

Central-Local Collaborative Research on Industrial Policies of New Energy Vehicle Charging and Changing Infrastructure

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Abstract

Driven by the “dual carbon” goals, the new energy vehicle (NEV) industry has seen rapid growth. However, the lack of adequate charging and swapping infrastructure has become a significant bottleneck for its development. This study focuses on the coordination between central and local policies in NEV charging and swapping infrastructure. It analyzes policy documents and charging station data from 14 provinces, cities, and the central government between 2017 and 2023 using the Latent Dirichlet allocation (LDA) model. The findings indicate that when only considering the coordination between central and local policies, the development level of local charging infrastructure is positively correlated with the coordination of these policies. Based on this, the study recommends enhancing information exchange mechanisms, optimizing policy formulation processes, establishing specialized coordination bodies, and strengthening supervision and evaluation linkages to improve policy coordination between central and local governments. These measures aim to promote the development of NEV charging and swapping infrastructure, thereby supporting the achievement of the “dual carbon” goals.

Keywords

New Energy Vehicles, Charging and Changing Infrastructure, Policy Research, Central-Local Coordination

1. Introduction

1.1. Project Background and Significance

Under the strategic framework of the “dual carbon” goals (peak carbon emissions by 2030, carbon neutrality by 2060), the new energy vehicle industry is seen as a

key driver for reducing emissions in the transportation sector. By the end of 2024, China's stock of new energy vehicles reached 80 million, accounting for 55% of the global total. The countries cumulative charging infrastructure has reached 12.818 million units (3.46 million public chargers and 9.358 million private chargers), with 12.818 million charging stations corresponding to 31.4 million new energy vehicles, giving a vehicle-to-charger ratio of about 1:2.45. However, the ratio of public chargers to vehicles is 1:9.13. This indicates that while China's new energy vehicle industry is developing rapidly, the inadequacy of charging and swapping infrastructure remains a significant constraint on further development. China's charging and swapping infrastructure has entered a new phase characterized by "equal emphasis on scale expansion and quality improvement". Although the overall vehicle-to-charger ratio meets standards, issues such as insufficient supply of public chargers, regional imbalance, and technical compatibility still exist. In the future, it will be necessary to optimize resource allocation through coordinated efforts between central and local governments, promote uniform technical standards, and foster market mechanisms to build a globally leading new energy ecosystem that is "efficiently replenished, safe and reliable, green and low-carbon". This will provide solid support for achieving the "dual carbon" goals and contribute to the healthy and steady development of the new energy vehicle industry and related sectors.

Scholars both domestically and internationally have studied charging infrastructure from multiple perspectives, including market development, profit models, usage efficiency, and practical applications, covering a wide range of topics such as industry development, operational models, planning and layout optimization, and case studies. However, in policy research, studies that simultaneously address charging and battery swapping infrastructure and focus on the synergy between central and local policies are relatively scarce. In existing literature, most studies on charging and swapping infrastructure use operations research methods to optimize operational decisions, while fewer studies focus on industrial policies. Among the studies on industrial policies for charging and swapping station infrastructure, many examine the effects and mechanisms of policies at a single level, with fewer studies evaluating the coordination between central and local policies. Therefore, in-depth research on the policy synergy between central and local governments regarding charging and swapping infrastructure in China can enhance policy relevance, optimize government funding allocation and utilization, accelerate industry development efficiency, ensure sustainable industry growth, and ultimately achieve more reasonable and effective policy formulation, promoting industry development in a collaborative and unified manner.

1.2. Literature Review

At present, the research status of new energy vehicle charging and changing infrastructure at home and abroad is summarized in three aspects. They are policy text analysis related research, policy coordination related research, and new en-

ergy vehicle charging and changing infrastructure policy related research.

1.2.1. Policy Text Analysis Related Research

Scholars research on policy evaluation mainly includes two categories: traditional evaluation and text mining evaluation. In traditional evaluation, methods such as expert scoring and content analysis are typically used to sort through and rate policies. This approach can systematically and intuitively analyze the focal points and implementation measures in policies, but it heavily relies on subjective interpretation of policy texts. Text mining, a method that uses computer technology to extract useful information from large-scale text data, is increasingly applied in policy research. Using text mining for policy evaluation can effectively handle unstructured information in policy texts, extract key points and challenges of policy implementation, and achieve analysis of policy themes and evolution processes. The text mining evaluation related to this project mainly includes: policy text classification and policy theme modeling.

1) Policy text classification

Policy text classification research aims to develop policy classification models through natural language processing, deep learning, and other technologies, categorizing policy texts into different classes or tags. For instance, Shen Ziqiang et al. (Shen et al., 2022) found that combining the BERT model with the TF-IDF method can improve the accuracy of automatic policy text classification, effectively categorizing science and technology policy texts. He et al. (He et al., 2019) proposed a technical demand potential hotspot identification model based on subject-verb-object structure semantic analysis, which was validated using network technology demand texts in the fields of new energy and energy conservation, dividing the technical demand layout at different stages of the technology lifecycle. Huo Chaoguang et al. (Huo et al., 2023) proposed an automatic policy tool classification model based on WordBERT and BiLSTM, and applied data governance and digital economy policy datasets as examples, finding that the automatic classification model has the highest accuracy.

2) Policy theme model

Policy theme model research primarily uses methods such as LDA topic modeling and Kmeans clustering to identify potential themes or topic structures in policy texts. The TF-IDF algorithm is employed to recognize key objectives and tasks in intelligent coal policies, and a relational network diagram is constructed based on changes in high-frequency words in policy texts across different years. Zhang Baojian et al. (Zhang et al., 2019) used text mining techniques to analyze typical data from science and technology innovation policies, employing K-means clustering to conduct thematic analysis of national science and technology innovation policies according to their content and nature. Wo et al. (Wo et al., 2022) identified key objectives and tasks in intelligent coal policies using the TF-IDF algorithm, analyzed the evolution of high-frequency words in policy texts over different years, and constructed a relational network diagram to achieve visual analysis of policy content over time. Zhang Tao and Ma Haiqun (Zhang and Ma,

2021) utilized LDA topic clustering and topic similarity calculation methods to analyze the hotspots and evolution of artificial intelligence policies in China, thereby clarifying the development trajectory of AI policies and proposing policy recommendations.

