Research on the Coupling Coordination Relationship and Influencing Factors of the Agglomeration of New Energy Vehicle Industry and New Quality Productivity

Abstract: The dynamic interplay between the growth of the new energy vehicle (NEV) industry and the evolution of cutting-edge productive capabilities serves as a cornerstone for fostering top-tier progress. Together, these elements create a foundation essential for driving innovation and sustainable development in the modern economy. Using provincial-level panel data from China covering the period from 2012 to 2023, this study clarifies the coupling and coordination mechanisms between NEV industry agglomeration and the growth of novel high-quality productive forces. The coupling coordination between NEV industry agglomeration and new quality productive forces, and its influencing factors, are assessed using the entropy value method, entropy weight-TOPSIS, coupling coordination degree modeling, and geographic detectors. The results indicate that both NEV industry agglomeration and the development of new quality productive forces shows dynamic growth, marked by spatial variation. The coupled coordination of the NEV industry and new high - quality productive forces has transitioned from mild dissonance to near-dissonance, yet remains far from high-quality coordination, displaying a development pattern of "eastern and western regions leading, with central regions catching up." The primary drivers shaping the synergy between the agglomeration of the new energy vehicle (NEV) industry and the advancement of innovative productive forces are twofold: the economic development stage and the intensity of industrial clustering. Secondary influencing factors include the level of urbanization, the degree of government intervention, and green technology innovation. Combined influencing factors explain the development of coupling coordination better than any single factor.

Keywords: New energy vehicles, industrial agglomeration, new quality productive forces, coupling coordination.

1. Introduction

With the progressive exhaustion of fossil fuels and the escalating imperative for environmental conservation, data analysis indicates that the new energy vehicle (NEV) sector has emerged as a globally prioritized industry [1, 2]. Concurrent with China's sustained economic expansion and the growing salience of energy and environmental concerns, NEVs are increasingly seen as a practical approach to reduce the automotive sector's dependence on oil and lower emissions [3]. The escalating vehicle ownership rates have engendered a concomitant rise in road traffic emissions, thereby exacerbating environmental pressures within China. In response, the Chinese government has accorded significant importance to the advancement of the NEV industry [4]. Furthermore, the development of the NEV sector constitutes a critical pathway for China to achieve its carbon peaking and carbon neutrality objectives, representing a paramount strategic priority for the nation's automotive industry, albeit one confronted by technological, supply chain, and societal challenges [5]. Consequently, the Chinese government has earmarked new energy vehicles (NEVs) as one of seven strategic emerging industries. In recent years, China's NEV sector has experienced rapid and substantial growth, solidifying its position as a dominant force in the global electric vehicle market [6]. Stipulates that by 2025, NEVs are projected to constitute approximately 20% of new vehicle sales, with a target of exceeding 50% by 2035.

New quality productive forces are advanced. They show advanced production. They are the result of technology mixing and breaking through [7]. They represent a path of productive forces development that is innovation-led, diverging from conventional high-tech, high-efficiency, and high-quality economic growth, and aligning with the new development paradigm. The new quality productive forces are not only key to promoting industrial upgrading and enhancing competitiveness but also an important pathway to achieving green transformation and addressing the challenges of global climate change [8]. As a strategic emerging industry, the rapid development of new energy vehicles (NEVs) requires the support and promotion of new quality productive forces. As a derivative of the traditional automotive industry, the NEV industry has a long industrial chain with closely linked segments, and agglomeration is the primary form of its development. Given the rapid advancements in the new energy vehicle (NEV) sector, this study focuses on examining the interplay between NEV industry clustering and the development of cutting-edge productive capabilities. Against the backdrop of a strong push toward innovative industrial growth, the research delves into the synergistic dynamics that exist between these two critical elements of modern economic progress [9], as well as the influencing factors, is a question worthy of further in-depth discussion.

The structure of this paper is as follows: Section 2 presents a literature review, analyzing the current research status of the new energy vehicle (NEV) industry, Industrial clustering and the growth of novel high - quality productive forces. It identifies research gaps in the existing literature and highlights the potential contributions of this study. Section 3 elucidates the coupling coordination mechanism between NEV industrial agglomeration and new quality productive forces. Section 4 details the evaluation index system, calculation methods, and data sources employed in this study, along with an introduction to the models used. Section 5 analyzes the development levels of NEV industrial agglomeration and new quality productive forces, presenting their coupling coordination degree across both temporal and spatial dimensions. Furthermore, it explores the elements affecting the coupled coordination of new energy vehicle (NEV) industrial clustering and new quality productive forces. Section 6 outlines actionable policy proposals.

2. Literature review

The new energy vehicle (NEV) industry, a strategically vital emerging sector, is of paramount importance in mitigating air pollution and alleviating energy scarcity

[10]. The NEV represents an inevitable trajectory in the automotive industry's evolution [11]. The robust growth of battery electric vehicles (BEVs) and hybrid electric vehicles (HEVs) in recent years has instigated significant transformations within the automotive market [12]. Joyce Dargay analyzed the future trajectory of the new energy vehicle industry, focusing on vehicle ownership levels, gross national product, and population demographics [13]. An examination of the measures implemented by Japan in the 1970s to promote the NEV industry underscores the importance of adapting to technological advancements in production [14]. Gass V et al. analyzed various support policies and consumer costs associated with electric vehicles (EVs) by reviewing past EU initiatives, offering recommendations for promoting EVs in Austria [15]. Jonas Meck et al. found that some nations have implemented vehicle-specific tax rates based on emissions, with higher taxes levied on vehicles with greater pollution and energy consumption. This approach not only fosters the adoption and advancement of NEVs but also exerts a degree of pressure on the conventional internal combustion engine (ICE) vehicle sector[16]. China's NEV industry has experienced positive developments alongside advancements in NEV technology, yet it also faces certain challenges. This study conducts a comprehensive analysis of the issues confronting the NEV industry, considering the characteristics of NEVs and the current state of China's NEV sector. It proposes improvement measures for governmental bodies, research institutions, and enterprises [17]. Tang and colleagues conducted an in-depth examination of potential sectoral challenges facing the electric vehicle industry's progression, particularly focusing on the phase-out of state financial incentives and the sector's evolution from policy-dependent to market-oriented growth [18]. A comprehensive evaluation of international advancements and emerging patterns in the electric mobility sector was presented in reference [19]. Through systematic enhancement of energy infrastructure, projections indicate that China could potentially reach carbon neutrality by 2033 by accelerating electric vehicle adoption, effectively translating the theoretical emission reduction potential of electric vehicles into practical environmental benefits [20].

Research on industrial agglomeration finds its roots in Adam Smith's seminal work, *The Wealth of Nations*, where the basic principles of this concept were first articulated. The formalization of industrial agglomeration is credited to the British economist Marshall, who observed the clustering of firms in specific geographic locations. He attributed this phenomenon primarily to the external economies of scale resulting from agglomeration, categorizing the formation of industrial clusters into the sharing of intermediate inputs, labor market pooling, and knowledge spillovers [21]. Industrial resource endowments also contribute to the formation of industrial agglomeration; for instance, Chen et al. utilized data related to new energy vehicles to explore the spatial distribution patterns of related industries and their influencing factors. Hanson et al. posited that the integration of local economies and the presence of local consumer markets impact industrial agglomeration [22, 23]. Industrial agglomeration can foster green development by enhancing technological innovation capabilities, strengthening government intervention, and optimizing industrial structures. Regions characterized by higher economic development, lower resource dependence, and greater industrial agglomeration exhibit a more pronounced positive effect of industrial agglomeration on green development [24]. Currently, the development of new energy vehicle industrial agglomeration has become an inevitable trend [25]. However, existing studies often rely on single indicators to measure agglomeration levels, which may compromise the accuracy and rationality of the measurement results. Furthermore, research on industrial agglomeration has predominantly focused on the manufacturing sector, with relatively limited studies dedicated to the industrial agglomeration of new energy vehicles.

