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Research article

The competitiveness measurement of new energy vehicle industry based on grey relational analysis

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Abstract: This study constructs an evaluation index system based on demand competitiveness, basic competitiveness, industrial agglomeration, industrial competition, industrial innovation, supporting industries, and government policy competitiveness. The study selected 13 provinces with good development of the new energy vehicle (NEV) industry as the sample. Based on the competitiveness evaluation index system, an empirical analysis was conducted to evaluate the development level of the NEV industry in Jiangsu with grey relational analysis and three-way decisions. The results reveal: 1) Under the absolute level of temporal and spatial characteristic attributes, the development of Jiangsu's NEV industry is in a leading position in the country, and the competitiveness level is closer to that of Shanghai and Beijing; 2) Under the incremental level, Jiangsu's incremental level ranks in the upper and middle reaches of 13 provinces, second only to Shanghai; 3) Under the volatility level, Jiangsu's industrial development fluctuates greatly, and the level of volatility lies in the middle reaches of the country. There is a big gap with Shanghai; 4) From the perspective of overall temporal and spatial characteristics, Jiangsu's overall industrial development level is in the first echelon in China, second only to Shanghai and Beijing, indicating that Jiangsu's NEV industry has a relatively good overall development level.

Keywords: new energy vehicle; competitive measurement; grey relational analysis; three way theory

1. Introduction

Achieving low carbon and zero discharge of hazardous chemicals in transportation is of vital importance to society. The new round of global scientific and technological revolution and industrial change is developing vigorously, and the automobile industry has entered an era of unprecedented changes in a century, accelerating the integration of automobiles with information and communication, energy and other fields. In the face of challenges, relevant countries have strengthened the overall planning, carry out systematic layouts, and strive to seize the opportunity to promote industrial development to a new level. In order to seize the major strategic opportunity of carbon neutral carbon peak, accelerate the transformation and upgrading of the automobile industry into electric, networked and intelligent, and promote the high-quality and sustainable development of the new energy vehicle industry in Jiangsu Province, according to the Notice of the General Office of the State Council on the Issuance of the Development Plan of New Energy Vehicle Industry (2021–2035) (Guo Ban Fa [2020] No. 39) and the "Jiangsu Province The 14th Five-Year Plan for National Economic and Social Development and the Outline of the 2035 Vision", Jiangsu Province has also issued the "14th Five-Year Plan for the Development of New Energy Vehicle Industry in Jiangsu Province", which is an important guiding significance for the future development of the industry.

As an important part of the Yangtze River Delta, Jiangsu Province has achieved excellent industrial scale and economic benefits in the field of new energy, but it still lacks technological innovation and industrial competitiveness in the development of the new energy vehicle industry. Therefore, to promote the sustainable development of Jiangsu's NEV industry and further enhance national competitiveness, it is necessary to evaluate the competitiveness and analyze the problems during development. This study first selects the competitiveness evaluation index in literatures to construct the competitiveness evaluation index system of the NEV industry in Jiangsu Province, constructs a grey relevancy clustering model based on a three-way decision, evaluates the new energy of Jiangsu province assesses the development level and problems of China's new energy vehicle industry competitiveness, and gives countermeasure suggestions for the improvement of China's new energy vehicle industry competitiveness.

2. Related literatures

NEVs refer to vehicles that use unconventional energy sources such as solar energy, wind energy, biomass energy, and electric energy converted from them as vehicle fuels, and use driving technologies and structures that are different from traditional vehicles to drive vehicles. China first proposed the concept of NEVs in the "863 plan" at the beginning of the "Eleventh Five-Year Plan" period, and has since attracted the attention of scholars. In a broad sense, NEVs include all vehicles that consume "new" energy. The "new" energy that currently drives cars can be electric energy, solar energy, and natural gas, such as new fuel cell, electric vehicles, hybrid electric vehicles, and pure electric vehicles. Fuel cell vehicles are superior to battery-pack electric vehicles in terms of quality, volume, cost, primary greenhouse gas emission reduction, and fuel filling time. In a narrow sense, a NEV is a vehicle that uses new energy as a power device and is manufactured with superb technology and structural equipment. In short, NEVs mainly refer to vehicles driven by new energy sources, including three main forms of pure electric vehicles, plug-in hybrid electric vehicles and fuel cell vehicles.

In the field of new energy competitiveness research, Zhan analyzed the competitiveness development of Fujian’s new energy automobile industry based on the “diamond model” [1]. Yuan et al. analyzed China’s new energy vehicle industry in terms of advantages, disadvantages, opportunities and challenges, and proposed to improve the competitiveness of China’s new energy vehicle industry by strengthening publicity and other means [2]. Yan constructed the evaluation system of Beijing’s new energy industry competitiveness from four dimensions: industrial innovation ability, market development ability, industrial strategic ability and industrial environment construction, and conducted quantitative research based on the analytic hierarchy process fuzzy comprehensive evaluation method. According to the evaluation results, he proposed countermeasures and suggestions to strengthen the competitiveness of Beijing’s new energy industry from four aspects: law and regulation construction, innovation mechanism, industrial upgrading and regional coordination [3]. Yang et al. evaluated the competitiveness of Hebei’s new energy industry from six aspects: foundation, technology, personnel, economy, environment and market [4]. In addition, scholars have made some achievements in the field of studying the evaluation index of the competitiveness of the new energy industry. Zhuang et al. analyzed the current situation of the international competitiveness of China’s automotive industry from the perspective of the global value chain through four segments: the research and development segment, the production segment, the sales segment, and the after-sales service segment [5]; Wang & Wang used the number of research and development institutions, the proportion of invested funds and talents to measure the strength and potential of the industry from the perspective of patent development [6]. Subsequently, scholars believe that the results reflected by a single dimension are too one-sided and subjective, and should be measured from multiple dimensions, such as “energy efficiency and environmental protection industrial base economic applicability facility dependence” [7], “effective competition innovation capability industrial chain cooperation” [8]. Subsequently, in order to better understand the business model innovation path of new energy vehicles, Zhang et al. added a business model layer on the basis of the three-layer framework of macro environment, system and technological niche, built a business model innovation path model from a multi-level perspective, and analyzed five typical business model innovation paths [9]. With the continuous maturity of the new energy vehicle market, people's understanding of the supply side and the demand side has gradually deepened, and the indicators related to the supply side and the demand side have also started to be included in the evaluation system when assessing the competitiveness of the new energy vehicle industry, such as the environmental and energy benefits and vehicle penetration rates of plug-in hybrid and electric vehicles [10], indicators such as total cost of hybrid vehicles, industrial policies and inter-industry cooperation [11].

There are many influencing factors for the development of the NEV industry, mainly in financial subsidies, government policies, related industry support, and technological innovation. Ma et al. [12] found that the positive cointegration relationship among market share, purchase subsidy, and tax exemption has an impact on the development of the NEV industry. Gong analyzed the factors influencing the international competitiveness of China’s new energy automobile industry by using Porter's “diamond model” analysis method, comprehensively combed the advantages and disadvantages of China’s new energy automobile industry development, and found the right focus for improving China’s new energy automobile industry’s international competitiveness. The research shows that China’s new energy automobile industry has obvious competitive advantages in terms of global market share, industrial chain integrity, and the number of self-owned brand automobile enterprises, etc., but there are deficiencies in international market expansion, some key technologies, industrial service support, high-end brand recognition [13]. Kim & Eun found that a country’s petroleum resource endowment is negatively correlated with automotive technological innovation, and the price of energy is related to NEV technology and energy improvement [14].

Regarding policy, Liu & Song [15] found that the core technology innovation policies in China and other countries have both invested considerable amounts in technology R&D (research and development). However, China's industrial policies have not been able to provide relevant companies with a good development environment and advanced technology [16]. China's NEV industry policy focuses on complete vehicles and is relatively contemptuous of raw materials and parts, causing an imbalance in the technological level of the industry's upstream and downstream [17]. In addition, scientific and technological services play a pivotal role in the scientific and technological innovation of the NEV industry and the transformation of scientific results. Supporting services of university libraries are essential to enhance the scientific and technological innovation capabilities of universities [18]. Ji et al. also studied how to promote the development and popularization of new energy vehicles and how to alleviate the financial pressure faced by the government [19].

According to the above discussion and analysis, there are still problems in the evaluation of the competitiveness level of the new energy vehicle industry. 1) The indicators for evaluating the level of competitiveness need to be improved. At present, there are relatively few studies on the development trend and evaluation of the competitiveness of emerging innovative industries. Most of the existing studies discuss and analyze them as a whole, without making clear distinction between the correlation and levels of indicators, and without forming a set of structural and complete evaluation systems. 2) The measurement method of competitiveness level needs to be improved. At present, the evaluation of the competitiveness of the NEV industry is mostly based on the diamond model, principal component analysis model, fuzzy comprehensive evaluation, grey relational analysis, cluster analysis and other methods [20,21]. These methods can qualitatively and quantitatively analyze the competitiveness of the NEV industry. However, the actual operation process is highly subjective, and there is no in-depth quantitative analysis of complex panel data including time and space dimensions. At the same time, considering that the evaluation of the new energy vehicle industry is a multi-attribute, multi-stage and multi-object panel data evaluation problem, in order to solve these problems, this paper uses panel data, grey correlation clustering analysis and three-way decision-related methods to build an evaluation method suitable for the characteristics of the new energy vehicle industry, and more reasonably measure the competitiveness of new energy vehicles in Jiangsu Province.

3. Competitiveness index system construction

The core issue of the evaluation of the competitiveness of the new energy vehicle industry in Jiangsu Province is to construct a new energy vehicle industry competitiveness evaluation index system. In this paper, the evaluation index system of the competitiveness of the new energy vehicle industry is constructed by combining the theories of industrial competitiveness and the characteristics of the new energy vehicle industry. The evaluation index system of the competitiveness of the new energy vehicle industry is completed by combining the theories related to industrial competitiveness and the characteristics of the new energy vehicle industry with the evaluation index systems of the traditional automobile industry and the new energy vehicle industry. The whole process consists of two parts, firstly, the selection of evaluation indexes, and secondly, the allocation of weights.

3.1. Basic ideas

The basic idea for the construction of the evaluation index system of the competitiveness of the new energy vehicle industry in this paper is: after getting familiar with the relevant theories of industrial competitiveness, comprehensively consider the characteristics of the new energy vehicle industry and the existing comprehensive evaluation index system of the competitiveness of the traditional automobile industry, and initially establish a comprehensive evaluation index system of the competitiveness of the new energy vehicle industry. In order to describe the characteristics, structure and element composition of the object more objectively, this paper establishes an evaluation index system based on the five principles of objectivity, comparability, scientificity, availability and systematicness, and the influencing factors and essential characteristics of the competitiveness of the new energy industry. The new energy industry competitiveness evaluation index system needs to be constructed from different angles and levels. The selected evaluation indicators cover the characteristics of the competitiveness of the new energy industry as much as possible, and objectively and comprehensively describe the development of the competitiveness of the new energy industry in Jiangsu Province.

