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Consumer Preferences for Electric Vehicle Charging Infrastructure Based on the Text Mining Method

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Abstract: The construction of charging infrastructure has a positive effect on promoting the diffusion of new energy vehicles (NEVs). This study uses natural language processing (NLP) technology to explore consumer preferences for charging infrastructure from consumer comments posted on public social media. The findings show that consumers in first-tier cities pay more attention to charging infrastructure, and the number of comments accounted for 36% of the total. In all comments, consumers are most concerned about charging issues, national policy support, driving range, and installation of private charging piles. Among the charging modes of charging piles, direct current (DC) fast charging is more popular with consumers. The inability to find public charging piles in time to replenish power during travel or high energy consumption caused by air conditioning is the main reason for consumers' range anxiety. Increasing battery performance, improving charging convenience, and construction of battery swap station are the main ways consumers prefer to increase driving range. Consumers' preference for charging at home is the main reason for their high attention to the installation of private charging piles. However, the lack of fixed parking spaces and community properties have become the main obstacles to the installation of private charging piles. In addition, consumers in cities with different development levels pay different amounts of attention to each topic of charging infrastructure. Consumers in second-tier and above cities are most concerned about charging issues. Consumers in third-tier and above cities pay significantly more attention to the installation of private charging piles than consumers in fourth-tier and fifth-tier cities. Consumers in each city have almost the same amount of attention to driving range.

Keywords: charging infrastructure; natural language processing; public comment assessment; consumer preferences; regional differences

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1. Introduction

To alleviate environmental pollution, energy security, climate change, and other issues, China has been promoting new energy vehicles (NEVs) since 2009. By the end of 2019, NEV ownership in China reached 3.81 million [1], accounting for 53% of total global NEVs [2]. Among them, pure electric vehicle (PEV) ownership reached 3.1 million, accounting for 81.19% of total national NEVs. Nevertheless, after 10 years of development, NEV ownership constituted only 1.46% of total national vehicles [1]. The main obstacles to the slow development of NEVs are the battery's driving range and the construction of charging infrastructures. Particularly for PEVs, limited driving range, long charging time, insufficient charging infrastructure, and high purchase costs have been the main characteristics that hinder consumers from choosing electric vehicles [3–6].

Some scholars have found that strengthening the construction of charging infrastructure can effectively reduce consumers' concerns about the driving range of PEVs and promote the diffusion of NEVs [7–12]. However, by the end of 2019, there were only 1.22 million charging infrastructures in China, including 516,000 public charging piles and 703,000 private charging piles [13]. The number of charging piles and NEVs are seriously mismatched. This raises some questions: To use NEVs more conveniently, which type of charging infrastructure do consumers prefer? In addition, in the process of using the charging infrastructure, what problems did consumers encounter, and how can these problems be solved?

Therefore, from the consumer preferences' perspective, some scholars have studied the satisfaction degree of different types of charging infrastructures to consumers' charging demand in different application scenarios (According to the different charging power, the charging mode of charging infrastructure is divided into direct current (DC) fast charging and AC slow charging. Based on different types, charging infrastructure is divided into public charging stations, private charging piles, and battery swap stations. Private charging piles are mainly installed by electric vehicle owners and belong to alternating current (AC) charging piles. Public charging stations are invested and constructed by enterprises and are usually equipped with DC fast charging piles. The battery swap station can replace the low-power battery of an electric car with a fully charged battery within a few minutes). On this basis, policymakers can adjust supply-side investment strategies consistent with consumers' preferences to better fulfill consumers' demand. Regarding the charging location, some scholars have found that most electric car owners tend to charge at home at night, followed by workplaces, and finally in public places [14–16], with parking lots being the most popular public charging place [15]. In addition, having a private charging pile can significantly affect people's willingness to buy electric vehicles. Consumers with private charging piles are almost twice as willing to buy electric vehicles as consumers who park their cars on streets [9]. As regards the charging mode, some scholars have found that fast chargers are used most frequently in public charging places [15]. In addition, fast charging and battery swap have a greater impact on the daily driving distance of consumers, which can effectively overcome the driving range limit of electric vehicles and increase the driving distance. This is essential for the wide market penetration and public acceptance of electric vehicles [17,18].

To analyze consumer preferences for different types of charging infrastructures, the main objectives of this study are: ① Clarify the main topics that consumers are concerned about regarding charging infrastructure. ② For each topic, clarify consumer preferences for charging infrastructure. ③ For consumers in cities with different development levels, analyze the differences in the preferences for charging infrastructure. It is important to study consumer preferences for charging infrastructure. First, consumers' preference for charging infrastructure is also the main factor affecting consumers' choice of NEVs. Second, by accurately grasping consumers' preferences for charging infrastructure, policymakers can have a more comprehensive understanding of consumer demands, thereby optimizing policies related to charging infrastructure, and better promoting the development of NEVs. Finally, by understanding consumers' demands for charging infrastructure in different usage scenarios and in different cities, charging infrastructure investors can calibrate their construction plans, increase the rate of return on investment, then increase investors' enthusiasm for investment in charging infrastructure and increase the number of charging infrastructures.

To analyze consumer preferences, utility theory is often used. Utility is a subjective psychological evaluation of consumers on the ability of goods to satisfy their own desires. Ordinal utility theorists propose to use consumer preferences to reflect consumers' preferences for different combinations of commodities, and to reflect consumers' evaluations of the utility level of different commodities according to the differences in consumers' preference for different commodities [19]. Consumer utility is an important indicator of measuring product quality and service level, and it has become an important means to maintain and improve consumer satisfaction and loyalty. Starting from consumer preferences to make corresponding operational decisions is of great significance for maintaining product competitiveness [20]. At present, most scholars use survey questionnaires [9,10,16,21], system simulations [8,22], or analysis of actual charging data of electric vehicles [15,17,23], in order to study consumers' preferences for charging infrastructure. With the development of communication technology, using online content to investigate public opinions can effectively avoid the complexity of interacting with respondents, making the data collection simple and the sampling rate high (close to 100%) [24]. Nevertheless, there are still few studies based on online text data analysis. Considering that consumers can express their true opinions more freely in online forums, this part should not be ignored.

The novelty of this study is as follows: First, the data are taken from China's main social media for discussing charging infrastructure, mainly including charging experience, problems encountered during charging, and opinions on current problems or future development of NEVs and charging piles; all data are free opinions given by consumers; and the data are more open and authentic. The second novelty is adopting text mining methods based on NLP technology. Text mining is an artificial intelligence technology that can extract meaningful information from text data. This method is widely used in topic recognition and opinion mining [25]. Using word frequency statistics, topic modeling, and keyword similarity analysis, it is possible to quickly extract meaningful keywords from a large number of texts, determine consumers' core concerns, and realize semantic associations between keywords to further mine consumers' preference for charging infrastructure. Text mining methods are more reliable than traditional analysis methods, and the analysis results have more reference value and practicality [26].

The remainder of this paper is organized as follows: Section 2 contains the research methods and data sources, Section 3 comprises the publication intensity analysis, the consumer comments mining, the regional difference analysis, and Section 4 puts forward the conclusions and policy implications.

2. Methodology and Data

2.1. Data Sources

The data of consumers' comments on charging infrastructure are collected from the main websites where consumers discuss charging infrastructure in China (e.g., Autohome (https://club.autohome.com.cn, accessed on 5 July 2020), PCauto (bbs.pcauto.com.cn, accessed on 5 July 2020), Xcar (http://www.xcar.com.cn/bbs/, accessed on 6 July 2020), Sina Weibo (https://m.weibo.cn/, accessed on 6 July 2020), and Zhihu (https://www.zhihu.com/, accessed on 7 July 2020)). We search with "charging pile" as the keyword, and then use Python web crawler technology to obtain the search results and store them in Excel. Finally, we collected 59,067 pieces of consumer discussion data on charging infrastructure. Each piece of data includes user name, date, province, city, data source, and comment. Part of the data is shown in Appendix A Table A1.

2.2. Methods

We analyze the consumer comment data from three dimensions, namely, publication intensity, consumer preferences, and regional differences. First, using the publication intensity analysis, analyze the difference in the amount of consumer attention to the charging infrastructure from the time dimension and the space dimension. Then, using consumer preference analysis, deeply dig into consumers' preferences for charging infrastructures. Finally, based on the differences in consumer preferences, we further explore the different concerns of consumers in cities with different development levels on charging infrastructure. It can follow the path of "intensity difference–preference difference–regional difference", step by step, and analyze consumers' preference for charging infrastructure. The analysis framework is shown in Figure 1.

