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Dynamic Evaluation and Regional Differences Analysis of the NEV Industry Development in China

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Abstract: In the transportation sector, new energy vehicles (NEVs) are critical to reduce CO_2 emissions in the context of carbon neutralization. The study of dynamic evaluation and regional difference analysis is helpful to the NEV industry development in policy design and industrial planning. In this study, based on the provincial data in China from 2016 to 2020, the grey target model and Dagum Gini coefficient method are employed for the dynamic evaluation and regional differences of the NEV industry development. The results were as follows: (1) The overall and provincial level of the NEV industry development showed an increasing pattern. The bull's eye degrees of Guangdong, which had the best development, were 0.4884, 0.5361, 0.6067, 0.6787, and 0.7047 during the study period. (2) The regional differences in the NEV industry development were significant. The east region had the best development, followed by the middle, the west, and the northeast regions. The intra-regional differences were expanding with different annual growth rates. (3) The inter-regional differences between the east and the other three regions were the largest. The regional differences in the NEV development are mainly derived from inter-regional dereference. (4) The D_1, D_2, and D_3 dimensions all contributed significantly to provinces with higher levels of development, while the D_4 dimension contributed significantly to provinces with lower levels of development. Based on these results, different provinces should take differentiated development strategies and enhancement paths to promote their NEV industry development.

Keywords: new energy vehicle; dynamic evaluation; regional difference; grey target; Dagum Gini coefficient

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1. Introduction

With the process of rapid industrialization and urbanization in China, transport vehicles have become a significant contributor to carbon emissions. Road vehicles accounted for nearly four-fifths of transport CO_2 emissions in 2020, as shown in Figure 1 [1,2]. As one of the world's largest vehicle markets, personal vehicle ownership in China reached 262 million in 2021 [2]. China put forward the strategic goals of carbon peaking and carbon neutralization in 2020 [1]. Under the tremendous pressure on carbon emission and energy consumption, new energy vehicles are the key to reducing CO_2 emissions. The NEV industry was listed as one of the seven critical fields of strategic emerging industries in 2009 [3]. In the context of carbon neutralization, China's NEV industry has grown rapidly in recent years, supported by a series of policies and subsidies [4], and NEV ownership in China has increased rapidly, increasing from 1.09 million in 2016 to 7.84 million in 2021 [2,5]. The rapid development of the NEV industry has provided a new impetus and added new vitality to China's economic growth. However, the NEV industry development in different provinces is inconsistent, and there are great imbalances in NEV industry development among provinces [6]. Research on regional differences in the NEV focuses on the NEV policies, subsidies, and market [7]. The regional differences in the NEV industry development are rarely mentioned. With The rapid development of the NEV industry, the growing disparity in industry development between regions has become an important factor affecting long-term economic development [8]. Therefore, overcoming the widening regional industry development gap and promoting growth are important challenges for most provinces and cities. This study attempts to construct a grey target model to dynamically evaluate the level of the NEV industry for all provinces in China and employs the Dagum Gini coefficient to explore the regional development differences in four regions. It is of important reference value for the national government in making differentiated development strategies to promote the development of the NEV industry, realization of energy conservation, and carbon emission reduction targets.

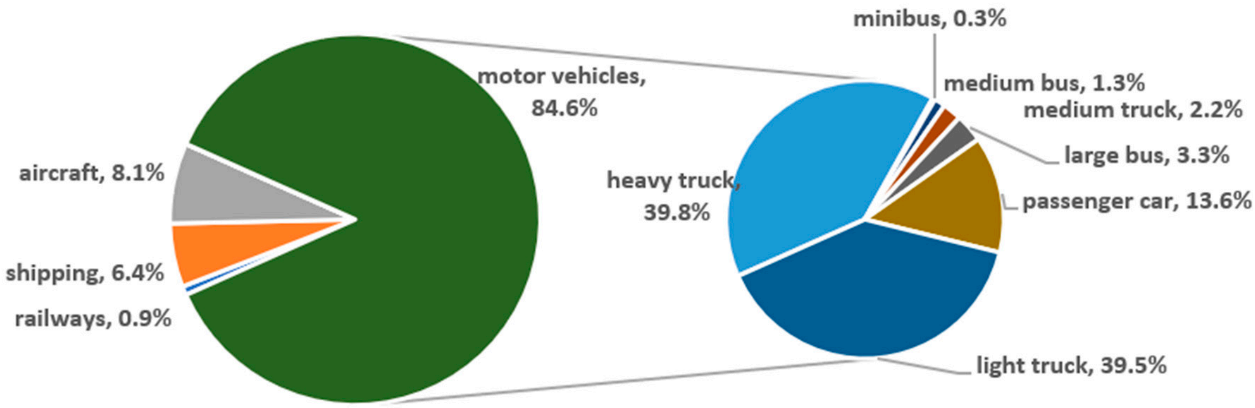

Figure 1. CO_2 emissions composition of traffic and motor vehicles.

NEVs have received more and more attention, and some researchers have studied the carbon reduction of NEVs from the perspective of comparing NEVs with fuel vehicles [9–15]. Shen et al. adopted a life cycle assessment to compare carbon emissions between NEVs and fuel vehicles [9]. Wu and Zhang established a comparison model to analyze energy consumption and CO_2 emissions that the NEV's CO_2 emissions were significantly reduced [10]. Adila et al. analyzed the synergy and co-benefits of reducing CO_2 and air pollutant emissions from the perspectives of private NEVs, taxis, and buses. This research concluded there were great environmental and economic benefits to implementing electric buses in Shanghai [11]. Gryparis et al. tried to evaluate the impact of the electric vehicle penetration on the electricity demand and related emissions inside the European Union, indicating that future electrification in transportation would support the efforts to reduce carbon emissions [12]. A multi-agents-based model of the CO_2 emission trading scheme for road transport was established to simulate the development paths of new energy vehicles (ETS-RT). The results reflected that the introduction of ETS-RT can effectively promote the leaping development of China's NEVs in the "post-subsidy era" [13]. Zhang et al. developed a systematic framework to support carbon reduction for an urban transport system [14]. The mentioned literature shows that NEVs are an efficient way to reduce CO_2 emissions and contribute significantly to carbon neutralization [15–17].

With the increasing ownership of new energy vehicles, some studies focus on NEVs' competitiveness compared NEVs to other types of vehicles. Delucchi and Lipman identified the vehicle component cost and performance characteristics that must be met for battery electric vehicles to be competitive with incumbent technologies [18]. Geoff Morrison et al. estimated battery electric vehicles to be the cheaper vehicle option, and battery electric vehicles had a cost advantage of USD 0.41 per mile [19]. Palmer et al. concluded that hybrid electric vehicle was the most popular type of energy vehicle among customers and occupied the highest market shares in UK, USA, and Japan [20]. Abdul and Yousaf identified local manufacturing as the best solution for improving the quality of hybrid electric vehicles, making them market-competitive in developing countries [21]. Diao et al. concluded that battery electric vehicles were economically competitive with conventional internal combustion engine vehicles in China when intangible costs, such as traffic policies, were considered in mega-cities [22]. Breetz and Salon reckoned battery electric vehicles would become cost-competitive with federal and state subsidies in 14 major cities in the US [23]. Amrut et al. contemplated the economic compatibility of conventional IC Engine Vehicles with battery electric vehicles, some types of battery electric vehicles reached cost parity, while some became more economical than internal-combustion engine vehicles in India [24]. When the annual distance traveling was more than 29,000 km and 23,000 km, Scorrano et al. elaborated that battery electric vehicles are more economical than petrol and diesel cars in Italy [25]. Refs. [18,19,21,25] show that the NEVs have strong competitiveness, especially with subsidy policies.

The literature on the development evaluation of the NEV industry mainly focuses on the evaluation method and the evaluation indicator system. In the aspect of the evaluation method, Qi et al. established a new three-dimensional diamond model to analyze the competitiveness of China's new-energy automobile industry and concluded that China's new-energy automobile industry has strong potential competitiveness [26]. Yuan et al. analyzed the strength, weaknesses, opportunities, and threats in China's new energy vehicle industry based on the diamond model, compared with developed countries [27]. Ruan et al. proposed a grey correlation model to evaluate the competitiveness of the NEV industry and showed that Guangdong's support had the largest change, policies promoting the expansion of promotion and marketing of industrial competitiveness [28]. Zheng et al. found that China's new energy vehicle business ecosystem was gradually forming, but it was highly dependent on policies, and self-development ability needs to be improved [29]. In the aspect of the evaluation indicator system, Bai et al. analyzed the competition in the global electric vehicle industry from the following dimensions: core technological innovation capability, the openness of the EV market, policy support, industrial scale, market size, and overall policy effects [30]. Cao et al. proposed the stakeholder engagement system to analyze the commitments and efforts needed from multiple stakeholders through policy implications, leading factors on the demand side, and technology innovation requirements on the supply side [31]. Pan et al. constructed a theoretical model of the innovative ecosystem of China's new energy automobile industry using the method of analogy analysis from the ecology perspective [32]. Wu et al. evaluated the competitiveness of the NEV industry from environmental factors, energy, technology, economy, and society [33]. The literature mentioned above pointed out that the development of the NEV industry has the following influencing factors: market, technology, policies, charging infrastructure, and so on. However, the factor of carbon emission reduction is rarely mentioned. In this study, we establish an index system of development evaluation in the context of carbon neutralization.