3.2. Weight measurement methods

Another key aspect of the comprehensive evaluation of the competitiveness of the new energy vehicle industry is the determination of the index weights, and the reasonableness of the weight system affects the accuracy and objectivity of the evaluation results. In order to get more comprehensive index weights, both subjective and objective factors have to be considered. Therefore, compared with the previous traditional expert scoring method, this paper adopts the AHP method [22] and entropy weight method [23] to calculate the subjective weights and objective weights of evaluation indicators, respectively, and the specific calculation process can be referred to the literature [22,23], which will not be repeated here.

3.3. Selection of evaluation indexes and model constructions

Combined with the existing excellent academic master's thesis and core journal evaluation indexes in the evaluation of the competitiveness of the new energy vehicle industry as shown in Table 1.

In this paper, considering the characteristics of the new energy vehicle industry, the existing comprehensive evaluation index system of the competitiveness of the traditional automobile industry, the representativeness of the indexes and the collectability of data, 26 indexes were selected from seven dimensions: demand competitiveness, infrastructure competitiveness, industrial agglomeration, industrial competition, industrial innovation, pillar industries and government policies, and a preliminary evaluation index system of the competitiveness of the new energy vehicle industry in Jiangsu Province was established as shown in Table 2, so as to evaluate the competitiveness of the new energy vehicle industry in Jiangsu Province.

Table 1. Evaluation indicators for competitiveness of new energy vehicle industry.

year	author	evaluation indexes
2004	Research Group on "China's Industrial Competitiveness", Renmin University of China [24]	7 primary indicators of competitive strength, growth competitiveness, market competitiveness, cost competitiveness, innovation competitiveness, investment competitiveness and management competitiveness and 49 other secondary indicators.
2012	Chen [25]	5 primary indicators of environmental competitiveness, innovation competitiveness, manufacturing competitiveness, parts competitiveness and market competitiveness and 19 other secondary indicators.
2013	Qi [26]	6 first-level indicators of government behavior, demand conditions, production factors, relevant support industries, competitors in the same industry and technology-based indicators and 14 other secondary indicators.
2014	Shi [27]	5 primary indicators of basic competitiveness, industrial support, display competitiveness, enterprise competitiveness and product competitiveness and 18 other secondary indicators.
2014	Wang & Wang [28]	4 primary indicators of environmental competitiveness, market competitiveness, production competitiveness and international competitiveness and 16 other secondary indicators.
2018	Tian [14]	Percentage of new energy vehicle sales, annual sales of private charging posts, national per capita disposable income, age share of population aged 25–44, number of school students per 100,000 population.
2022	Xu [29]	4 primary indicators of competitive environment, competitive strength, competitive potential, competitive ability and 15 other secondary indicators.

3.3.1. Demand competitiveness

Demand competitiveness refers to consumers' demand for NEV products and services in the region. Sufficient demand is the endogenous power for companies to improve product services. The most classic theory for industry competitiveness evaluation is Porter's diamond model, which regards trial production requirements, demand conditions, related industry support, and competition in the industry as key factors, and meanwhile summarizes government actions and opportunities as an external auxiliary factors. Regional total output value per capita and per capita disposable income are a reflection of regional economic strength, economic vitality, and people's consumption ability. The new energy vehicle industry is not a defense-military industry, and the development of the new energy industry relies mostly on the purchase volume of private consumers; China has set a mandatory roll-out schedule for traditional fuel cars, and the private car ownership is the replacement volume of potential new energy vehicles [20]. Industrial scale is the basis of industrial development, only a certain amount of asset accumulation and fixed asset investment can continuously and steadily expand the production scale and maintain a certain level of output and competitiveness, the higher the output, the larger the industrial scale, the more likely it is to achieve economies of scale and enhance the competitive advantage of the industry, so the production capacity of new energy vehicles in a region can be measured by the output of new energy vehicle industrial vehicles [26,30]. NEV sales refer to the actual sales volume of NEVs in the region, which can also measure the competitive ability of regional new energy vehicles to a certain extent [31]. Therefore this study selected per capita disposable income, regional GDP, per capita, private car ownership, NEV industry, vehicle output, and NEV sales as secondary indicators of demand competitiveness.

Table 2. Evaluation Index System of NEV Industry Competitiveness.

First level indicator	Secondary indicator	Weight
Demand competitiveness	Per capita disposable income (yuan)	0.035
	Regional GDP per capita (yuan)	0.048
	Private car ownership (10,000 units)	0.042
	NEV industry vehicle output (10,000 units)	0.041
	NEV sales (10,000 units)	0.049
Infrastructure competitiveness	Automobile-related major colleges (institutes) (number of undergraduate colleges)	0.039
	Public charging (exchanging) station and pile (10,000 seats)	0.041
Industrial agglomeration	Number of enterprises above designated size	0.037
	Total assets of NEV industry (100 million)	0.035
	NEV industry output value (100 million)	0.068
	Regional GDP	0.04
	Average number of employees in the NEV industry (10,000 people)	0.032
	NEV export volume (10,000 units)	0.037
Industrial competition	Market share	0.034
	Profit ratio of sales	0.032
	Growth rate of the number of enterprises above designated size	0.039
	Number of NEV companies (ten thousand)	0.031
Industrial innovation	NEV patent applications	0.047
	Proportion of high-level employees	0.033
	Total output value of new industrial products (100 million yuan)	0.032
	NEV technology research and development expenses (100 million yuan)	0.028
Supporting industries	Number of supporting enterprises	0.041
	Total output value of supporting enterprises (100 million yuan)	0.027
	Number of NEV experience stores (houses)	0.042
Government policy	Government investment (ten thousand yuan)	0.039
	Tax reduction and exemption policy	0.031

3.3.2. Infrastructure competitiveness

Infrastructure competitiveness refers to the basic competitiveness that the resource endowment conditions relate to the NEV industry, while abundant infrastructure and human resources indicate greater competitiveness. New energy charging infrastructure and vehicle promotion and application are greatly related, and the delay in the development of the layout of charging piles will hinder the promotion of new energy vehicles. 2020 government also made it clear that the construction and popularization of charging facilities will be the focus of support for the new energy vehicle industry during the 14th Five-Year Plan. Talent is a strategic resource and a decisive factor for economic and social development. The number of colleges and universities with automobile majors directly determines the number of higher education talents in automobile majors in a region. More colleges and universities indicate stronger talent-based competitiveness in the region and richer human resources for industrial development. The number of universities with automotive-related majors reflects the basic competitiveness of talents in a region [20]. Richer infrastructure and human resources indicate stronger competitiveness. This study selects the number of auto-related professional colleges, public charging (exchange) stations, and the number of piles as the measurement indicators of basic competitiveness [20,31].

3.3.3. Industrial agglomeration

Industrial agglomeration is caused by the differences in resource endowment between regions and the external effects of industrial agglomeration. Therefore, indicators representing the degree of industrial agglomeration are selected to reflect regional competitiveness. This paper selects the number of enterprises above the designated size, the total assets of the NEV industry, the output value of the NEV industry, the regional GDP, the average number of employees in the NEV industry and the export volume of NEVs reflecting the degree of industrial agglomeration [20,21,31]. The number of enterprises above the designated size is used to reflect the number of core enterprises in the NEV industry of a region [21]. The total assets of the NEV industry refer to the accumulation of assets of all enterprises engaged in the NEV industry in a region [21]; the output value of the NEV industry refers to the annual total output value of the new energy industry in a region; the regional GDP is used to measure the economic level of a region, and this indicator indirectly reflects the concentration of NEVs in a region [21]; the average number of employees in the NEV industry refers to the average value of the total number of employees in the industry [21]; the export volume of NEVs is the volume of foreign exports, reflecting the international competitiveness of the NEV industry in a region [21].

3.3.4. Industrial competition

Industrial competition refers to the overall competitive situation of the NEV industry in the region. This study selects market share and sales profit rates, the growth rate of the number of enterprises above the designated size, and the number of NEV enterprises are the measurement indicators of the degree of industrial competition [20,21,30]. Industrial market share refers to the ratio of the main business income of the NEV industry to the main business income of the automobile industry, reflecting the industry market share [21]; the sales profit rate refers to the NEV industry's ratio of total profit to the main business income of the NEV industry. This indicator indirectly reflects the degree of competition in the industry [21]; the growth rate of the number of enterprises above the designated size reflects the change in the number of enterprises, The degree of competition [21]; the number of new energy companies refers to all NEV companies included in a region, reflecting the degree of industrial competition within the region [20].

3.3.5. Industrial innovation

Industrial innovation power refers to the creative ideas produced by enterprises in the region during the production of NEVs and their ability to transform them into creative products. This study selects the number of NEV patent applications, the proportion of high-level employees, the total output value of new industrial products, and the R&D cost of NEV technology to measure industry innovation [13,21,26,31]. The number of NEV patent applications and the proportion of high-level employees; the total output value of new industrial products reflects the innovation level of the NEV industry [21]; the NEV technology R&D costs were accumulated funds invested in the R&D process, reflecting the level of regional R&D investment [31].

3.3.6. Supporting industries

Supporting industry refers to the development status of industries related to the development of the NEV industry in the cluster area. The supporting industries for NEVs mainly include the battery industry, the electric motor industry, and the electronic control system industry. The development of the new energy battery industry directly affects the safety and endurance of NEVs. The energy storage status of the chips required by the electronic control system is directly related to the energy storage of NEVs. This paper selects the number of supporting companies, the total output value of supporting companies, and the number of NEV experience stores as the measurement indicators for the pillar industries [20,21,31]. The number of supporting enterprises and the total output value of supporting enterprises directly reflect the strength of the relevant supporting industries in the region; the NEV experience store is an offline entity for end consumers, showing consumers the high-tech, policy preferences, service guarantee and other functions of NEVs, and is an important way to support consumer purchases, so the number of offline experience stores is selected to measure the status of supporting industries [21].