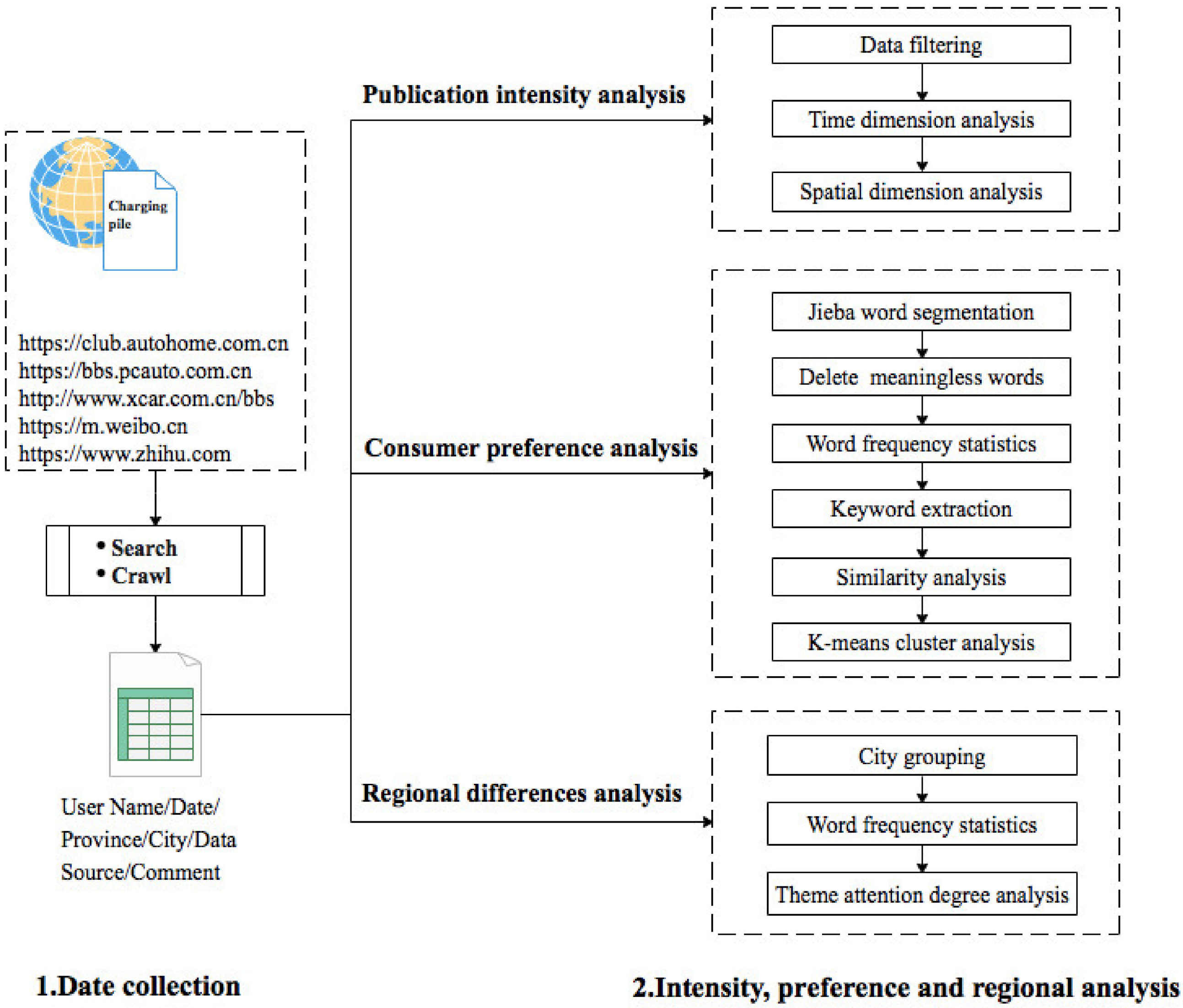


Figure 1. Data analysis steps.

2.2.1. Publication Intensity Analysis

We analyze the changes in the number of comments posted by consumers from the time dimension and space dimension.

First, for publication intensity analysis, to prevent the statistical deviation caused by the same user replying to the same post multiple times, only one record is kept for the same user in the same month. In the end, 26,706 records were retained.

Second, we analyze the evolutionary characteristics of the number of comments on charging infrastructure posted by consumers on a monthly basis.

Finally, we analyze the distribution characteristics of the number of comments on charging infrastructure posted by consumers in different cities.

2.2.2. Data Preprocessing

Before using the text mining method to analyze consumer comments, it is necessary to preprocess all the comments. First, use Jieba word segmentation technology (Jieba is a Python Chinese word segmentation component, which provides a dictionary of Chinese character prefixes. For the words in the prefix dictionary, a directed acyclic graph (DAG) is constructed, and word segmentation can be completed through dynamic programming. For words that do not exist in the prefix dictionary, a hidden Markov model is needed. In addition, developers can also specify their own custom dictionary to include words that are not in the Jieba thesaurus, and adding new words by themselves can ensure a higher accuracy rate. For a more detailed introduction, please visit: https://github.com/fxsjy/jieba, accessed on 20 December 2020) to decompose the comments into words. Second, use the stop word list (Stop words refer to certain words that are automatically filtered out before or after processing natural language data (or text) in order to save storage space and improve search efficiency in information retrieval. Stop words are usually divided into two categories. One is functional words with no actual meaning, such as "the", "is", and "at". The other is words that are widely used, such as "want", which are difficult to help narrow the search range and reduce search efficiency) to delete all meaningless words. The purpose of deleting stop words is to keep only the words with the greatest meaning [27].

2.2.3. Keyword Extraction

Keyword extraction is a technique or process for extracting key and important terms from unstructured text data. It is one of the simplest but most powerful techniques for extracting essential information from text [27]. We use term frequency–inverse document frequency (TF-IDF) algorithm to extract keywords from all comments. Furthermore, to be able to perform cluster analysis on all comments, we also use the TF-IDF algorithm to extract a keyword from each comment.

TF-IDF is a digital statistical method that can determine the weight of each term (or word) in each document. The weight is used to evaluate the importance of the term (or word) in the document, and the importance of the term (or word) increases in proportion to the amount that appears in the document [28]. TF-IDF is expressed as the product of the two metrics tf and idf, where tf is the term frequency, and idf is the inverse document frequency.

The term frequency is calculated as follows:

$$tf(w,D) = \frac{n_{wD}}{\sum n_D} \tag{1}$$

where $tf(w,D)$ represents the tf of word w in document D; n_{wD} represents the times of word w appears in document D; and $\sum n_D$ represents the total number of words in document D.

The inverse document frequency is calculated as follows:

$$idf(w) = \log\left(\frac{C}{df(w)+1}\right) \tag{2}$$

where $idf(w)$ represents the idf of word w; C represents the total number of documents in the corpus; and $df(w)$ represents the total number of documents with word w in the corpus.

Thus,

$$tfidf = \frac{n_{wD}}{\sum n_D} \times \log\left(\frac{C}{df(w)+1}\right) \tag{3}$$

where $tfidf$ is the weight of each keyword calculated using the TF-IDF algorithm.

2.2.4. Keyword Similarity Analysis

The main purpose of keyword similarity analysis is to analyze and measure the distance between two keywords. The keyword similarity can identify some keywords that are closest to the central keyword, help us classify consumers' preferences, then summarize and analyze consumers' preferences for charging infrastructure. First, we use the "word2vec" algorithm in the Python programming language to extract the feature vectors of all comments. Then, we use the "most_similar" function to calculate 20 words that are closest to each keyword that consumers care about most.

3. Results and Discussion

3.1. Publication Intensity

3.1.1. Time Dimension

Figure 2 shows the change in the amount of consumer discussions about charging infrastructure (red track) and the change in NEV sales (green track) in the time dimension. We noticed that the number of consumer discussions on charging infrastructure is highly consistent with the change trajectory of NEV sales. Both were very limited before 2015 and gradually increased after 2015. This finding indicates that, in the early stage of the development of NEVs, because of the low NEV ownership, consumers paid less attention to charging infrastructure. However, with the successive release of NEV promotion policies, the NEV ownership has gradually increased, with the development of charging infrastructure lagging behind the development of NEVs. In 2015, the ratio of the number of charging piles to NEV ownership was as high as 7.8:1 [29]. Therefore, more consumers have begun to use social media to publish their experience, attitudes, or difficulties faced in the use of charging infrastructure, which has gradually increased the number of discussions on charging infrastructure.