1.2.2. Policy Coordination Related Research

Policy synergy can also be described as policy coordination, policy consistency, and policy integration. Essentially, it requires mutual support and cooperation among various policy entities to maximize the synergy of policies and provide new approaches for solving cross-sectoral and cross-departmental issues, thereby avoiding incompatibilities, disharmonies, and policy conflicts (Liu et al., 2020). Effective policy synergy is more conducive to enhancing policy performance, while the lack of policy synergy can lead to the failure of public policies. From the perspective of policy elements, policy synergy refers to the consistency within or between policy entities, objectives, tools, and recipients (Zhang et al., 2014a); from the perspective of policy objectives, policy synergy involves public intervention aimed at achieving common goals by minimizing policy overlap, duplication, and conflict, and alleviating the inefficiencies caused by policy fragmentation. From the perspective of policy entities, policy synergy is when higher-level governments transcend existing policy boundaries and the responsibilities of individual functional departments to integrate policies across different departments through certain methods and means, characterized by cross-sectoral linkage (Ma & Hong, 2018). Policy synergy includes vertical synergy, horizontal synergy, and temporal synergy.

Vertical collaboration includes the synergy between international organizations and countries; the synergy between higher and lower levels of government; and the synergy between government and its subordinate agencies. Scholars use methods such as policy tool analysis and text mining to analyze policy objectives and texts. Zhang and Bai (Zhang & Bai, 2017) proposed the PDM method to examine the synergy between the central government and the new energy vehicle policy system in the Beijing-Tianjin-Hebei region, and combined content coding to analyze how incentive policies promote the adoption of new energy vehicles. Zhang and Qin (Zhang & Qin, 2018) extracted keywords from national and provincial-level new energy vehicle policies to compare the focus areas of policy tools at the national and provincial levels, thereby analyzing the coordination mechanisms between central and local governments.

Horizontal collaboration includes coordination among countries, provinces (cities/counties), and departments at the same level of government. Scholars have analyzed mechanisms of cooperation among government departments using methods such as social network analysis and policy design perspectives. Yang et al. (Yang et al., 2020) constructed a joint policy release network and calculated the eigenvector centrality of each node to analyze changes in the institutions jointly releasing information technology policies. Zhang Lei et al. (Zhang et al., 2020) designed scoring criteria from two dimensions: policy intensity and policy

measures, constructing a quantitative model for policy synergy to analyze the coordination and evolution of new energy vehicle policies and related departments.

Time synergy encompasses theme transformation and effectiveness diffusion. Scholars use methods such as entropy value and coupling coordination degree to analyze the degree of synergy. Wang et al. (Wang et al., 2022), through the coupling coordination degree model and spatial autocorrelation method, clarified the relationship between industrial economy, natural resources, and environmental quality, and analyzed the spatiotemporal synergy degree of industries, resources, and the environment using provincial panel data.

1.2.3. Research on Policies Related to Charging and Changing Infrastructure for New Energy Vehicles

The distribution of major policy tools for new energy vehicle charging infrastructure mainly includes two categories: economic and non-economic (Wang & Liang, 2021). Economic policy tools refer to measures that incentivize specific groups through economic means. Economic policy tools for charging infrastructure include subsidies for the construction of charging facilities, operational subsidies for charging facilities, and subsidies for the construction and operation of charging platforms. For property or parking lot owners, these tools provide parking space subsidies, rewards or penalties based on the performance evaluation of property charging facility construction, and rewards or penalties for units that install their own charging facilities (such as incorporating unit installation into energy-saving and emission reduction assessments). For users, these tools offer electricity price discounts or subsidies, and reduced parking fees during charging periods. Non-economic policy tools primarily refer to measures that use monetary incentives as a means. From the perspective of the lifecycle of charging infrastructure construction and operation, these tools mainly include planning tools, construction tools, and operational tools.

Some scholars have studied the policy effects and mechanisms of charging and swapping infrastructure. For example, Zhang Yong (Zhang et al., 2014b) found that in developed countries, the construction of electric vehicle charging infrastructure has been relatively well advanced, with governments playing varying degrees of auxiliary roles in its development. Methods include the U.S. proposing pilot arrangements to provide free infrastructure, the UK providing substantial funding to large electrical companies to build new charging stations to support the development of electric vehicle networks, and Israel promoting industrial development through tax incentives. It is evident that most governments act as macro-regulators, offering policy conveniences and financial support. Under government leadership, power companies and electric vehicle manufacturers, among other diverse entities, participate in the construction of electric vehicle charging infrastructure. The government plays a role as an investor and financier, and a necessary supporter of fiscal subsidies (Guo et al., 2018). We collected policy texts on new energy charging facilities from 2009 to 2022 from the central government and the Beijing-Tianjin-Hebei region, using policy text analysis, social network

analysis, and synergy models to evaluate the evolution of central policies and the synergistic effects of policies in the Beijing-Tianjin-Hebei region.

2. Theoretical analysis and hypothesis

2.1. Theoretical Analysis

2.1.1. LDA Model Research Principles

LDA (Latent Dirichlet allocation) model is a topic model based on probabilistic graph model (Song et al., 2023). Its research principles are mainly reflected in the following aspects:

1) Three-layer Bayesian probability model

LDA assumes that the process of generating a document collection is a random process. It starts with the topic distribution of a document, which then generates the words within the document. Each document can be viewed as a mixture of multinomial distributions of topics, where each topic is a multinomial distribution of words. Specifically, the document, topic, and word form a three-tier structure. Through this structure, LDA can capture the underlying topic information in documents, providing a foundation for policy text analysis.