The mentioned literature on the NEV industry mainly focuses on the advantages of carbon emission and the evaluation development level of the NEVs. Still, the dynamic evaluation and regional differences in the NEV industry are rarely mentioned. The dynamic evaluation can provide the temporal evolution trend of the NEV industry development for a province and the horizontal comparison with other provinces and cities at a time point. The regional difference analysis provides conditions for us to study the intra-regional differences of the NEV industry, the intra-regional differences of the NEV industry development, their contribution to the overall difference, and the horizontal comparison with other provinces and cities at a certain time point. In the present study, the research on the development of the NEV industry focuses on the dynamic evaluation of the provincial level and regional differences. The research contributions of this paper are as follows. Firstly, in the context of carbon neutralization, the evaluation index system of provincial development of the NEV industry is established, mainly from four dimensions: economic, technology, new energy vehicle, and carbon neutralization. Secondly, this study adopts a grey target method to dynamically evaluate the provincial development of the NEV industry in China, which replaces the perspective of NEV enterprises with the perspective NEV industry, the temporal characteristics of the NEV industry development are revealed from the provincial and regional perspectives. Finally, the Dagum Gini coefficient method is employed to measure the regional differences in the NEV industry development and decompose the overall differences into intra-regional differences, inter-regional differences, and transvariation intensity.

The remainder of the research is arranged as follows. Section 2.1 constructs the grey target model, introduces Dagum Gini coefficient method, and lists the data sources. Section 3 calculates and analyzes the provincial development of the NEV industry in China and the subitem ability from four dimensions. Section 4 explores the regional differences based on the Dagum Gini coefficient method. Section 5 discusses the theoretical value and implications. Section 6 summarizes the major conclusions and future work.

2. Methods and Materials

In this section, we explain the construction of a grey target model for dynamic evaluation and introduce the Dagum Gini coefficient method for the regional differences (Section 2.1); then, we establish an evaluation index system for the NEV industry in the context of carbon neutralization and list the data sources (Section 2.2).

2.1. Methods

The grey target theory is an essential part of Deng's grey theory and has had a wide application in many fields since it was put forward by Professor Deng [34,35]. The grey bull's eye degree was defined as a degree of partial proximity (or partial closeness) between two curves, which was determined by the mean values of grey relational coefficients according to Mahmoudi et al. [36,37]. The key step of grey target theory is to build a standard pattern; Xu regarded the optimal sequence as the standard pattern, put forward the evaluation method based on grey target theory, and obtained the evaluation values and sequencing results of the evaluation objects [38]. The mentioned evaluation methods are suitable for the static evaluation of two-dimensional data. They cannot compare the development level of multiple systems at different time points and the dynamic cumulative level in a certain period [39]. For the three-dimensional data, the dynamic grey target method is built by using the optimal sequence as the referring sequence. The weights of time points are derived from the grey entropy theory in Section 2.1.2. The method has the advantages of such dynamic evaluation methods as grey target theory, ideal matrix method, and quadratic weighting method. During the research period, this method can compare the development level of multiple research objects at an appointed time point, obtain the temporal evolution trend of a research object, and obtain the overall development level. Pattern recognition, grading, optimization, and ranking can be carried out based on the evaluation results.

2.1.1. Grey Target Model

Assume that $A = \{A_1, A_2, \cdots, A_i, \cdots, A_n\}(i = 1, 2, \cdots, n)$ is a vector of n objects, $C = \{C_1, C_2, \cdots, C_j, \cdots C_m\}(j = 1, 2, \cdots, m)$ is a vector of m criteria, and $T = \{1, 2, \cdots, k, \cdots t\}(k = 1, 2, \cdots, t)$ is a vector of time series. The raw data in the t-th time point can be written as a matrix as follows:

$$X(k) = \begin{bmatrix} x_{11}(k) & x_{12}(k) & \cdots & x_{1m}(k) \\ x_{21}(k) & x_{22}(k) & \cdots & x_{2m}(k) \\ \vdots & \vdots & \ddots & \vdots \\ x_{n2}(k) & x_{n2}(k) & \cdots & x_{nm}(k) \end{bmatrix}$$

The raw vector in the matrix $X(k)$ describes n objects, and the column vector denotes the criteria. $X_{ij}(k)$ indicates the observational value of the j-th criterion on the i-th object in the t-th time point.

Matrix $X(k)$ is composed of primary data. The index system has m criteria consisting of benefit criteria and cost criteria.

For the benefit criteria, the larger values are better, $X_j^*(k)$ is the maximum of the i-th column vector in matrix $X(k)$.

$$x_j^*(k) = \max_{1 \le i \le n}\left\{x_{ij}(k)\right\} = \max\left\{x_{1j}(k), x_{2j}(k), \cdots, x_{ij}(k), \cdots, x_{nj}(k)\right\} \tag{1}$$

For the cost criteria, the smaller values are better, $X_j^*(k)$ is the minimum of the i-th column vector in the matrix $X(k)$.

$$x_j^*(k) = \min_{1 \le i \le n}\left\{x_{ij}(k)\right\} = \min\left\{x_{1j}(k), x_{2j}(k), \cdots, x_{ij}(k), \cdots, x_{nj}(k)\right\} \tag{2}$$

The sequence $X_j^*(k)$ is obtained by the above Equations (1) and (2) and is defined as the optimal vector of the t-th time point. Then, $X^*(k)$ is expressed in Equation (3):

$$X^*(k) = \{x_1^*(k), x_2^*(k), \cdots, x_i^*(k), \cdots, x_n^*(k)\} \tag{3}$$

The transformation equations of the grey target can be defined, and the decision maker compares the behavior vector to the optimal vector. Equation (4) is for the benefit criterion, and Equation (5) is for the cost criterion. We can calculate the grey target transformation of the optimal vector $Y^*(k) = \left\{y_1^*(k), y_2^*(k), \cdots, y_i^*(k), \cdots, y_n^*(k)\right\}$.

$$y_{ij}(k) = \frac{x_{ij}(k) - \min\limits_i(x_{ij}(k))}{\max\limits_i(x_{ij}(k)) - \min\limits_i(x_{ij}(k))} \tag{4}$$

$$y_{ij}(k) = \frac{\max\limits_i(x_{ij}(k)) - x_{ij}(k)}{\max\limits_i(x_{ij}(k)) - \min\limits_i(x_{ij}(k))} \tag{5}$$

Suppose $Y^*(k)$ is the standard sequence or the bull's eye sequence; obviously,$Y^*(k) = \{1, 1, \cdots, 1, \cdots, 1\}$; $y_i(k) = \left\{y_{1i}(k), y_{1i}(k), \cdots, y_{ji}(k), \cdots, y_{ni}(k)\right\}$ is the behavior sequence. Comparing each $y_{ji}(k)$ to the corresponding best value $y_i^*(k)$, the absolute value sequence is calculated by Equation (6) and recorded as

$$\Delta_j(k) = \left\{\Delta_{1j}(k), \Delta_{2j}(k), \cdots, \Delta_{nj}(k)\right\}$$

$$\Delta_{ij}(k) = \left|y_{ij}(k) - y_j^*(k)\right| \tag{6}$$

Suppose that $\max(\Delta_{ij}(k))$ is the maximum of all behavior sequences in the matrix $Y(T)$ and $\min(\Delta_{ij}(k))$ is the minimum of all behavior sequences in the matrix $Y(T)$. The extremal formulas can be written as

$$\begin{aligned} \max(\Delta_{ij}(k)) &= \max_i \max_j \Delta_{ij}(k) \\ \min(\Delta_{ij}(k)) &= \min_i \min_j \Delta_{ij}(k) \end{aligned} \tag{7}$$

Define $\gamma_{ij}(k)$ as the bull's eye coefficient and ζ as the distinguishing coefficient. The bull's eye coefficient implies the information of proximity between $x_{ij}(k)$ and $x_j{}^*(k)$, and the higher coefficient indicates better proximity. $\zeta(\zeta \in (0, 1))$ is used to modify the difference among bull's eye coefficients. The research of sensitivity analysis and empirical research commonly use the value of $\zeta = 0.5$ [40,41]. The bull's eye coefficient can be formulated as

$$\gamma_{ij}(k) = \frac{\min(\Delta_{ij}(k)) + \zeta\max(\Delta_{ij}(k))}{\Delta_{ij}(k) + \max(\Delta_{ij}(k))} \tag{8}$$

Define $\gamma_i(k)$ as the bull's eye degree. The bull's eye degree indicates the information of proximity between $X_i(k)$ and $X^*(k)$. The value of $\gamma_i(k)$ is larger, and the object is preferred. The bull's eye degree can be formulated as

$$\gamma_i(k) = \frac{1}{m}\sum\nolimits_{j=1}^{m} \gamma_{ij}(k) \tag{9}$$

2.1.2. Weight of Time Point

Weigh vector of t time points plays an essential role in the dynamic evaluation of time series. The weight vector is written as:

$$W = (\omega_1, \omega_2, \cdots, \omega_k, \cdots, \omega_t), \sum\nolimits_{k=1}^{t} \omega_k = 1$$

where ω_k denotes the weight of the k-th time point, and the time-point weighted indicates different importance of different time points. Decision maker prefers the latest time-point data, which contain more information and contribute to decision making more effectively. The smaller the value of ξ, the more attention is attracted to the latest time point, and then an importance matrix is formed (see Table 1) [42].

