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Analysis of the Current Development Status of New Energy Vehicle Charging Piles in Beijing Based on Data Mining

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Abstract: In recent years, the number of new energy vehicles (NEVs) in China has grown rapidly, becoming an important driver of economic growth. The construction and promotion of new energy vehicle charging piles play a significant role in addressing energy and environmental issues and in promoting high-quality economic development. This study focuses on Beijing, using word cloud analysis and the ISM (Interpretative Structural Modeling) model to analyze the influencing factors of NEV charging piles, including usage efficiency, safety, and faults. Based on the analysis of these factors, corresponding solutions are proposed to provide feasible recommendations for the promotion of NEV charging piles in Beijing. The goal is to assist China's automotive industry in achieving the "dual carbon" targets, facilitate the transformation of the energy structure, and promote high-quality economic and social development.

Keywords: Charging Piles; New Energy Vehicles; Carbon Neutrality; Energy Economy; Data Mining

1. Introduction

The report in October 2022 emphasized the need to proactively and steadily advance carbon peak and carbon neutrality goals, accelerate the planning and construction of a new energy system, and actively participate in global climate change governance. Transportation emissions have become a major source of greenhouse gas emissions, making the development of NEVs one of the key pathways to achieve these environmental goals [1]. In recent years, NEVs have become a new growth point in China's economic development, particularly in foreign trade. Currently, the global automotive industry is undergoing a critical period of technological transformation and upgrading [2]. The promotion of NEVs is of significant importance in achieving the "dual carbon" goals, driving the transformation and upgrading of the automotive industry, and fostering the high-quality development of the energy economy.

The main challenge currently faced by China in promoting NEVs lies in the inadequacy of charging infrastructure. Therefore, research on the current state and promotion path of NEV charging piles is particularly necessary. Existing studies have already established a foundation in areas such as NEV consumer preferences, the layout of charging piles, and safety issues. For example, in "The Pile-to-Vehicle Ratio of Public Charging Piles," it is considered that the supply and demand for charging electricity are influenced by multiple factors, and a method system for calculating the development targets of the pile-to-vehicle ratio is established [3]. In "Analysis of Consumer Upgrade Willingness and Preferences in the NEV Market," consumer preferences regarding the price, performance, and after-sales service of NEVs are analyzed [4]. With the rapid development of the NEV industry, charging piles, as an essential infrastructure, have received widespread attention. Below is a comprehensive analysis of related literature. Zhang Houming (2020) pointed out that the current layout of NEV charging piles in China has flaws. His study emphasized the importance of rational layout for improving the utilization rate of charging piles and suggested several optimization directions [5]. He Shu (2019) delved into the optimization of public charging pile layouts. The study likely used data analysis and model-building methods to explore how to reasonably allocate the number of charging piles based on the demand of different regions to improve resource utilization [6]. Qiao Lixing (2022) also focused on layout issues and

suggested that innovative strategies could be used to mitigate the negative impacts of irrational layouts. For example, private pile sharing could be introduced to enhance the overall utilization of charging facilities [7]. Xiao Qian et al. (2017) proposed a business model that combines charging facilities with the internet. The study likely detailed how online-offline data interaction can optimize the layout of charging piles, improve vehicle and pile information collection channels, and provide users with more precise charging services. This cross-industry cooperation model helps charging pile operators reduce operational pressure and generate profits through multiple channels, such as cooperating with advertisers and data service providers [8]. Hu Yong et al. (2023) observed the current development status of the NEV charging pile industry and focused on policy and institutional aspects. The study suggested that relevant supporting policies, such as tax incentives, should be improved to promote the development of the charging pile industry. It may also have mentioned the need for dynamic adjustments to policies based on market changes and regional differences to better support charging pile operators and ensure the construction and operation of the charging pile network [9].