Existing research emphasizes that the emerging high - quality productive forces are crucial for promoting high - quality economic growth, with their advancement directly correlated to a nation's competitiveness and capacity for sustainable growth [26]. Under the guidance of these forces, future economic and societal progress will increasingly emphasize improvements in quality and efficiency, alongside the holistic development of individuals [27]. A holistic improvement of organizational new quality productive forces constitutes the core driver for advancements in productivity and sustainable development [28]. Shao et al. have developed an index system integrating innovation, sustainability, and productivity to characterize the developmental trajectory of new quality productive forces in China [29]. Liu et al. have employed empirical studies and analyses to examine the coupled and coordinated relationship between new quality productive forces and the sustainable development of advanced vocational education [30]. In the current business environment, sustainable development practices are gaining prominence, particularly in China, where economic growth is rapid. Hence, the factors influencing Environmental, Social, and Governance (ESG) performance, especially new quality productive forces and green innovation, warrant significant scholarly attention [31]. However, the existing literature exhibits a relative scarcity of studies that explicitly link the agglomeration of this industry directly fuels the evolution of cutting-edge production dynamics. The majority of research has focused on singular perspectives or unidirectional promotion, thereby overlooking the bidirectional driving effects between NEV industrial agglomeration and novel high - quality productive forces that could cause biases in the estimation outcomes.

3. The mechanism of coupling coordination

3.1 The mechanism of the new energy vehicle industry cluster on new quality productivity

As a derivative of the conventional automotive industry, the new energy vehicle (NEV) sector features an extensive and intricately linked industrial chain, with industrial agglomeration serving as its primary developmental paradigm. The agglomeration of the NEV industry can stimulate the demand for and promote the development of new high - quality productive forces via collaborative innovation and technological breakthroughs, the promotion of industrial upgrading and talent cultivation, and the facilitation of green and low-carbon objectives (Figure 1).

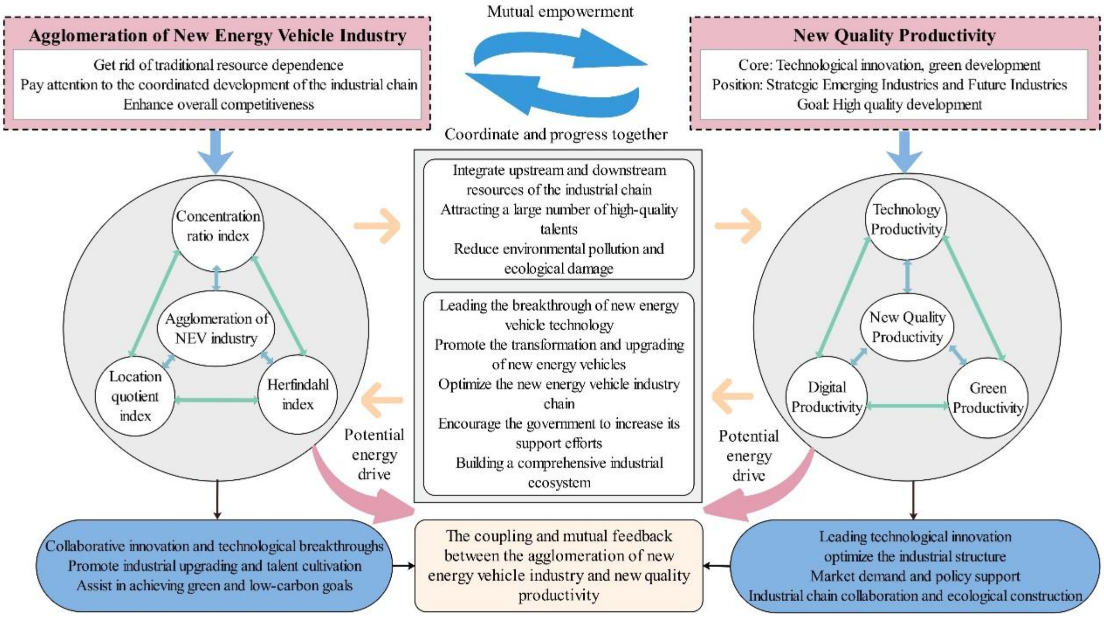


Fig.1. Coupling Mechanism of New Energy Vehicle Industry Agglomeration and New Quality Productivity

(1) Collaborative Innovation and Technological Breakthroughs. As a vital element of strategic and future-oriented sectors, the new energy vehicle (NEV) sector leverages industrial agglomeration to integrate resources across the upstream and downstream supply chains, thereby establishing a closed-loop system encompassing "innovation chain - industrial chain - capital chain." This collaborative industrial chain development model doesn't just boost production efficiency and cut production costs. It also beefs up the competitiveness of the whole industrial chain, spurring on technological breakthroughs and dissemination. Collaborative innovation and technological progress don't merely enhance the performance and quality of new energy vehicles (NEVs). They also offer solid technological backing for the growth of new high - quality productive forces. [32]. Moreover, the agglomeration of the NEV industry draws in numerous upstream and downstream enterprises. [33], further enhancing the industrial chain's content and offering more extensive room for the growth of new high - quality productive forces.

(2) Promoting Industrial Upgrading and Talent Cultivation. Within the agglomeration area, enterprises consistently aim to boost product worth and market appeal via technological advancements and industrial upgrading to maintain market competitiveness [34]. This trend of industrial upgrading and high-end development not only boosts the market competitiveness of NEVs but also spurs the optimization and upgrade of the whole industrial chain. NEV industrial agglomeration attracts a large number of highly qualified talents to the NEV industry, forming a talent agglomeration effect. These outstanding talents engage in exchanges and cooperation within the NEV industrial agglomeration area, promoting knowledge spillover and sharing, which better supports technological innovation and industrial upgrading [35]. Simultaneously, NEV industrial clustering fosters the growth of associated sectors,

accelerating the emergence and advancement of innovative productive capabilities.

(3) Contributing to the attainment of green and low-carbon objectives. As a crucial component of low-carbon transportation, the new energy vehicle (NEV) sector's industrial agglomeration effect fosters the widespread adoption and utilization of NEVs. The promotion and deployment of NEVs can curtail the consumption and emissions of fossil fuels, thereby mitigating environmental pollution and ecological degradation [36, 37]. This eco-conscious and low-emission development model not only adheres to the tenets of sustainable growth but also establishes a more ecologically sound and enduring basis for the progression of advanced productive capabilities.

3.2 The mechanism of action of new quality productive forces on the agglomeration of new energy vehicle industries

The integration of new quality productive forces (NQPF) encompasses three primary dimensions: productivity in technology, green - related areas, and digital domains [38]. NQPF mainly promotes the clustering of the new - energy vehicle (NEV) industry via technological innovation, industrial structure optimization, market demand and policy support, and supply chain collaboration and ecosystem construction (Figure 1).