Table 1. ξ values and descriptions.

ξ value	Descriptions
0.1	Attach extreme importance to the latest data of time points
0.3	Attach significant importance to the latest data of time points
0.5	Attach equal importance to all data of time points
0.7	Attach significant importance to the initial data of time points
0.9	Attach extreme importance to the initial data of time points
0.2,0.4,0.6,0.8	The importance is between the above two adjacent levels

Grey entropy and time temperature are combined to calculate the weights of time points [43].

$$\begin{gathered} \max\left(-\sum\nolimits_{k=1}^{t} \omega_k \ln \omega_k\right) \\ s.t.\ \xi = \sum\nolimits_{k=1}^{t} \tfrac{t-k}{t-1}\, \omega_k \\ \sum\nolimits_{k=1}^{t} \omega_k = 1 \\ k = 1, 2, \cdots, t,\ \omega_k \in [0,1] \end{gathered} \tag{10}$$

$W = (\omega_1, \omega_2, \cdots, \omega_k, \cdots, \omega_t)$ is the weight vector of time series and the bull's eye degree $\gamma_i(k)$ of the i-th object in t-th time point. k is the serial number of time series, and the function of the comprehensive bull's eye degree γ_i is

$$\gamma_i = \sum_{k=1}^{t} \gamma_i(k) \times \omega_k \tag{11}$$

According to all comprehensive bull's eye degrees, we can sort n objects.

As a final step, the comprehensive bull's eye degrees are divided into 10 levels: [0.9, 1], [0.8, 0.9], [0.7, 0.8], [0.6, 0.7], [0.5, 0.6], [0.4, 0.5], [0.3, 0.4], [0.2, 0.3], [0.1, 0.2], and [0.0, 0.1]. The number of levels can be reduced according to the value range of the bull's eye degrees.

2.1.3. Dagum Gini Coefficient and Its Decomposition

In terms of measuring the degree of regional differentiation, the Thiel index method and Dagum Gini coefficient method are most commonly used. The Theil index can subdivide the regional and intra-regional differences, and it does not consider the distribution of subgroups when measuring the balance between different regions; it reduces the accuracy of the research conclusions [44]. The Dagum Gini coefficient is decomposable and highly sensitive to resource allocation, which can measure overall differences and decompose overall differences into inter-regional and intra-regional differences [44,45]. This method overcomes the limitations of the traditional Gini coefficient and the cross-overlap defect of samples between groups caused by Theil index [46]. The Dagum Gini coefficient can accurately derive the sources and contributions of differences, and the method has been applied by many scholars in the study of differences in various fields [45–47].

To deeply explore the regional differences and temporal characteristics of the development in China's NEV industry, we employed the Dagum Gini coefficient model to measure and decompose the regional differences into intra-regional differences, inter-regional differences, and intensity of transvariation. It provides theoretical references for the formulation of government policy in the NEV industry and the construction of regional NEV industry conservation coordination mechanisms. The measurement formula of Dagum Gini coefficient is as follows:

$$G = \frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{nj}\sum_{r=1}^{nh}\left|y_{ij}-y_{hr}\right|}{2\overline{Y}n^2} \tag{12}$$

where G is the overall Gini coefficient of the NEV industry development, $\overline{y}$ is the mean value of the comprehensive bull's eye degree for all provinces, n is the number of all provinces,$y_{ij}(y_{hr})$ denotes the comprehensive bull's eye degree of any province in the region $j(h)$, k represents the number of different regions, and $n_j(n_h)$ is the number of all provinces in the region.

Based on the evaluation of the provincial development of the NEV industry, the Dagum Gini coefficient method was employed to decompose the Gini coefficient G into three parts: the intra-regional differences G_W (distribution differences of the development of the NEV industry among provinces in a region); inter-regional differences G_{nb} (distribution differences of the NEV industry development among provinces in different regions); and intensity of transvariation G_t(remainder of the Gini coefficient due to the crossing impact of the NEV industry development among different regions). The relational expression among the three parts is: $G = G_W + G_{nb} + G_t$ $G = G_W + G_{nb} + G_t$. The three calculation formulas are Equations (15)–(17). The intra-regional Gini coefficient in region j is written as G_{jj}, which can be expressed as Equation (13). The inter-regional Gini coefficient between regions j and h is written as G_{jh}, which can be expressed as Equation (14), where $p_j = n_j n, s_j = n_j\overline{Y}_j/n\overline{Y}$.

$$G_{jj} = \frac{\sum_{j=1}^{\mathrm{nj}}\sum_{r=1}^{nh}\left|y_{ij}-y_{hr}\right|}{2n_j n_j \overline{y}j} \tag{13}$$

$$G_{jh} = \frac{\sum_{j=1}^{\mathrm{nj}}\sum_{r=1}^{nh}\left|y_{ij}-y_{hr}\right|}{2n_j n_j(\overline{y}_j+\overline{y}_h)} \tag{14}$$

$$G_W = \sum_{j=1}^{k} G_{jj}p_j s_j \tag{15}$$

$$G_{nb} = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}(p_j s_h + p_h s_j)D_{jh} \tag{16}$$

$$G_t = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}(p_j s_h + p_h s_j)(1-D_{jh}) \tag{17}$$

D_{jh} is defined as the relative influence of the NEV industry development between regions j and h, and is expressed as Equation (18). d_{jh} is defined as the relative difference in the NEV industry development between regions j and h, and is expressed as Equation (20), which can be regarded as a mathematical expectation of the sum of all sample values satisfying $y_{ji} - y_{nr} > 0$ in region j and h. p_{jh} is defined as the first moment of transvariation of the NEV industry development between region j and h, and is expressed as Equation (19), which can be regarded as a mathematical expectation of the sum of all sample values satisfying $y_{nr} - y_{ji} > 0$ in regions j and h.

$$D_{jh} = \frac{d_{jh} - p_{jh}}{d_{jh} + p_{jh}} \tag{18}$$

$$p_{jh} = \int_0^\infty dF_h(y) \int_0^y (y - x) dF_j(x) \tag{19}$$

$$d_{jh} = \int_0^\infty dF_j(y) \int_0^y (y - x) dF_h(x) \tag{20}$$

2.2. Materials

2.2.1. Data Source

This study regarded the provincial administrative area as the evaluation object. China has thirty-four provincial-level administrative areas, including twenty-three provinces, five autonomous regions, four municipalities directly under the central government, and two special administrative regions. According to the short history of the NEV charging point and data acquisition, the study period was from 2016 to 2020. All the research data used in the present study were collected from the National Bureau of Statistics, EPS Database, Book of Energy-saving and New Energy Vehicles, China Electric Vehicle Charging Infrastructure Promotion Alliance, and Carbon Emission Accounts and Datasets. Due to the lack of data on the NEV industry and Carbon neutralization, Hong Kong, Macao, Taiwan, and Tibet Autonomous Region were not considered evaluation objects. Thus, thirty provinces were considered as the research objects in this paper, and a small number of missing data were filled in by the moving average method. All data analysis was executed in SPSS and Microsoft Excel, while the graphical representation was handled in Microsoft Excel.

2.2.2. Index System

In the context of carbon neutralization, China's government strongly supports the development of the NEV industry. The NEV industry can stimulate the new economy and bring positive external environmental effects, including carbon emission reduction, air quality improvement, and the pressure on oil consumption reduction. The carbon neutralization goal puts forward systematic carbon emission reduction requirements for the development of new energy vehicles. Under the pressure of carbon emission reduction, the NEV industry development should emphasize supply chain links, such as market promotion and NEV manufacturing, and pay attention to the complete industrial systems such as electric energy and regional economics.

The following principles were considered for establishing the index system: scientific and objective principles, concise and systematic principles, feasible and comparable principles, representative and oriented principles, and purposeful and dynamic principles. Starting from the essence and influencing factors of provincial development of the NEV industry, referring to the mentioned research literature, we built a comprehensive evaluation index system from four dimensions: social and economic, technology, new energy vehicle, and carbon neutralization [29–32].

The economic dimension is used to evaluate economic and social conditions. These are the basis for the development of the NEV industry, mainly from the perspectives of provincial production capacity, residents' income level, government expenditures, and provincial transportation base. Its sub-indicators include GDP and government expenditures—energy conservation, per capital disposable income, and highway mileage. The technology dimension was used to evaluate the provincial technological level and innovation capability, mainly from the perspectives of R&D input and R&D output based on the industrial enterprises above the designated size. Its sub-indicators include invention-patent application, technology market turnover, R&D expenditure, sales volume of new products, and R&D personnel full-time equivalent. The new energy vehicles dimension was used to evaluate the current production capacity and market promotion of new energy vehicles, mainly from the perspectives of industry assets of new energy vehicles, production of the new energy vehicle, ownership of the new energy vehicle, and construction of charging point. Its sub-indicators include industry assets of new energy vehicles, production of the new energy vehicle, ownership of the new energy vehicle, and the number of charging points. The carbon neutralization dimension evaluates provincial energy consumption and new energy production, mainly from the perspectives of total apparent CO_2 emissions, energy consumable power generation, and energy clean power generation. Its sub-indicators include total apparent CO_2 emissions, thermal power generation, hydropower generation, and new energy power generation.

