. Compared to regions with electricity supplied by coal where emission reduction from using NETs tend to dimmish, rapid expansion of renewables in recent years could incentivize low-carbon truck charging. NET can also be an effective tool to absorb excessive renewable electricity during the generation peak, alleviating impact to grid and distributed to electricity market due to mismatch of supply and demand. Like the challenges faced by early electric car adoption, adequate charging infrastructure is crucial to support electric truck charging. However, different from passenger vehicle usage, commercial trucks operate more intensively, have longer range requirements and need more frequent energy replenishment given their heavy-duty usage profile. Currently, charging duration exceeding 45 minutes encroaches upon the effective operating hours of commercial vehicles (NETs in this case), further compressing fleet profit margins.

Therefore, there is a more urgent demand for high-efficient cost-effective charging technologies, e.g. battery swapping and high-power charging system (e.g. 600 kW) [19]. The high-power charging will lead to the surge demand and hence in regions with robust grid systems are likely to lead the truck electrification.

Need When determining the regional NET deployment prioritization, one should evaluate both the regions where the technology's advantages are most beneficial and where its adoption would address the greatest need - maximizing both suitability and impact. China has launched Air Quality Continuous Improvement Action Plan in 2023 [20] that by 2025, PM2.5 concentrations in all prefecture-level and above cities shall drop by 10% compared to 2020 levels, with the ratio of heavy pollution days (AQI > 200) controlled below 1%. Total emissions of NOx and VOCs shall each decline by over 10% from 2020 levels. They also set localized targets to address regional disparity. HDTs are one of the largest contributors to the mobile source emissions of NOx and create negative impacts on human health and react with VOCs in the presence of sunlight to form the ozone. This motivates the shift to NET. The level of freight movement (both current and future) also reflects the market needs for truck electrification. Logistics industry has experienced rapid growth due to the emergence of e-commerce in China in the past decades and is expected to increase with supporting policies in place. This not only demands higher freight capacity but also urges a green transformation of the logistics industry. By 2022, China's operational logistics parks were predominantly concentrated in the eastern and southeastern coastal regions [21]. The success of truck electrification could also help the industry as a whole to move forward by demonstrating technology feasibility and demonstrating business models, untapping potential in less-developed logistics connectivity and infrastructure modernization of central and western regions [22].

Policies Government policies in China drive the truck electrification, which shape the market adoption, technological innovation, and infrastructure development. It can include regulatory and mandatory policies, various financial incentives and key industry and innovative demonstration projects etc. China accelerates the phase-out of freight vehicles by replacing all Class III and below emission standard diesel trucks and early retirement of Class IV standard diesel trucks [24]. China launched a 2-year nationwide pilot program, running from 2023 to 2025, for full electrification of public sector vehicles (this term refers to official vehicles, urban buses, sanitation trucks, postal and courier vehicles, urban logistics distribution vehicles, and other similar categories) [25]. At provincial and city level, local governments have introduced a series of policies to promote NET adoption, primarily focusing on road priority rights, such as urban access privileges, expressway toll reductions or exemptions and priority in obtaining operation licenses etc. In Hangzhou, Zhejiang A-licensed medium-duty new energy truck (NEMDT) and NEHDT are allowed nightly from 7PM to 7AM to access to the urban core area (excluding expressways) without a travel permit [26]. The most significant effect is observed in narrowing the TCO gap between BETs and diesel trucks since they benefit from longer operation hours and wider coverage in cities [27].

Environmental Conditions Operating conditions that include climate, terrain, and extreme temperatures could also determine the feasibility, performance, and adoption rate of NET across different regions. Battery charging and vehicle power consumption temperature dependent. Abundant studies pointed out the negative impact of sub-zero temperatures on vehicle performance [23],[30],[31],[32]. This is also why vehicle electrification level in Northeast China where winter is longer and colder, is generally lower than that in Southeast China. China's topography is renowned for its complexity and diversity. This not only affects the industrial development but also energy consumption of NET. Compared to regions with climbing steep grades, NETs driven in flat terrain tend to consume less energy under otherwise identical conditions.

4 Scenario analysis and results

Using the above framework described, the initial analysis was completed for two selected scenarios of truck electrification (focusing on HDT) as a first attempt to show their deployment prioritization in China. This methodology produced the results as the 'heatmap' of truck electrification prioritization by province.