2) Potential topic extraction

In the study of policies related to charging and swapping infrastructure for new energy vehicles, the LDA model can uncover potential themes by training on a large volume of policy documents. For example, the model might identify themes such as “charging facility construction”, “battery technology research and development”, and “subsidy policies”. Each theme is represented by a set of related words and their corresponding probabilities, reflecting the varying levels of focus on different aspects of the theme. By analyzing these themes and their word distributions, policymakers’ priorities and preferred development directions in the new energy vehicle charging and swapping infrastructure industry can be better understood.

2.1.2. Documents-Topic Distribution and Topic-Word Distribution

For each policy document, the LDA model infers the probability distribution of the document across various topics, known as the document-topic distribution. This helps to understand the main topics and their significance in each policy document. Additionally, the model can determine the word distribution within each topic, referred to as the topic-word distribution. For instance, under the topic “charging facility construction”, it may include terms like “charging station”, “charging pile”, and “layout planning”, along with their corresponding probabilities. By analyzing the document-topic distribution and the topic-word distribution, one can gain a more comprehensive and accurate understanding of the semantic information and core content of the policy text, providing a solid foundation for subsequent policy analysis.

1) Parameter estimation and model training

The LDA model employs methods such as variational inference and Gibbs sampling for parameter estimation and model training. During the training process,

the model continuously adjusts the parameters of document-topic distribution and topic-word distribution to maximize the likelihood of the observed data (i.e., the words in the policy text). Through multiple iterations, the model gradually converges to a stable solution, resulting in model parameters that effectively reflect the thematic structure of the policy text. In the study of policies for new energy vehicle charging and swapping infrastructure, setting the parameters for model training, such as the number of iterations and learning rate, is crucial for enhancing the model's accuracy and stability.

2) Model evaluation and topic number determination

To ensure the effectiveness and reliability of the LDA model, it is essential to evaluate the model and select an appropriate number of topics during the research process. Common methods include calculating perplexity (Perplexity) and other metrics. A lower perplexity indicates better data fitting. By testing different numbers of topics and calculating their corresponding perplexities, the topic number with the lowest perplexity can be selected as the optimal one. Additionally, the interpretability and semantic coherence of topics can be assessed manually to determine an appropriate number of topics. In the policy analysis of new energy vehicle charging and swapping infrastructure, determining an appropriate number of topics helps accurately extract policy themes, avoiding inaccurate or incomplete analysis due to too many or too few topics.

3) Advantages in policy analysis

The LDA model can automatically extract potential themes from a large volume of policy documents without manual annotation, significantly enhancing the efficiency of policy analysis. When faced with a vast number of central and local policies on new energy vehicle charging and swapping infrastructure, the LDA model can quickly categorize these documents into different themes, saving time and effort that would otherwise be spent on manual reading and organizing. Moreover, the LDA model can uncover hidden thematic structures in the text, revealing the key points and trends of the policies, thus providing new perspectives and methods for policy research (Blei et al., 2003). By analyzing the evolution of policy themes, one can understand the focus and direction of policy development at different stages, which can serve as a reference for policy adjustments and optimizations.

4) Limitations and countermeasures

The LDA model is quite sensitive to parameter selection, requiring experience to determine the appropriate number of topics and other parameters. In the policy research on new energy vehicle charging and swapping infrastructure, a reasonable number of topics can be selected through multiple trials and comparisons, considering metrics such as perplexity and an understanding of the policy context. The results are somewhat uncertain, with different training sessions potentially yielding different outcomes. To address this issue, a fixed random seed can be set during model training, or an ensemble learning approach can be used to analyze the results from multiple models. Limited semantic and contextual understanding

of documents may lead to inaccurate or unreasonable topic segmentation. In practical research, thorough preprocessing of policy texts, including removing stop words and performing stem extraction, along with manual analysis and interpretation, can enhance the accuracy of topic segmentation.

In summary, the LDA model serves as an effective tool for text analysis in the research on policies related to the charging and swapping infrastructure of new energy vehicles. This tool can provide convenient and efficient data analysis, offering a solid basis for studying the coordination between central and local governments. By deeply understanding and reasonably applying the principles of the LDA model, researchers can better extract information from policy documents, analyze the consistency and coordination of central and local policies, and provide robust policy support for the development of the new energy vehicle charging and swapping infrastructure industry (Qiao & Xu, 2024).

2.2. Hypothesis Formulation

Based on the analysis of existing research, this paper puts forward a hypothesis that the development level of local charging infrastructure is positively correlated with the central-local coordination of new energy vehicle charging and changing infrastructure industrial policy.

3. Research Design

3.1. Data Sources

The primary focus of this study on the coordination between central and local governments in the construction of new energy vehicle charging and swapping infrastructure is the 30 provinces outside the Xizang Autonomous Region in Chinese mainland region. In terms of policy documents, the study examines the policies issued by the central government and the 30 provinces and cities from 2017 to 2023. These policies are categorized into two levels: central and local (provincial). The main data for these policy documents comes from official websites of the central and provincial governments, ensuring the accuracy of the information.

In terms of the number of charging infrastructure, this paper selected the number of charging piles in 30 provinces and cities from 2017 to 2023 as the research object. Due to the epidemic, the data in 2020 and 2021 could not be collected. The data source of the number of charging infrastructure in this study is China Economic Data.

3.2. Analysis of Basic Policy Situation

The main provincial research subjects of this study on the central-local coordination of new energy vehicle charging and swapping infrastructure focus on fourteen regions: Beijing, Hebei, Shandong, Tianjin, Jilin, Guangdong, Hainan, Hubei, Hunan, Guizhou, Sichuan, Jiangsu, Shanghai, and Zhejiang. These fourteen regions are divided into four parts according to their location: Northern Region, Southern Region, Western Region, and Eastern Region. By conducting word fre-

The network diagram highlights key nodes such as “new energy vehicles”, “infrastructure”, “State Council”, “development”, and “construction”. The close connection between “new energy vehicles” and “infrastructure” underscores their interdependence, which is crucial for the success of policies. The extensive connections at the “State Council” node highlight its central coordinating role. Other nodes, including “power batteries”, “local governments”, and “enterprises”, illustrate the collaboration among central authorities, local governments, and businesses in infrastructure development and industry promotion. This network reflects a systematic approach where multiple stakeholders work together under central guidance to advance the new energy vehicle industry (Figure 4).