3. Evaluation Results

In this section, we present the evaluation of the bull's eye degrees for thirty provinces from 2016 to 2020 (Section 3.1), evaluate the subitem ability from four dimensions of the NEV industry (Section 3.2), and analyze spatial distribution characteristics of the NEV industry development (Section 3.3).

3.1. Dynamic Results of Development Evaluation in the NEV Industry

Dynamic evaluation helps to grasp the overall situation and development trend for evaluation objectives [38]. The present investigation employed the grey target method (Section 2.1.1) to dynamically evaluate the provincial development of the NEV industry from four dimensions: economic, technology, NEV, and carbon neutralization. For comparison purposes, the mean values of thirty provinces were introduced as the reference variable, with a total of thirty-two evaluation objects. Table 2 shows the outcomes of the grey target models and the ranking of thirty provinces. The value range of the bull's eye degree was from 0.3467 to 0.7454, and the comprehensive bull's eye degrees were divided into five levels: [0.7, 0.8], [0.6, 0.7], [0.5, 0.6], [0.4, 0.5], and [0.3, 0.4].

Table 2. Bull's eye degree and ranking of the NEV industry from 2016 to 2020.

Province	Bull's Eye Degree						Ranking					
	2016	2017	2018	2019	2020	Total	2016	2017	2018	2019	2020	Total
Guangdong	0.4884	0.5361	0.6067	0.6787	0.7454	0.7047	1	1	1	1	1	1
Jiangsu	0.4599	0.4732	0.4975	0.5134	0.5468	0.5301	2	2	2	2	2	2
Beijing	0.4368	0.4481	0.4555	0.4828	0.5295	0.5069	3	3	3	3	3	3
Shandong	0.4176	0.4290	0.4377	0.4375	0.4962	0.4729	4	4	6	7	4	4
Zhejiang	0.4070	0.4174	0.4413	0.4556	0.4794	0.4667	7	7	5	4	5	5
Shanghai	0.4106	0.4281	0.4426	0.4511	0.4788	0.4659	6	5	4	5	6	6
Sichuan	0.4111	0.4228	0.4289	0.4379	0.4625	0.4512	5	6	7	6	7	7
Hubei	0.4064	0.4169	0.4197	0.4235	0.4247	0.4234	8	8	8	8	9	8
Qinghai	0.3784	0.3825	0.3807	0.4043	0.4285	0.4157	15	15	17	9	8	9
Average	**0.3853**	**0.3920**	**0.4012**	**0.4086**	**0.4214**	**0.4148**	**9.5**	**8.5**	**8.5**	**8.5**	**9.5**	**8.5**
Anhui	0.3825	0.3863	0.3944	0.3985	0.4103	0.4046	11	11	10	14	10	10
Henan	0.3796	0.3841	0.3972	0.4028	0.4080	0.4044	14	12	9	10	11	11
Yunnan	0.3842	0.3894	0.3933	0.4003	0.4073	0.4033	10	10	11	11	12	12
Hebei	0.3759	0.3806	0.3910	0.3991	0.4051	0.4010	17	17	12	12	13	13
Hunan	0.3797	0.3834	0.3881	0.3985	0.4025	0.3991	13	13	13	13	14	14
Tianjin	0.3687	0.3722	0.3803	0.3912	0.3938	0.3907	19	19	18	15	15	15
Fujian	0.3729	0.3774	0.3831	0.3890	0.3922	0.3897	18	18	15	17	16	16
Shaanxi	0.3627	0.3707	0.3771	0.3830	0.3921	0.3873	24	20	20	18	17	17
Chongqing	0.3900	0.3904	0.3825	0.3828	0.3881	0.3864	9	9	16	19	18	18
Jilin	0.3770	0.3823	0.3839	0.3891	0.3845	0.3853	16	16	14	16	20	19
Guangxi	0.3817	0.3825	0.3788	0.3770	0.3845	0.3820	12	14	19	20	19	20
Jiangxi	0.3639	0.3667	0.3698	0.3765	0.3801	0.3775	23	23	25	21	21	21
Liaoning	0.3674	0.3689	0.3731	0.3756	0.3779	0.3764	20	21	22	22	22	22
Inner Mongolia	0.3641	0.3661	0.3699	0.3736	0.3773	0.3751	22	24	24	23	23	23
Shanxi	0.3540	0.3578	0.3666	0.3678	0.3719	0.3696	29	27	27	24	24	24
Hainan	0.3657	0.3676	0.3669	0.3675	0.3688	0.3682	21	22	26	25	25	25
Guizhou	0.3582	0.3597	0.3618	0.3656	0.3669	0.3657	25	25	28	26	26	26
Xinjiang	0.3551	0.3572	0.3743	0.3621	0.3643	0.3643	28	28	21	28	27	27
Gansu	0.3558	0.3572	0.3711	0.3606	0.3621	0.3623	27	29	23	29	29	28
Heilongjiang	0.3566	0.3594	0.3597	0.3623	0.3628	0.3622	26	26	30	27	28	29
Ningxia	0.3467	0.3473	0.3615	0.3492	0.3499	0.3507	30	30	29	30	30	30

Guangdong had the strongest development in the NEV industry, which belonged to the first level. Jiangsu and Beijing had a very strong development in the NEV industry, which belonged to the third level. Shandong, Zhejiang, Shanghai, Sichuan, Hubei, Qinghai, Anhui, Henan, Yunnan, and Hebei had a strong development in the NEV industry, which belonged to the fourth level. The remaining provinces had a relatively weak development of the NEV industry, and the provinces were as follows: Hunan, Tianjin, Fujian, Chongqing, Shaanxi, Jilin, Guangxi, Jiangxi, Inner Mongolia, Liaoning, Hainan, Shanxi, Xinjiang, Gansu, Guizhou, Heilongjiang, Ningxia. The mean value of thirty comprehensive bull's eye degrees was 0.4148 and ranked between eighth and ninth. Compared with the average value, eight provinces were above the average, and twenty-two provinces were below the average; the data implied great provincial imbalances in the NEV industry development.

In addition, according to the evaluation values and ranking of thirty provinces from 2016 to 2020, the ranking order of each year was relatively stable, except that there were several order fluctuations. During the study period, the top three of each year always were Guangdong, Jiangsu, and Beijing, and they were always in the leading position in the NEV industry. The top three were far ahead of other provinces. The ranking of Shandong declined in 2019 and 2018, caused by the technology dimension, and there was a substantial reduction in R&D input. The other provinces could also be analyzed for the corresponding reasons for the ranking inconsistencies from the data of grey-target transformation.

Figure 2 is the line chart of the bull's eye degrees of provincial development. There were five lines for the five-time points, and the red line was for the comprehensive result. Guangdong, Jiangsu, Beijing, Shangdong, Zhejiang, and Shanghai were the six fastest-growing provinces and cities. Figure 2 also shows the lines of the five-time points were inconsistent, implying that the temporal differences in the provincial development in these provinces are quite large. These six provinces and cities are in a superior position, most of which are close to the coastline and share the dividend of reform and opening up. They belong to an export-oriented economic structure and have good financial and industrial foundations, effectively promoting the NEV industry's development. The provinces and cities with the slowest growth are as follows: Ningxia, Heilongjiang, Gansu, Xinjiang, Guizhou, Hainan, Shanxi, Inner Mongolia, Liaoning, Jiangxi, Guangxi, Jilin, and Chongqing. Figure 2 also shows that, among the provinces and cities that ranked 18–30, the lines of the five-time points overlap, implying that the temporal differences in the provincial development in these provinces are very small. These provinces and cities are relatively backward in their economic development level; most belong to an inward-oriented economic structure. Their policies and industrial structure have restricted local economic development, which has caused the development of the NEV to lag.

3.2. Subitem Ability Evaluation from Four Dimensions

The dynamic evaluation method based on the grey target theory was used to evaluate four dimensions from 2016 to 2020 (Economic, Technology, NEV, and Carbon neutralization), respectively. The annual bull's eye degrees were calculated, and the entropy method determined the time point weights. Table 3 shows the bull's eye degrees based on the proposed grey target model and the ranking of thirty provinces from the view of four dimensions, and the value range of the bull's eye degree was from 0.3346 to 0.7969. The comprehensive bull's eye degrees were also divided into five levels: [0.7, 0.8], [0.6, 0.7], [0.5, 0.6], [0.4, 0.5], and [0.3, 0.4].