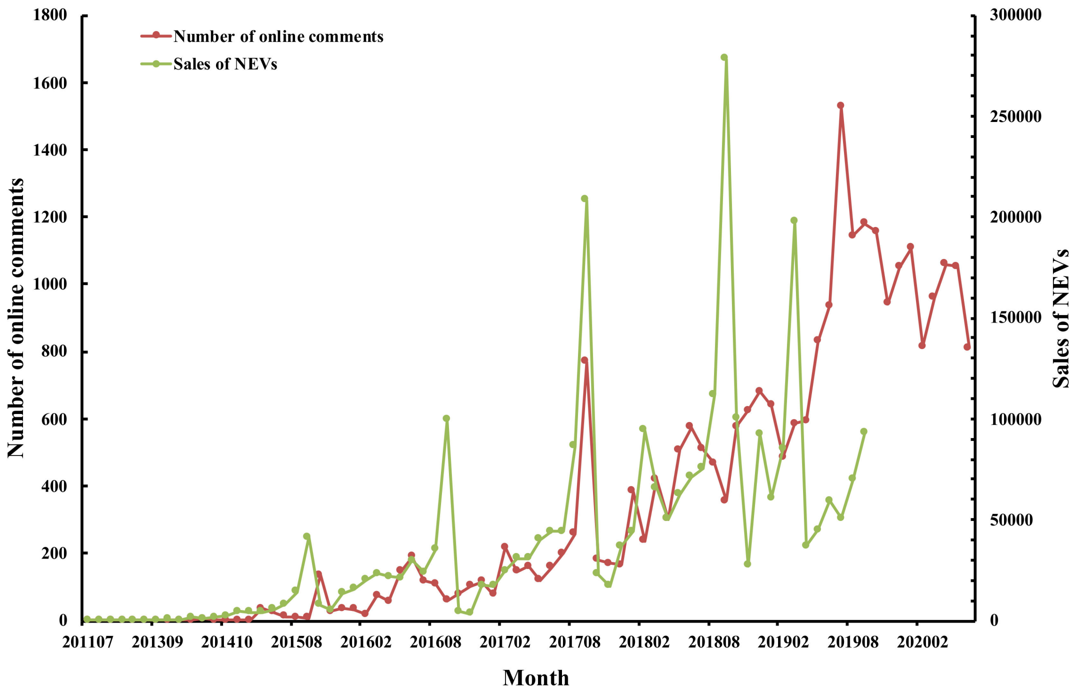


Figure 2. Monthly publication intensity and the sales of NEVs.

3.1.2. Spatial Dimension

Figure 3 shows the number of consumer discussions about charging infrastructure in different regions. From the perspective of spatial distribution, the five cities that pay the most attention to charging infrastructure are Beijing, Shanghai, Chengdu, Shenzhen, and Guangdong. Among them, Beijing, Shanghai, Shenzhen, and Guangzhou belong to first-tier cities, and the number of comments posted by consumers on charging infrastructure accounted for 36% of all comments. In addition, these four cities have adopted restrictions on the purchase of internal combustion engine vehicles (ICEVs). Compared with ICEVs, these cities have adopted more tolerant promotion measures for NEVs, especially PEVs. Therefore, consumers in these cities will pay more attention to NEVs, and they will have more discussions on charging infrastructure.

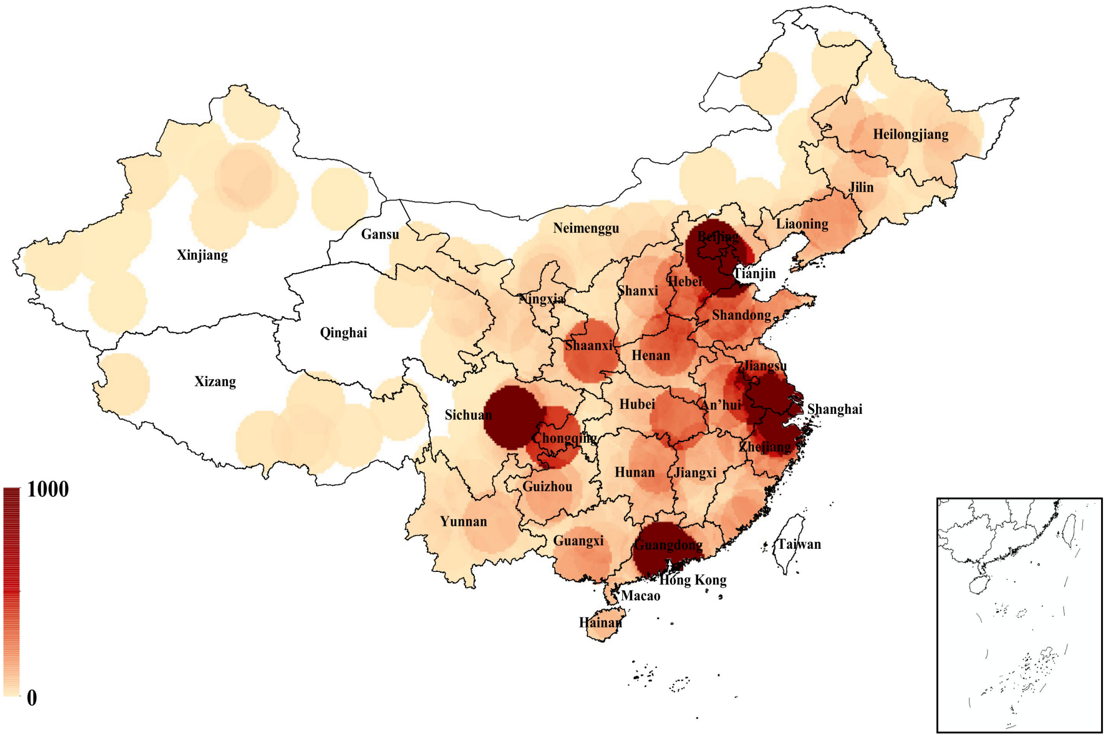


Figure 3. Distribution of consumer comments in different regions.

3.2. Consumer Preference Analysis

3.2.1. Word Frequency Statistics

After word segmentation, we counted the occurrence frequency of each term, and generated the word cloud (Figure 4), where the higher the frequency, the larger the font displayed in the word cloud. In addition, after excluding basic words such as "charging pile", "electric vehicle" and "new energy vehicle", the top 30 high-frequency words are shown in Table 1.

Table 1. Word frequency statistics of consumer comments.

No.	Word	Frequency	No.	Word	Frequency	No.	Word	Frequency
1	charging	27,790	11	Not	4616	21	feeling	4043
2	driving range	9932	12	parameters	4614	22	develop	4041
3	battery	7566	13	service	4506	23	car owner	4032
4	install	6178	14	market	4461	24	China	3965
5	kilometer	6143	15	design	4457	25	electricity	3848
6	vehicle type	6070	16	Drive	7679	26	charging station	3802
7	buy	5686	17	technology	4414	27	system	3685
8	win	5571	18	enquiry	4401	28	new	3616
9	BYD	4879	19	Tesla	4360	29	want	3603
10	month	4848	20	Time	4326	30	high	3561

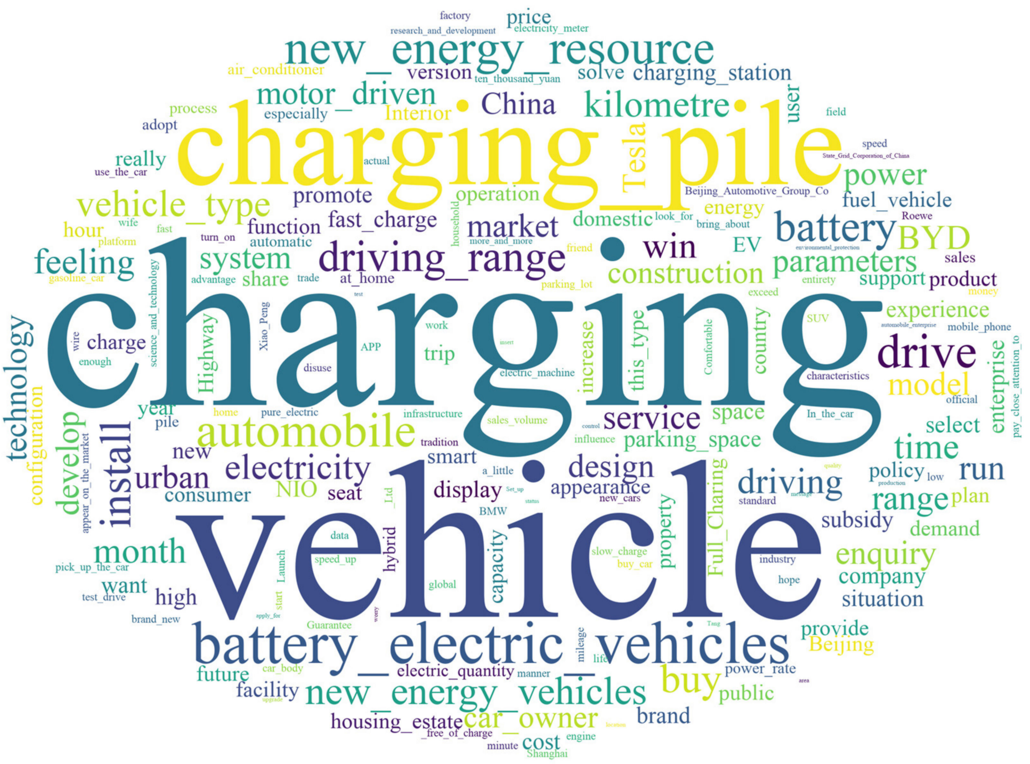


Figure 4. Word cloud of consumer comments.