Existing literature has explored various issues related to NEV charging piles from multiple perspectives, such as layout optimization, business model innovation, and policy support. These studies provide valuable references and ideas for addressing the current challenges in the construction and operation of NEV charging piles, and they also lay the foundation for future in-depth research and practical development. However, existing research has not extensively explored issues such as charging pile operation and maintenance, as well as consumer preferences for the charging piles themselves. Furthermore, there has been little regional or personalized analysis of the current status and promotion suggestions for charging piles specifically tailored to Beijing.

This paper conducts a multidimensional and in-depth exploration of the NEV charging pile topic, systematically analyzing existing policies based on data mining and identifying core influencing factors such as usage rate, safety, and faults, along with their related sub-factors. It constructs an influencing factor framework. Based on these findings, a series of targeted and comprehensive recommendations are proposed to effectively promote the theoretical research and practical application of NEV charging piles, thus providing a solid foundation for the sustainable development of the industry.

2. Methodology

This study combines data mining with the ISM method, employing a mixed approach of quantitative and qualitative analysis. It analyzes high-frequency keywords in text data and reveals the interrelationships and hierarchical structure among these keywords. By using data mining techniques, a word cloud visualization is employed to analyze the text data, extracting the core concepts within the text. The ISM method is then applied to construct causal relationships and hierarchical structures, uncovering the complex relationships hidden in the data.

2.1 Data Mining Methods

Data mining is a process of extracting potential and valuable information from large datasets [10-12]. In text data analysis, word clouds are a commonly used visualization tool that helps researchers identify high-frequency keywords and their significance from large volumes of text [13]. Word clouds display the most important words and potential themes in a text by visually representing the frequency of word occurrences, with the size of the word being proportional to its frequency [14].

In this study, the process of generating word clouds includes the following steps:

2.1.1 Data cleaning and preprocessing

Data preprocessing is a crucial step to ensure the accuracy of the analysis results. The raw text data is first cleaned by removing meaningless characters, punctuation, and HTML tags, which are considered noise. Then, a standard stopword list is used to eliminate common words like “of”, “is”, “at”, and others that hold no significant meaning, avoiding their interference with the keyword analysis results.

2.1.2 Word segmentation and frequency statistics

The text is segmented using a word segmentation tool, and the frequency of each word is calculated. Through word

segmentation and frequency statistics, the keywords and their frequencies in the text are effectively extracted, providing data support for the subsequent word cloud generation.

2.1.3 Generating the word cloud

The frequency data of the words is converted into a visual word cloud using Wordart. The core idea of the word cloud is that the higher the frequency of a word, the larger its font size in the word cloud; conversely, words with lower frequency appear with smaller fonts. This approach allows researchers to easily identify the most frequent and important keywords in the text.

Through the word cloud, researchers can observe which keywords dominate the text and which represent the core concepts of the research. The word cloud not only provides a clear visual effect for the study but also supports qualitative analysis. By observing the shape of the word cloud and the distribution of keywords, researchers can make preliminary judgments about the hot topics in the data and further explore the relative importance of various concepts in the text.

2.2 ISM Model

ISM is a qualitative analysis method used to construct the relationships between elements within a system and reveal their inherent hierarchical structure and causal chains. The ISM method is particularly suitable for uncovering the dependencies and influence pathways between elements in complex systems [15]. In this study, the ISM method is applied to further analyze the keywords of influencing factors extracted through the word cloud and to build a structured relationship model between them. The advantage of the ISM method lies in its ability to help researchers clarify complex causal relationships and hierarchically categorize keywords based on their level of influence, thus illustrating their relative positions within the system.

The main steps of ISM analysis include the following: based on expert judgment or preliminary analysis, a relationship matrix is constructed between the keywords. This matrix is used to describe the mutual influence between each pair of keywords. By analyzing the relationship matrix, the direct and indirect influence paths between the keywords are identified. Based on these paths, the keywords are further categorized hierarchically. The higher the level of a keyword, the greater its influence, and it is typically placed at the top of the model. The hierarchical classification helps researchers understand the position and role of different keywords within the overall system. Based on the results of the hierarchical analysis, the ISM model is constructed. The ISM model is a visualized structure that shows the causal relationships and hierarchy between the keywords. Through the ISM model, researchers can clearly understand the interdependencies between the keywords and their roles within the overall structure [16].