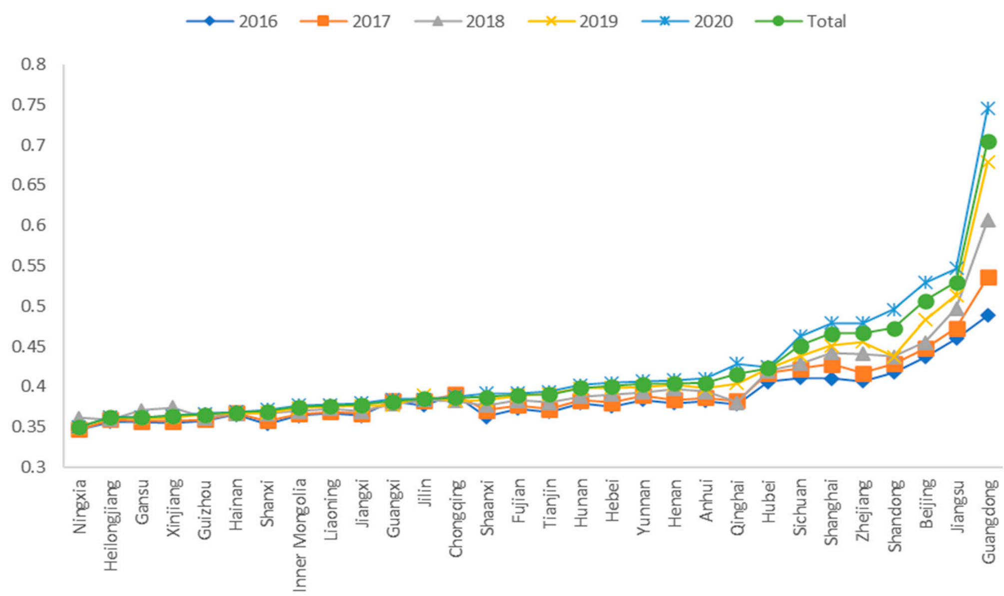

Figure 2. Bull's eye degree of the provincial development in the NEV industry.

Table 3. Subitem ability evaluation of four dimensions and ranking.

Province	D_1: Economic		D_2: Technology		D_3: NEV		D_4: Carbon Neutralization	
	Degree	Rank	Degree	Rank	Degree	Rank	Degree	Rank
Guangdong	0.6806	1	0.7083	1	0.7949	1	0.4812	4
Jiangsu	0.5803	2	0.4304	7	0.6567	2	0.3802	12
Sichuan	0.5606	3	0.3712	17	0.3750	11	0.5101	2
Shandong	0.5393	4	0.4911	4	0.4436	5	0.3759	14
Shanghai	0.5307	5	0.5602	2	0.4000	6	0.3582	25
Beijing	0.5271	6	0.5229	3	0.5100	3	0.4004	6
Zhejiang	0.5003	7	0.4262	8	0.5017	4	0.3933	7
Henan	0.4972	8	0.3880	14	0.3753	10	0.3520	28
Hubei	0.4912	9	0.4342	6	0.3893	8	0.3855	10
Hebei	0.4912	10	0.3863	15	0.3625	14	0.3663	18
Hunan	0.4690	11	0.3806	16	0.3775	9	0.3643	21
Yunnan	0.4588	12	0.3418	23	0.3421	23	0.4842	3
Average	**0.4583**	**12.5**	**0.4028**	**9.5**	**0.3941**	**6.5**	**0.3935**	**6.5**
Anhui	0.4579	13	0.4078	11	0.3929	7	0.3497	30
Jiangxi	0.4378	14	0.3578	21	0.3560	18	0.3595	24
Fujian	0.4359	15	0.3587	20	0.3699	12	0.3924	8
Inner Mongolia	0.4342	16	0.3420	22	0.3393	25	0.3912	9
Chongqing	0.4292	17	0.4001	12	0.3561	17	0.3718	16
Shaanxi	0.4285	18	0.3943	13	0.3666	13	0.3500	29
Guizhou	0.4202	19	0.3400	24	0.3417	24	0.3648	20
Heilongjiang	0.4174	20	0.3391	26	0.3421	22	0.3545	26
Shanxi	0.4164	21	0.3672	18	0.3431	21	0.3540	27
Liaoning	0.4147	22	0.3634	19	0.3587	16	0.3709	17
Xinjiang	0.4135	23	0.3349	28	0.3363	27	0.3796	13
Tianjin	0.4075	24	0.4242	9	0.3600	15	0.3634	22
Guangxi	0.4005	25	0.4188	10	0.3446	19	0.3719	15
Jilin	0.3948	26	0.4497	5	0.3445	20	0.3621	23
Gansu	0.3947	27	0.3367	27	0.3388	26	0.3841	11
Qinghai	0.3769	28	0.3347	30	0.3344	30	0.6371	1
Hainan	0.3742	29	0.3399	25	0.3347	29	0.4307	5
Ningxia	0.3697	30	0.3347	29	0.3358	28	0.3659	19

The economic dimension: Guangdong was extremely strong and belonged to the second level; Jiangsu and Beijing were very strong and belonged to the third level; Shandong, Sichuan, Shanghai, Henan, Hebei, Hubei, and Zhejiang were strong and belonged to the fourth level; Qinghai, Hainan, and Ningxia were weak, and belonged to the sixth level; the remaining provinces belonged to the fifth level. Compared with the average, twelve provinces were above the mean value, and eighteen provinces were below the average.

The technology dimension: Guangdong was the strongest and belonged to the first level; Jiangsu was extremely strong and belonged to the second level; Beijing and Zhejiang were strong and belonged to the fourth level; Shandong, Shanghai, and Anhui were relatively strong and belonged to the fifth level; the remaining provinces were weak and belonged to the sixth level. Nine provinces were above the average compared to the mean value, and twenty-one provinces were below the average.

The NEV dimension: Guangdong was the strongest and belonged to the first level; Shanghai and Beijing were very strong and belonged to the third level; Shandong and Jiangsu were strong and belonged to the fifth level; Tianjin, Hubei, Jilin, Zhejiang, Anhui, Chongqing, Guangxi, Shaanxi, Hunan, Hebei, and Henan were relatively strong; the remaining provinces were weak and belonged to the sixth level. Six provinces were above the average compared to the mean value, and twenty-four provinces were below the average.

The carbon neutralization dimension: Qinghai was very strong and belonged to the third level; Sichuan, Guangdong, Yunnan, and Hainan were strong and belonged to the fourth level; Beijing, Fujian, Gansu, Zhejiang, Inner Mongolia, Xinjiang, and Ningxia were relatively strong, and belonged to the fifth level; the remaining provinces were weak and belonged to the sixth level. Six provinces were above the average compared to the mean value, and twenty-four provinces were below the average.

The subitem abilities of the four dimensions for every province were different. From the overall development perspective, the D_1, D_2, and D_3 dimensions had a relatively large contribution to the NEV industry development. The D_4 dimension had relatively small contributions to the provincial development of the NEV industry. The provinces and cities of the subitem ability values from the three dimensions exceeded 0.4: Guangdong, Jiangsu, Shangdong, Shanghai, Beijing, and Zhejiang. As the developed provinces and cities of the country, these six provinces and cities were far ahead of the rest of the country in terms of invention patent application, technology market turnover, R&D expenditure, and government expenditures. Continuous input kept the three dimensions in the six provinces and cities leading the country. By contrast, the three provinces with the lowest scores were Qinghai, Hainan, and Ningxia. Hainan is a province with large tourism industry. Its scientific research institutions were fewer, and its investment in innovation was not high, so the development of the NEV industry was slow. Influenced by geographical factors, Ningxia and Qinghai had a low level of economic development, which, together with the restriction of scientific and technological innovation, led to the backwardness of the new energy industry. In general, the subitem abilities of the D_2 dimension, D_3 dimension, and D_4 dimensions are basically similar to the comprehensive evaluation results of the NEV industry development. For the D_4 dimension, its subitem ability is contrary to the comprehensive evaluation results of the NEV industry development. The better the economy and industry, the greater the pressure on carbon emissions in the province and cities. Despite the efforts of developed regions to reduce carbon emissions per unit of GDP output, it is difficult to reduce total carbon emissions when the total GDP is rising. Therefore, new energy power generation is greatly influenced by natural conditions, and it is very difficult to improve new energy generation in restricted areas.

3.3. Spatial Distribution Characteristics of the NEV Industry Development

Wu indicated that the geographical differences in the competitiveness of new energy vehicles in China's provinces were obvious from the static evaluation perspective [34]. In this study, we described the spatial and regional differences in the NEV industry development from the perspective of dynamic evaluation and temporal evolution.

Table 3 and Figure 2 demonstrate that the NEV industry development in most provinces has grown rapidly. The higher the ranking, the greater the growth rate of development. The development level of the NEV industry always ranked first with a growth rate of 11.15%, and the mean value of growth rate in thirty provinces was 2.27%. Spatial imbalance existed in the NEV industry development of different provinces. Based on the NEV industry development in the thirty provinces, the spatial distribution map of the NEV industry development in China was drawn with the software Dycharts to show the spatial differentiation characteristics of the NEV industry development. Figure 3 intuitively shows the changes in the NEV industry development over five years for each province in 2016 and 2020, which describe the spatial differentiation patterns. The darker the green color, the better the development. Figure 3 shows that, although there were some changes, there was still a spatial differentiation pattern on the whole, and the NEV industry development of samples was fairly uneven. Five categories were distinguished among thirty provinces.