Both figures demonstrate that the central government’s policies have adopted a comprehensive strategy for the charging and swapping infrastructure of new energy vehicles. They highlight the leadership of top bodies like the State Council, infrastructure development, the technological component (power batteries), and the collaboration among stakeholders, including local governments and enterprises. The focus on green development and market regulation ensures sustainable and orderly growth, positioning new energy vehicles as a key sector in national development.

3.3. Research Methods

First, the collected data is cleaned. Then, a LDA model is established to determine the optimal number of topics for central policy documents and those from 30 provinces and cities. After determining the optimal number of topics, the LDA model is trained again to obtain the topic distribution and keywords for each topic in the central policy documents and those from 30 provinces and cities. Finally, based on the topic distribution rules provided by the LDA model, the policy consistency index of the policy documents is calculated.

By collecting and organizing data, we obtained the number of charging infrastructure facilities in 30 provinces and cities from 2017 to 2023. We used the number of charging infrastructure facilities as the dependent variable, the policy consistency index of policy documents as the independent variable, and the population density and GDP of each province as control variables for regression analysis. This analysis aims to understand how the coordination between central and local governments in policy documents affects the implementation of policies and the development of charging infrastructure.

4. Research Results

4.1. Optimal Number of Topics Acquisition

The perplexity (perplexity) and coherence (coherence) are commonly used to evaluate the LDA topic model. A lower perplexity or higher coherence indicates a better model. However, some past studies have shown that perplexity is not a good indicator. Therefore, this study selects coherence to evaluate the model and select the optimal topic.

Using Python as our tool for constructing the LDA model, we set 2 and 10 as the upper and lower bounds for the number of topics, respectively, and conducted a cyclic test with a step size of 1 to find the optimal number of topics. As shown in the figure below, the left side displays the perplexity curve, while the right side shows the coherence line graph. The perplexity curve shows a monotonically decreasing trend, indicating that more topics are generally better for the optimal topic selection. However, the non-monotonic trend of the coherence line graph on the right alerts us to the strategy for selecting the optimal number of topics. Ultimately, we chose the 7 with the highest coherence in the range of 2 to 10 as the optimal number of topics for our LDA model.

4.2. LDA Analysis of Central Policy Text

As shown in the figure below, according to the LDA model we built, we obtained the distribution law of policy texts of 30 provinces and the central government after training the LDA model (Figure 5).

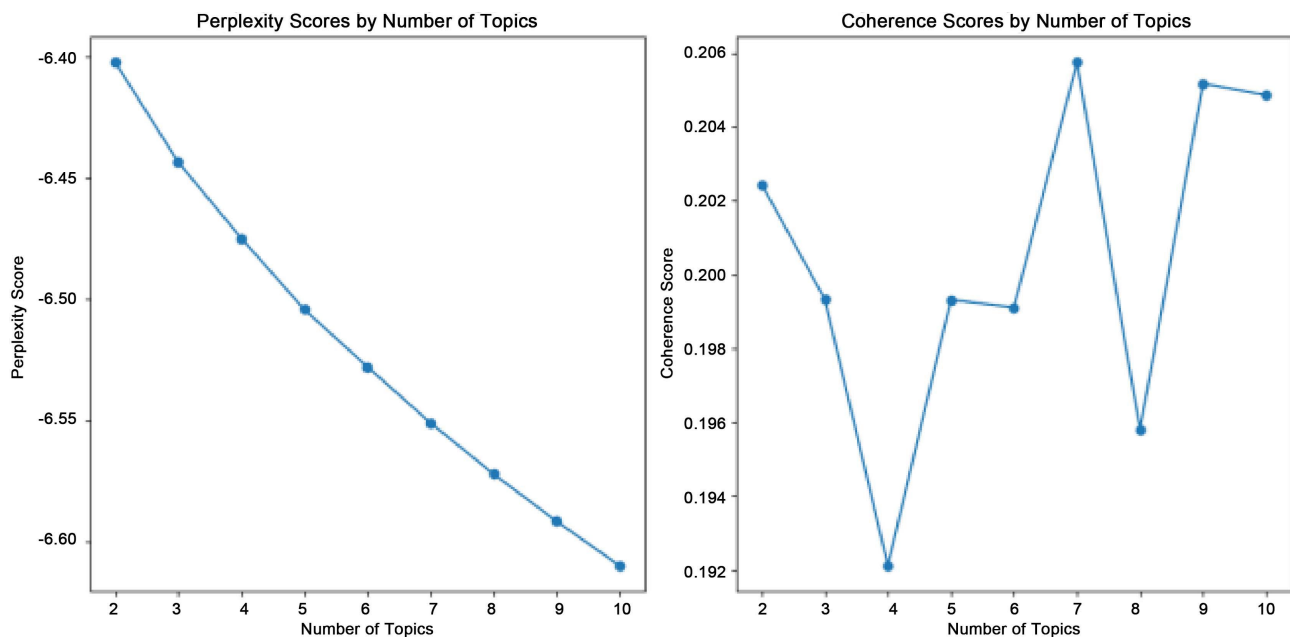


Figure 5. LDA analysis result graph.

4.3. Calculation of Policy Consistency Index

As illustrated in the table below, we calculated the policy consistency index for each province (Table 1). The calculation method is as follows: For the j -th topic, let the frequency of this topic in the central policy text be $f_{c,j}$ and the frequency in the local policy text be $f_{l,j}$. Let the average probability of the central policy text on the j -th topic be $p_{c,j}$ and the average probability of the local policy text on the j -th topic be $p_{l,j}$. The difference in the average probability of the topic is $d_j = |p_{c,j} - p_{l,j}|$ (Table 2).

Table 1. Provincial theme distribution laws chart.