It can be found that the five words most frequently discussed are "charging", "driving range", "battery", "installation", and " kilometer". Indicating that the focus of consumers on charging infrastructure is to extend the driving range of NEVs through convenient charging modes. Using word frequency analysis, it can also be found that consumers' preferred strategies for extending the driving range of NEVs mainly include, first, technically improving the storage capacity of NEV batteries ("batteries" appeared 7566 times); second, strengthening the construction of charging infrastructure, including the installation of private charging piles ("installation" appeared 6178 times) and the construction of public charging stations ("charging stations" appeared 3802 times), and, finally, reducing the waiting time, through the construction of battery swap stations ("battery swap" appeared 1835 times).

3.2.2. Keyword Extraction and Similarity Analysis

Based on word frequency statistics, we use the TF-IDF algorithm to extract the 200 most important keywords from all comments. Then, we use the word2vec model to convert all comments into word vectors, and use the "most_similar" function to calculate the terms most similar to the main keywords. Finally, according to the similarity between the keywords, the main topics that consumers pay attention to are classified (Table 2). The weight of keywords is calculated according to Equation (3). Table 2 only shows the first 10 topic words of each topic.

Table 2. Keyword topics.

Topic 1: Charging		Topic 2: Installation of Private Charging Piles		Topic 3: Driving Range		Topic 4: National Policy	
Keywords	**Weights**	**Keywords**	**Weights**	**Keywords**	**Weights**	**Keywords**	**Weights**
charging	0.0243	install	0.0094	range	0.0160	market	0.0093
charging pile	0.0180	service	0.0089	kilometer	0.0096	China	0.0088
battery	0.0120	enterprise	0.0071	trip	0.0054	development	0.0080
charging station	0.0087	property	0.0060	highway	0.0046	construction	0.0078
model	0.0065	parking place	0.0059	solve	0.0042	subsidy	0.0065
time	0.0062	community	0.0052	air conditioner	0.0041	city	0.0062
fast charging	0.0055	electricity meter	0.0041	battery power	0.0040	policy	0.0053
hour	0.0054	free	0.0039	drive	0.0039	future	0.0052
place	0.0048	State Grid Corporation of China	0.0030	exceed	0.0037	country	0.0042
fully charged	0.0044	apply for	0.0030	minute	0.0035671	facility	0.0039

Table 2 shows that the topics most discussed by consumers about charging infrastructure are charging, driving range, installation of private charging piles, and national policy support. For charging, the weights of "mode", "charging station", "fast charging", and "charging time" rank high, indicating that, when consumers use public charging facilities, they prefer to use DC fast charging to reduce the waiting time. For driving range, "highways" and "air conditioners" rank high, indicating that long-distance travel or rapid consumption of electricity caused by air conditioners are the main factors that consumers want to increase the construction of charging infrastructure. For private charging pile installation, "installation" has the highest weight, indicating that consumers are more inclined to install private charging piles for charging at home. However, the weights of "community", "property", and "parking space" are also ranked high, indicating that residential properties and fixed parking spaces are the main factors affecting the installation of private charging piles. For policy support, the weights of "development", "construction", and "subsidies" rank high, indicating that consumers hope that the country can develop charging infrastructure and improve charging convenience.

3.2.3. Visualization of Similarity Correlation Network

Based on the topic classification in Table 2, "charging pile", "electric vehicle", "charging", "range", "property", and "policy" are used as the main keywords; then, we calculated the similarity between other terms and the main keywords. Subsequently, for each main keyword, the 20 most similar terms were selected (Figure 5).

Figure 5 suggests that, when "charging" is the central keyword, the most discussed topics of the charging pile are charging mode, charging time, and charging speed. Among them, the similarities between "DC charging", "short time", "public charging pile", and "charging" are all higher than the similarity between "AC charging" and "charging", indicating that consumers prefer to use DC charging to shorten the charging time; especially when traveling for long distances, consumers are more inclined to use fast charging to shorten the waiting time [30]. Obviously, "AC charging", "slow charging", and "charging" also have a high degree of similarity. This is mainly because AC charging is cheap and economical [31], and AC charging is more convenient for consumers to recharge electric vehicles at home at night [15,32]. However, when consumers use public charging stations, especially during long-distance travel, they are more inclined to use DC fast charging to reduce the charging time [30]. Furthermore, "too slow" is one of the terms with the highest similarity to "charging", which suggests that consumers are still not satisfied with the charging speed of the current charging infrastructure. According to consumer comments, consumers believe that the charging speed is too slow, mainly because the electric vehicle has insufficient range during driving, and when it is necessary to use a public charging pile to charge, the waiting time for charging is too long. In particular, the highway service area during holidays is often very congested, and queueing up for charging takes a lot of time.

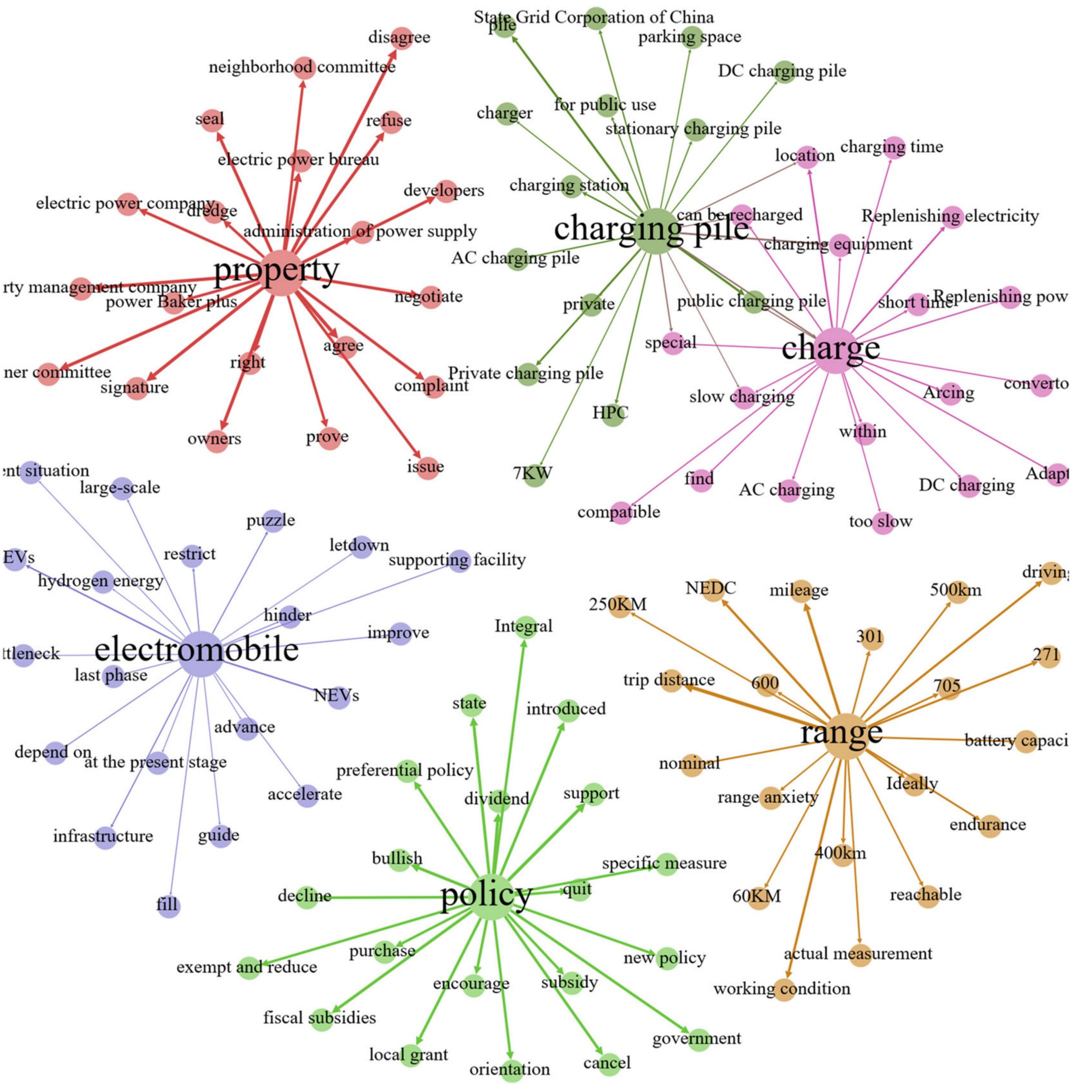


Figure 5. Keyword similarity analysis.