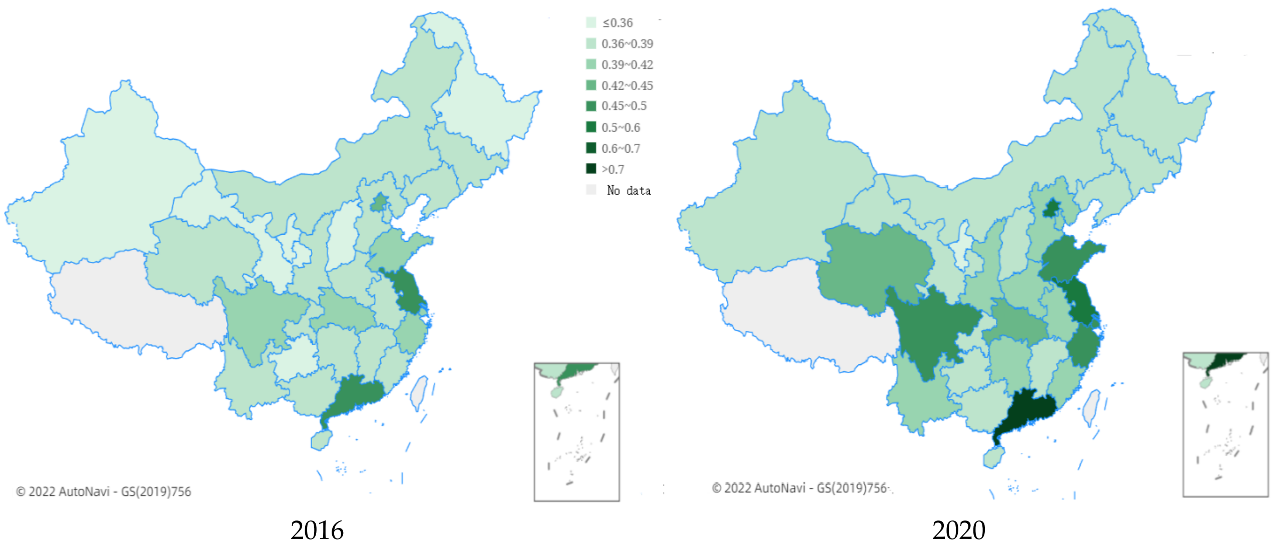

Figure 3. Spatial distribution of the NEV industry development in 2016 and 2020.

Guangdong, Jiangsu, and Beijing belonged to the first echelon, ranking 1st to 3rd, respectively. Their bull's eye degrees exceeded 0.5000 and greatly exceeded 0.4293 (the mean value of thirty provinces). These data reflected the three provinces had extremely strong development in the NEV industry. Especially for the Guangdong province, the bull's eye degrees during the evaluation period were 0.4884, 0.5361, 0.6067, 0.6787, and 0.7047. Shandong, Shanghai, Zhejiang, Sichuan, and Hubei belonged to the second echelon, ranking 4th to 8th, respectively. Their bull's eye degrees exceeded 0.4293, which was the average of thirty provinces. These data reflect that the five provinces had very strong development in the NEV industry. The bull's eye degrees of the other 22 provinces were lower than 0.4293, the average value of thirty provinces. Guizhou, Heilongjiang, and Ningxia belonged to the last echelon, ranking 28th to 30th, respectively. Their bull's eye degrees were lower than 0.3700. These data reflect that three provinces had a weak development of the NEV industry. Especially in the Ningxia province, the bull's eye degree was 0.3577, and the development of the NEV industry was the weakest.

To reflect the social and economic development of different regions in China, four economic regions are divided (due to the lack of data, there were thirty provinces taken as the research objects in this paper): the east region, the northeast region, the middle region, and the west region. Figure 4 shows the NEV industry development evolution trends in four regions of China. The overall development of the four regions showed a growth trend.

The mean values of the comprehensive bull's eye degrees were: the east region—0.5308, the middle region—0.4128, the west region—0.3659, and the northeast region—0.3901. These illustrate that the regional development differences in the NEV industry were obvious. In terms of overall results, the east region was at an upstream level, the west region was at the downstream level, and the northeast and middle regions were at the midstream level. As shown in Figure 4, the development variation trend for the east, middle, and northeast regions shows a stable upward trend, and the differences among regions have increased over time. In contrast, the development variation trend of the west region is relatively stable and shows a weak fluctuating upward trend. The data indicate the effects of a series of policies and subsidies adopted by the government on the NEV industry, and that China's NEV industry was in a period of rapid-growth development.

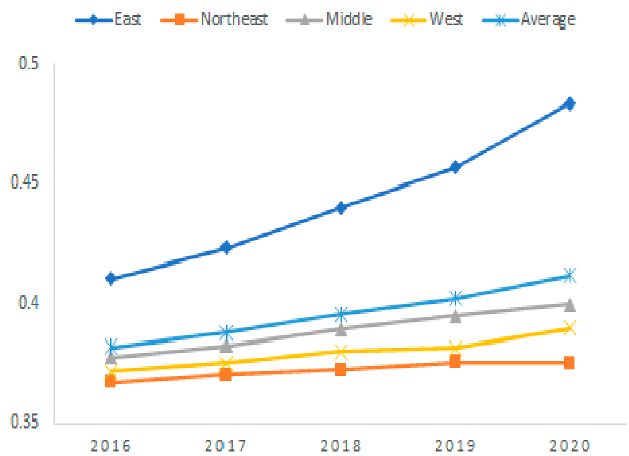

Figure 4. The regional development levels.

From the perspective of temporal evolution, the overall development level of China's NEV industry has steadily improved. Still, the regional gap in development is widening, especially in provinces and cities where the economic development potential has not been fully activated. In general, the development of the new energy vehicle industry shows a spatial pattern of "the east leading, the central catching up, the northeast and the west lagging." The pattern is because the country first started the development strategy in the east region. After laying a good foundation, the industrial transformation and upgrading in the east region were carried out. The good economic foundation and industrial structure of the east region, coupled with related policies of the NEV industry, were also carried out the first pilot in the east region; these caused the fastest development of the NEV industry in the east region. The development of the NEV industry in the middle region lagged behind that in the east. Still, with the support of industrial policies in the middle region and regional cooperation with the east region, the development of the NEV industry in the central region were boosted. The northeast and western regions were lagging more obviously. The northeast region is China's old industrial agglomeration area. Several industrial transformations and policy adjustments restricted the development of the NEV industry in the northeast. The lagging private economy was a major shortcoming in the west region, and the lack of pressure on carbon emissions and relevant policies limited the development of the NEV industry.

4. Dagum Regional Differences Analysis

To further study the regional imbalance of the NEV industry development in four regions, the Dagum Gini coefficient method was employed to measure the regional development disparity of the NEV industry development from the following perspectives: overall difference, intra-regional difference, inter-regional difference, and transvariation intensity of the development level of the NEV industry in the western, central, and northeast regions. The calculation results are shown in Table 4.

Table 4. Measurement and decomposition of the Dagum Gini coefficient.

Dagum Gini Coefficient		2016	2017	2018	2019	2020
Total Gini coefficient		0.0426	0.0498	0.0563	0.0680	0.0840
Intra-regional Gini coefficient	East	0.0534	0.0646	0.0795	0.0945	0.1122
	Northeast	0.0124	0.0137	0.0145	0.0159	0.0128
	Middle	0.0234	0.0258	0.0253	0.0252	0.0250
	West	0.0271	0.0295	0.0228	0.0337	0.0433
Inter-regional Gini coefficient	East–Northeast	0.0581	0.0692	0.0860	0.0997	0.1283
	East–Middle	0.0525	0.0623	0.0743	0.0852	0.1087
	East–West	0.0581	0.0689	0.0805	0.0978	0.1200
	Northeast–Middle	0.0227	0.0245	0.0284	0.0306	0.0349
	Northeast–West	0.0222	0.0235	0.0204	0.0270	0.0334
	Middle–West	0.0269	0.0295	0.0281	0.0347	0.0397
Contribution (%)	G_w	25.50%	25.45%	24.36%	25.11%	24.70%
	G_{nb}	55.93%	57.80%	63.49%	63.20%	63.56%
	G_t	18.57%	16.75%	12.16%	11.69%	11.75%

4.1. Overall Regional Differences and Intra-Regional Differences

Figure 5 describes the trends of the overall Gini coefficient of the NEV industry development in four regions of China from 2016 to 2020. According to Figure 5, the overall Gini coefficient of development level tends to increase. The Gini coefficient was between 0.0426 and 0.084, the overall differences in the development level extended steadily over time, and the development imbalances increased. During the study period, the overall development Gini coefficient reached the maximum of 0.084, and the mean annual growth rate of the overall difference was 18.47%, demonstrating that the overall differences in China's NEV industry development extended.

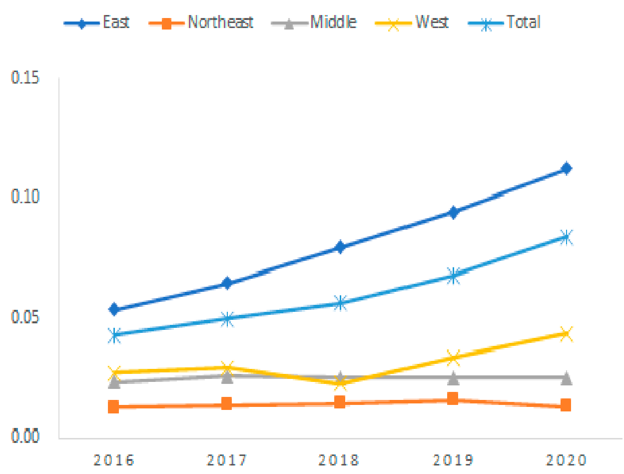

Figure 5. The intra-regional Gini coefficient of the NEV industry.