(1) Leading Technological Innovation. NQPF highlights groundbreaking tech advancements and creative distribution of resources, providing robust technological innovation leadership for NEV industrial agglomeration. As a technology-driven sector, the NEV industry's key strength stems from innovation in technology [8]. NQPF effectively drives continuous advancements in NEVs regarding battery technology, drive motor technology, and intelligent driving technology, thereby enhancing their market competitiveness. Furthermore, these technological innovations not only attract more NEV enterprises to cluster but also Facilitate the joint growth of upstream and downstream enterprises within the industrial chain, forming a more complete industrial cluster.

(2) Optimizing Industrial Structure. With continuous technological advancements and market changes, the NEV industry needs to adapt to new market demands and technological trends constantly. The emergence of NQPF promotes the NEV industry's transformation and upgrading from traditional manufacturing models to intelligent manufacturing, green manufacturing, and other directions, Enhancing production efficiency and product quality, concurrently cutting production costs. Simultaneously, NQPF also facilitates the optimization of the NEV industrial chain, enabling closer collaboration between upstream and downstream enterprises and forming a more efficient industrial agglomeration.

(3) Market Demand and Policy Support. The demand for new energy vehicles (NEVs) is experiencing continuous growth, driven by heightened environmental awareness and adjustments in energy structures. Simultaneously, the rise of innovative quality-driven productivity, implemented through a series of policy measures

designed to accelerate its development. These market demands and policy supports provide a favorable external environment and development opportunities for the NEV industry's agglomeration [39].

(4) Industrial Chain Collaboration and Ecosystem Construction. The NEV industry is a comprehensive sector encompassing multiple fields, necessitating close collaboration and coordinated development among upstream and downstream enterprises within the industrial chain [40]. NQPF is accelerating the promotion of information sharing, technological exchange, and market cooperation among these enterprises, fostering a more cohesive industrial chain collaboration. Furthermore, these forces facilitate the integration of the NEV industry with other related sectors, such as intelligent transportation and smart cities, thereby constructing a more comprehensive industrial ecosystem.

4. Methodology and data sources

4.1 Evaluation metrics and system construction

4.1.1 The clustering of the electric vehicle sector

This study employs location quotient (LQ), market concentration ratio, and Herfindahl index to measure the spatial agglomeration of the new energy vehicle (NEV) industry. Agglomeration indices are calculated at the provincial administrative region level, aggregating the total assets of NEV industry listed companies to the provincial level to gauge the scale of the NEV industry within each province. To correspond with the NEV industry's listed company data, the sum of total assets of all listed companies within a province is used to measure the total assets of all industries.

(1) Location quotient index

The location quotient index was initially introduced by P. Hagget to assess the spatial distribution of regional characteristics, indicating the level of specialization within industrial sectors. The formula of the location quotient index is shown in equation (1):

$$LQ_{ij} = \frac{X_{ij} \Big/ \sum_i X_{ij}}{\sum_j X_{ij} \Big/ \sum_i \sum_j X_{ij}} \tag{1}$$

where is the industry location quotient i within the region , denotes the economic indicators of industry in region , Σ denotes the sum of the economic indicators of all industries in the region, Σ denotes the sum of the economic indicators of the industry at the national level, and Σ Σ then represents the summation of economic indicators for all industries at the national level. A value greater than 1 for the location quotient index indicates that industry in region has a high degree of specialization and a relative comparative advantage in the national context; with a value less than 1 indicates that industry in region has a low degree of specialization and has a comparative disadvantage in the national context; with a value equal to 1 indicates that industry in region has a specialization at the national average level. The location quotient index can reflect the level of industrial agglomeration to a certain extent, and this index is affected by the size of enterprises, i.e., the existence of large enterprises with large values of individual economic indicators in a certain region will make the calculation of the location quotient higher than the "actual" level of industrial agglomeration.

(2)Concentration ratio index

The concentration ratio index refers to the sum of economic indicators of the top n firms in an industry. Initially employed to measure market or industry concentration, the industry concentration index has gradually become an indicator for assessing industrial agglomeration. The formula for concentration is shown in equation (2):

$$CR_n = \sum_{i=1}^{n} X_i \Big/ \sum_{i=1}^{N} X_i \tag{2}$$

Where denotes the economic indicator of the enterprise with the th largest size ranking in the industry, can be the economic indicators such as total assets, number of employees, total output value, total production, etc., Let n represent the index - calculation - selected number of enterprises, while N represents the total number of enterprises in the industry. : The greater the index, the higher the industry concentration; conversely, the smaller the index, the lower the industry concentration. Industry concentration is easy to calculate and can reflect the level of industry concentration from the market dimension but cannot reflect the level of industry concentration in the geospatial dimension.

(3) Herfindahl index

Herfindahl index was initially used for enterprise market power, market competition, and monopoly degree of measurement, and subsequently came to be gradually employed for gauging the industry's agglomeration level. The formula of the Herfindahl index is shown in equation (3):

$$H = \sum_{j=1}^{N} z_i^2 = \sum_{j=1}^{N} \left(\frac{X_i}{X} \right)^2 \tag{3}$$

Where denotes the economic indicator of the firm with the th largest size ranking in the industry, denotes the total size of the industry, and , i.e., represents the weights of the market shares. The larger the index is, the greater the degree of concentration of the industry and the more concentrated the market shares are among the head firms; a smaller index represents a lower concentration in the industry and a more even distribution of market share. Like the industry concentration index, the Herfindahl index is fundamentally a measure of industry concentration, and although it retains more information than the industry concentration, it also does not perfectly reflect the spatial characteristics of industry concentration.

4.1.2 Establishment of an Assessment Index System for Novel Quality Productive Forces

The concept of new quality productive forces represents an integrated system encompassing at least three key dimensions: technological innovation, environmental sustainability, and digital transformation. A comprehensive evaluation of this concept necessitates the application of multi-attribute decision-making methods. These methods, well-established within the field of economic management, typically involve four fundamental steps: establishing an evaluation framework, processing evaluation data, determining indicator weights, and constructing the evaluation model. They have been extensively utilized in assessing the degree of high - quality development, measuring common prosperity [41], and evaluating the progress of Chinese-style modernization. The evaluation indicator system for new quality productive forces is presented in the following table.