3.3.7. Government policy

Government policy competitiveness refers to the policy support formulated by the local government to promote the development of the local NEV industry, including government capital investment, subsidies for NEV companies, and tax relief. This paper selects government capital investment and tax reduction and exemption policies as the measure of government policy competitiveness [20,21]. Government investment refers to the policy support funds accumulated by the regional government to promote the development of the NEV industry [20,21]. The tax reduction and exemption policy is the number of special policies provided by the local government for enterprises engaged in the NEV industry [20]. These two indicators are used to measure the degree of government support for the NEV industry.

4. Research methods

Grey relevancy clustering is a method of classifying research objects according to their degree of association. Liu et al. [32] pointed out that there are a large number of practical and scientific problems in reality, which urgently need to be studied using high-dimensional data such as panel data. Therefore, correlation modeling and clustering analysis of panel data are very valuable research directions. Among the clustering methods under panel data, grey relevancy clustering has the advantage of not requiring a high sample size and time length. At present, the evaluation of the competitiveness of the NEV industry is mostly based on the diamond model, principal component analysis model, fuzzy comprehensive evaluation, grey relational analysis, cluster analysis and other methods [20,21]. These methods can qualitatively and quantitatively analyze the competitiveness of the NEV industry. However, these methods are highly subjective in practice and have a single form, which cannot fully exploit the information contained in the panel data and have low credibility. The grey clustering method has a great advantage in dealing with the "information-poor" clustering problem. The comprehensive evaluation using cluster analysis can classify the object categories and attributes by combining the spatial and temporal attributes of the panel data. Therefore, based on the theory of three-way decision-making, this study combines the grey correlation analysis method and constructs a grey correlation clustering method for panel data based on three-way decision-making to accurately grasp the differences and characteristics of different attributes of the research objects, to more reasonably evaluate the competitiveness of the new energy vehicle industry in Jiangsu Province, and to improve the timeliness of policies and programs.

Panel data is a more complex form of data structure. It is the repeated observations of the nodes of the research object in different periods on the cross-section. It also contains cross-sectional data and time series, and has the characteristics of two dimensions of space and time. There is a decision-making information system based on panel data $S=\{U,A,V,C\}$, where $U=\{1,2,...,N\}$ is the cluster object collection; $A=\{a_1,a_2,...,a_m\}$ is the index collection; $V=\cup v_{ij}^t(i=1,2,...,n;\ j=1,2,...,m;t=1,2,...T)$ is the panel data range, where v_{ij}^t is the cluster object i 's observation value about the index j at the time t, and $C=\{c_1,...,c_l,...,c_q\}(l=1,2,...,q)$ represents the object's spatiotemporal feature attribute collection.

Definition 1. Suppose $x_{ij}(t)$ is the dimensionless measurement value of the index value v_{ij}^t of the index $j(j=1,2,...,m)$ of the time object $i(i=1,2,...,N)$ at time $t(t=1,2,...,T)$. For $i=1,2,...,n;\ j=1,2,...,m;t=1,2,...T$, if $\Delta x_{ij}(t)$, $\bar{x}_i(j)$ and $S_i(j)$ respectively represent the increment of the index j of the object i at time t, the mean value and standard deviation of the index j, and satisfy $\mu_{ij}(t)=\frac{\Delta x_{ij}(t)}{x_{ij}(t)}$, $\eta_i(j)=\frac{S_i(j)}{\bar{x}_i(j)}$, we called the matrix

$$x_i(t)=\begin{bmatrix} x_{i1}(1) & x_{i2}(1) & \dots & x_{ij}(1) & \dots & x_{im}(1) \\ x_{i1}(2) & x_{i2}(2) & \dots & x_{ij}(2) & \dots & x_{im}(2) \\ \vdots & \vdots & \dots & \vdots & \dots & \vdots \\ x_{i1}(t) & x_{i2}(t) & \dots & x_{ij}(t) & \dots & x_{im}(t) \\ \vdots & \vdots & \dots & \vdots & \dots & \vdots \\ x_{i1}(T) & x_{i2}(T) & \dots & x_{ij}(T) & \dots & x_{im}(T) \end{bmatrix},\ i=1,2,...,N$$

$$\mu_i(t)=\begin{bmatrix}\mu_{i1}(2)\ \mu_{i2}(2)\ldots\ \mu_{ij}(2)\ \ldots\ \mu_{im}(2)\\ \vdots\quad \vdots\quad \ldots\quad \vdots\quad \ldots\quad \vdots\\ \mu_{i1}(t)\ \mu_{i2}(t)\ \ldots\ \mu_{ij}(t)\ \ldots\ \mu_{im}(t)\\ \vdots\quad \vdots\quad \ldots\quad \vdots\quad \ldots\quad \vdots\\ \mu_{i1}(T)\ \mu_{i2}(T)\ \ldots\ \mu_{ij}(T)\ \ldots\ \mu_{im}(T)\end{bmatrix},\ i=1,2,\ldots,N$$

$$\eta_i=\left[\eta_{i1}\ \eta_{i2}\ \ldots\ \eta_{ij}\ \ldots\ \eta_{im}\right],\ i=1,2,\ldots,N$$

the absolute level matrix, incremental level matrix, and volatility level matrix under panel data for the object i, respectively.

Among them, $\Delta x_{ij}(t)=x_{ij}(t)-x_{ij}(t-1)$, $\bar{x}_i(j)=\frac{\sum_{t=1}^{T}x_{ij}(t)}{T}$, $S_i(j)=\frac{\sum_{t=1}^{T}(x_{ij}(t)-\bar{x}_i(t))^2}{T-1}$.

This paper sets the spatiotemporal characteristics of the research object as absolute level, incremental level, and volatility level, and denoted as c_1,c_2,c_3, then there are $l=1,2,3$, $q=3$. Suppose $\gamma_{ij_l}(t)$ is the measured value of the spatiotemporal characteristic attribute c_l of the index j at the time t of the object i, which represents the spatiotemporal characteristic attribute value of the absolute quantity level, the incremental level and the volatility level. Correspondingly, the spatiotemporal characteristic matrix can be defined.

Definition 2. Suppose $\gamma_{ij_l}(t)$ is the measured value of the index j at the moment t under the temporal and spatial characteristics c_l of the object i, and for $\forall i\in U$, $\forall a_j\in A$, $c_l\in C$, $i=1,2,\ldots,n;\ j=1,2,\ldots,m;t=1,2,\ldots T$, we called a matrix

$$\gamma_{i_l}(t)=\begin{bmatrix}\gamma_{i1_l}(1)\ \gamma_{i2_l}(1)\ \ldots\ \gamma_{ij_l}(1)\ \ldots\ \gamma_{im_l}(1)\\ \gamma_{i1_l}(2)\ \gamma_{i2_l}(2)\ldots\ \gamma_{ij_l}(2)\ \ldots\ \gamma_{im_l}(2)\\ \vdots\quad \vdots\quad \ldots\quad \vdots\quad \ldots\quad \vdots\\ \gamma_{i1_l}(t)\ \gamma_{i2_l}(t)\ \ldots\ \gamma_{ij_l}(t)\ \ldots\ \gamma_{im_l}(t)\\ \vdots\quad \vdots\quad \ldots\quad \vdots\quad \ldots\quad \vdots\\ \gamma_{i1_l}(T)\ \gamma_{i2_l}(T)\ \ldots\ \gamma_{ij_l}(T)\ \ldots\ \gamma_{im_l}(T)\end{bmatrix}$$

as the measure value matrix, has the characteristic property of time and space c_l at the moment t about the index j_l for the object i.

According to Definitions 1 and 2, it can be seen that $\gamma_{i_1}(t)=x_i(t)$, $\gamma_{i_2}(t)=\mu_i(t)$, $\gamma_{i_3}(t)=\eta_i(t)$. Larger absolute and increment levels and smaller volatility levels indicate better performance. For spatiotemporal characteristic attributes c_1, the index j_1 satisfies $j_1=1,2,\ldots,m_1$ and $m_1=m$; for spatiotemporal characteristic attributes c_2, the index j_2 satisfies $j_2=1,2,\ldots,m_2$ and $m_2=m$; for spatiotemporal characteristic attributes c_3, the index j_3 satisfies $j_3=1,2,\ldots,m_3$ and $m_3=m$, that is, $j_1=j_2=j_3=j=1,2,\ldots,m$.

For $\forall i,k \in U$, let $d_{ik}^{lj_l}$ and d_{ik}^{j} respectively represent the distance between the object i and k with the index $j(j=1,2,...,m)$ under the set of temporal and spatial feature attributes c_l and time feature attributes C. The absolute, incremental level attributes, and the distance of the fluctuating level attribute of the object i and k with respect to the index $j(j=1,2,...,m)$ can be represented with $d_{ik}^{1j}, d_{ik}^{2j}, d_{ik}^{3j}$ respectively. Among them, $d_{ik}^{1j} = \frac{1}{T}\sum_{t=1}^{T}\left|x_{ij}(t) - x_{kj}(t)\right|$, $d_{ik}^{2j} = \frac{1}{T-1}\sum_{t=1}^{T-1}(|\mu_{ij}(t) - \mu_{kj}(t)|)$, $d_{ik}^{3j} = |\eta_{ij}\text{-}\eta_{kj}|$. Smaller value indicates that the object i and the object k are more similar in terms of the index development degree; and d_{ik}^{2j} describes the trend difference between the object i and the object k in relation to the index $j(j=1,2,...,m)$ increase value over time. If the object i and k have the same change in the index $j(j=1,2,...,m)$ over time, the more similar between i and k, the smaller the distance, and vice versa; d_{ik}^{3j} characterizes the degree of volatility of the index value of the index $j(j=1,2,...,m)$ between the object i and the object k over time. If the similarity between the two individuals is greater, the distance between the object i and the object k is smaller, then we have

$$d_{ik}^{*j} = \sum_{l=1}^{q} w_l^{C} d_{ik}^{lj} = \sum_{l=1}^{3} w_l^{C} d_{ik}^{lj} \tag{4.1}$$

Among them, w_l represents the weight of the spatiotemporal feature attribute c_l, and $w_l^C \in [0,1]$, $\sum_{l=1}^{q} w_l^C = 1$.

Considering that the grey relational analysis judges whether the relationship is close, according to the similarity of the geometric shape of the sequence curve, the grey relational analysis method can be used to measure the distance between the research object i and k about the relevant index $j(j=1,2,...,m)$ under the time characteristic attribute set C. Accordingly, the grey relational coefficient of indicator j under the time characteristic attribute set C is:

$$d_{ik}^{j} = \frac{\min_i \min_j d_{ik}^{*j} + \rho \max_i \max_j d_{ik}^{*j}}{d_{ik}^{j} + \rho \max_i \max_j d_{ik}^{*j}} \tag{4.2}$$

where $\rho \in (0,1)$.