4.1 Scenario description

Table 2: Truck electrification application scenarios [28]

S/N	Scenario	Corresponding vehicle type	Characteristics	Single trip/leg distance (km)

1	Mining site transport	HDT	Fixed routes, site space for battery swapping	50
2	Logistics trunk transport	HDT	Long-haul, cross-province	500

Table 2 describes the characteristics of selected scenarios. Scenario 1 is chosen since a series of quantitative and qualitative indicator measurements suggest that mining sites could be suitable to develop electric commercial vehicles in China [28]. This use case features fixed routes and relatively shorter travel distance compared to trunk transport. It has a certain scale of electrification application given its advantage in TCO parity time. However, this scenario requires a more efficient charging solution given its industrial nature in continuous long operating hours. Battery swapping is growing rapidly in China as an alternative to megawatt charging solution before it is in place. It is achieved by replacing a depleted battery quickly with a fully charged one at a dedicated station. Compared to traditional charging stations, battery swapping stations will need larger space to store and charge spare batteries after they are swapped as well as higher capital investment. Hence in the later assessment, the number of battery swapping stations is one of the indicators. Scenario 2 is chosen since the logistics industry is an energy-intensive sector with significant GHG emissions. Freight transport and distribution alone contribute up to 85% of the sector's emissions and hence promoting the electrification of transport vehicles is a critical measure for logistics decarbonization. Logistic truck transport scenario is less developed due to the gap between the technology maturity and the market scales up, but the single-vehicle emission reduction potential from replacing fuel vehicles with NEV is relatively high for this scenario. [29]

4.2 Analysis framework for selected scenarios

Due to data availability and varying policies at different levels, data is collected and analyzed at the provincial level. Therefore, some indicators mentioned in Section 3 that are unique to smaller scales—such as city policies, utility programs, traffic congestion along certain corridors, and grades along routes—were not considered in this initial analysis. This is not intended to imply that these factors are not important. Rather, this reflects the scope and scale of the analysis. A minimum of two indicators for each dimension are selected. attempting to prioritize selected scenarios at provincial level in this analysis. The framework describes truck electrification as shifting to BET. Fuel-cell electric truck (FCET) will not be considered in this analysis. In the scenarios of truck electrification for mining sites, the key promotion areas are focused on mineral resource-based cities, highly driven by environmental protection policies. In the scenario of truck electrification for logistics, it is promoted in cities with strong economies, favorable policy environment and relatively well-developed charging infrastructure. Based on these relevant dimensions, relevant and quantifiable indicators were summarized in Table 3 and data for each of the indicators at the provincial level are evaluated.

Table 3: Framework for prioritizing truck electrification application scenarios in China

Category	Indicator	Metric	Explanation
Energy supply	Renewable	PV installation capacity	Cheaper electricity prices help to improve the operational cost-effectiveness of NET. NET smart charging is also seen as complementary to renewable energy optimal consumption.
	Charging infrastructure	Public charging points	An extensive charging network in a province is crucial to NET deployment in the case of long-haul transport.
		Battery swapping stations	Battery swapping can help achieving efficient charging by replacing a depleted battery quickly with a fully charged one at a dedicated station.
Need	Air quality	Amount of each major pollutants in waste gas emission (NO_x, PMs)	Deployment of NET can help to reduce pipeline emissions. Carbon emissions can be further reduced if they are refueled with green electricity.
	Freight movement	Industrial intensity	Industrial density refers to the concentration of economic activities within a given area, directly influencing transportation demand, e.g. number of

			logistics centers, mine sites etc.
		Road freight turnover	A measure of freight transport that the total amount of goods over total distance transported via road.
Policy	Supportive policies at provincial level	Operational subsidies and/or privileged road access in place	Provincial level supportive polices and subsidies act as major pillars to drive NET deployment soon, especially after the phase-out of national purchase subsidies.
	Green transport demonstration projects	Number of demonstration projects in each province	Demonstration projects usually link with high prioritization on NET promotion, suggesting specific incentives.
Environmental conditions	Temperature	Number of heating degree days (HDD)	Extreme temperature has negative impacts on battery performance and hence the driving range, especially when the temperature is low.
	Extreme weather events	Number of days for poor travel conditions	Extreme climate events including snow, freezing conditions and torrential rainfall, etc., have adverse impact transportation feasibility and energy supply and hence affect NET operation

An overview of how we conducted the analysis is included below, and a more detailed description of the analytical methodology, including metrics and data sources, can be found in a separate **Technical Appendix**.