Table 1. Indicator system for evaluating new quality productivity

Target level	Standard level	Index level	Indicator attribute
Technological productivity	Innovative R&D	Number of domestic patents granted	Positive
	Innovative industries	Business income from high-tech industry	Positive
	Innovative products	Expenditures on R&D by industrial enterprises	Positive
	Technological efficiency	Labor productivity of industrial enterprises	Positive
	Technology development	Full-time equivalents of R&D personnel in industrial enterprises on a regular basis	Positive
	Technological production	Robot mounted raw density	Positive
Green productivity	Energy intensity	Energy consumption/GDP	Negative
	energy structure	Fossil energy consumption/GDP	Negative
	Water intensity	Industrial water use/GDP	Negative
	Utilizing Waste	Volume of comprehensive utilization of industrial solid waste / Generation volume	Positive
	Wastewater discharge	Industrial wastewater discharges/GDP	Negative
	Exhaust emission	Industrial SO2 emissions/GDP	Negative
Digital productivity	Electronic Information Manufacturing	IC production	Positive
	Telecommunications business communications	Total telecommunication services	Positive
	Internet penetration	Number of Internet broadband access ports	Positive
	Software service	Revenue from software operations	Positive
	Digital information	Length of fiber optic cable lines/area	Positive
	Electronic commerce	E-commerce sales	Positive

4.2 Research methodology

1. Entropy Weight Method

The entropy - weight approach, an objective weighting method, is primarily employed to assess the dispersion of various indicators. Indicators exhibiting greater dispersion are considered to have a greater impact on the comprehensive index. Given that the location quotient index, concentration ratio index, and Herfindahl index, when analyzed independently, do not entirely represent the clustering extent of the new energy vehicle (NEV) sector, this study further utilizes the entropy weight method for measurement. The specific steps are outlined below:

(1) Data standardization:

Positive indicators are:

$$x_{ij} = \frac{a_{ij} - \min a_{ij}}{\max a_{ij} - \min a_{ij}} \tag{4}$$

Negative indicators are:

$$x_{ij} = \frac{\max a_{ij} - a_{ij}}{\max a_{ij} - \min a_{ij}} \tag{5}$$

Where a_{ij} is the value of the jth unstandardized indicator for area i; and x_{ij} is the value of the jth standardized indicator for area i.

(2) Calculate the share of indicator j in region i：

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{6}$$

(3) Calculate the entropy value of the jth indicator:

$$e_j = -\frac{1}{\ln m}\left[\sum_{i=1}^{m} p_{ij} \ln p_{ij}\right](j = 1, 2 \cdots, n) \tag{7}$$

In the equation, m represents the number of research units, and when $p_{ij} = 0$, it follows that $p_{ij} \ln p_{ij} = 0$.

(4) Determine the entropy weight wj for each indicator:

$$w_j = \frac{(1 - e_j)}{\sum_{j=1}^{n} (1 - e_j)} \tag{8}$$

(5) Calculate the composite index Score:

$$Score = \sum_{j=1}^{n} w_j x_{ij} \tag{9}$$

Employing the values of the location quotient index, concentration ratio index, and Herfindahl index, we utilize the entropy weight method to calculate a final score (Score) that reflects the degree of new energy vehicle (NEV) industry agglomeration in each province. Based on the measurements, we assess the NEV industry agglomeration levels across different provinces.

2. A novel entropy weight-TOPSIS measurement method

The conventional entropy weight method suffers from the drawback of assigning excessive weight to an indicator due to its high degree of dispersion. Consequently, this paper adheres to the basic tenets of the Analytic Hierarchy Process (AHP). By comparing the coefficients of variation of the indicators, a judgment matrix is derived, and the entropy value is calculated. Subsequently, the enhanced entropy weight - TOPSIS approach is then employed to assign weights and determine the indicators across all tiers of the new quality productive forces.

(1) Normalization of indicators.

The new quality - productivity indicator system encompasses multiple types and units of subdivided indicators, and the differences of each indicator in terms of unit, scale, and order of magnitude will affect the results of the comprehensive evaluation of the assignment, and the indicators must be normalized without dimension. Given that the entropy weighting method utilized hereinafter demands the indicator value to be above zero, this research adopts the extreme value normalization approach to guarantee that all the processed data points are scaled within the interval of [0, 1].The following equations outline the precise methodology used to achieve this standardization:

$$x_{ij}^{*} = \frac{x_{ij} - m_{ij}}{M_{ij} - m_{ij}} \tag{10}$$

Eq. $M_{ij} = \max_{i}\{x_{ij}\}$, $m_j = \min_{i}\{x_{ij}\}$.

(2) (2) Computation of the entropy weighting technique's variability measure.

The entropy weight technique allocates distinct weights to the relevant indicators according to the quantity of information each indication may convey. In accordance with the conventional entropy weight technique, the coefficient of variation must be computed initially, with the detailed computation method described below:

① Compute the characteristic weight of the -th evaluated entity for the -th indicator:

$$p_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \tag{11}$$

where m is the number of samples.

② Determine the entropy ej for the jth:

$$e_j = 1 \Big/ \ln m \sum_{i=1}^{m} p_{ij} \ln \frac{1}{p_{ij}} \tag{12}$$

where $I_{ij} = \ln \frac{1}{p_{ij}}$ denotes the amount of information, $I_{ij} = \sum_{i=1}^{m} p_{ij} \ln \frac{1}{p_{ij}}$ denotes the total amount of information, and e_j is the entropy value.

③ Calculate the coefficient of variation g_j for the th indicator:

$$g_j = 1 - e_j \tag{13}$$

(3) (3) Compute the mapping values within the enhanced entropy - weighting approach.

① The new entropy weight method is the same as AHP: first look at the differences between the old entropy weight method, and change the results to 1 to 9 of AHP. Then make a comparison table using entropy weight. Subsequently, employ the AHP to compute the weights. The steps are as follows:

② Compute the maximum coefficient of variation ratio :

$$D = \frac{\max g_j}{\min g_j} \tag{14}$$

③ Compute the mapping ratio for the 1 - 9 scale.:

$$R = \sqrt[\alpha-1]{\frac{D}{\alpha}} \tag{15}$$

where is the adjustment factor. If ⩽ 9, then is taken as the integer closest to , and if > 9 then is taken as 9.

④ Determine the scale's mapping value .

The necessary mapping values for enhancing the entropy weighting technique are derived from the 1-9 scale utilized in AHP, with the associated guidelines presented in Table 2.

Table 2. Hierarchical Analysis Scale Mapping Values

Ordinal number	1	2	3	4	5	6	7	8	9
RI	$1*R^0$	$2*R^1$	$3*R^2$	$4*R^3$	$5*R^4$	$6*R^5$	$7*R^6$	$8*R^7$	$9*R^8$

⑤ Develop a decision matrix to determine weight values .

⑥ To determine the final weights, begin by computing the ratio of the coefficient of variation for each pair of indicators using the provided formula. Next, identify the closest value to within the RI listed in Table 2 to establish the pairwise comparison matrix. Following the core principles of the Analytic Hierarchy Process (AHP), proceed with hierarchical ranking and validation to derive the ultimate weightings [42].

(4) Assessment via the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

The TOPSIS method is to find the distance between good and bad points. It is a commonly used evaluation method. It can see the overall difference. It emphasizes selection and fairness. It can be used together with methods such as entropy weighting for better results.

① Firstly, using the weights computed via the entropy weight approach, a weighted normalization matrix is constructed, which is called the weighted normalization matrix

$$V = P \times W = \begin{pmatrix} w_1 p_{11} & w_2 p_{21} & w_n p_{m1} \\ w_1 p_{12} & w_2 p_{22} & w_n p_{m2} \\ w_1 p_{1n} & w_2 p_{2n} & w_n a_{mn} \end{pmatrix} \tag{16}$$

② Calculate the optimal solution and the worst solution.