When "range" is the central keyword, "range anxiety" is one of the most similar terms. Therefore, we further used "range anxiety" as the central keyword to explore consumers' discussions on the issue of "range anxiety" (Figure 6). Figure 6 suggests that the core reason for consumers' range anxiety is that they cannot find charging piles, which is mainly reflected in three aspects: first, during long-distance travel, the charging pile cannot be found in time to recharge the electric vehicle; second, in winter, turning on the air conditioner consumes a lot of electricity, resulting in a significant reduction in the actual driving range, but charging infrastructure is insufficient to supplement the electricity in time; the third aspect is the technical shortcomings faced at the current stage. Therefore, consumers' preference for "range" can be summarized as the demand for increasing the construction number and construction density of charging infrastructure.

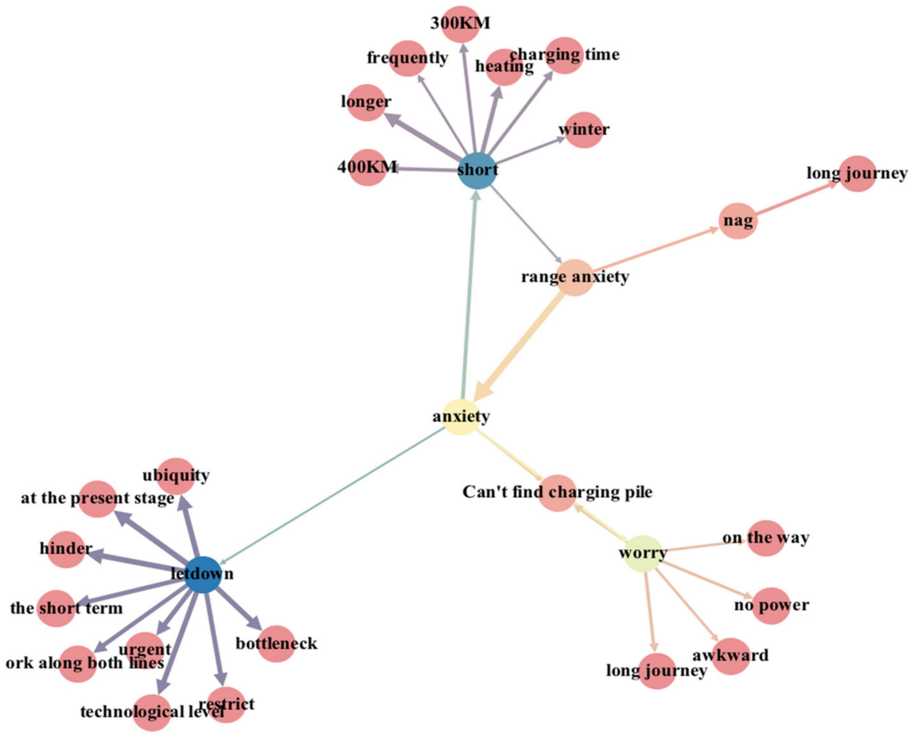


Figure 6. Analysis of related words in range anxiety.

At present, because the main influencing factor for the installation of private charging piles is community property, for the topic of the installation of private charging piles, we use "property" as the central keyword to analyze the most similar terms. Figure 5 shows that consumers discuss the most about whether the community property agrees to install private charging piles, and the main solution when the property refuses to install private charging piles. As the policy stipulates that families first need to have a fixed parking space in the community, and then after obtaining the consent of the community property, they can apply to the electric power bureau to install private charging piles. However, due to limited parking spaces, many communities cannot provide residents with fixed parking spaces. Additionally, because electric vehicles have charging safety problems, many properties refuse residents' applications for installation of private charging piles. According to a survey initiated by D1EV (http://www.d1ev.com/, accessed on 20 December 2020) in September 2019, among the surveyed car owners who have purchased NEVs, 73% of the car owners cannot install a private charging pile, 44% of them have no fixed parking spaces, and 38% of them are obstructed by the community property. Among the car owners who have installed private charging piles, 52% have been obstructed by the property during the installation process [33]. When the property rejects the residents' application for the installation of charging piles, similarity analysis shows that consumers usually continue to apply to the owners' committee, and when property and owner's committee are unsuccessful in negotiation, they will complain to the higher-level government agency. However, based on the survey conducted by D1EV, only 27% of the car owners who participated in the survey successfully installed private charging piles [33], which shows that, when consumers encounter the obstacle of the property, the effect of negotiation and complaint is minimal.

3.2.4. K-Means Cluster Analysis

We first use the TF-IDF algorithm to extract a keyword from each comment, and then manually correct the keywords to accurately reflect the main content of the comment. Finally, we use the K-means algorithm to cluster all the comments and obtain the classification shown in Table 3.

Table 3. K-means clustering results.

Cluster No.	Key Features
0	can, electric vehicle, charging, still, not
1	new energy, car, charging, development, market
2	this, charging, problem, can, still
3	driving range, mileage, kilometer, charging, anxiety
4	installation, property, charging, meter, community
5	charge, can, question, convenient, not

Table 3 shows that categories 0, 2, and 5 are related to charging, category 1 deals with the future development of NEVs, category 3 is concerned with driving range, and category 4 is related to the installation of private charging piles. Therefore, the results of the cluster analysis correspond to the above topic classification. Figure 7 shows the final clustering results. It suggests that consumers are most concerned about the charging performance of the charging infrastructure, followed by the use of the charging infrastructure to extend the driving range. Furthermore, the two major categories of charging and driving range highly overlap, which indicates that, compared with the installation of private charging piles and policy support, consumers are more concerned about the charging mode of the charging infrastructure and the use of charging convenience to increase the driving range of NEVs.

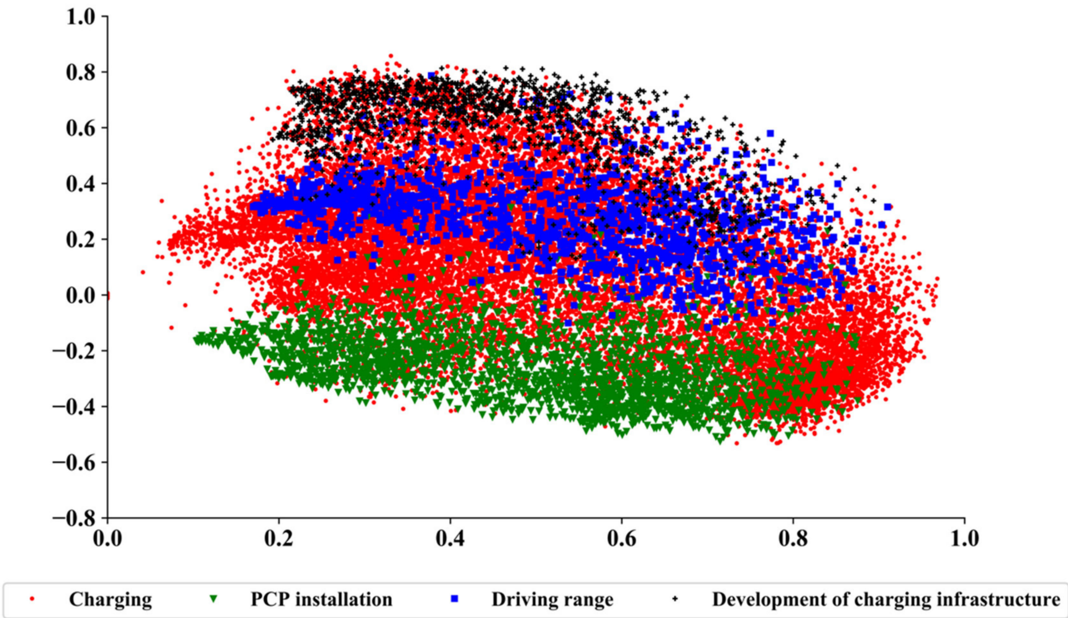


Figure 7. K-means analysis.

3.3. *Regional Difference Analysis*

To explore the preference differences of consumers in cities with different development levels, we divided the sample cities into first-tier cities, new first-tier cities, second-tier cities, third-tier cities, fourth-tier cities, and fifth-tier cities based on the "2020 City Business Charm Ranking List" released by the New First-tier Cities Research Institute (see Appendix A Table A2 for details) (Website: https://www.yicai.com/news/100648666.html, accessed on 20 December 2020. This report assesses China's 337 prefecture-level and above cities based on collected commercial store data of 170 mainstream consumer brands, and user behavior data and city statistics of 18 leading internet companies in various fields).