Correspondingly, the grey relational degree of the time characteristic attribute set C between i and k is:

$$d_{ik}^{C}=\sum_{j=1}^{m}w_j d_{ik}^{j} \tag{4.3}$$

Among them, w_j is the weight of the index $j(j=1,2,...,m)$ under the time characteristic attribute set C, $0\le w_j\le 1$, $\sum_{j=1}^{m}w_j=1$.

Definition 3. Suppose that d_{ik}^{C} represents the distance of the decision-making object i,k with respect to the set of temporal and spatial characteristic attributes C. For $\forall i,k\in U$, if $d_{ik}^{C}=d_{ki}^{C}$ is satisfied, then it is called a matrix

$$d=\begin{bmatrix} d_{11}^{C} & d_{12}^{C} & \dots & d_{1k}^{C} & \dots & d_{1n}^{C}\\ d_{21}^{C} & d_{22}^{C} & \dots & d_{2k}^{C} & \dots & d_{2n}^{C}\\ \vdots & \vdots & \dots & \vdots & \dots & \vdots\\ d_{i1}^{C} & d_{i2}^{C} & \dots & d_{ik}^{C} & \dots & d_{in}^{C}\\ \vdots & \vdots & \dots & \vdots & \dots & \vdots\\ d_{n1}^{C} & d_{n2}^{C} & \dots & d_{nk}^{C} & \dots & d_{nn}^{C} \end{bmatrix}$$

The relational distance matrix of multiple spatiotemporal feature attribute objects.

Definition 4. d is the distance matrix of multi-attribute feature objects. For $\forall i,k\in U,C$, $\alpha\in[0,1]$, if $d_{ik}^{C}\ge\alpha$, i,k are called the same class. Correspondingly, the classification of multi-attribute feature objects under the critical value α is called the α grey relational clustering of multi-attribute feature objects. α can be determined according to the needs of the actual problem. The closer α is to 1, the finer the classification, and there are fewer objects in each component; smaller α indicates coarser classification, and there are more variables in each component. Generally, $\alpha=0.5$.

The clustering threshold of the clustering method based on grey relational analysis is generally given by the decision maker in advance, so it is highly subjective and lacks scientific rationality. In addition, in actual situations, objects do not only belong to a certain set (category) and do not belong to a certain set (category). There are also objects between belonging to a certain set and not belonging to a certain set. Therefore, to more scientifically and reasonably reflect the category of the object and discuss the threshold, this paper draws on the three decision-making theories and introduces two parameters α,β into the grey relational clustering model.

Definition 5 supposes there is a multitemporal feature attribute decision clustering problem. For $\forall i,k\in U,C$, $0\le\beta\le\alpha\le 1$, the decision object has the following three possible relationships:

(1) If $d_{ik}^{C}\ge\alpha$, the decision object i,k is the same kind of relationship.

(2) If $\beta<d_{ik}^{C}<\alpha$, the decision object i,k is an uncertain relationship.

(3) If $d_{ik}^{C}\le\beta$, then the decision object i,k is a non-homogeneous relationship.

Correspondingly, a set of possible relationships of objects i can be defined.

Definition 6. For $\forall i\in U,C$, $0\le\beta\le\alpha\le 1$, if the grey relational degree between any object k and the object i with respect to the spatiotemporal characteristic attribute set is d_{ik}^{C}, then the classification situation of the decision object with respect to the spatiotemporal characteristic attribute set can be defined as:

$$SC_C^{(\alpha,\beta)}(i)=\{k \in U \,|\, d_{ik}^C \geq \alpha\} \tag{4.4}$$

$$UC_C^{(\alpha,\beta)}(i)=\{k \in U \,|\, \beta < d_{ik}^C < \alpha\} \tag{4.5}$$

$$NC_C^{(\alpha,\beta)}(i)=\{k \in U \,|\, d_{ik}^C \leq \beta\} \tag{4.6}$$

When $\alpha = \beta$, $UC_C^{(\alpha,\beta)}(i)=0$, the grey relational clustering method degenerates to the classical grey relational clustering method. The classic grey relational clustering method is a special case of the model constructed, and the model constructed in this study is an extension and generalization of the classic grey relational clustering.

This paper uses Bayesian decision reasoning to determine the grey relational clustering threshold α and β with the decision rough set method. For any $i,k \in U$, the corresponding loss function is generated under two states and three relations (action plans), as shown in Table 3. Regarding $\forall i,k \in U$, the two states of the relationship are belonging to or not belonging to a category, respectively. In addition, there are three relations or action plans $O=\{o_S, o_U, o_N\}$; let o_S, o_U, o_N represent the three action plans, where each means that the object must belong to the same category $SC_A^{(\alpha,\beta)}(i)$, may belong to the same category $UC_A^{(\alpha,\beta)}(i)$, and certainly do not belong to the same category $NC_A^{(\alpha,\beta)}(i)$; suppose λ_{SS}, λ_{US}, and λ_{NS} respectively indicate that the decision-maker adopts the loss function that o_S, o_U, o_N belong to the same category $SC_A^{(\alpha,\beta)}(i)$; and λ_{SN}, λ_{UN}, λ_{NN} indicate that the loss function that o_S, o_U, o_N does not belong to the same category $NC_A^{(\alpha,\beta)}(i)$.

Table 3. Loss function on state and action plan about $i,k \in U$.

Plan	Same as i	Different from i
o_S	λ_{SS}	λ_{SN}
o_U	λ_{US}	λ_{UN}
o_N	λ_{NS}	λ_{NN}

Theorem 1. For $0 \leq \lambda_{SS} \leq \lambda_{US} \leq \lambda_{NS}$, $0 \leq \lambda_{NN} \leq \lambda_{UN} \leq \lambda_{SN}$, A, $i,k \in U$,
(1) If $\varepsilon_{ik}^A \geq \alpha$, then $k \in SC_A^{(\alpha,\beta)}(i)$;
(2) If $\beta < \varepsilon_{ik}^A < \alpha$, then $k \in UC_A^{(\alpha,\beta)}(i)$;
(3) If $\varepsilon_{ik}^A \leq \beta$, then $k \in NC_A^{(\alpha,\beta)}(i)$, where

$$\alpha = \frac{(\lambda_{SN} - \lambda_{UN})}{(\lambda_{SN} - \lambda_{UN}) + (\lambda_{US} - \lambda_{NS})} \tag{4.7}$$

$$\beta = \frac{(\lambda_{UN} - \lambda_{NN})}{(\lambda_{UN} - \lambda_{NN}) + (\lambda_{NS} - \lambda_{SS})} \tag{4.8}$$

$$\gamma = \frac{(\lambda_{SN} - \lambda_{NN})}{(\lambda_{SN} - \lambda_{NN}) + (\lambda_{NS} - \lambda_{SS})} \tag{4.9}$$

5. Case analysis

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

5.1. Sample

The data is by the end of 2019. Thirteen provinces with good development of NEV industry across China were selected as the sample. Data include per capita disposable income, regional GDP, per capita, regional GDP, and the number of enterprises above the designated size are from the "China Statistical Yearbook 2019" and the "2019 National Economic Development and Social Development Bulletin" of various provinces; automotive-related majors data for universities, public charging (replacement) stations, and piles are from the 2017–2019 "China Automobile Market Yearbook" and "China Electric Vehicle Charging Pile Industry Research Report"; market share, sales profit margin, and growth rate of the number of enterprises above designated size , The number of NEV companies, the number of private cars, the NEV industry's vehicle production, and the NEV sales data are derived from the data of the automobile industry statistical yearbook 2017–2019; the total assets of the NEV industry, the output value of the NEV industry, The average number of employees in the NEV industry, the export volume of NEVs, the number of supporting companies, the total output value of supporting companies, and the number of NEV experience stores are collected from the "Blue Book Series-China NEV Industry Development Report 2019"; government funds Data on investment and tax reduction and exemption policies are compiled from the official website of each province; the number of NEV patent applications, the proportion of high-level employees, the total output value of NEVs, and the NEV technology research and development expenses are derived from the new energy released by the State Intellectual Property Office An analysis report on the patent situation of the automobile industry. For the data vacancy, the exponential smoothing method is used to estimate the missing data. The data is shown in Tables S1–S3(Please find attached for more detail).

5.2. Measurement of the competitiveness level of NEV industry

The level of competitiveness of Jiangsu's NEV industry is measured with a grey relational analysis model. This paper uses AHP method and entropy method to calculate the evaluation index weights respectively, the weights of each indicator can be determined $\omega_1 = 0.035, \omega_2 = 0.048, \omega_3 = 0.042$, $\omega_4 = 0.041, \omega_5 = 0.049, \omega_6 = 0.039$, $\omega_7 = 0.041, \omega_8 = 0.037, \omega_9 = 0.035,$ $\omega_{10} = 0.068, \omega_{11} = 0.04$, $\omega_{12} = 0.032, \omega_{13} = 0.037,$ $\omega_{14} = 0.034, \omega_{15} = 0.032$, $\omega_{16} = 0.039, \omega_{17} = 0.031,$ $\omega_{18} = 0.047, \omega_{19} = 0.033, \omega_{20} = 0.032,$ $\omega_{21} = 0.028, \omega_{22} = 0.041$, $\omega_{23} = 0.027, \omega_{24} = 0.042, \omega_{25} = 0.039,$ $\omega_{26} = 0.032$. After the dimensionless processing of the above data, the data of each province under the spatiotemporal characteristic attribute set can be obtained with Eqs (4.1) and (4.2) (see Tables 4–6). According to the method of determining the weights of spatiotemporal feature attributes used by [33] to obtain spatiotemporal feature attributes, the weights are as follows: $\omega_1^C = 0.55, \omega_2^C = 0.25, \omega_3^C = 0.20$.

Then we calculate the ideal value of each index under each spatiotemporal feature to obtain the distribution sequence. Among them, the ideal value of the increment level and the increment level attribute for each index is the maximum value of all provinces, and the ideal value of the volatility level attribute for each index is the minimum value.

Table 4. Dimensionless data of each province under the attribute of absolute quantity level.