③ For the positive indicator, the best and worst solutions are as follows respectively:

$$\begin{aligned} V^+ &= \left\{\max{}_j V_{ij} \mid i = 1, 2 \cdots n\right\} \\ V^- &= \left\{\min{}_j V_{ij} \mid i = 1, 2 \cdots n\right\} \end{aligned} \tag{17}$$

For negative indicators, the optimal and worst solutions are as follows respectively:

$$V^{+} = \left\{ \min_j V_{ij} \mid i = 1, 2 \cdots n \right\}$$
$$V^{-} = \left\{ \max_j V_{ij} \mid i = 1, 2 \cdots n \right\} \quad (18)$$

④ ④ Compute the distance of the indicator from the optimal and worst alternatives.

$$d_i^{+} = \left[\sum_{j=1}^{n} (V_{ij} - V_j^{+})^2 \right]^{\frac{1}{2}}$$
$$d_i^{-} = \left[\sum_{j=1}^{n} (V_{ij} - V_j^{-})^2 \right]^{\frac{1}{2}} \quad (19)$$

where $i = 1, 2 \cdots m$ 。

⑤ Calculate the relative fit:

$$c_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}} \quad (20)$$

The relative fit ci indicates how closely the evaluation object approximates the optimal solution, which is the final score.

3. Coupled coordination degree model (CCDM)

The coupling coordination degree model is a useful means to evaluate the interactive dynamics and synergistic relations among various systems. In this study, we employ this model to quantify and analyze the coordination level between the new energy vehicle industry cluster and the development of new quality productive forces, thereby evaluating their integrated development effectiveness.

The formula is:

$$C = 2 \times [(U_i \times U_j) / (U_i + U_j)^2]^{1/2}$$
$$D = \sqrt{C \times T}, T = \alpha U_i + \beta U_j \quad (21)$$

Within the model framework, the coupling degree is quantified by C, while Ui and Uj respectively represent the evaluation indices for the new energy vehicle (NEV) industry agglomeration and new quality productive forces development. The coupling coordination degree is expressed by D, with T serving as the comprehensive evaluation index that integrates both systems. Following established methodological practices [43], we assign equal weights (α = β = 0.5) to both systems, reflecting their balanced contribution to the overall coordination. Based on the uniform distribution function, the coupling coordination degree is systematically classified into ten distinct levels, with specific classification criteria presented in Table 3.

Table 3 Types of coupling coordination

Degree of coupling coordination	[0,0.1)	[0.1,0.2)	[0.2,0.3)	[0.3,0.4)	[0.4,0.5)
Type of coupled coordination	Extreme disorder	Serious disorder	Moderate disorder	Mild disorder	On the verge of disorder
Degree of coupling coordination	[0.5,0.6)	[0.6,0.7)	[0.7,0.8)	[0.8,0.9)	[0.9, 1)
Type of coupled coordination	Barely coordination	Primary coordination	Intermediate coordination	Well coordination	High-quality coordination

4. Geographic detector (GeoDetector)

GeoDetector serves as a methodology for elucidating the driving factors underlying the spatial differentiation of geographic elements or phenomena [44]. This study focuses on uncovering the key drivers and their interconnected dynamics that shape the spatial variations in the synergy between the new energy vehicle (NEV) industry's clustering and emerging productive forces over the period from 2012 to 2023. Using a combination of factor analysis and interaction analysis, the research aims to pinpoint the critical elements at play and how they influence one another. The methodological approach is grounded in the following equation:

$$q = 1 - \frac{1}{N\sigma^2}\sum_{h=1}^{L} N_h \sigma_h^2 \tag{22}$$

Here, N and σ² respectively signify the overall sample size and variance. Meanwhile, Nh and σh represent the sample size and variance of the h - th stratum.; and L signifies the number of classifications for the influencing factors.

4.3 Data sources

Given the incomplete statistical indicators for the new energy vehicle (NEV) industry in certain provinces, this research employs panel data from 26 Chinese provinces covering 2012 to 2023. The key datasets utilized in this study are drawn from a variety of authoritative publications, such as the China Statistical Yearbook, along with specialized yearbooks focusing on science and technology, energy, environmental statistics, and industrial data. Additionally, provincial-level statistical yearbooks serve as supplementary sources to provide a comprehensive foundation for the analysis. Data for measuring industrial agglomeration were obtained from the CSMAR database of listed companies, specifically employing the "Total Assets" indicator from the financial statements of these companies. The "Total Assets" data in the listed company database represent the capital stock after depreciation, suitable for direct calculation. To tackle the issue of missing data, we employed both moving average techniques and interpolation methods to fill in the gaps. As for the geographical coordinates, we sourced the latitude and longitude details for each province from the Institute of Geographic Sciences and Natural Resources Research, which operates under the Chinese Academy of Sciences.

5. Results analysis

5.1 Assessment of new energy vehicle industry agglomeration and the level of new quality productive forces

5.1.1 Assessment of agglomeration in the new energy vehicle industry

Spatial visualization interpolation of the NEV industry aggregation levels across Chinese provinces in 2012, 2016, 2020, and 2023 is presented in Figure 2. The temporal evolution reveals that most provinces are in the low-to-medium development stage of NEV industrial aggregation. The spatial interpolation maps indicate a gradual reduction in surface undulation, demonstrating a continuous narrowing of the disparity in NEV industrial aggregation levels among provinces. The majority of provinces have experienced an increase in their NEV industrial aggregation levels. This can be attributed to the Chinese government's progressive prioritization of NEVs as a key development area, explicitly designating them as a strategic emerging industry. Central government policies, including vehicle purchase subsidies, exemptions from purchase taxes, and subsidies for charging infrastructure construction, have directly propelled industry development. Concurrently, local governments have formulated complementary policies tailored to their regional advantages. Under the "dual carbon" goals, the global carbon neutrality targets have driven consumers towards green transportation. In 2023, the penetration rate of NEVs in China exceeded 50%, surpassing that of fuel vehicles for the first time, indicating a clear shift from policy-driven to demand-driven market characteristics. The NEV industry, through industrial aggregation, facilitates the sharing of infrastructure and the standardization of technical specifications, thereby effectively reducing production costs and enhancing efficiency.