Central	0.018317821	0.01216317	0.010192913	0.014941	0.94523311	0.0131635	0.01129311
Beijing	0.027592208	0.02668838	0.8094483	0.023627	0.029119715	0.035551	0.04798555
Tianjin	0.8259773	0.02415316	0.03619733	0.032098	0.02879618	0.022352329	0.030480392
Hebei	0.030052785	0.03170842	0.053826593	0.776494	0.04791334	0.039099175	0.020905666
Shanxi	0.030052785	0.03170842	0.053826593	0.776494	0.04791334	0.039099175	0.020905666
Inner Mongolia	0.02074744	0.0402388	0.06038385	0.025936	0.06113622	0.7704351	0.021122634
Liaoning	0.808707	0.2276514	0.044666827	0.034238	0.022523284	0.040973313	0.026126409
Jilin	0.031951133	0.02654461	0.04151758	0.026271	0.7980256	0.02390803	0.05178174
Heilongjiang	0.03724463	0.8031517	0.018644966	0.027056	0.02165391	0.06830424	0.023944674
Shanghai	0.029204443	0.045456525	0.042516485	0.026191	0.7865804	0.026004188	0.044046875
Jiangsu	0.018798858	0.8183966	0.022481035	0.037732	0.027676065	0.040239826	0.034775056
Zhejiang	0.22540918	0.12662895	0.24756835	0.10957	0.11456031	0.07240039	0.10386272
Anhui	0.025143784	0.05234504	0.041349947	0.771901	0.033019323	0.023624672	0.052615862
Fujian	0.04789954	0.7882297	0.03940825	0.038917	0.025094602	0.03281041	0.27640143
Jiangxi	0.01685912	0.0268126	0.040970806	0.035078	0.0451254	0.04795899	0.78719467
Shandong	0.07252124	0.02538404	0.03676605	0.035764	0.040854722	0.7658761	0.022834264
Henan	0.021426352	0.026606506	0.047447603	0.041899	0.81167245	0.025545541	0.025402095
Hunan	0.035413265	0.02301034	0.024785742	0.041516	0.04568831	0.8035241	0.026061954
Hubei	0.07968161	0.14153862	0.13708007	0.216172	0.15715407	0.18388084	0.084492974
Guangdong	0.024059774	0.035483345	0.75914705	0.023387	0.053897038	0.08056129	0.23464391
Guangxi	0.021064052	0.73716015	0.12259757	0.023389	0.039520983	0.022073913	0.03419474
Sichuan	0.03127838	0.03139671	0.75767756	0.04061	0.020474063	0.022407038	0.0961577
Guizhou	0.03205288	0.018875163	0.7565724	0.096362	0.02115359	0.041094944	0.0338892
Yunnan	0.050608822	0.024043193	0.035163008	0.030523	0.039653394	0.018018713	0.79651
Shaanxi	0.7921812	0.02389385	0.045311294	0.043934	0.023658978	0.035479296	0.035540972
Gansu	0.07359059	0.021548878	0.02058411	0.022668	0.7955577	0.039913766	0.026136616
Qinghai	0.027304523	0.07436554	0.042883728	0.039141	0.77281517	0.02150756	0.021982225
Ningxia	0.101991326	0.20800532	0.15066798	0.103157	0.10954021	0.17212504	0.15451282
Xinjiang	0.06968796	0.056655344	0.7618318	0.041862	0.029236319	0.01995744	0.02076924
Hainan	0.042096354	0.04592438	0.033081513	0.801128	0.019426761	0.036818746	0.021523807
Chongqing	0.025944524	0.033623394	0.042696685	0.106305	0.022492578	0.035214808	0.7337235

$$\text{Theme coverage consistency: } c_1 = \frac{\sum_{j=1}^k \min(f_{c,j}, f_{i,j})}{\sum_{j=1}^k \max(f_{c,j}, f_{i,j})}$$

$$\text{Theme focuses on consistency: } c_2 = 1 - \frac{\sum_{j=1}^k w_j d_j}{\sum_{j=1}^k w_j}$$

$$\text{Policy consistency index: } c_3 = 0.75c_1 + 0.25c_2$$

Table 2. Policy consistency index chart.

Theme Coverage Consistency	Theme Focus Consistency	Policy Consistency Index
0.056985582	0.741866616	0.22820584
0.056805872	0.741768058	0.228046418
0.067455754	0.747237912	0.237401293
0.067455754	0.747237912	0.237401293
0.074947321	0.751015875	0.243964459
0.048221126	0.710714146	0.213844381
0.765421639	0.961555709	0.814455156
0.052883554	0.739735218	0.22459647
0.747982729	0.958285645	0.800558458
0.056187243	0.741441555	0.227500821
0.106317253	0.766279899	0.271307914
0.059141461	0.742982476	0.230101715
0.048488361	0.705180946	0.212661508
0.065071876	0.746024585	0.235310053
0.063499205	0.745221155	0.233929692
0.78667537	0.965454799	0.831370227
0.066205387	0.746602176	0.236304584
0.132670799	0.778449559	0.294115489
0.063718354	0.718779036	0.227483524
0.062754901	0.744840091	0.233276199
0.052238124	0.739397966	0.224028085
0.052609771	0.739592263	0.224355394
0.063009929	0.745660692	0.23367262
0.053982185	0.740308089	0.225563661
0.761631912	0.960850581	0.811436579
0.727459838	0.954352718	0.784183058
0.103291791	0.76484559	0.26868024
0.05705026	0.741901624	0.228263101
0.05166592	0.739098892	0.223524163
0.053342805	0.739974836	0.225000812

4.4. Number of Charging and Changing Infrastructure Facilities

The chart below shows the number of charging infrastructure in each province in 2023 (Figure 6).