	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Per capita disposable income (yuan)	0.5945	1.0000	0.9725	0.7152	0.3922	0.3945	0.3664	0.3428	0.3749	0.5103	0.3515	0.4555	0.5598
Regional GDP per capita (yuan)	0.7641	0.9764	0.9826	0.6587	0.4492	0.3533	0.2991	0.3391	0.3289	0.6192	0.3290	0.4418	0.5875
Private car ownership (10,000 units)	1.0000	0.3980	0.4803	0.8783	0.4495	0.4694	0.9163	0.7606	0.6291	0.3540	0.6383	0.7749	0.6576
NEV industry vehicle output (10,000 units)	0.4468	0.7538	0.1391	0.3076	0.3792	0.4286	0.1553	0.3273	0.6835	0.1163	0.1614	0.7721	0.6131
NEV sales (10,000 units)	0.7418	0.4361	0.3850	0.5001	0.1213	0.1235	0.1868	0.2845	0.1634	0.1791	0.2255	0.3382	0.7174
Automobile-related major colleges (institutes) (number of undergraduate colleges)	0.9454	0.5299	0.9206	0.4876	0.8309	0.6263	0.7495	0.7443	0.5748	0.4807	0.6631	0.8892	0.8070
Public charging (exchanging) station and pile (10,000 seats)	0.9878	0.8469	0.8340	0.3508	0.2127	0.1285	0.2918	0.1323	0.2998	0.4344	0.1764	0.3676	0.8999
Number of enterprises above designated size	0.6265	0.6754	0.2158	0.6777	0.4997	0.8000	0.0717	0.2003	0.0123	0.0045	0.0314	0.0864	0.0941
Total assets of NEV industry (100 million)	0.8778	0.9438	1.0000	0.8973	0.6823	0.6852	0.7595	0.2515	0.1783	0.0965	0.2051	0.2164	0.2538
NEV industry output value (100 million)	0.9630	0.8705	0.8404	0.7776	0.5655	0.5457	0.5795	0.6173	0.4172	0.1262	0.2638	0.1633	0.2142
Regional GDP	0.9288	0.3364	0.3124	0.5765	0.4018	0.3673	0.3593	0.4961	0.3359	0.3677	0.4141	0.6692	1.0000
Average number of employees in the NEV industry (10,000 people)	0.9221	0.9697	0.9640	0.3147	0.5581	0.4967	0.3043	0.2043	0.2355	0.1949	0.5501	0.5650	0.5721
NEV export volume (10,000 units)	0.8861	0.9605	0.9929	0.7330	0.4990	0.4533	0.1701	0.1768	0.1227	0.0948	0.0754	0.0499	0.0744
Market share	0.9449	0.9881	0.9597	0.9518	0.5873	0.4676	0.5075	0.4434	0.3398	0.2592	0.2523	0.2728	0.2794
Profit ratio of sales	0.5921	0.9556	0.6863	0.5682	0.5472	0.8100	0.4740	0.5061	0.4166	0.4212	0.4601	0.4605	0.4609
Growth rate of the number of enterprises above designated size	0.6853	0.9656	0.6650	0.1722	-0.0816	0.1489	0.3469	0.4038	0.2850	0.2202	0.3312	0.2838	0.3257
Number of NEV companies (ten thousand)	0.8582	0.7877	0.2990	0.8566	0.9432	0.7869	0.1801	0.1738	0.0965	0.0803	0.1204	0.0929	0.1130
NEV patent applications	0.6286	0.9792	0.7394	0.5630	0.4442	0.4067	0.1462	0.0455	0.3161	0.0736	0.2702	0.2461	0.1966
Proportion of high-level employees	0.8630	0.9298	0.9733	0.7909	0.6504	0.5818	0.4382	0.3628	0.4065	0.3111	0.4096	0.3162	0.2910
Total output value of new industrial products (100 million yuan)	0.8633	0.9496	0.9486	0.9889	0.5470	0.5631	0.6324	0.6569	0.4713	0.1471	0.1957	0.1871	0.2260

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	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
NEV technology R&D expenses (100 million yuan)	0.6911	0.8455	1.0000	0.7683	0.5366	0.6091	0.4499	0.4380	0.3822	0.4748	0.4903	0.3976	0.4131
Number of supporting enterprises	0.4983	0.3949	0.7987	1.0000	0.5073	0.4388	0.6363	0.7009	0.7987	0.2013	0.2658	0.0684	0.1329
Total output value of supporting enterprises (100 million yuan)	0.5505	0.6306	0.8769	1.0000	0.4273	0.3657	0.3042	0.2709	0.2426	0.1810	0.2717	0.1933	0.1564
Number of NEV experience stores (houses)	0.4101	0.5385	0.9000	0.8806	0.4372	0.4261	0.4212	0.0944	0.1457	0.2651	0.5135	0.2658	0.3095
Government investment (ten thousand yuan)	0.6484	0.8302	1.0000	0.8932	0.3249	0.2897	0.2715	0.2547	0.1988	0.1737	0.2502	0.1846	0.1976
Tax reduction and exemption policy	0.8440	1.0000	0.8774	0.7462	0.6321	0.6060	0.5186	0.4271	0.3536	0.2855	0.3550	0.2910	0.4040

Table 5. Dimensionless data of each province under the attribute of incremental level.

	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Per capita disposable income (yuan)	0.0020	0.0000	0.0028	0.0040	-0.0182	0.0087	0.0073	0.0033	0.0129	0.0034	0.0097	-0.0017	0.0021
Regional GDP per capita (yuan)	-0.0230	-0.0219	0.0261	-0.0164	0.0308	-0.0171	-0.0910	-0.0055	0.0510	0.0318	0.0162	-0.0428	-0.0279
Private car ownership (10,000 units)	0.0000	0.3818	0.0596	0.0085	0.0426	0.0450	0.0079	0.0568	0.0058	0.0134	0.0077	0.2001	0.1788
NEV industry vehicle output (10,000 units)	-0.5685	0.3249	-0.9962	0.1173	-0.2759	0.4414	0.4775	0.1409	0.0295	-0.1066	-0.0101	-1.0812	0.3985
NEV sales (10,000 units)	-1.7174	-0.2824	-0.0645	-0.1727	0.0994	-0.2916	-0.4010	-0.2395	-0.1021	-0.0060	-0.2213	-0.0868	0.1293
Automobile-related major colleges (institutes) (number of undergraduate colleges)	-0.0161	-0.0012	0.0041	0.4753	-0.0263	-0.0321	-0.0399	-0.0222	-0.0159	-0.0119	-0.0201	0.0042	-0.0096
Public charging (exchanging) station and pile (10,000 seats)	-0.0190	0.0678	0.1067	0.3506	0.2628	0.2793	0.1622	0.1891	0.3856	-0.0727	0.4566	0.4275	0.1292
Number of enterprises above designated size	0.1747	0.2198	0.5964	0.1817	0.0996	-0.7500	0.0431	0.1272	0.5154	0.3806	0.1357	0.4007	0.4362
Total assets of NEV industry (100 million)	-0.0778	-0.0409	0.0000	-0.0183	-0.2603	-0.2334	-0.1653	-0.2464	0.0709	0.1812	-0.0195	0.0673	0.1055

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	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
NEV industry output value (100 million)	-0.0625	0.1459	0.2270	0.2546	0.0131	0.0963	0.1504	0.0914	0.2539	-0.0838	-0.2203	0.2878	0.2564
Regional GDP	-0.0079	0.0345	0.0343	0.0048	0.0445	0.0003	-0.0987	0.0163	0.0292	0.0519	0.0329	-0.0259	0.0000
Average number of employees in the NEV industry (10,000 people)	-0.0466	-0.0500	0.0222	-0.4320	0.1521	0.2964	0.4272	0.2373	0.4370	0.4726	0.3159	0.2837	0.2444
NEV export volume (10,000 units)	-0.0386	0.0073	0.0106	-0.4366	-0.0926	0.0322	-0.9945	-1.4411	-0.2087	0.0255	0.1603	-0.1907	-0.1315
Market share	0.0154	0.0179	0.0016	-0.0795	0.3591	0.3067	0.1660	0.1263	0.1106	0.3701	0.5417	0.4536	0.4198
Profit ratio of sales	-3.4756	-0.0103	-4.4263	-3.0044	-3.1741	-0.0235	-3.1390	-3.0958	-3.1829	-3.4750	-2.8556	-3.0626	-3.0881
Growth rate of the number of enterprises above designated size	0.1876	-0.0059	-4.0094	0.8738	1.4756	1.1137	0.2060	0.2615	0.2806	0.1856	0.3243	-0.1147	0.0035
Number of NEV companies (ten thousand)	-0.3700	-0.1396	0.4271	-0.0095	-0.0055	0.0013	-0.0219	-0.0094	0.1919	0.2403	0.3285	0.2127	0.2176
NEV patent applications	0.2141	-0.0333	0.1199	0.1259	0.2387	0.2304	0.3089	-0.3827	0.1712	0.6728	0.4044	0.2505	0.3065
Proportion of high-level employees	-0.0522	-0.0848	0.0400	-0.0432	-0.0788	-0.0045	0.1495	0.2291	0.3031	0.2833	0.5051	0.3522	0.4653
Total output value of new industrial products (100 million yuan)	0.0492	0.0492	0.0513	-0.0172	0.0460	0.0432	0.0513	0.0656	0.1319	-0.2271	0.0476	0.1779	0.2730
NEV technology research and development expenses (100 million yuan)	0.0339	0.0140	0.0000	0.0230	0.0646	0.0365	0.0591	0.1243	0.1179	0.0820	0.0773	0.1109	0.1043
Number of supporting enterprises	0.0340	0.0192	-0.0622	0.0000	-0.0974	0.0182	-0.1253	-0.1356	-0.0622	0.2154	0.1229	0.3782	0.1229
Total output value of supporting enterprises (100 million yuan)	0.0197	0.0513	0.0126	0.0000	0.0507	0.0734	0.1046	0.1459	0.1500	0.2226	0.1053	0.2048	0.2655
Number of NEV experience stores (houses)	0.1938	0.1513	-0.2143	0.1336	0.1795	0.3339	0.0173	0.1126	0.0740	0.2142	0.1368	0.0811	0.1952
Government investment (ten thousand yuan)	0.0490	0.0190	0.0000	-0.0303	0.0201	-0.0292	-0.0249	-0.0280	-0.0002	-0.0285	0.0250	-0.0246	-0.1028
Tax reduction and exemption policy	-0.0367	0.0000	0.0241	0.1449	0.0964	0.0354	0.0296	0.0982	0.1503	0.2849	0.2818	0.3354	0.2345

Table 6. Dimensionless data of each province under the attribute of volatility level.