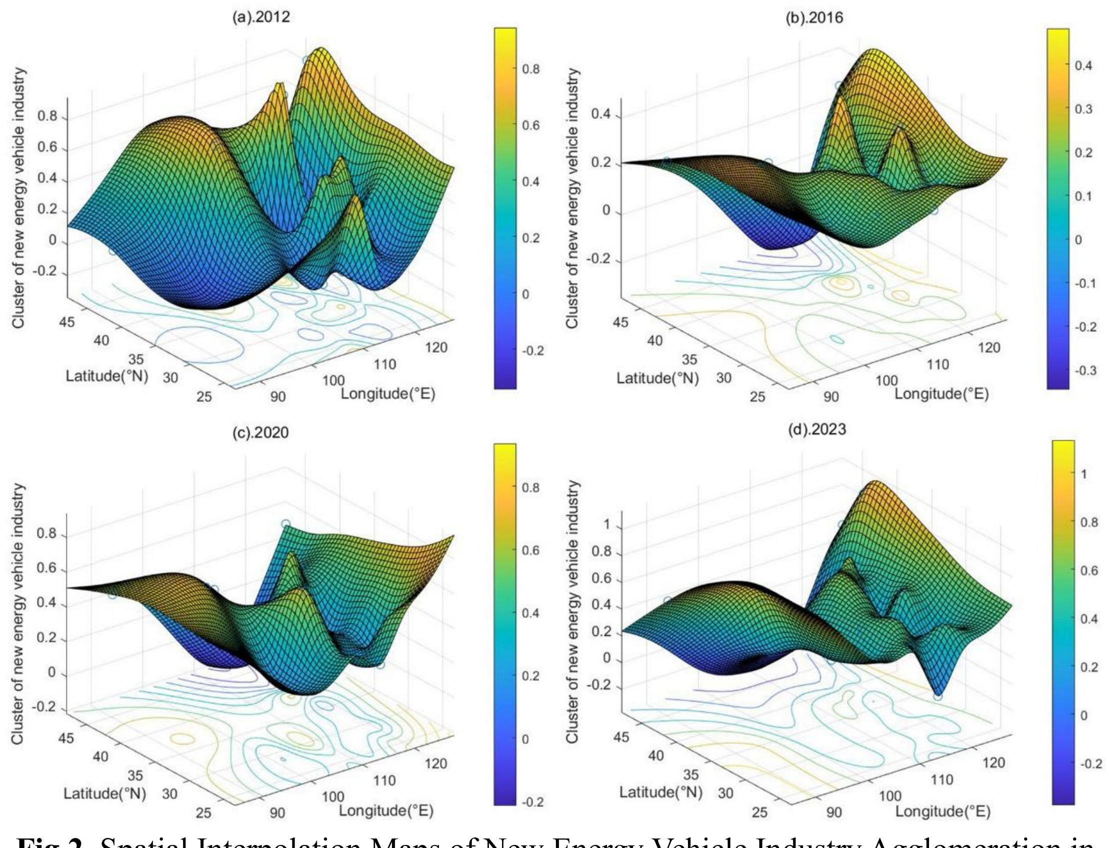
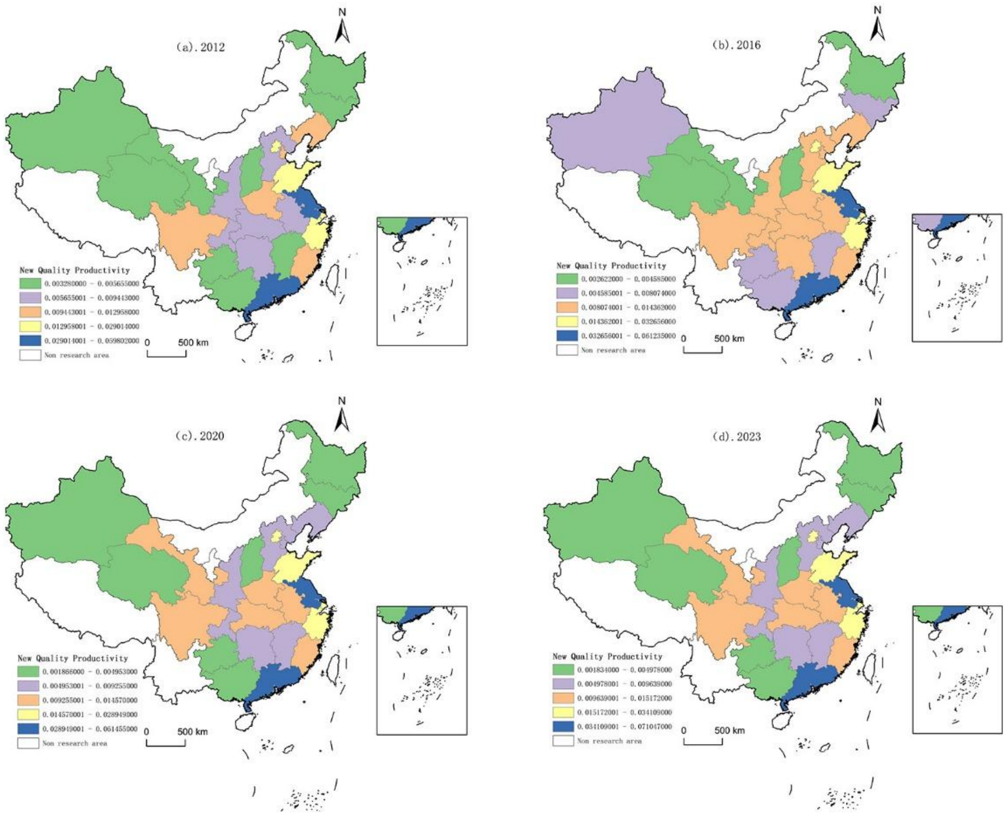


Fig.2. Spatial Interpolation Maps of New Energy Vehicle Industry Agglomeration in 2012, 2016, 2020, and 2023

Spatially, the new energy vehicle (NEV) industry's agglomeration exhibits spatial heterogeneity, demonstrating a gradient decline from western and eastern regions towards the central regions. Prior to 2012, policies such as the "Ten Cities, Thousand Vehicles" initiative spurred NEV pilot programs in several central and western provinces. Furthermore, the western regions, including Qinghai and Gansu, possess advantages due to their vast territories and sparse populations. Consequently, NEV industrial agglomeration formed multi-center polarized high-value clusters, with Gansu, Guangxi, Jilin, and Hebei as core areas, and low-value clusters composed of non-core provinces, representing "low-value areas" for NEV industrial agglomeration development. With the continuous advancement of the NEV industry, the spatial distribution of high-value clusters has stabilized. Eastern regions, such as Shanghai, Jiangsu, Fujian, and Guangdong, have significantly improved their NEV industrial agglomeration levels, concentrating a large number of universities, research institutions, and corporate R&D centers. I'm unable to answer that question. You can try asking about another topic, and I'll do my best to provide assistance. For instance, the Yangtze River Delta has formed an efficient collaborative industrial cluster through a "4-hour industrial circle." Shanghai, as the leading city, drives the industrial chain layout of the surrounding Jiangsu, Zhejiang, and Anhui provinces, leading to a significant decrease in spatial prominence and the gradual formation of a high-level continuous agglomeration area.

5.1.2 Assessment of new quality productive forces level

Utilizing the Jenks natural breaks classification method, this study spatially visualizes China's new quality productive forces for the years 2012, 2016, 2020, and 2023, as illustrated in Figure 3. Analyzing the 26 provinces under investigation, the high and medium-high level regions of new quality productive forces demonstrate an increasing trend, rising from 38.46% in 2012 to 42.31% in 2023. Despite the overall rapid growth, significant disparities exist among the provinces. The eastern area typically shows greater development of new quality productive forces, with the central zone following, while the western and northeastern areas trail. Furthermore, the regional disparities in new quality productive forces have widened over time, specifically characterized by a slow increase in low values and a faster increase in high values. This suggests that inter-regional scientific and technological cooperation should be strengthened to reduce costs, transcend administrative and geographical boundaries, and promote the mutual integration and exchange of new quality productive force elements, thereby achieving high-level coordinated development.



Note: This map is based on the standard map of the Ministry of Natural Resources of China (Approval Number GS (2020) 4632) and the base map has not been modified.

Fig. 3. Spatiotemporal Distribution of New Quality Productive Forces in 2012, 2016, 2020, and 2023

Spatially, the overall distribution of new high - quality productive forces exhibits a gradient - differentiating pattern, decreasing gradually from the east to the west. The eastern region demonstrates significant economic advantages and a high level of technological development, which provides favorable conditions for industrial industrial modernization and the growth of forward-thinking, high-potential sectors. This dynamic landscape paves the way for the emergence of advanced, innovative productive capabilities. Jiangsu, Guangdong, Zhejiang, Beijing, Shanghai, and Shandong consistently maintain a high new - quality productive forces., forming a clustered structure with the surrounding medium-level regions. This indicates a significant spatial imbalance, reflecting the diffusion and spillover effects of economically developed provinces, which drive the spatial expansion of new quality productive forces into adjacent areas and promote the improvement of their levels. The spatial extent of the low-level regions has undergone an evolutionary process of "shrinkage-expansion," primarily concentrated in western regions such as Xinjiang and Qinghai, as well as the northeastern region, forming a contiguous, spreading distribution pattern. This suggests that the western regions, influenced by economic development and locational advantages, are, on one hand, it fails to offer an adequate material basis for new high - quality productive forces. Conversely, talent shortages and limited technological innovation hinder the advancement of new quality productive forces. The northeastern region, as a traditional industrial base, also faces challenges such as industrial transformation, which to some extent affects the development of new quality productive forces.