4.5. Regression Analysis

The following figure shows the results of regression analysis in which the number

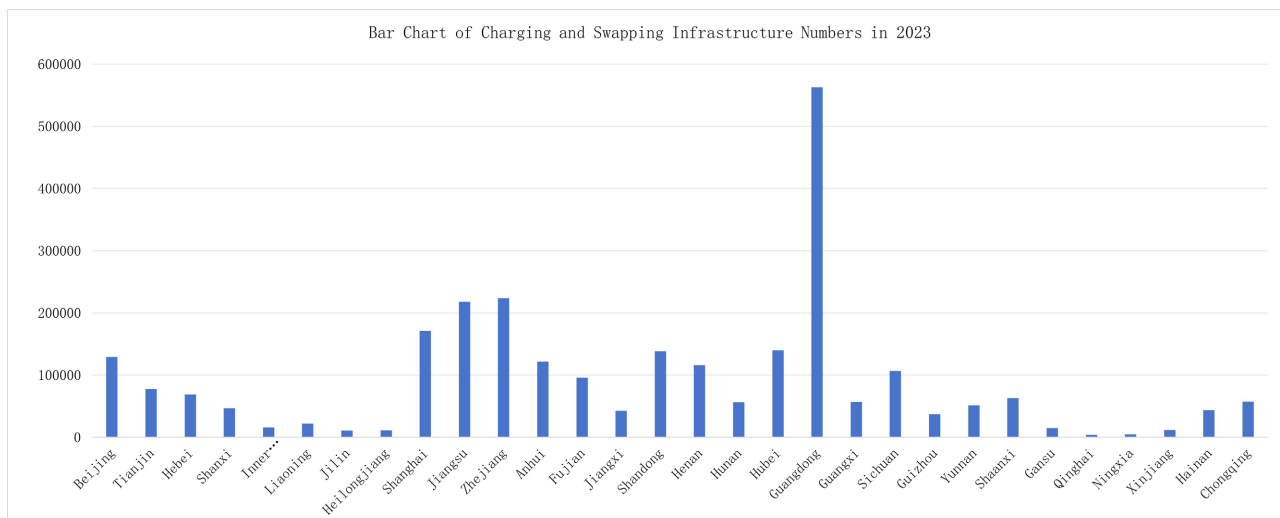


Figure 6. Bar chart of charging and swapping infrastructure numbers in 2023.

of charging infrastructure in each province in 2023 is taken as the dependent variable, the policy consistency index of each province is taken as the independent variable, and GDP and population density are taken as control variables (Table 3).

Table 3. Regression analysis graph.

(a)								
Summary output								
Regression Statistics								
Multiple R	0.871734448							
R Square	0.759920947							
Adjusted R Square	0.732219518							
Standard Error	55803.12853							
Observed Value	30							
(b)								
Analysis of Variance								
	df	SS	MS	F	Significance F			
Regression Analysis	3	2.56274E+11	85424675244	27.43255	3.2468E-08			
Residuals	26	80963717996	3113989154					
Total	29	3.37238E+11						
(c)								
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower Limit 95.0%	Upper Limit 95.0%
Intercept	-35039.20907	25185.9873	-1.391218405	0.17595	-86809.74741	16731.32927	-86809.74741	16731.32927
X Variable 1	2.022631706	1.497477215	1.350692809	0.188433	-1.055476794	5.100740206	-1.055476794	5.100740206
X Variable 2	2.733324423	0.342588363	7.978450882	1.86E-08	2.029123959	3.437524888	2.029123959	3.437524888
X Variable 3	5587.257577	51672.302	0.108128676	0.914724	-100626.6804	111801.1955	-100626.6804	111801.1955

The final regression analysis model is: $y = 2.02x_1 + 2.73x_2 + 5587.26x_3 - 35039.21$.

Where y is the number of charging infrastructure, x_1 is GDP, x_2 is policy consistency index and x_3 is population density.

5. Conclusions and Recommendations

5.1. Analysis of Policy Coordination between Central and Local Governments

The analysis reveals that the impact of policies on charging and swapping infrastructure for new energy vehicles is multidimensional. The alignment between central and local policies in terms of themes and key tasks demonstrates strong consistency, establishing a unified framework for the development of charging and swapping infrastructure. By reducing local implementation discrepancies and focusing on key areas, this approach can create a national policy orientation and resource integration effect.

Meanwhile, the level of economic development and population density are fundamental factors influencing infrastructure construction. Areas with active economies and concentrated populations, due to strong demand, are more likely to achieve scale effects in infrastructure development. Policy coordination can amplify this advantage, encouraging local areas to optimize their infrastructure layout based on their unique resources. The current imbalance in regional infrastructure development highlights differences in policy implementation and resource acquisition efficiency. To address this, it is essential to strengthen the central-local coordination mechanism, improve policy adaptability, and enhance the effectiveness of policies in underdeveloped regions. This will drive the balanced and sustainable development of charging and swapping infrastructure through policy coordination.

5.2. Recommendations

- 1) Strengthen the information interaction mechanism

Building a unified information platform:

Platform Function Design: Develop an information platform for new energy vehicle charging and swapping infrastructure that includes features such as policy updates, project progress tracking, and facility data analysis. Central and local governments should designate specific departments or personnel to maintain the platform and update data, ensuring timely policy releases, accurate project information, and comprehensive facility data. For example, the policy updates module will provide real-time updates on the latest policy documents and announcements regarding new energy vehicle charging and swapping infrastructure from both central and local authorities. The project progress tracking module will visually present the progress of new and ongoing projects in various regions through charts, including start times, expected completion times, and actual progress. The facility data analysis module will conduct multi-dimensional analyses of data such

as the number of charging stations, their distribution areas, and usage frequency, providing data support for decision-making.

Information Security Assurance: Establish a stringent information security management system, utilizing advanced encryption technologies and access control mechanisms to ensure the security and confidentiality of data on the platform. Define the access permissions for different users: central government departments can view all national data for macro analysis and decision-making; local government departments can only view and manage data within their regions; enterprise users can view data related to their business operations based on authorization. Regularly conduct security vulnerability scans and repairs to prevent data breaches and malicious attacks.

Establish information feedback channels:

Feedback Zone Setup: A dedicated feedback zone has been established on the information platform. Local governments can use this zone to provide real-time feedback on challenges and specific needs encountered during the implementation of central government policies. The feedback should clearly describe the issues, their causes, and proposed solutions, enabling the central government to quickly understand and respond. For example, if local governments encounter difficulties in building charging stations due to limited land resources while implementing the central government's subsidy policy for charging station construction, they can use the feedback zone to detail the specific constraints on land resources and propose alternative solutions, such as constructing multi-level charging stations or using idle spaces to build centralized charging and swapping stations.