	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Per capita disposable income (yuan)	0.0000	0.0000	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000
Regional GDP per capita (yuan)	0.0005	0.0005	0.0009	0.0004	0.0008	0.0002	0.0030	0.0003	0.0017	0.0014	0.0003	0.0009	0.0005
Private car ownership (10,000 units)	0.0000	0.3086	0.2967	0.0001	0.0009	0.0010	0.0001	0.0026	0.0000	0.0001	0.0001	0.0428	0.0252
NEV industry vehicle output (10,000 units)	0.1222	0.1127	0.0671	0.0146	0.0283	0.1255	0.0532	0.0074	0.0777	0.0054	0.0019	0.2019	0.1945
NEV sales (10,000 units)	0.2695	0.0266	0.0125	0.0123	0.0014	0.0079	0.0202	0.0129	0.0015	0.0018	0.0096	0.0026	0.0881
Automobile-related major colleges (institutes) (number of undergraduate colleges)	0.0095	0.0052	0.0053	0.2165	0.0056	0.0021	0.0019	0.0058	0.0001	0.0003	0.0009	0.0007	0.0013
Public charging (exchanging) station and pile (10,000 seats)	0.0005	0.0082	0.0114	0.0727	0.0213	0.0231	0.0109	0.0063	0.0783	0.0061	0.0545	0.1717	0.0189
Number of enterprises above designated size	0.0618	0.1174	0.4611	0.0579	0.0247	0.1500	0.0008	0.0101	0.0150	0.0021	0.0018	0.1121	0.1263
Total assets of NEV industry (100 million)	0.0049	0.0016	0.0000	0.0003	0.0428	0.0352	0.0221	0.0129	0.0010	0.0038	0.0002	0.0013	0.0032
NEV industry output value (100 million)	0.0043	0.0245	0.0690	0.0682	0.0023	0.0184	0.0152	0.0108	0.0339	0.0018	0.0236	0.0187	0.0181
Regional GDP	0.0001	0.0006	0.0006	0.0000	0.0010	0.0000	0.0032	0.0002	0.0003	0.0013	0.0006	0.0004	0.0000
Average number of employees in the NEV industry (10,000 people)	0.0040	0.0028	0.0011	0.0315	0.0157	0.0639	0.1453	0.0737	0.0665	0.0747	0.0902	0.0605	0.0516
NEV export volume (10,000 units)	0.0090	0.0009	0.0002	0.0909	0.0039	0.0196	0.0420	0.0573	0.0083	0.0008	0.0026	0.0017	0.0012
Market share	0.0003	0.0004	0.0035	0.0064	0.1553	0.0640	0.0199	0.0096	0.0046	0.0715	0.2116	0.1249	0.0838
Profit ratio of sales	0.3314	0.0062	0.3750	0.3203	0.3086	0.0356	0.2492	0.2621	0.2179	0.2654	0.2498	0.2661	0.2451
Growth rate of the number of enterprises above designated size	0.0295	0.0037	0.3523	11.2296	-2.6571	0.8033	0.0454	0.0553	0.0464	0.0145	0.0667	0.0033	0.0003
Number of NEV companies (ten thousand)	0.0702	0.0135	0.5844	0.0054	0.0078	0.0119	0.0004	0.0062	0.0043	0.0060	0.0192	0.0091	0.0091
NEV patent applications	0.0921	0.0013	0.0734	0.0673	0.1002	0.1157	0.0277	0.0115	0.0147	0.0729	0.1110	0.0507	0.0514
Proportion of high-level employees	0.0037	0.0061	0.0022	0.0024	0.0057	0.0017	0.0116	0.0280	0.0542	0.0333	0.1623	0.0609	0.0939
Total output value of new industrial products (100 million yuan)	0.0035	0.0039	0.0026	0.0004	0.0034	0.0047	0.0018	0.0035	0.0098	0.0082	0.0010	0.0070	0.0307

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	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
NEV technology research and development expenses (100 million yuan)	0.0008	0.0002	0.0000	0.0004	0.0024	0.0009	0.0019	0.0079	0.0059	0.0035	0.0032	0.0054	0.0050
Number of supporting enterprises	0.0026	0.0002	0.0029	0.0000	0.0049	0.0005	0.0090	0.0113	0.0029	0.0115	0.0045	0.0139	0.0023
Total output value of supporting enterprises (100 million yuan)	0.0004	0.0018	0.0001	0.0000	0.0013	0.0023	0.0038	0.0066	0.0064	0.0111	0.0033	0.0099	0.0141
Number of NEV experience stores (houses)	0.0187	0.0142	0.0333	0.0179	0.0217	0.0759	0.0167	0.0032	0.0025	0.0148	0.0120	0.0052	0.0297
Government investment (ten thousand yuan)	0.0028	0.0010	0.0000	0.0008	0.0002	0.0003	0.0002	0.0003	0.0000	0.0002	0.0002	0.0003	0.0027
Tax reduction and exemption policy	0.0018	0.0000	0.0005	0.0180	0.0066	0.0072	0.0020	0.0055	0.0102	0.0352	0.0509	0.0573	0.0401

Table 7. The grey relational coefficient under the absolute level attribute.

	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Per capita disposable income (yuan)	0.5715	1.0000	0.9516	0.6550	0.4708	0.4718	0.4605	0.4514	0.4638	0.5248	0.4547	0.4983	0.5512
Regional GDP per capita (yuan)	0.6962	0.9582	0.9688	0.6131	0.4954	0.4554	0.4355	0.4500	0.4462	0.5868	0.4463	0.4921	0.5673
Private car ownership (10,000 units)	1.0000	0.4732	0.5100	0.8164	0.4956	0.5048	0.8660	0.6931	0.5932	0.4557	0.5992	0.7061	0.6123
NEV industry vehicle output (10,000 units)	0.4943	0.6872	0.3858	0.4385	0.4656	0.4862	0.3903	0.4457	0.6308	0.3796	0.3920	0.7035	0.5829
NEV sales (10,000 units)	0.6769	0.4895	0.4679	0.5196	0.3810	0.3816	0.3994	0.4305	0.3926	0.3971	0.4112	0.4497	0.6568
Automobile-related major colleges (institutes) (number of undergraduate colleges)	0.9082	0.5350	0.8719	0.5135	0.7618	0.5914	0.6834	0.6789	0.5598	0.5101	0.6162	0.8300	0.7370
Public charging (exchanging) station and pile (10,000 seats)	0.9779	0.7794	0.7651	0.4544	0.4072	0.3829	0.4330	0.3840	0.4358	0.4888	0.3964	0.4609	0.8438
Number of enterprises above designated size	0.5915	0.6249	0.4081	0.6266	0.5194	0.7300	0.3681	0.4034	0.3538	0.3520	0.3583	0.3718	0.3738
Total assets of NEV industry (100 million)	0.8157	0.9059	1.0000	0.8404	0.6299	0.6321	0.6921	0.4195	0.3969	0.3744	0.4049	0.4083	0.4202
NEV industry output value (100 million)	0.9359	0.8068	0.7721	0.7086	0.5545	0.5435	0.5626	0.5856	0.4813	0.3823	0.4235	0.3926	0.4076
Regional GDP	0.8836	0.4490	0.4402	0.5608	0.4748	0.4609	0.4577	0.5176	0.4488	0.4610	0.4800	0.6205	1.0000
Average number of employees in the NEV industry (10,000 people)	0.8741	0.9469	0.9376	0.4411	0.5503	0.5180	0.4374	0.4046	0.4143	0.4018	0.5459	0.5542	0.5583

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	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
NEV export volume (10,000 units)	0.8260	0.9319	0.9871	0.6695	0.5191	0.4973	0.3945	0.3965	0.3813	0.3740	0.3690	0.3627	0.3688
Market share	0.9075	0.9785	0.9306	0.9182	0.5672	0.5039	0.5234	0.4928	0.4503	0.4220	0.4197	0.4265	0.4287
Profit ratio of sales	0.5701	0.9241	0.6329	0.5560	0.5443	0.7400	0.5069	0.5226	0.4811	0.4830	0.5004	0.5006	0.5008
Growth rate of the number of enterprises above designated size	0.6322	0.9402	0.6175	0.3951	0.3333	0.3885	0.4530	0.4756	0.4306	0.4095	0.4471	0.4302	0.4451
Number of NEV companies (ten thousand)	0.7923	0.7180	0.4355	0.7904	0.9049	0.7173	0.3974	0.3956	0.3744	0.3703	0.3807	0.3735	0.3788
NEV patent applications	0.5929	0.9629	0.6748	0.5531	0.4932	0.4768	0.3878	0.3617	0.4416	0.3686	0.4256	0.4177	0.4023
Proportion of high-level employees	0.7979	0.8851	0.9530	0.7211	0.6073	0.5639	0.4905	0.4591	0.4768	0.4398	0.4781	0.4416	0.4327
Total output value of new industrial products (100 million yuan)	0.7982	0.9147	0.9133	0.9799	0.5442	0.5531	0.5953	0.6118	0.5056	0.3880	0.4021	0.3995	0.4113
NEV technology research and development expenses (100 million yuan)	0.6364	0.7778	1.0000	0.7001	0.5385	0.5804	0.4957	0.4904	0.4668	0.5073	0.5148	0.4731	0.4795
Number of supporting enterprises	0.5187	0.4719	0.7288	1.0000	0.5232	0.4907	0.5979	0.6438	0.7288	0.4037	0.4242	0.3673	0.3841
Total output value of supporting enterprises (100 million yuan)	0.5461	0.5941	0.8145	1.0000	0.4857	0.4602	0.4373	0.4259	0.4166	0.3977	0.4261	0.4013	0.3906
Number of NEV experience stores (houses)	0.4783	0.5396	0.8439	0.8192	0.4900	0.4852	0.4830	0.3739	0.3876	0.4239	0.5264	0.4241	0.4392
Government investment (ten thousand yuan)	0.6060	0.7610	1.0000	0.8350	0.4448	0.4322	0.4261	0.4205	0.4030	0.3956	0.4190	0.3988	0.4026
Tax reduction and exemption policy	0.7762	1.0000	0.8152	0.6806	0.5952	0.5785	0.5290	0.4856	0.4555	0.4308	0.4561	0.4327	0.4757

Table 8. The grey relational coefficient under the incremental level attribute.