Then, we conducted word segmentation and word frequency statistics on the consumer comments in each group, and exclude "charging piles" "new energy" "cars" "new energy vehicles", and "electric vehicles". We analyze the preference differences of consumers in different city levels for charging infrastructure, by examining the top 50 high-frequency words of each city level (Appendix A Table A3).

Word frequency analysis shows that consumers in different city levels have the same concerns about charging infrastructure, including charging problems, the installation of private charging piles, driving range, and charging modes. Therefore, we classify these high-frequency words based on the topic classification in Table 2. Additionally, the category "NEV characteristics" has been added to count consumers' discussions on the performance of NEVs (Figure 8).

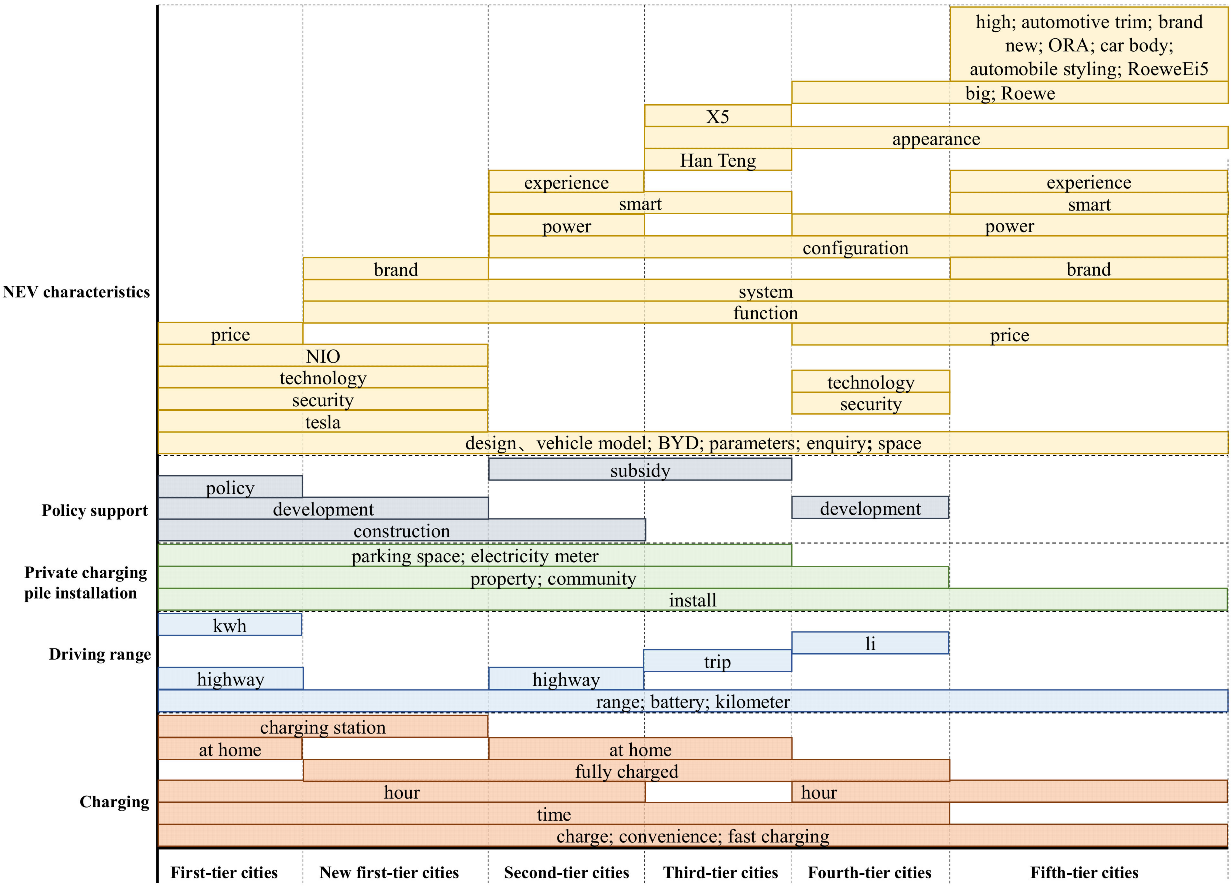
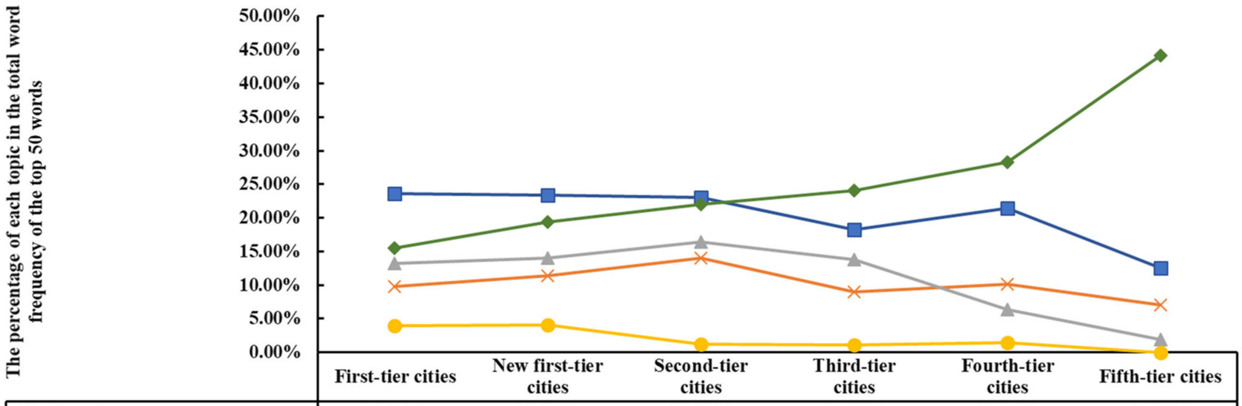


Figure 8. The topic classification of the top high-frequency words in each city level.

According to the grouping results, we calculate the attention degree paid by consumers in different city levels to each topic using Equation (4). The calculation results are shown in Figure 9:

$$AD_{ik} = \frac{\sum_{j=1}^{J} WF_{ijk}}{\sum_{n=1}^{50} SWF_{nk}} = 1,\ 2,\ 3,\ 4,\ 5;\ k = 1,\ 2,\ 3,\ 4,\ 5,\ 6 \tag{4}$$

where AD_{ik} is the attention degree of consumers in the k-th city group to the i-th topic (unit: %); WF_{ijk} is the word frequency of the j-th term in the i-th topic of the k-th city group; and $\sum_{n=1}^{50} SWF_{nk}$ is the sum of the word frequencies of the top 50 terms of the k-th city group.



	First-tier cities	New first-tier cities	Second-tier cities	Third-tier cities	Fourth-tier cities	Fifth-tier cities
Charging	23.56%	23.33%	22.98%	18.21%	21.47%	12.54%
Driving range	9.83%	11.33%	13.97%	9.04%	10.09%	6.99%
Private charging pile installation	13.16%	14.00%	16.45%	13.73%	6.36%	1.94%
Policy support	3.96%	4.07%	1.26%	1.10%	1.41%	0.00%
NEV characteristics	15.55%	19.36%	22.04%	24.01%	28.31%	44.21%

Figure 9. The percentage of each topic in the total word frequency of the top 50 words.

Figures 8 and 9 show that consumers in different city levels have different concern priorities for each topic. First, consumers in second-tier and above cities pay more attention to charging than other topics, including the convenience of charging, charging mode, charging time, charging at home, etc. However, consumers in third-tier and later cities pay significantly more attention to NEV characteristics than other topics. Second, regarding the installation of private charging piles, consumers in third-tier and above cities pay significantly more attention than consumers in fourth-tier and fifth-tier cities. Third, consumers in different city levels pay similar attention to the driving range, which is about 10%, indicating that the driving range of electric vehicles is a common concern for all consumers. Fourth, with the decline of city levels, consumers' attention to the characteristics of NEVs has gradually increased, especially in fifth-tier cities, where the attention degree is as high as 44.21%. Fifth, compared with other consumers, consumers in first-tier cities and new first-tier cities pay more attention to government policy support for charging infrastructures.

Furthermore, an interesting phenomenon is found through Appendix A Table A3. The word "friend" is gradually rising in the word frequency rankings of fourth-tier cities and fifth-tier cities. This finding indicates that, in areas where the economy is relatively underdeveloped, consumers' understanding and acceptance of NEVs are gradually being influenced by social relation.

4. Conclusions and Policy Implications

4.1. Conclusions

This study uses NLP technology to explore consumers' preferences for charging infrastructure from consumers' discussions published in online media. Then, we analyze the differences between consumers' concerns on charging infrastructure in different city levels.