4.3 Scenario 1 result

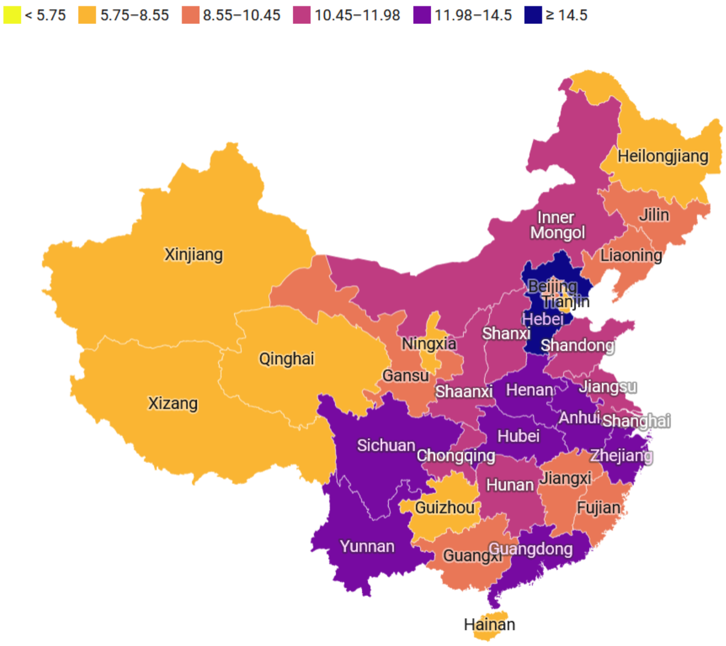

Figure 2: Heatmap of Prioritizing Regions for Electric Truck Deployment for Scenario 1

In terms of selection of charging technology, battery swappable NEHDTs are favored for this scenario given their effectiveness in charging time [10] and hence more weights are given to provinces with more developed battery swapping stations and battery swappable NEHDT policies. The higher the score, the more likely the prioritization of NEHDT deployment should happen. Shown in Figure 3, Hebei is identified as the province with highest priority given the province's struggle to reduce air pollutants, aligning with various ongoing demonstration projects.

4.4 Scenario 2 result

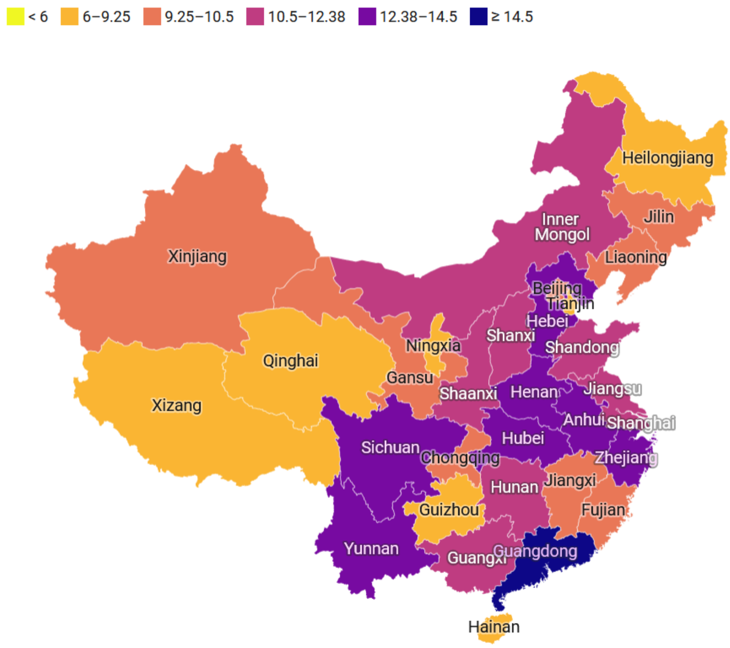

Figure 3: Heatmap of Prioritizing Regions for Electric Truck Deployment for Scenario 2

The provinces for Scenario 2 with high priority are seen in the central-eastern part of China where there are significant logistics hubs presented and are in the strategically in the long-distance transport corridor. This implies higher needs for freight movement. Shown in Figure 3, Guangdong is identified as the province with highest priority given the province's advancement in extensive charging network provision. It has the highest number of public charging points in China by end of 2024. The climate in Guangdong is relatively warm and compared to provinces in the very northern part of China, it has advantage in maintaining the desired driving range for long-haul transport.

5 Conclusion and recommendations

5.1 Summary

Trucks, especially HDT, represent a small portion of total vehicles but contribute a disproportionately large share of GHG air pollutants. Electrifying them can significantly cut emissions from the transportation sector. Yet, compared to China's acknowledged progress in passenger vehicle electrification, the penetration of NET is still slow. The success of NET adoption helps to demonstrate business viability, triggers industrial competition and influences policies. Given limited resources, to identify the key regions for truck electrification in China is crucial. To address it, the study identified four dimensions and associated indicators to assess truck electrification, offering a framework for policymakers, fleet operators, and infrastructure planners to determine how to prioritize NEHDT deployment. An illustrative analysis was conducted for two truck electrification scenarios in China.

5.2 Future works

Real-world data from early deployments of electric trucks in the scenarios identified should be collected and studied. The lessons learned will be used to compare with the deployment progress and therefore refine both the framework and analysis. Using the framework outlined above, the similar analysis can be applied to other critical sectors that urges for transport decarbonization in China given the applicability in limited scenarios in this study. Additionally, the analysis identifies the regions with the highest priority for electric trucks for now. As technologies and environmental policies develop further, future research should have regular updates and stakeholder engagement to review the framework and identify critical factors to ensure long-term sustainability. For example, the emerging concepts such battery banks to decouple battery and vehicle ownership and trucks used in virtual power plant (VPP) bring more economic benefits to truck electrification. The synergy between different dimensions should be addressed.

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