Regular Communication Meetings: The central government regularly organizes video or in-person meetings involving representatives from local governments, industry experts, and corporate representatives to conduct in-depth discussions on issues arising during policy implementation. During these meetings, local governments can provide detailed feedback on the actual situations of the issues raised, while the central government promptly addresses any questions and adjusts its policies based on the opinions and suggestions from all parties. Additionally, the meetings may invite industry experts to introduce and analyze new technologies and trends in the field of new energy vehicle charging and battery swapping infrastructure, providing professional insights for policy formulation.

Policy Adjustment Mechanism: The central government adjusts and optimizes policies based on feedback and meeting discussions. A rapid response mechanism for policy adjustments is established to promptly issue supplementary notices or revise documents for urgent and widespread issues. For issues requiring in-depth research and argumentation, a dedicated policy research team is formed to conduct thorough research and analysis, ensuring the scientific and rational nature of policy adjustments. Adjusted policies are promptly released on the information platform, and local governments are organized to study and implement them.

2) Optimize the policy formulation process

Joint policy drafting by central and local governments:

The formation of the joint drafting team: For major policies concerning the charging and swapping infrastructure for new energy vehicles, the central government's relevant ministries lead the effort. They select individuals with rich experience and a deep understanding of local conditions from various local government departments, and invite renowned experts and scholars in the industry to form the joint drafting team. For instance, when drafting policies on the layout planning of charging and swapping facilities for new energy vehicles, professionals are selected from the development and reform commissions, energy bureaus, and transportation bureaus of various provinces and cities. Experts in energy research and transportation planning are also invited to join the team, ensuring that the drafting team has a broad range of professional knowledge and extensive practical experience.

Research and Opinion Collection: Before drafting the policy, the joint drafting team conducted extensive research. They visited charging and swapping facilities in various locations, engaged with new energy vehicle (NEV) companies and users, and distributed questionnaires to gain a comprehensive understanding of the current state of NEV charging and swapping infrastructure, existing issues, and the needs and suggestions of all stakeholders. For instance, field visits revealed that in some remote areas, the weak power grid infrastructure makes it difficult to connect charging stations to the power grid. Conversations with NEV companies indicated their desire for clearer and more stable standards and subsidy policies for charging facility construction. Questionnaires also gathered user feedback on the convenience and speed of charging.

Policy content formulation: Based on the research findings, fully incorporate local experiences and demands, and the drafting team collaborates to formulate the policy content. During the policy formulation process, emphasis is placed on both the universality and adaptability of the policies to local conditions. The policy should reflect the central government's overall strategy and goals for the construction of charging and swapping infrastructure for new energy vehicles, while also allowing local governments to make flexible adjustments based on local conditions. For example, when formulating the subsidy policy for charging pile construction, the overall principles and standards for subsidies are clearly defined, while also allowing local governments to determine specific subsidy amounts and methods within a certain range based on factors such as local economic development levels and the number of new energy vehicles.

Policy pilot and dynamic adjustment:

Pilot area selection: Before the new policy is implemented, representative areas are chosen based on factors such as economic development levels, the status of the new energy vehicle industry, and geographical environments. For example, economically developed coastal cities with a high number of new energy vehicles, as well as less economically developed cities in central and western regions with significant market potential for new energy vehicles, are selected as pilot areas. Ad-

ditionally, regions with diverse geographical features, including mountainous, plain, and plateau areas, are considered to ensure that the pilot areas cover a wide range of conditions.

Pilot Tracking and Evaluation: The central and local governments jointly establish a pilot work tracking and evaluation team to monitor and assess the implementation of policies in pilot areas. This team regularly collects data on policy implementation, project progress, and user feedback from these areas. Using scientific evaluation methods and indicators, they conduct a comprehensive and objective assessment of the policy's effectiveness. For example, by analyzing indicators such as the number of charging stations built, usage rates, and user satisfaction, they evaluate the policy's impact on promoting the construction of charging stations and improving the quality of charging services. By monitoring indicators like the sales volume and market share of new energy vehicles, they assess the policy's role in advancing the development of the new energy vehicle industry.

Policy Adjustment and Improvement: Based on the feedback from pilot projects and evaluation results, promptly identify issues and deficiencies in the policies. Organize relevant departments and experts to conduct research and discussions, making targeted adjustments and improvements to the policies. For effective measures, summarize the experiences and gradually promote them to other regions. For problematic policy clauses, revise or supplement them to ensure the policies are scientifically sound and effective. The adjusted policies will continue to be tested and optimized in the pilot areas, and once they mature, they will be rolled out nationwide.

3) Establish a special coordination agency

Establish a central-local coordination working group:

The team is composed of leaders and key personnel from relevant ministries, including the National Development and Reform Commission, the National Energy Administration, and the Ministry of Industry and Information Technology, as well as leaders from local government departments responsible for the construction of new energy vehicle charging and swapping infrastructure. The central-local collaborative working group is headed by a leader from a central government ministry, who coordinates the group's activities. Several deputy leaders, from local government departments, assist the leader in carrying out the group's tasks. Additionally, based on the needs of the work, multiple sub-groups are established within the group, including policy formulation, project promotion, technical support, and supervision and assessment, with clear responsibilities and tasks defined for each sub-group.

Regular Meeting System: Establish a system for regular meetings, where the working group holds at least one online or offline meeting per month to discuss major issues in the construction of new energy vehicle charging and swapping infrastructure. The meeting topics include policy formulation and adjustments, project planning and approval, resource allocation and coordination, and the unification of technical standards. For example, discussions may focus on coordinat-

ing central and local fiscal funds to ensure adequate funding for charging and swapping infrastructure projects; and researching how to unify the technical standards for charging stations nationwide to facilitate interoperability among different brands and manufacturers.