With the rapid increase in NEV ownership, consumers' attention to charging infrastructure has rapidly increased, and the number of comments on charging infrastructure published in online media has also increased rapidly. From a spatial perspective, consumers in first-tier cities pay more attention to charging infrastructure, and the number of comments accounts for 36% of the total.

Analyzing consumer comments, we found that the four topics that consumers are most concerned about are charging, policy support, driving range, and the installation of private charging piles. For charging, consumers are very concerned about the charging mode of charging piles. Although AC charging is economical, DC charging can greatly reduce the waiting time for charging, which is more popular with consumers. For driving range, long-distance travel and high energy consumption of air-conditioning are the main factors that consumers pay close attention to for the driving range of NEVs. Inability to find public charging piles in time to replenish power during long-distance travel or the shortened driving range caused by air conditioners is the main reason for consumers' range anxiety. The ways consumers prefer to increase the driving range mainly include improving battery performance, increasing the number of charging piles, and building swap stations to reduce waiting time. Consumers prefer to charge electric vehicles at home, so they are highly concerned about the installation of private charging piles. This is also consistent with the views of some scholars: that charging at home is the most influential location in encouraging consumers to purchase PEVs [11,14,16]. However, the lack of fixed parking spaces and community properties has become the most important factor hindering consumers from applying for the installation of private charging piles. Consumers' attention to national support policies mainly tends to increase the number and density of charging infrastructure through policy support, and improve the convenience of charging.

Analysis of regional differences found that consumers in different city levels have different concerns about charging infrastructure. Consumers in second-tier and above cities are most concerned about charging, while consumers in third-tier and below cities are most concerned about the characteristics of NEVs. Consumers in third-tier and above cities pay significantly more attention to private charging pile installation than consumers in fourth-tier and fifth-tier cities. However, consumers in all cities pay almost the same attention to driving range. In addition, the analysis also found that consumers in fourth-tier cities and fifth-tier cities are more inclined to increase their understanding of NEVs through social relationships.

4.2. Policy Implications

Based on the results, the policy implications for the future development of charging infrastructure are summarized as follows.

To effectively alleviate the range anxiety of NEV owners, government needs to increase the number and density of charging infrastructure. However, in the early stage of construction of public charging stations, a large amount of capital needs to be invested in infrastructure construction and the purchase of charging piles. The investment cost is exorbitant. Therefore, the government or national enterprises should scale up their leadership in the construction of charging stations. Additionally, as regards charging stations led by private companies, the subsidy policy, preferential operation policies, and charging station operation business models should be improved to reduce the operating costs, increase the rate of return on investment, and attract enterprises to participate in the investment of charging stations. In addition, the government can also use existing parking lots to convert some parking spaces into parking spaces for NEVs. Obviously, the management system for NEV parking spaces should also be strengthened to reduce the phenomenon of ICEVs occupying NEV parking spaces. In addition, the maintenance and management system of public charging piles should be improved to ensure that every public charging pile is usable.

While increasing the number of charging piles, the government should also improve the municipal planning and use advanced technologies, such as big data and the Internet of Things, to monitor the number of NEVs and charging frequency in the region. Then, big data analysis technology should be used to plan more charging stations or public charging piles for charging high-frequency areas to increase the density of charging infrastructures. The number of DC fast charging piles, particularly in expressway service areas, should be appropriately increased to reduce the waiting time for charging.

Furthermore, the construction intensity and management system of battery swapping stations should be improved to realize the combination of charging and swapping, enrich the models of NEVs with the intent of improving the driving range, and further alleviate the range anxiety of NEV owners.

Regarding the installation of private charging piles, the government should adjust the current policies. On the one hand, the problem of installing private charging piles for NEV owners without fixed parking spaces should be solved through appropriate policy. On the other hand, it is necessary to clarify the benefit distribution of the power grid, power bureau, community property, and other related entities during the installation of private charging piles to ensure that each entity can obtain certain benefits. Especially for community properties, clear policies should be formulated to allow them to charge reasonable installation service fees, in order to increase the enthusiasm of the properties to cooperate with installation and maintenance. At the same time, the peak-to-valley price policy should also be used to attract consumers to charge off-peak to reduce power grid fluctuations.

Analysis of regional differences found that consumers in different city levels pay different attention to charging infrastructure. Therefore, different NEV marketing plans can be formulated for different consumer characteristics. For consumers in third-tier and above cities, increasing the number and density of charging piles can attract consumers to purchase NEVs. For consumers in fourth-tier and below cities, they can be attracted by better NEV performances. At the same time, social relationships can also be used to attract fourth-tier and below city consumers to buy NEVs.

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Appendix A

Table A1. Examples of consumers' comments.

User Name	Date	Province	City	Data Sources	Comment
Small seven-day tour	16 April 2020	Shanghai		PCauto [a]	Charging at home is convenient, so it is necessary to install a private charging pile.
Chushu Xiaole	9 January 2019	Jiangsu	Taizhou	PCauto	It's so troublesome to go outside to charge.
Citizen76 no regrets	9 January 2019	An'hui	Hefei	PCauto	Our community has built many charging piles this year.

Table A1. *Cont.*

User Name	Date	Province	City	Data Sources	Comment
Soaring up	24 March 2018	Guangdong	Shenzhen	Zhihu [b]	I care more about the charging time. For a long distance, you can run hundreds of kilometers after entering the gas station in a few minutes. One oil gun can add many cars in half an hour. However, it takes at least half an hour for an electric car...A charging pile can only fill one or two cars in an hour. In this way, the time spent in queuing and charging is a bit unacceptable. The most unacceptable thing is that I can't afford the electric car that I like.
White paper without words Zonciu	4 April 2018	Guangxi	Nanning	Zhihu	The driving range is not a big problem. The biggest problem is that the charging speed is slow. When the ICEV runs out of gasoline, it can start again immediately after refueling, and the PEV has to be charged slowly.
Tiger Hero	24 June 2020	Sichuan	Chengdu	Xcar [c]	All public parking spaces can be quickly charged, which can solve the problem of running long distances.
Jinxuan Xie	9 April 2020	Shanghai		Sina Weibo [d]	What if the community does not allow to install the charging piles, will the government come forward to coordinate?
Pinocchio	27 May 2020	Shandong		Sina Weibo	Our community property does not allow to install charging piles in the underground parking spaces. What should I do?
Mr. Van Gogh CVN18	9 April 2020	Beijing		Sina Weibo	The charging time of PEV is less than 30 min, or the actual driving range is more than 800 km when the air conditioner is turned on. Otherwise, it's really troublesome to run out of power halfway.
Xiaoxiao smiles smiles	4 September 2019	Guangdong	Shenzhen	Autohome [e]	It's enviable to be able to install a charging pile, so commuting is basically zero fuel consumption
X puppet	4 August 2019	Guangdong	Shenzhen	Autohome	It is very good that the community can install charging piles, and it will be much more convenient to charge in the future.
ak7m9ycm3	20 September 2019	Sichuan	Chengdu	Autohome	As long as the charging pile is solved, the NEVs will work well.
Shanghai Little Frog	3 April 2020	Shanghai		Autohome	On the premise that there is a place to charge and the driving range is long, PEVs are definitely better than ICEVs. But the ICEV refuels quickly and is convenient for long-distance driving.

Notes: [a] Website: bbs.pcauto.com.cn (accessed on 20 December 2020). [b] Website: https://www.zhihu.com/ (accessed on 20 December 2020). [c] Website: http://www.xcar.com.cn/bbs/ (accessed on 20 December 2020). [d] Website: https://m.weibo.cn/ (accessed on 20 December 2020). [e] Website: https://club.autohome.com.cn (accessed on 20 December 2020).

Table A2. The group of city level.