The Dagum method was employed to decompose the overall Gini coefficient to analyze the inter-regional difference in China's east, middle, west, and northeast regions. Figure 5 also shows the intra-regional differences Gini coefficient of China's NEV industry development and their evolution trends from 2016 to 2020. The intra-regional coefficient of the east region was the largest, followed by the west region, the middle region, and the northeast region; the mean annual growth rates of four regions were: east region—20.40%, the west region—12.39%, the middle region—1.69%, and the northeast region—0.81%. During the study period, the intra-regional coefficient in the east region of China showed a steady upward trend with the value ranging from 0.0534 to 0.1122, indicating that the intra-regional differences of the east region were in an upward trend and consistent with the overall differences. The main reason was that the top three provinces (Guangdong, Jiangsu, and Beijing) were in the east region. These provinces had excellent development foundations and rapid growth in the NEV industry. The intra-regional coefficient in the west region showed a fluctuating upward trend, with the value ranging from 0.0228 to 0.0433, indicating that the intra-regional differences in the west region were upward. The minimum value was in the middle of the study period. The Gini coefficients trend in the middle region (from 0.0234 to 0.0258) and northeast region (from 0.0124 to 0.0159) in China were relatively steady, presenting the intra-regional differences between the two regions remained relatively stable.

The reasons for the gradual expansion of the differences between regions are multi-faceted. The NEV industry is an emerging industry with high technological requirements. The development of the NEV industry in the east region is in line with the requirements of the east region for industrial characteristics. The east region seizes the opportunity of a national development strategy for the NEV industry and makes it a new economic growth point. Regarding carbon emission pressure, the east region is the largest, the middle and northeastern regions are the second largest, and the west region is the smallest. Different pressures lead to different driving forces for the government to promote NEVs. The weak new energy infrastructure in the west will also affect the development of the NEV industry.

4.2. Inter-Regional Differences

The inter-regional Gini coefficient was calculated using the Dagum Gini coefficient method to explore the differences in the development level between regions. Figure 6 shows the inter-regional differences in the development level and their evolution in four regions. As shown in Figure 6, the inter-regional differences show relatively similar trends in the east–northeast, east–middle, and east–west regions, indicating greatly upward trends. The Gini coefficient of the east–northeast region was the largest, followed by the east–west and east–middle region. The mean annual growth rates of inter-regional differences were: east–northeast—21.92% (from 0.0581 to 0.1283), east–middle—19.98% (from 0.0525 to 0.1087), and east–west region—19.86% (from 0.0581 to 0.1200). Similarly, the inter-regional differences in the northeast–middle region indicated a relatively stable state with slight increasing trends during the study period, from 0.0227 in 2016 to 0.0349 in 2020. The mean annual growth rate of inter-regional differences in the northeast–middle region was 11.42%.

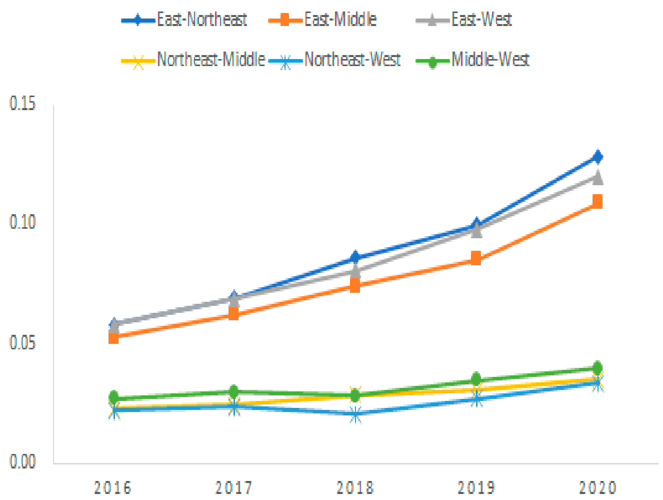

Figure 6. The inter-regional Gini coefficient.

The inter-regional differences showed similar trends in the northeast–west and middle–west regions, indicating fluctuating upward trends. The mean annual growth rates of inter-regional differences were: northeast–west at 10.81% and middle–west at 10.15%. The Gini coefficient of inter-regional difference in the northeast–west region was in the range of 0.0224 to 0.0334 and reached the lowest value in 2018. The Gini coefficient of inter-regional difference in the middle–west region ranged from 0.2069 to 0.0397 and fluctuated values.

The inter-regional Gini coefficients between the east region and the other three regions were larger than 0.0525, and the remaining inter-regional Gini coefficients were less than 0.397. The data indicate that the inter-regional difference gaps were more vast between the east region and the other region, the remaining inter-regional difference gaps were smaller, and all the gaps of inter-regional differences expanded over the years at different speeds.

4.3. Source and Contribution of Regional Differences

The sources of the overall regional differences in the development level of the NEV industry in four different regions can be decomposed into three parts: the contribution rate of intra-regional differences, the contribution rate of inter-regional differences, the contribution rate of intensity of transvariation. The relevant data are shown in Table 4.

Figure 7 displays the sources and contributions of regional differences of the intra-regional differences (G_w), inter-regional differences (G_{nb}), and intensity of transvariation (G_t). Their mean contribution percentages were: G_w 25.02%, G_{nb} 60.80%, and G_t 14.18%. The contribution percentage of inter-regional differences was the largest, followed by the contribution percentage of the intra-regional differences. The contribution percentage of transvariation intensity of the three parts was the smallest. The values of the G_{nb} showed a slight upward trend during the study period, from 55.93% in 2016 to 63.56% in 2020, indicating that the inter-regional differences were the major reason for the corresponding regional differences, and the mean annual growth rate of G_{nb} was 3.25%. The variation range of G_w was between 24.36% and 25.50%. The values of G_w showed that the contribution trend of the intra-regional difference was relatively steady, with a mean annual decreasing rate of 0.79%. The data of G_w indicate that the intra-regional differences were not the major reason for the corresponding regional differences and had a stable impact on the corresponding regional differences. The contribution values of transvariation intensity decreased from 18.57% in 2016 to 11.75% in 2020, and the values of G_t showed the contribution percentage of the transvariation intensity was on a moderately decreasing trend, with the mean annual decreasing rate of 10.82%. It reached the lowest value of 11.69% in 2019. The data of G_t indicate that the transvariation intensity had a smaller impact on the corresponding regional differences than the intra-regional and inter-regional differences.

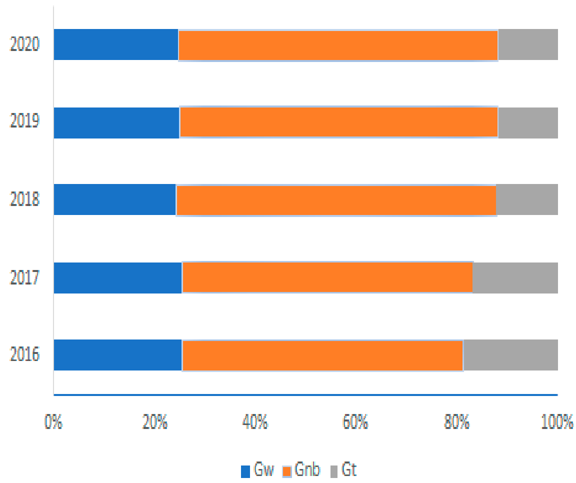

Figure 7. The source and contribution of the differences.

5. Discussion and Implications

5.1. Theoretical Value

This paper employed the grey target method to evaluate the provincial development of the NEV industry. To demonstrate the effectiveness of the proposed method in this paper, the evaluation results of the NEV development of 30 provinces and cities were compared to the grey relational method in the literature [38]. The comparison ranking of the top ten provinces and cities is shown in Table 5. As can be seen from Table 5, the ranking results of the two methods had some similarities. The two methods were consistent in reflecting the NEV industry development in a certain period. There were four provinces and cities with the same ranking in the top 10 of the two methods, and Guangdong was always first place. However, there were still some differences in the ranking results between the two methods. Specifically, the ranking order of Hubei and Anhui changed somewhat between the two methods; other rankings changed very little or remained the same. The differences in the evaluation results of the two methods are mainly caused by the different construction mechanisms of the evaluation methods, which also reflect the different emphasis on the modeling ideas of different methods. Moreover, both methods are based on the grey theory. Still, the proposed dynamic grey target method in this study takes the optimal value of the index among the evaluated objects during the whole research period as the reference sequence. In contrast, the method in the literature [38] takes the optimal value of the index of every year as the reference sequence. In this study, both horizontal and vertical comparisons are feasible. The proposed method enriches the evaluation effect and can effectively extend the applicability of the grey theory for panel data.

Table 5. The NEV development ranking comparison of 10 provinces and cities.