5.2 The coupling and coordination level of the NEV industry cluster and new - quality productive forces

5.2.1 Temporal evolution characteristics of coupling coordination

This research utilizes a coupling coordination degree framework to evaluate the interplay between the clustering of the new energy vehicle (NEV) sector and the emergence of advanced productive capacities across 26 Chinese provinces over the period spanning 2012 to 2023. The temporal variations and type proportions are illustrated in Figures 4 and 5. Figure 4 reveals an "M"-shaped fluctuating upward trend in the coupling coordination degree between NEV industry agglomeration and new quality productive forces, characterized by "rise-decline-rise-decline," with a mean value of 0.4437, indicating a state of near-coordination. Between 2012 and 2023, the overall coupling coordination degree rose from 0.3528 to 0.4964., transitioning from mild imbalance to near imbalance. The proportions of severely imbalanced, moderately imbalanced, and mildly imbalanced provinces decreased, while the number of provinces nearing imbalance, barely coordinated, and initially coordinated increased. However, there remains considerable room for development towards high-quality coordination (Figure 5). New quality productive forces emphasize high-tech, high-efficiency, and green characteristics, with innovation at the core, directly driving breakthroughs in NEV technologies such as battery technology, intelligent driving, and energy efficiency. Market competition in the NEV sector compels technological innovation. The continuous optimization of "three-electric" technologies (battery, motor, and electronic control) and the rapid implementation of intelligent connected vehicle technologies stem from companies' competition for market share and the upgrading of user demands. This "demand-R&D-application" closed loop accelerates the transformation of technology into productive forces. Local governments, by establishing NEV industry agglomeration zones, promote collaborative innovation among upstream and downstream enterprises, forming a complete chain of "vehicle manufacturing-core components-intelligent connected technology-supporting services." This not only cuts production expenses but also speeds up technology dissemination and standardization. Furthermore, consumer demand for intelligent and green products drives automakers to accelerate technology iteration and product upgrades, creating a positive cycle between the market's demand for high-efficiency, diversified products and the supply of new quality productive forces.

Figure 4 illustrates that the temporal variations in the coupling coordination degree across the three major regions generally align with the national trend. The eastern region, leveraging its robust industrial foundation and elevated economic development, possesses inherent advantages in the advancement of the new energy vehicle (NEV) industry. These regions benefit from comprehensive industrial chains, advanced manufacturing technologies, and abundant innovation resources, providing substantial support for NEV sector development. Concurrently, a higher level of economic development translates to greater market demand and enhanced consumer purchasing power, thereby accelerating the NEV industry's expansion. The coupling coordination degree between the NEV industry's agglomeration and new - quality productive forces rose from 0.4182 in 2012 to 0.5958 in 2023, suggesting a state of just - about - coordinated development. In the central and western regions, the coupling coordination degrees climbed from 0.3063 and 0.3178 in 2012 to 0.4366 and 0.432 in 2021 respectively. They shifted from a slightly disharmonious state to one that's on the verge of disharmony. In recent years, the central and western regions have been actively addressing their shortcomings through national policy support and their rich natural and labor resources. They have been fostering NEV industry agglomeration by introducing and assimilating advanced technologies and leveraging their existing industrial base in traditional manufacturing, which has also promoted the enhancement of new quality productive forces. While the coupling coordination degree in the central and western regions shows progress, these areas continue to experience dissonance.

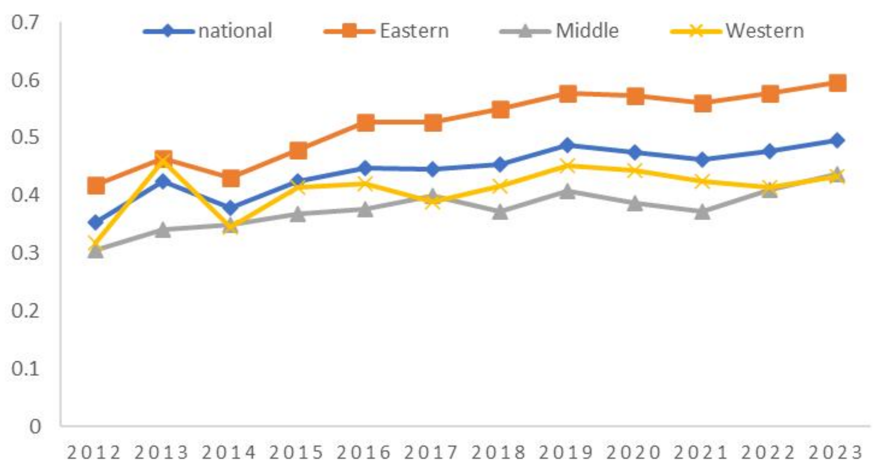


Fig.4. Temporal Variation of the Coupling Coordination Degree between the Agglomeration of New Energy Vehicle Industry and New Quality Productivity from 2012 to 2023

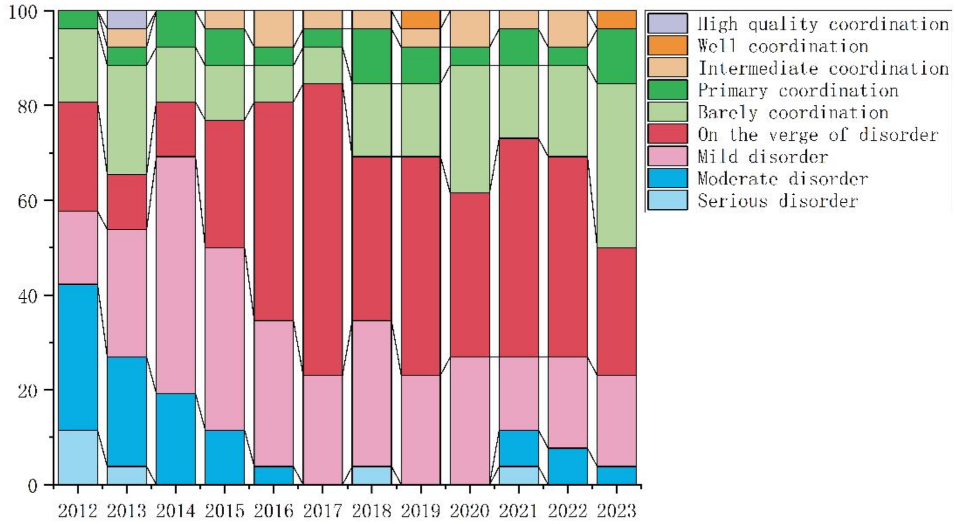


Fig.5. Temporal changes in the proportion of coupling coordination types between the aggregation of the new energy vehicle industry and new quality productive forces from 2012 to 2023