3. Results

3.1 Policy Analysis of Charging Piles in Beijing Based on Data Mining

In recent years, the government has actively promoted the construction of NEV charging piles. The office issued the “Guiding Opinions on Accelerating the Construction of Electric Vehicle Charging Infrastructure,” which clearly defined the development direction of the charging pile industry. Local governments have also introduced policies to promote the construction of charging piles in residential areas, office districts, and public spaces. The implementation of these policies has provided strong support for the development of the charging pile industry. In response to the national call, various regions have implemented differentiated measures based on actual needs, forming a broad and supportive network. Beijing has introduced incentive policies, such as the “Pilot Work Plan for the Unified Construction and Unified Service of NEV Charging in Residential Areas,” aimed at solving the charging difficulties for residents. Additionally, it plans to build 10,000 public charging piles to accelerate the construction of a modern infrastructure system [17-19].

The following is a word cloud created based on relevant national and local policies:

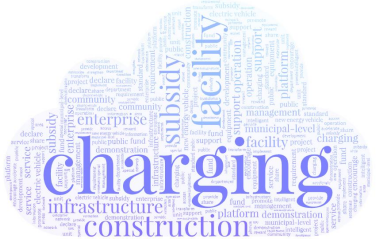

Figure 1. Word Cloud of NEV Charging Pile Policies

In figure 1, the frequency of word appearances visually reflects the core focus and direction of the policies. For example, the frequent appearance of "charging" and "facility" highlights the critical role of charging infrastructure as the foundation of the entire NEV ecosystem. The word "construction" indicates that the large-scale development of the charging infrastructure network is a key task at present, requiring comprehensive consideration and resource investment from planning to implementation. The high frequency of "subsidy" reflects the economic incentive measures in the policy aimed at encouraging businesses to participate in the construction and operation of charging facilities. Subsidies can effectively reduce business costs and risks, accelerating industry development. The prominence of the word "enterprise" in the word cloud suggests that enterprises are key players in the implementation of the policies. Whether it's infrastructure construction companies, NEV manufacturers, or service operators, each will play a role under the guidance of the policies and work collaboratively.

Through the implementation of these policies, the charging pile infrastructure has significantly improved. However, further optimization of policy implementation is still needed, including strengthening coordination between regions and enhancing the precision of resource allocation. With the continuous growth in the number of NEVs, improving the coverage and service capacity of the charging infrastructure network will be an important direction for future policy adjustments.

3.2 Construction of the NEV Charging Pile Influencing Factor System Based on Data Mining

Charging piles, as an essential supporting facility for electric vehicles, are influenced by a variety of factors. To improve the adoption rate of charging piles and enhance user experience, it is crucial to understand the multiple factors that affect their performance. This chapter will construct a word cloud based on literature [20-24] and explore the influencing factors of charging piles from multiple dimensions, offering corresponding suggestions.

As shown in Figure 2, among the influencing factors of NEV charging piles, several key elements play a crucial role in their performance and user experience. For instance, the high frequency of words like "Quantity" and "Location" indicates the importance of the layout of charging piles. A sufficient number of charging piles, along with well-thought-out placement, can better meet users' charging needs, reduce the time cost of finding a charging pile, and thus improve user satisfaction with NEV usage.

Figure 2. Word Cloud of NEV Charging Pile Influencing Factors

"Safety" and "Environment" are also core concerns. Safety is the primary consideration in the design, construction, and operation of charging piles, as ensuring the safety of users and vehicles during the charging process is critical. Environmental factors relate to how well charging piles adapt to the surrounding environment and the potential impact they may have on it. This includes issues such as whether the piles can function properly under harsh weather conditions and whether they are environmentally friendly. The high frequency of "Power" related terms reflects the critical importance of a stable power supply for the proper functioning of charging piles. Both the charging power and the stability of the power source directly affect the user's charging experience.