City Level	City Name
First-tier cities	Beijing, Shanghai, Guangzhou, Shenzhen
New first-tier cities	Chengdu, Hangzhou, Chongqing, Wuhan, Xi'an, Suzhou, Tianjin, Nanjing, Changsha, Zhengzhou, Dongguan, Qingdao, Shenyang, Hefei, Foshan
Second-tier cities	Wuxi, Ningbo, Kunming, Dalian, Fuzhou, Xiamen, Harbin, Jinan, Wenzhou, Nanning, Changchun, Quanzhou, Shijiazhuang, Guiyang, Nanchang, Jinhua, Changzhou, Nantong, Jiaxing, Taiyuan, Xuzhou, Huizhou, Zhuhai, Zhongshan, Taizhou, Yantai, Lanzhou, Shaoxing, Langfang, Baoding
Third-tier cities	Weifang, Yangzhou, Haikou, Shantou, Luoyang, Urumqi, Linyi, Tangshan, Zhenjiang, Yancheng, Huzhou, Ganzhou, Taizhou, Jining, Hohhot, Xianyang, Zhangzhou, Jieyang, Jiangmen, Guilin, Handan, Wuhu, Sanya, Fuyang, Huai'an, Zunyi, Yinchuan, Hengyang, Shangrao, Liuzhou, Zibo, Putian, Mianyang, Zhanjiang, Shangqiu, Yichang, Cangzhou, Lianyungang, Nanyang, Jiujiang, Xinxiang, Xinyang, Xiangyang, Yueyang, Bengbu, Zhumadian, Chuzhou, Weihai, Suqian, Zhuzhou, Ningde, Xingtai, Chaozhou, Qinhuangdao, Zhaoqing, Jingzhou, Zhoukou, Maanshan, Qingyuan, Suzhou, Anshan, Anqing, Heze, Yichun, Huanggang, Tai'an, Nanchong, Lu'an, Daqing, Zhoushan
Fourth-tier cities	Changde, Weinan, Xiaogan, Lishui, Yuncheng, Dezhou, Xuchang, Xiangtan, Jinzhong, Anyang, Sanming, Kaifeng, Chenzhou, Maoming, Shaoyang, Deyang, Longyan, Nanping, Huainan, Huangshi, Yingkou, Bozhou, Rizhao, Xining, Quzhou, Dongying, Jilin, Shaoguan, Zaozhuang, Baotou, Huaihua, Xuancheng, Linfen, Liaocheng, Meizhou, Panjin, Jinzhou, Yulin, Beihai, Baoji, Fuzhou, Jingdezhen, Yulin, Shiyan, Shanwei, Xianning, Yibin, Jiaozuo, Pingdingshan, Binzhou, Ji'an, Yongzhou, Yiyang, Qiannan, Dandong, Qujing, Leshan, Southeast Guizhou, Zhangjiakou, Huangshan, Ordos, Yangjiang, Luzhou, Enshi, Hengshui, Tongling, Chengde, Honghe, Dali, Datong, Luohe, Gourd Island, Heyuan, Loudi, Yanbian, Qiqihar, Yan'an, Fushun, Lhasa, Tongren, Changzhi, Dazhou, Ezhou, Xinzhou, Luliang, Huaibei, Puyang, Meishan, Chizhou, Jingmen
Fifth-tier cities	Hanzhong, Liaoyang, Wuzhou, Yingtan, Baise, Bijie, Qinzhou, Yunfu, Jiamusi, Chaoyang, Guigang, Lijiang, Siping, Neijiang, Liupanshui, Anshun, Sanmenxia, Chifeng, Xinyu, Mudanjiang, Jincheng, Zigong, Benxi, Fangchenggang, Tieling, Suizhou, Guangan, Guangyuan, Tianshui, Suining, Pingxiang, Xishuangbanna, Suihua, Hebi, Xiangxi, Songyuan, Fuxin, Jiuquan, Zhangjiajie, Southwest Guizhou, Baoshan, Zhaotong, Karamay, Hulunbuir, Hezhou, Tonghua, Yangquan, Hechi, Laibin, Yuxi, Ankang, Tongliao, Dehong, Chuxiong, Shuozhou, Yili, Wenshan, Jiayuguan, Liangshan, Ziyang, Xilin Gol, Ya'an, Pu'er, Chongzuo, Anqing, Bayinguoleng, Ulanchabu, Baishan, Changji, Baicheng, Xing'an, Dingxi, Kashgar, Baiyin, Longnan, Zhangye, Shangluo, Heihe, Hami, Wuzhong, Panzhihua, Bayannaoer, Bazhong, Jixi, Wuhai, Lincang, Haidong, Shuangyashan, Aksu, Shizuishan, Alxa, Haixi, Pingliang, Liaoyuan, Linxia, Tongchuan, Jinchang, Hegang, Yichun, Linzhi, Guyuan, Mighty, Danzhou, Turpan, Ganzi, Zhongwei, Nujiang, Hotan, Diqing, Gannan, Aba, Daxinganling, Qitaihe, Shannan, Xigaze, Tacheng, Bortala, Qamdo, Altay, Yushu, Hainan, Kizilsu, Ali, Haibei, Huangnan, Guoluo, Nagqu, Sansha

Table A3. Statistics of high-frequency words in different city levels.

First-Tier Cities		New First-Tier Cities		Second-Tier Cities		Third-Tier Cities		Fourth-Tier Cities		Fifth-Tier Cities	
Words	Frequency	Words	Frequency	Words	Frequency	Words	Frequency	Words	Frequency	Words	Frequency
charging	6478	charging	3440	Charging	1629	charging	951	charging	825	charging	483
installation	1771	installation	1167	installation	647	installation	410	driving range	286	not bad	229
question	1728	question	1103	driving range	588	buy	318	buy	252	driving range	223
driving range	1566	battery	964	Battery	471	Hanteng	312	compare	236	feel	191
battery	1565	driving range	962	Buy	409	driving range	266	installation	231	compare	177
Buy	1256	buy	782	Km	398	compare	228	use	178	buy	176
Km	1209	property	769	property	394	good	215	battery	173	think	170
Need	1181	km	708	meters	306	battery	202	km	165	this	170
parking space	1162	Tesla	665	model	294	property	192	design	164	design	166
Tesla	1061	community	631	parking space	293	use	188	large	162	BYD	152

Table A3. *Cont.*

First-Tier Cities		New First-Tier Cities		Second-Tier Cities		Third-Tier Cities		Fourth-Tier Cities		Fifth-Tier Cities	
Words	**Frequency**	**Words**	**Frequency**	**Words**	**Frequency**	**Words**	**Frequency**	**Words**	**Frequency**	**Words**	**Frequency**
owner	1041	use	604	community	271	model	188	convenient	160	Roewe	144
property	868	parking space	591	good	261	design	183	parameters	159	like	140
compare	864	technology	505	vehicle	250	feel	179	power	153	configuration	138
community	832	meter	476	design	246	km	175	inquiry	152	model	132
service	807	convenient	466	convenient	238	parking space	171	model	150	system	124
vehicle	800	fast charge	420	choice	238	convenient	165	BYD	150	space	123
Time	761	service	415	time	221	parameters	161	space	142	convenient	121
parking lot	737	time	408	BYD	219	X5	157	time	129	parameters	121
company	706	parameters	407	mode	216	owner	156	like	129	large	118
NIO	703	China	404	hours	212	configuration	152	fast charge	126	installation	116
convenient	700	development	400	install	212	space	151	property	124	inquiry	116
technology	698	Design	394	drive	202	inquiry	147	service	123	appearance	116
hours	695	vehicle	393	power	196	power	142	choice	122	high	115
not bad	670	NIO	392	parameters	195	meters	134	technology	117	use	113
fast charging	655	charging station	385	function	194	community	130	situation	116	smart	111
install	646	owner	382	fast charging	193	choice	128	drive	113	choice	102
development	643	construction	371	space	185	system	126	security	110	km	102
construction	641	inquiry	371	owner	183	hybrid	125	fuel	105	service	101
parameter	620	model	368	inquiry	180	consumer	123	vehicle	102	power	100
charging station	612	safety	359	hybrid	179	BYD	123	mode	102	Ei5	99
design	596	hours	356	capacity	178	like	122	this	101	Roewe ei5	99
model	581	system	347	Tesla	177	smart	115	development	99	function	94
china	569	company	339	smart	173	fast charging	115	system	95	interior	94
BYD	562	city	338	technology	172	company	113	hour	93	battery	93
inquiry	560	mode	335	fully charged	169	travel	110	configuration	93	fast charging	82
space	545	market	334	highway	168	install	107	community	91	new	82
process	543	space	319	provide	167	model	106	city	90	brand	80
beijing	542	drive	311	safe	165	vehicle	103	appearance	89	a car	77
system	540	function	310	construction	162	display	101	fully charged	88	this car	76
city	539	fuel	306	fuel	161	market	100	price	88	buy a car	69
meter	533	hybrid	306	system	160	time	97	main	87	fuel	69
drive	513	highway	305	charge	156	this	97	market	86	Euler	69
fuel	505	dynamics	301	service	156	fuel	96	charge	85	friends	68
home	504	brand	296	home	148	home	95	mile	84	experience	66
free	495	power	295	drive	148	fully charged	94	owner	84	price	65
find	491	lines	295	support	147	lines	93	functions	83	hours	64
price	474	fully charged	292	City	146	appearance	93	home	83	worry	62
safe	468	BYD	291	experience	145	subsidy	92	buy a car	81	drive	62
mode	468	charge	286	pick up a car	144	support	92	friends	81	voice	62
policy	467	subsidy	284	configuration	143	function	92	Roewe	79	body	61

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