	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Per capita disposable income (yuan)	0.9951	0.9942	0.9955	0.9960	0.9862	0.9981	0.9975	0.9957	1.0000	0.9957	0.9985	0.9935	0.9951
Regional GDP per capita (yuan)	0.9841	0.9846	0.9941	0.9870	0.9920	0.9867	0.9553	0.9918	0.9831	0.9916	0.9985	0.9755	0.9819
Private car ownership (10,000 units)	0.9942	0.8575	0.9794	0.9980	0.9868	0.9857	0.9977	0.9806	0.9968	0.9998	0.9977	0.9222	0.9305
NEV industry vehicle output (10,000 units)	0.7924	0.8768	0.6875	0.9551	0.8849	0.8382	0.8269	0.9455	0.9926	0.9489	0.9898	0.6698	0.8520
NEV sales (10,000 units)	0.5619	0.8826	0.9663	0.9228	0.9625	0.8793	0.8428	0.8979	0.9508	0.9916	0.9046	0.9570	0.9502

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	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Automobile-related major colleges (institutes) (number of undergraduate colleges)	0.9871	0.9937	0.9961	0.8276	0.9826	0.9801	0.9768	0.9844	0.9872	0.9890	0.9853	0.9961	0.9900
Public charging (exchanging) station and pile (10,000 seats)	0.9858	0.9758	0.9594	0.8680	0.8988	0.8928	0.9370	0.9264	0.8562	0.9629	0.8334	0.8426	0.9502
Number of enterprises above designated size	0.9320	0.9147	0.7918	0.9293	0.9624	0.7442	0.9866	0.9510	0.8154	0.8579	0.9476	0.8513	0.8398
Total assets of NEV industry (100 million)	0.9608	0.9763	0.9942	0.9862	0.8904	0.9001	0.9257	0.8954	0.9745	0.9295	0.9856	0.9761	0.9600
NEV industry output value (100 million)	0.9671	0.9435	0.9120	0.9018	0.9999	0.9638	0.9417	0.9658	0.9021	0.9583	0.9049	0.8898	0.9011
Regional GDP	0.9907	0.9904	0.9904	0.9964	0.9859	0.9944	0.9521	0.9985	0.9927	0.9827	0.9911	0.9828	0.9942
Average number of employees in the NEV industry (10,000 people)	0.9739	0.9724	0.9958	0.8330	0.9410	0.8867	0.8427	0.9082	0.8396	0.8284	0.8799	0.8913	0.9055
NEV export volume (10,000 units)	0.9773	0.9975	0.9990	0.8316	0.9546	0.9914	0.6878	0.6042	0.9092	0.9943	0.9377	0.9160	0.9389
Market share	0.9989	0.9978	0.9950	0.9600	0.8651	0.8831	0.9355	0.9514	0.9578	0.8614	0.8076	0.8343	0.8451
Profit ratio of sales	0.3889	0.9897	0.3333	0.4238	0.4105	0.9839	0.4132	0.4166	0.4099	0.3889	0.4362	0.4192	0.4172
Growth rate of the number of enterprises above designated size	0.9270	0.9916	0.3556	0.7205	0.6028	0.6685	0.9199	0.8993	0.8924	0.9278	0.8770	0.9456	0.9958
Number of NEV companies (ten thousand)	0.8529	0.9357	0.8427	0.9900	0.9918	0.9948	0.9846	0.9900	0.9254	0.9071	0.8755	0.9174	0.9156
NEV patent applications	0.9169	0.9796	0.9540	0.9516	0.9077	0.9108	0.8823	0.8487	0.9334	0.7708	0.8501	0.9033	0.8832
Proportion of high-level employees	0.9715	0.9578	0.9879	0.9754	0.9603	0.9922	0.9420	0.9112	0.8844	0.8914	0.8185	0.8674	0.8307
Total output value of new industrial products (100 million yuan)	0.9839	0.9839	0.9830	0.9866	0.9853	0.9865	0.9830	0.9768	0.9491	0.9024	0.9846	0.9308	0.8951
NEV technology research and development expenses (100 million yuan)	0.9906	0.9995	0.9942	0.9955	0.9773	0.9895	0.9796	0.9522	0.9548	0.9698	0.9718	0.9577	0.9604
Number of supporting enterprises	0.9906	0.9972	0.9673	0.9942	0.9527	0.9976	0.9414	0.9373	0.9673	0.9164	0.9528	0.8587	0.9528
Total output value of supporting enterprises (100 million yuan)	0.9970	0.9830	0.9999	0.9942	0.9833	0.9735	0.9603	0.9435	0.9418	0.9137	0.9600	0.9204	0.8978
Number of NEV experience stores (houses)	0.9247	0.9413	0.9072	0.9484	0.9302	0.8736	0.9980	0.9570	0.9732	0.9168	0.9471	0.9702	0.9241
Government investment (ten thousand yuan)	0.9840	0.9972	0.9942	0.9809	0.9968	0.9814	0.9833	0.9819	0.9942	0.9817	0.9946	0.9834	0.9505
Tax reduction and exemption policy	0.9782	0.9942	0.9950	0.9439	0.9637	0.9900	0.9925	0.9630	0.9417	0.8908	0.8920	0.8731	0.9092

Table 9. The grey relational coefficient under the attribute of volatility level.

	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Per capita disposable income (yuan)	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Regional GDP per capita (yuan)	0.9999	0.9999	0.9998	0.9999	0.9999	1.0000	0.9995	0.9999	0.9997	0.9997	0.9999	0.9998	0.9999
Private car ownership (10,000 units)	1.0000	0.9479	0.9498	1.0000	0.9998	0.9998	1.0000	0.9995	1.0000	1.0000	1.0000	0.9924	0.9955
NEV industry vehicle output (10,000 units)	0.9787	0.9803	0.9882	0.9974	0.9950	0.9781	0.9906	0.9987	0.9863	0.9990	0.9997	0.9653	0.9665
NEV sales (10,000 units)	0.9542	0.9953	0.9978	0.9978	0.9998	0.9986	0.9964	0.9977	0.9997	0.9997	0.9983	0.9995	0.9845
Automobile-related major colleges (institutes) (number of undergraduate colleges)	0.9983	0.9991	0.9991	0.9629	0.9990	0.9996	0.9997	0.9990	1.0000	1.0000	0.9998	0.9999	0.9998
Public charging (exchanging) station and pile (10,000 seats)	0.9999	0.9985	0.9980	0.9872	0.9962	0.9959	0.9981	0.9989	0.9862	0.9989	0.9904	0.9703	0.9966
Number of enterprises above designated size	0.9891	0.9795	0.9241	0.9898	0.9956	0.9740	0.9999	0.9982	0.9973	0.9996	0.9997	0.9804	0.9780
Total assets of NEV industry (100 million)	0.9991	0.9997	1.0000	0.9999	0.9924	0.9938	0.9961	0.9977	0.9998	0.9993	1.0000	0.9998	0.9994
NEV industry output value (100 million)	0.9992	0.9957	0.9879	0.9880	0.9996	0.9967	0.9973	0.9981	0.9940	0.9997	0.9958	0.9967	0.9968
Regional GDP	1.0000	0.9999	0.9999	1.0000	0.9998	1.0000	0.9994	1.0000	0.9999	0.9998	0.9999	0.9999	1.0000
Average number of employees in the NEV industry (10,000 people)	0.9993	0.9995	0.9998	0.9944	0.9972	0.9888	0.9748	0.9870	0.9883	0.9869	0.9842	0.9893	0.9909
NEV export volume (10,000 units)	0.9984	0.9998	1.0000	0.9841	0.9993	0.9965	0.9926	0.9899	0.9985	0.9999	0.9995	0.9997	0.9998
Market share	0.9999	0.9999	0.9994	0.9989	0.9731	0.9887	0.9965	0.9983	0.9992	0.9874	0.9637	0.9782	0.9853
Profit ratio of sales	0.9443	0.9989	0.9374	0.9460	0.9479	0.9937	0.9575	0.9554	0.9626	0.9549	0.9574	0.9548	0.9582
Growth rate of the number of enterprises above designated size	0.9948	0.9993	0.9410	0.3333	0.6788	0.8748	0.9920	0.9903	0.9918	0.9974	0.9883	0.9994	0.9999
Number of NEV companies (ten thousand)	0.9876	0.9976	0.9057	0.9990	0.9986	0.9979	0.9999	0.9989	0.9992	0.9989	0.9966	0.9984	0.9984
NEV patent applications	0.9839	0.9998	0.9871	0.9882	0.9825	0.9798	0.9951	0.9979	0.9974	0.9872	0.9806	0.9911	0.9909
Proportion of high-level employees	0.9993	0.9989	0.9996	0.9996	0.9990	0.9997	0.9979	0.9950	0.9904	0.9941	0.9719	0.9893	0.9835
Total output value of new industrial products (100 million yuan)	0.9994	0.9993	0.9995	0.9999	0.9994	0.9992	0.9997	0.9994	0.9983	0.9986	0.9998	0.9988	0.9946
NEV technology research and development expenses (100 million yuan)	0.9999	1.0000	1.0000	0.9999	0.9996	0.9998	0.9997	0.9986	0.9989	0.9994	0.9994	0.9990	0.9991

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	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Number of supporting enterprises	0.9995	1.0000	0.9995	1.0000	0.9991	0.9999	0.9984	0.9980	0.9995	0.9980	0.9992	0.9975	0.9996
Total output value of supporting enterprises (100 million yuan)	0.9999	0.9997	1.0000	1.0000	0.9998	0.9996	0.9993	0.9988	0.9989	0.9980	0.9994	0.9982	0.9975
Number of NEV experience stores (houses)	0.9967	0.9975	0.9941	0.9968	0.9962	0.9867	0.9970	0.9994	0.9996	0.9974	0.9979	0.9991	0.9947
Government investment (ten thousand yuan)	0.9995	0.9998	1.0000	0.9999	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9995
Tax reduction and exemption policy	0.9997	1.0000	0.9999	0.9968	0.9988	0.9987	0.9996	0.9990	0.9982	0.9938	0.9910	0.9899	0.9929

Table 10. The grey relational degree of each province under each spatiotemporal characteristic attribute.

Grey relational degree with ideal point	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Absolute quantity attribute	0.7320	0.7643	0.7535	0.6766	0.5244	0.5174	0.4973	0.4806	0.4645	0.4275	0.4496	0.4754	0.5141
Incremental attributes	0.9220	0.9629	0.9076	0.9202	0.9253	0.9315	0.9162	0.9179	0.9240	0.9164	0.9155	0.8970	0.9107
Volatility attribute	0.9931	0.9956	0.9849	0.9677	0.9826	0.9900	0.9953	0.9959	0.9956	0.9957	0.9928	0.9918	0.9924
Spatiotemporal feature attribute set	0.9509	0.9797	0.9565	0.9118	0.8342	0.8342	0.8211	0.8125	0.8051	0.7828	0.7939	0.8031	0.8280

Table 11. The ranking of the grey relational degree under the spatiotemporal characteristics of each province and the ideal object.