3.3 Deep Influence Factor Analysis of NEV Charging Piles Based on ISM

Through the analysis of the word cloud of influencing factors for NEV charging piles, the following ISM model is constructed, as shown in Figure 3. The goal is to present the hierarchical relationships and interactions between these influencing factors in a structured way, in order to gain a deeper understanding of how these factors collaboratively influence the performance and usage of NEV charging piles.

3.3.1 Influencing factors of charging pile usage efficiency

The usage efficiency of charging piles

determines the convenience and satisfaction of users in real-world scenarios. An efficient charging infrastructure network can enhance the experience of electric vehicle users and promote the widespread adoption of NEVs. The factors influencing the usage efficiency of charging piles include installation location, power setting, number of units, and maintenance management.

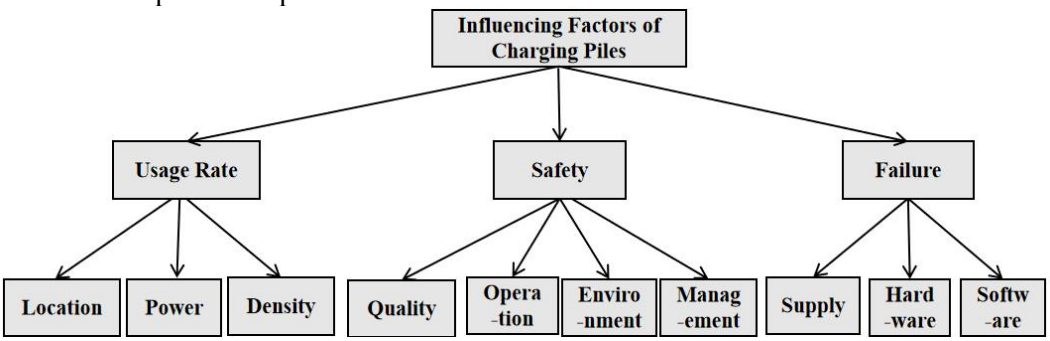

Figure 3. ISM Model of NEV Charging Pile Influencing Factors

3.3.1.1 Installation location

The installation location of charging piles is a core factor determining their usage efficiency. A rational site selection should fully consider user demand. At the same time, the installation location should account for environmental conditions, ensuring good ventilation, excellent waterproofing, and providing sufficient space for passage to prevent users from abandoning use due to inconvenient operation. Charging stations in remote or poorly accessible locations often lead to idle charging piles or low utilization rates, resulting in resource waste.

3.3.1.2 Charging power

Charging power is one of the key factors influencing charging efficiency. Currently, charging piles on the market are mainly divided into AC charging piles (slow charging) and DC charging piles (fast charging). AC charging piles are suitable for long-stay locations, such as residential parking lots, while DC fast-charging piles primarily serve user scenarios that require rapid recharging within a short time, such as highway service areas or urban fast-charging stations. Too low a power output may result in long waiting times for users, reducing the equipment's turnover rate; while too high a power output may place strain on the power grid and significantly increase construction costs.

3.3.1.3 Number and density of charging piles

The number and distribution density of charging piles directly affect the user's charging experience and the utilization rate of the facilities. With the rapid growth of the NEV market, a high-density charging pile network can effectively reduce user waiting times during peak hours. Particularly in high-traffic areas such as commercial districts and residential areas, a reasonable number of charging piles can prevent charging difficulties caused by mismatched supply and demand. However, in areas with lower demand, such as rural or suburban regions, blindly pursuing high-density layouts may lead to resource underutilization.

3.3.2 Influencing factors of charging pile safety

Safety is the primary consideration for electric vehicle users when choosing charging facilities. Safety issues with charging piles may arise from the equipment itself, user behavior, external environmental factors, and management mechanisms. In-depth analysis and improvement of these factors are crucial to ensuring the safe and reliable operation of charging facilities.