Provinces	Guangdong	Jiangsu	Beijing	Shandong	Zhejiang	Shanghai	Sichuan	Hubei	Qinghai	Anhui
This paper	1	2	3	4	5	6	7	8	9	10
The literature [38]	1	2	4	3	5	7	6	10	9	8

The results of this paper show that, with the support of a series of national policies and subsidies, the new energy vehicle industry has developed rapidly and has become a new economic growth point. The national policies of the NEV industry are listed in Table 6. These supportive policies are the driving force behind the development of the new energy vehicle industry. The maximum average annual growth rate is 11.15% in Guangdong, and the smallest ones are negligible. The better the ranking, the faster the growth rate. The results in this paper show significant differences in the development of different provinces, and the regional gap is widening. Many factors contribute to the differences. In addition to the four aspects mentioned above, there are many policies, such as subsidy policies. For the new-energy subsidy policies, there are two different views. One view is that the subsidy policy can promote the rapid development of NEVs and technological innovation investment [48], especially in the east coastal area and non-state-owned enterprises [49]. The other view is that government subsidy policy may induce enterprises to take advantage of information asymmetry [50] and become addicted to rent-seeking subsidies policymaking [51]. Xiong et al. applied the dual difference model to study the implementation effect and region difference of various promotion policies of NEVs [52]. The evolution of subsidy policies of the NEV is as follows. From 2010 to 2012, the subsidy policy of the NEV was implemented in five pilot cities, and the subsidies were only for private purchases of NEV types. The five pilot cities are Shanghai, Changchun, Shenzhen, Hefei, and Hangzhou. Three cities belong to the east region, and two cities belong to Guangdong. In other words, the promotion action of new energy vehicles in the east region started earliest, laying a solid foundation for the later take-off of the new energy vehicle industry. From 2013 to 2017, the scope of the subsidy policy was expanded to eighty-eight pilot cities for implementation, and subsidies are available for all new energy vehicle types. From 2018 to 2022, the scope of the subsidy policy was extended to the whole country, and subsidies are available for all new energy vehicle types. The above analysis is about the impact of industry planning and subsidy policies on the results, as well as promotion policy, supporting facilities policy, etc.

Table 6. Development planning policies of the NEV industry in recent years.

Date	Agent	Policy Name
September 2020	Ministry of Finance, Ministry of industry and information technology, Ministry of Science and Technology, Development and Reform Commission, National Energy Administration	Notice on the demonstration application of fuel cell vehicles
April 2020	Ministry of Finance, State Administration of Taxation, Ministry of industry and information technology	Announcement of the policy of exemption from vehicle purchase tax for new energy vehicles
September 2019	Ministry of Finance, Ministry of industry and information technology, Ministry of Transport, Development and Reform Commission	Notice on supporting the promotion and application of new energy buses
November 2018	Development and Reform Commission, National Energy Administration, Ministry of industry and information technology, Ministry of Finance	Action plan for improving the charging guarantee capacity of new energy vehicles
April 2017	ministry of industry and information technology, Development and Reform Commission, Ministry of Science and Technology	Medium- and long-term development plan of automobile industry
May 2015	the State Council	Made in China 2025

5.2. Implications

Based on the research results, the implications of this paper on the NEV industry development are as follows.

(1) Rationally optimize the regional industrial layout and carry out cross-regional industrial cooperation.

The NEV industry in the east and middle regions has developed very well, while it has not developed well in the west and northeast regions. For industry-intensive areas, the local governments should plan the development of the new energy industry with a higher vision and fully utilize the existing development advantages to secure their leading position in the NEV industry [53]. They should also learn from well-known international NEV manufacturers, consolidate their low-end products, and occupy the global market share with strong competitive advantages. For less dense industrial regions, such as the northeast and west regions, local governments should increase their efforts to promote NEVs. The local government should cultivate the NEV market by cultivating the concept of environmental protection and green travel among consumers while increasing incentives for consumers to purchase new energy vehicles. Further, most provinces and cities should cooperate in technology research, energy supply, infrastructure construction, etc., to reduce administrative barriers. Promote the development of the NEV industry in an orderly manner and narrow the regional gap.

(2) Improve China's new energy vehicle industry policy and customize differentiated development strategies based on local conditions

The related NEV policies have contributed significantly to China's NEV industry development. At the beginning of the subsidy policy for NEVs in China, substantial subsidies significantly contributed to vehicle enterprises quickly opening and occupying the market [54]. High-subsidy policies are not sustainable, and the market-based subsidy mechanism should be gradually established to create a fair market environment for the NEV industry [55]. Regarding technology policies, the government should focus on unified planning and deployment of cutting-edge technology for the NEV industry. Further, financial support should be granted to independent innovation projects of some NEV enterprises. Meanwhile, relevant patent protection measures should be improved. Regarding customizing differentiated development strategies based on local conditions, each province and city should refer to the results of this study, quantitatively evaluate each index and subitem ability, and take targeted measures to make up for the shortcomings in response to the inferior aspects. It is recommended that Ningxia, Heilongjiang, and Gansu improve technological research and development and Internet technology innovation to reduce their reliance on the advantages of energy structure. The NEV industry is a typical example of the easiest integration of modern manufacturing and advanced service industries, and it is recommended that each province and city extend the value-added industrial chain according to its advantages.

(3) Improve the construction of supporting industries and after-sales guarantee solid waste recycling mechanism

The quality of NEVs products and the perfection extent of supporting industries are very important for the safe driving of new energy vehicles. The history of the private NEV market is shorter than other types of cars. In recent years, the frequent outbreak of many safety accidents in NEVs caused people to worry about the safety performance of NEVs. Hence, people focus on the quality and reliability of NEVs. In order to protect and maintain the legitimate personal safety and property safety of NEV consumers, it is necessary to establish strict industry production standards and an after-sales guarantee system. The construction of the NEV solid waste recycling industry benefits the safety and reuse of China's resources and has specific benefits for environmental protection. Currently, the structure of NEV-supporting facilities, such as charging piles and hydrogen refueling stations in China, lags behind the promotion of new energy vehicles in China. Therefore, especially in the provinces and cities where the construction of charging piles is weak, the structure of supporting infrastructure related to new energy vehicles should also be strengthened. This can reduce the gap between NEV infrastructures among provinces and cities and bring convenience to consumers. However, it should be combined with the local population density, residents' income, and consumers' acceptance of NEVs.

6. Conclusions and Future Work

In the context of carbon neutralization, NEVs are critical to reducing CO_2 emissions, and the NEV industry has provided a new impetus and added new vitality to local economic growth. This study constructed an indicator system and evaluated the provincial development of the NEV industry from 2016 to 2020 in China using the grey target method. The overall differences in the four regions were decomposed by the Dagum Gini coefficient method based on the provincial evaluation results. The main conclusions of this study are as follows.

(1) The provincial level of the NEV industry development showed an increasing pattern. The higher the ranking, the greater the growth rate of development. The evaluation data revealed that the order of thirty provinces was relatively stable from 2016 to 2020. The top three always were Guangdong, Jiangsu, and Beijing. Especially for Guangdong province, the bull's eye degrees during the study period were 0.4884, 0.5361, 0.6067, 0.6787 and 0.7454, respectively, reflecting a rapidly increasing development trend. The last three were Guizhou, Heilongjiang, and Ningxia. The results also show the spatial imbalances in the provincial development of the NEV industry. This proposed method evaluated the NEV industry development level for each year, which takes the optimal value of the index among the evaluated objects during the whole research period as the reference sequence. Therefore, compared with the literature [38], we can also analyze the temporal evolution trend of one province.

(2) The overall and regional development of the NEV industry was on an upward trend. The mean value of bull's eye degrees in the four regions were: the east region—0.5308, the middle region—0.4128, the west region—0.3659, and the northeast region—0.3901. The regional differences were obvious. Regarding regional results, the east region was at the upstream level. The west region belongs to the downstream level. The overall difference in China's NEV industry development expanded from 2016 to 2020. The intra-regional differences in the NEV industry development in the east region were the largest, followed by the west region, middle region, and northeast region, and the mean annual growth rates of four regions were: east region—20.40%, the west region—12.39%, middle region—1.69%, and the northeast region—0.81%. The NEV industry in the east region had the best development and the largest intra-regional difference. The overall development of the NEV industry was

calculated with time point weight, which emphasizes the recent data and better reflects the development characteristics of the NEV industry than using the average of development levels during the study period.

(3) The inter-regional coefficient trends between the four regions expanded gradually at different speeds during the study period. The inter-regional difference gaps between the east and the other three regions were much larger than the remaining regions and expanded with a mean annual growth rate of 20.58%. The contribution percentage of inter-regional differences was the largest, followed by the intra-regional differences and transvariation intensity, indicating that the inter-regional differences were the major reason for the corresponding regional difference with a slight upward trend. The contribution percentages of transvariation intensity were the smallest, with a moderately decreasing trend during the period.

(4) The evaluation results of subitem ability showed that the D_1, D_2, and D_3 dimensions had relatively large contributions to the provincial development of the NEV industry. The D_4 dimension had relatively small contributions. For the first-ranked Guangdong province, the subitem ability values of four dimensions were 0.6806, 0.7083, 0.7949, and 0.4812, reflecting that the three subitem abilities were strong. For the last three provinces, the subitem ability of the D_4 dimension was relatively strong and contributed greatly to the comprehensive results; the subitem abilities of the other three dimensions were weak.

This research evaluated the regional competitiveness of the new energy vehicles industry by using the grey target theory, referred to as the optimal sequence, and provided new theoretical insight. However, this research also has its limitations. Due to the difficulty of data collection, there were 17 criteria in the index system, which were insufficient. How to add evaluating criteria and collect data aiming to accurate the result remains to be researched. As the new energy industry is an emerging industry, supportive policies are crucial to the development of the industry, and it is a research direction to evaluate the promotion effect of local policies on the industry. Additionally, the dynamic grey target model proposed in this paper can effectively evaluate the panel data, and it works well to fully and effectively extend the applicability of the grey target model to the panel data. However, the research on panel data is not only limited to dynamic evaluation but also includes the development or growth trends, which are worthy of further study in the future.

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