Grey Relational Degree Sorting	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Absolute quantity attribute	3	1	2	4	5	6	8	9	11	13	12	10	7
Incremental attributes	5	1	12	6	3	2	9	7	4	8	10	13	11
Volatility attribute	6	3	11	13	12	10	5	1	4	2	7	9	8
Spatiotemporal feature attribute set	3	1	2	4	6	5	8	9	10	13	12	11	7

Table 12. The grey relational degree of the competitiveness of NEVs in each province.

	Jiangsu	Shanghai	Beijing	Zhejiang	Hubei	Hunan	Hebei	Henan	Anhui	Fujian	Sichuan	Shandong	Guangdong
Jiangsu	1.0000	0.9063	0.8736	0.8847	0.8831	0.8641	0.8731	0.8588	0.8525	0.8437	0.8499	0.8533	0.8654
Shanghai		1.0000	0.9024	0.8842	0.8679	0.8784	0.8568	0.8466	0.8468	0.8359	0.8440	0.8320	0.8471
Beijing			1.0000	0.8769	0.8551	0.8355	0.8474	0.8330	0.8356	0.8245	0.8301	0.8223	0.8304
Zhejiang				1.0000	0.8833	0.8679	0.8689	0.8584	0.8540	0.8348	0.8466	0.8389	0.8385
Hubei					1.0000	0.9291	0.9181	0.9036	0.9034	0.8905	0.9083	0.8879	0.8828
Hunan						1.0000	0.9155	0.8968	0.9027	0.8849	0.9054	0.8782	0.8797
Hebei							1.0000	0.9519	0.9386	0.9119	0.9298	0.9086	0.9068
Henan								1.0000	0.9392	0.9093	0.9242	0.9087	0.9034
Anhui									1.0000	0.9327	0.9394	0.9327	0.9214
Fujian										1.0000	0.9398	0.9310	0.9290
Sichuan											1.0000	0.9373	0.9264
Shandong												1.0000	0.9462
Guangdong													1.0000

Table 13. Loss function of clustering decision.

Plan	Loss function	
	Same as i	Different from i
o_S	$\lambda_{SS} = 0.13$	$\lambda_{SN} = 0.85$
o_U	$\lambda_{US} = 0.29$	$\lambda_{UN} = 0.59$
o_N	$\lambda_{NS} = 0.92$	$\lambda_{NN} = 0.21$

The ideal distribution sequence at the absolute level is (1, 0.9826, 1, 0.7721, 0.7418, 0.9454, 0.9878, 0.8, 1, 0.963, 1, 0.9697, 0.9929, 0.9881, 0.9556, 0.9656, 0.9432, 0.9792, 0.9733, 0.9889, 1, 1, 1, 0.9, 1 and 0.2855).

The ideal distribution sequence at the incremental level is (0.0129, 0.0510, 0.3818, 0.4775, 0.4566, 0.5964, 0.1812, 0.2878, 0.0519, 0.4726, 0.1603, 0.5417, -0.0103, 1.4756, 0.4271, 0.6728, 0.5051, 0.2730, 0.1243, 0.3782, 0.2655, 0.3339, 0.0490 and 0.3354).

The ideal distribution sequence at the volatility level is (0, 0.002, 0, 0.0019, 0.0014, 0.0001, 0.0005, 0.0008, 0, 0.0018, 0, 0.0011, 0.0002, 0.0003, 0.0062, -2.6571, 0.0004, 0.0013, 0.0017, 0.0004, 0, 0, 0, 0.0025, 0 and 0).

The grey relational coefficients of each province under each spatiotemporal characteristic attribute were presented in Tables 7–9.

Considering the weight of each indicator, the grey relational degree of each province to the ideal object under each spatiotemporal characteristic attribute can be obtained in Table 10.

We sort the grey relational degree of each province and the ideal object under the spatiotemporal characteristic attributes, as shown in Table 11.

Under the absolute level of temporal and spatial characteristics, the development of Jiangsu's NEV industry is in a leading position in the country. The development level is relatively close to that of Beijing and Shanghai under the absolute level. Jiangsu has a good foundation for the development of the NEV industry, a solid foundation of science and technology talent, clear policy support, and a relatively high level of regional wealth. These are the powerful driving forces supporting the development of the NEV industry. Jiangsu should strengthen its emphasis on the NEV industry, strengthen policy support, improve the construction of supporting facilities for talent, ensure the sustainable and healthy development of Jiangsu's NEV industry, stabilize the first echelon of domestic NEV industry development, and create an internationalization industry.

Under the incremental level of spatiotemporal characteristic attributes, Jiangsu's incremental level ranks among the upper and middle reaches of 13 provinces, second only to Shanghai. During 2017–2019, Jiangsu's NEV industry has been in a state of rapid development, and the incremental level of the industry has also been maintained at a relatively high level. The rapid development of Jiangsu's NEV industry is inseparable from various measures taken by the provincial government during 2017–2019. For example, based on the foundation of industrial development, focusing on the development of electronic information and equipment, manufacturing industries related to the NEV industry, and building NEVs complete vehicle and parts industry clusters. However, although Jiangsu's incremental development level remains at the forefront of China, there is still a big gap between the scale, number, and internationalization level of NEV companies introduced in the development process in Jiangsu. To develop Shanghai's NEV industry, Jiangsu should build on the existing resource advantages of the province, integrate the new energy upstream and downstream industrial chain, and create a NEV industry with Jiangsu characteristics.

Under the volatility level, Jiangsu's industrial development fluctuates greatly, and the level of volatility lies in the middle reaches of the country, which is far from Shanghai. Provinces with small development volatility can be divided into two types. One is that the early development level is low, and the later development level is also low. Therefore, the overall development of the industry does not show large volatility; another is that the early-stage development level is relatively high, and the later stage development level is also maintained at a relatively high level, so the overall development level of the industry has not seen major volatility. Shanghai is clearly in the second category. Its NEV industry has been maintained at a relatively high level of development, so the volatility level of industrial development is relatively low. The high level of volatility in Jiangsu indicates that, on the one hand, Jiangsu's support for the development of the NEV industry lags behind Shanghai. On the other hand, after realizing the importance of the NEV industry, Jiangsu has intensified its efforts to cultivate the industry. The policy support has been improved, so the development of the NEV industry remained at a relatively high level in 2017–2019. For Jiangsu, it should continue to strengthen support for the development of the NEV industry, improve innovation, management and optimization services, promote the development of NEV technology and industry integration, and maintain the rapid development of the NEV industry.

From the perspective of overall temporal and spatial characteristics, Jiangsu's overall industrial development level is in the first echelon of China, second only to Shanghai and Beijing, indicating that Jiangsu's overall development level of the NEV industry is relatively good. Meanwhile, among the sub-attributes of temporal and spatial characteristics, Jiangsu's absolute and incremental development levels are still at the forefront of China, but the level of volatility is relatively low, and the volatility of industrial development is relatively large. For Jiangsu, more attention should be paid to cultivating the sustainability of the development of the NEV industry to ensure that the NEV industry in Jiangsu can still maintain strong vitality and competitiveness in the future. Jiangsu should integrate the advantageous resources related to the NEV industry in the province, create a NEV industry development model, establish a regional development policy with Jiangsu characteristics, and ensure that the province's NEV industry leads the country. In addition, Jiangsu should focus on domestic and foreign market development, improve brand competitiveness, and strive to form international competitiveness.

5.3. Cluster analysis of NEV industry

This study uses dimensionless data to calculate the similarity distance between any two provinces under the attributes of absolute level, incremental level, and volatility level, and then calculate the index of each province and city under the spatiotemporal feature attribute with Eq (4.1). The grey relational analysis is used to calculate the correlation between any two provinces (Table 12). Finally, with three decisions to determine the threshold, a cluster analysis of the competitiveness of the NEV industry in each province is carried out.

Taking into account the government's emphasis on the development of high-tech industries and the risk of correct decision-making during evaluation, the loss function of the manager's decision-making status and action plan for the development of provincial high-tech industries is obtained (Table 13).

The grey relational clustering threshold can be obtained by Eqs (4.7) and (4.8):

$$\alpha = \frac{\lambda_{CA} - \lambda_{NA}}{\lambda_{CA} - \lambda_{NA} + \lambda_{NC} - \lambda_{CC}} = 0.8000$$

$$\beta = \frac{\lambda_{NA} - \lambda_{AA}}{\lambda_{NA} - \lambda_{AA} + \lambda_{AC} - \lambda_{NC}} = 0.3762$$

The class set can be further divided into three categories, the first category: Jiangsu, Shanghai and Beijing; the second: Zhejiang; third: Hubei, Hunan, Hebei, Henan, Anhui, Fujian, Sichuan, Shandong and Guangdong. Therefore, the competitiveness of the NEV industry in Jiangsu is closer to that of Shanghai and Beijing.

6. Conclusions

This study measures the competitiveness of NEV industry of 13 provinces in China. This study shows that: 1) Under the absolute level of temporal and spatial characteristic attributes, the development of Jiangsu's NEV industry is in a leading position in China, and its competitiveness level is closer to that of Shanghai and Beijing; 2) Under the incremental level, Jiangsu ranks in the upper and middle reaches of 13 provinces, second only to Shanghai; 3) Under the volatility level, Jiangsu's industrial development fluctuates greatly, and the volatility level is in the middle reaches. There is a big gap with Shanghai; 4) From the perspective of overall temporal and spatial characteristics, Jiangsu's overall industrial development level is in the first echelon in China, second only to Shanghai and Beijing, indicating that Jiangsu's overall development level of NEV industry is relatively high. According to the clustering results, the competitiveness of the NEV industry in Jiangsu is closer to that of Shanghai and Beijing.

Based on the development plan of Jiangsu's new energy vehicle industry, and considering the gap between Jiangsu and the benchmark cities in calculating the main indicators, this paper proposes the following management enlightenment: 1) Improve the construction of charging infrastructure (scientific layout of charging facilities and power exchange facilities, improve the service level of charging facilities, and encourage business model innovation). 2) Increase the promotion of new energy vehicles, such as the government and the public sector playing a leading role in promoting new energy vehicle consumption. 3) Improve the technological innovation capability, such as the government increasing R&D investment, and automobile enterprises cooperating with key scientific research institutions and scientific research centers. 4) Improve the supporting parts industry, such as cross-regional cooperation and the introduction of leading enterprises. 5) Industrial support policies were introduced, such as increasing technical subsidies, and increasing subsidies and incentives for R&D enterprises on public relations and technical issues. 6) Jiangsu should integrate the relevant advantageous resources of the new energy vehicle industry, create a new energy vehicle industry development model, formulate regional development policies with local characteristics, pay attention to domestic and foreign market development, build brand competitiveness, and strive to form international competitiveness.

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Conflict of interests

The authors declare no conflict of interest.

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