3.3.2.1 Equipment quality

High-quality equipment and strict manufacturing standards are the foundation for ensuring the safety of charging piles. Internal electronic components such as capacitors and resistors may fail due to aging, overheating, or corrosion in humid environments, leading to safety issues like short circuits or overcurrent. Additionally, improper wiring or damaged connectors can increase the risk of accidents, potentially causing electric shocks or fires.

3.3.2.2 User operation behavior

Improper user behavior is also an important source of safety issues with charging piles. Overcharging for extended periods can lead to battery overheating or damage. Using the equipment in humid environments may result in leakage accidents. Failing to inspect the

integrity of the connectors as required can cause short circuits.

3.3.2.3 Impact of environmental conditions

Extreme weather conditions (such as heavy rain, high temperatures, or severe cold) can significantly affect the operation of charging piles. For example, high humidity may cause circuit board short circuits or equipment rust, while high temperatures can trigger the overheating protection function of charging piles, causing the equipment to shut down.

3.3.2.4 Completeness of management mechanisms

The lack of a comprehensive management system is often the root cause of frequent safety incidents with charging piles. In some areas, charging piles lack a sound inspection system and emergency response mechanism, leading to long-standing safety hazards.

3.3.3 Influencing factors of charging pile failures

Charging piles may experience failures due to a variety of reasons during actual operation. This not only affects the user experience but also may impact the operational efficiency of the entire electric vehicle charging network.

3.3.3.1 Power supply issues

An unstable power supply environment can lead to frequent disconnections or failures to start the charging pile, such as voltage fluctuations in the power grid or line short circuits. In addition, power lines exposed to high loads for extended periods tend to age, which can cause equipment malfunctions.

3.3.3.2 Hardware damage

Hardware failure is one of the main causes of charging pile dysfunction. The aging or damage of internal components can lead to partial loss of functionality. Mechanical parts such as charging nozzles and sockets, due to frequent use or external impacts, may develop cracks, looseness, or other issues.

3.3.3.3 Software system abnormalities

The software system of the charging pile controls the core operation of the equipment. If there are program errors, version incompatibilities, or communication interruptions, users may be unable to use the equipment properly. Improving the stability and maintainability of the software is a key measure to reduce the occurrence of failures.

In conclusion, the usage efficiency, safety, and failure rates of charging piles are influenced by a range of factors. From scientifically planning installation locations to optimizing equipment technology, improving management mechanisms, and enhancing user awareness, every step plays a crucial role in the overall performance of charging piles. To meet the rapid development needs of electric vehicles, collaborative efforts from the government, enterprises, and society are necessary to build an efficient, safe, and intelligent charging network, thereby promoting the sustainable development of the electric vehicle industry.

4. Recommendations

4.1 Policy Recommendations for Usage Rate

4.1.1 Scientific planning of installation locations

Relevant government departments should issue guidelines for the planning of charging pile installation locations, guiding charging pile operators to place the charging piles in areas with convenient transportation, high foot traffic, and concentrated vehicle numbers. Installing charging piles in such areas can effectively improve their usage rate. A multi-department coordination mechanism should be established, with collaboration between urban planning departments, traffic management departments, and charging pile operators. In newly developed commercial areas, residential communities, and public parking lots, spaces for charging piles should be reserved, and the number and distribution density of charging piles should be clearly defined in the planning.

4.1.2 Adjusting charging power and density

For charging piles in different areas, charging power should be reasonably configured based on local vehicle types and user needs. For example, in locations such as highway service areas and logistics parks, where vehicles urgently need quick charging, high-power charging piles should be prioritized. Charging pile quantities and density should be adjusted according to the local electric vehicle ownership and growth forecast. Regular assessments of charging pile usage in each area should be conducted, and for regions with high usage rates and charging queues, additional charging piles should be added. In areas with low usage rates, the layout should be reasonably adjusted to avoid resource wastage.