Communication and Coordination Mechanism: The working group establishes an efficient communication and coordination mechanism to ensure smooth information flow and close collaboration between the central and local governments. By setting up work groups and regularly reporting progress, the group ensures timely communication of requirements and tasks, as well as the sharing of experiences and issues. Any disagreements or conflicts that arise during the work are promptly resolved through consultation and mediation to avoid impacting the project's progress and effectiveness. For instance, if a local government encounters inconsistencies with central policies during project approval, it can consult relevant central government departments through the work group. Upon understanding the situation, the central government departments provide timely guidance and coordination to ensure the project proceeds smoothly.

Establish expert advisory team:

Expert Selection and Appointment: Invite authoritative experts and scholars from the industry to form an expert advisory team. These experts will cover a wide range of fields, including energy, transportation, power, and information technology. Through open selection and recommendation processes, select experts with deep academic expertise and extensive practical experience in the field of new energy vehicle charging and swapping infrastructure. For example, experts in areas such as new energy vehicle battery technology, charging facility construction and operation, and smart grid technology will be selected from universities, research institutions, and industry associations. They will be awarded appointment letters that clearly define their responsibilities and rights.

Consultation Service Content: The expert consultation team provides comprehensive professional consulting services to the central-local collaborative working group. During policy formulation, they assess the scientific, rational, and practical aspects of policies, offering professional advice and suggestions. In project evaluation, they use their expertise and technical skills to evaluate and analyze the technical solutions, economic benefits, and environmental impacts of projects. In addressing technical challenges, they leverage their professional strengths to provide solutions for technical issues encountered in the construction and operation of charging and swapping infrastructure. For instance, when formulating policies for the integration and interaction between new energy vehicles and the power grid, the expert consultation team evaluates the vehicle-grid interaction technology, electricity pricing policies, and market mechanisms involved in the policies, proposing optimization suggestions to ensure that the policies align with technological trends and market dynamics.

Regular Communication Mechanism: Establish a regular communication mechanism between the expert advisory team and the central-local collaborative

working group. Regularly organize experts to conduct specialized lectures, seminars, and other activities to share the latest research findings and industry trends. Additionally, the central-local collaborative working group can consult the expert advisory team as needed and invite experts to participate in the decision-making and evaluation of major projects. For example, organize an expert seminar every quarter to discuss and exchange ideas on hot topics in the field of new energy vehicle charging and swapping infrastructure. Before making decisions on major projects, invite experts to conduct on-site research and evaluations to provide a scientific basis for the decision-making process.

4) Strengthen the linkage between supervision and assessment

Unified supervision and assessment standards:

Indicator System Development: The central government establishes a comprehensive supervision and evaluation system that covers policy implementation, the progress and quality of facility construction, and operational service levels. In terms of policy implementation, the system evaluates local governments' compliance with central policies, including the dissemination of policy documents, the formulation and execution of implementation measures, etc. Regarding the progress and quality of facility construction, it assesses whether the number and progress of charging stations and battery swap stations meet planning requirements and whether the construction quality meets relevant standards. Concerning operational service levels, it evaluates the utilization rate, failure rate, and user satisfaction of charging facilities. For example, it stipulates that the number of charging stations must meet a certain ratio of the annual plan, the construction quality must comply with national and industry standards, the average monthly utilization rate of charging facilities must reach a certain level, and user satisfaction must exceed a certain score.

Refinement and Implementation of Standards: Local governments, based on the supervision and evaluation criteria set by the central government and considering local conditions, further refine these standards and assign specific tasks to departments and individuals. They clearly define the timelines, methods, and reward and punishment measures for evaluations to ensure the smooth implementation of the evaluation process. For example, local governments break down the task of building charging stations to each district and county, setting specific requirements for the number and quality of charging stations to be completed within a certain period. A regular inspection and notification system is established, rewarding districts and counties that perform well and holding those that fail to meet their targets accountable.

Carry out joint supervision and inspection:

The establishment of the joint inspection team: The central and local governments form a joint inspection team, comprising staff from relevant departments of the central government, local government authorities, and industry experts. The team's responsibilities and tasks are clearly defined, and a detailed inspection plan and process are established to ensure the comprehensiveness and objectivity

of the inspection work. For example, the joint inspection team is responsible for regularly inspecting the construction and operation of new energy vehicle charging and swapping infrastructure in various regions. The inspection covers policy implementation, facility construction progress and quality, and operational service levels. The inspection plan specifies the time, location, method, and key points of the inspection.

Regular and irregular spot checks: The joint inspection team conducts regular inspections of the construction and operation of charging and swapping infrastructure in various regions, with comprehensive inspections carried out every six months or annually. Additionally, based on work requirements, spot checks are conducted irregularly in key areas and for major projects. During these inspections, the team uses methods such as reviewing documents, on-site visits, questionnaire surveys, and discussions with relevant personnel to gain a thorough understanding of the situation. For example, during regular inspections, the team reviews local government policy documents, project approval materials, and construction progress reports related to the construction of charging and swapping infrastructure. They also visit the construction sites of charging piles and stations to check the operational status and maintenance records of the facilities. Questionnaire surveys are used to gather user feedback and suggestions on the use of charging facilities. Furthermore, the team engages with local government departments and company executives to understand the issues and challenges encountered in the work.

Implementation of Reward and Punishment Measures: Regions with high policy coordination and significant work achievements will be commended and rewarded. This includes issuing honor certificates, providing financial incentives, and offering preferential policies to encourage local governments to actively develop new energy vehicle charging and swapping infrastructure. For regions that lag behind in coordination and progress, corrective actions will be urged, requiring them to formulate and implement rectification measures within a specified timeframe. Regions that fail to meet the rectification requirements will face public criticism, and relevant individuals will be held accountable. For example, regions that excel in the development of new energy vehicle charging and swapping infrastructure will receive financial rewards from the central government and priority support in project approvals and policy initiatives. For regions that lag behind in coordination, the central government will order them to rectify within a set period and regularly monitor their progress. If the rectification is not satisfactory, the relevant individuals will be held strictly accountable.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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