4.2 Policy Recommendations for Safety

4.2.1 Establish strict quality standards and certification systems

The government should develop stringent quality standards for charging piles, covering aspects such as electrical safety, mechanical structure, and fire resistance. Charging piles should be included in the national 3C certification product catalog, and only charging piles that pass strict quality certification should be allowed to enter the market. A dedicated quality supervision agency should be established to conduct regular and random inspections of charging pile manufacturers. For products that do not meet the quality standards, the agency should order the company to make corrections or recall the products, along with appropriate penalties.

4.2.2 Standardize operational procedures and training

A unified operational standard for charging piles should be developed, requiring charging pile operators to prominently display user manuals on the charging piles and to push operational tutorials to users through apps or other platforms. Charging pile operators should provide operational training for new users or offer online training videos. At the same time, companies should be encouraged to develop easy-to-use, safe charging pile systems with clear safety prompts to reduce accidents caused by improper operation.

4.2.3 Enhance environmental adaptability in construction and management

Charging pile environmental adaptability construction standards should be issued, requiring outdoor charging piles to be equipped with protective features such as waterproofing, lightning protection, sunshade, and cold resistance. For new charging pile projects, their environmental adaptability design should be strictly reviewed during the approval process. Operating companies should regularly inspect and maintain the environmental adaptability of outdoor charging piles. Charging piles that are damaged due to environmental factors should be repaired or replaced promptly.

4.2.4 Strengthen safety management measures

Charging pile operators should establish comprehensive safety management systems, including regular safety inspections, equipment maintenance records, and fault handling mechanisms. Operators should set up a 24-hour safety hotline to ensure timely response to emergency safety incidents. Relevant government departments should strengthen supervision and inspection of safety management by operating companies. Companies that fail to manage safety properly should be publicly criticized and required to make corrections within a specific time. For companies that repeatedly fail to address safety issues, their operational qualifications should be revoked according to the law.

4.3 Policy Recommendations for Failures

4.3.1 Strengthen power supply assurance and management

The power supply departments should ensure a stable and reliable power supply for charging piles. For large charging pile clusters, such as those in highway service areas and large commercial center charging stations, dedicated power supply facilities, like dual-circuit power supply systems, should be installed to minimize faults caused by power supply issues. The government should introduce policies that encourage power companies to sign long-term, stable power supply agreements with charging pile operators, clearly specifying the power supply quality and fault handling responsibilities in the contracts.

4.3.2 Standardize hardware and software maintenance

Standards and regulations should be established for the maintenance of both hardware and software of charging piles, requiring operators to regularly inspect, repair, and replace charging pile hardware according to these standards. For instance, charging guns should be inspected and maintained after a specified number of plug-in cycles. Regarding the software, operators should set up a software update mechanism to promptly address software bugs and upgrade features. Government departments could establish a software quality supervision platform to monitor the software maintenance practices of operators. Furthermore, software companies should be encouraged to develop charging pile software systems with self-diagnostic and remote repair capabilities to improve fault-handling efficiency.

5. Conclusion

Against the backdrop of China's “dual carbon”

strategy, the promotion of new energy vehicles (NEVs) has become an essential path to achieving carbon neutrality. The research team extensively reviewed relevant literature on NEVs and charging piles to understand the current development status and existing challenges, followed by an integrated analysis. Based on this, the paper presents a series of practical strategic recommendations, including optimizing charging pile layout, enhancing operation and maintenance management, broadening profit channels for operators, and promoting standardized market practices. As a pioneer in the promotion of NEVs, Beijing's experience in charging pile construction and development will serve as a positive model for the NEV industry nationwide and even globally. The research team hopes that the findings of this study will contribute to the development of NEV charging piles in Beijing, foster the healthy growth of China's NEV industry, and make a meaningful contribution to the achievement of the "dual carbon" goals.

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