5.2.2 Spatial distribution characteristics of coupling coordination degree

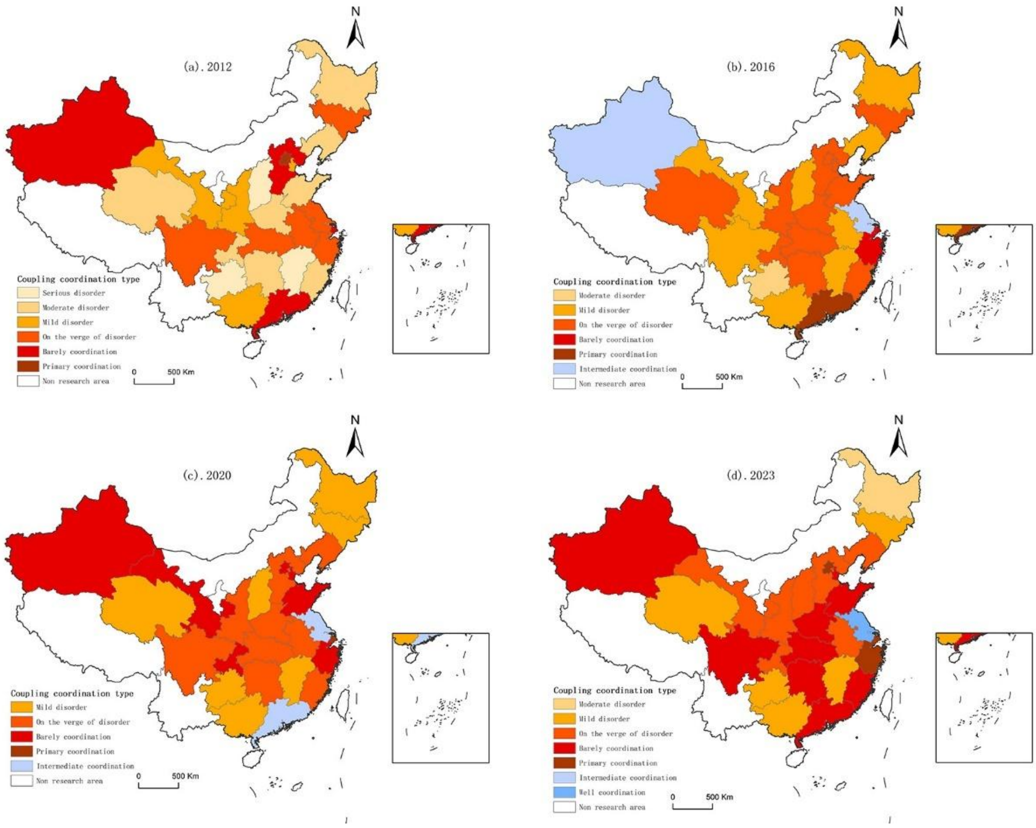
By leveraging ArcGIS software, the study maps out the synergy between the clustering of the new energy vehicle (NEV) sector and the emergence of advanced productive forces over the period spanning 2012 to 2023, as depicted in Figure 6. Back in 2012, the level of integration and coordination between these two areas was notably underwhelming, with most provinces in a moderate imbalance state, forming a contiguous distribution. Jilin, Sichuan, Hubei, Anhui, Zhejiang, and Jiangsu were on the verge of imbalance; Gansu, Shaanxi, and Guangxi were in a mild coordination state; and Shanxi, Guizhou, and Jiangxi were in a severe imbalance state. During this period, the development constraints faced by each province were complex and far-reaching. Negative factors such as institutional barriers, structural imbalances, and factor misallocation led to a slow progress in the NEV industry agglomeration and the development of new quality productive forces, resulting in a low coupling coordination degree.

By 2016, The coupling - coordination degree in each province had notably enhanced. Firstly, the area of moderate imbalance was greatly reduced, with only Guizhou remaining in a moderate imbalance state, while the area of mild imbalance expanded. Secondly, Qinghai, Shaanxi, Chongqing, Hunan, Shandong, and Fujian upgraded to a state of near imbalance; Zhejiang upgraded to a barely coordinated state; Guangdong jumped to a primary coordination state; and Jiangsu and Xinjiang jumped to an intermediate coordination state. During this time, most provinces underwent substantial shifts, suggesting that the progress of a fresh wave of industrial transformation and technological innovation spurred the ongoing growth of new -

quality productive forces. Simultaneously, the introduction of a series of low-carbon policies accelerated the development and agglomeration of the NEV industry. The NEV industry continuously promotes technological and industrial innovation, achieving a virtuous cycle by building a highly efficient and collaborative industrial system. Leveraging its promoting effect on new quality productive forces, it also expands the matching and interactive space between the two, ensuring a dynamic improvement in the coupled and coordinated development.

The provincial coupling coordination level demonstrated a significant leap in 2020, with no provinces classified as moderately imbalanced; Guangdong and Jiangsu achieved intermediate coordination. Despite some regression in a few provinces in 2023, the overall coordination level showed an upward trend, with Jiangsu Province advancing to a state of good coordination. The State Council's "Strategy for Advancing Energy-Efficient and Alternative Fuel Vehicles", released in 2012, laid a foundation for long-term development. Post-2020, local governments further refined policies, establishing cross-industry technology alliances and forming a "basic research-application transformation-industrialization" chain in collaboration with universities and research institutions to enhance the efficiency of modern quality-driven production . The market share of new energy vehicles reached 25.6% in 2022, with sales increasing by 33.5% year-on-year in 2023. This large-scale production reduced costs, creating a positive feedback loop.

Overall, the coupling coordination presents a development pattern of "East and West leading, Central region catching up." National-level advanced manufacturing clusters enhance regional competitiveness through policy support and resource integration. The eastern coastal regions focus on high-end manufacturing and intelligent connected vehicle technology, while the western regions leverage lithium resources to develop battery materials, forming a complementary relationship. The central and western regions undertake marginal industries transferred from the east, combining them with local labor advantages to create new growth poles. Although all provinces experienced significant shifts in coupling coordination, only 12 provinces achieved a state of coordination in the later stages of the study, less than half of the total research area. the advancement of new quality productive forces across various phases. In contrast, the coupling of new energy vehicle industry clusters and with emerging productive forces in other regions is hampered by uneven growth trajectories, resulting in a lack of synergy and diminished collaborative potential.



Note: This map is derived from the standard map of China's Ministry of Natural Resources. (Approval Number GS (2020) 4632) and the base map has not been modified.

Fig.6. Spatiotemporal Variations in Coupling Coordination for 2012, 2016, 2020, and 2023

5.3 Analysis of factors influencing coupling coordination

5.3.1 Selection of influencing factors

(1) Economic development level (X1): Advances in the economy amplify the spillover effects of new quality productive forces on NEV industry growth [45], strengthening the transmission efficiency of the impact mechanism, and is represented by regional per capita GDP. (2) Urbanization level (X2): Urbanization drives the flow of population, capital, and material elements, influencing the aggregation and diffusion of the NEV industry, and affecting changes in social, economic, and ecological factors, broadening the impact and radiation range of new quality productive forces on the NEV industry aggregation, and is represented by the urbanization rate. (3) Industrial agglomeration degree (X3): With the growth in the level of industrial clustering, the NEV industry can form economies of scale, further reducing costs and enhancing competitiveness. The burgeoning NEV sector is driving the evolution of advanced productive capabilities by fostering technological breakthroughs, streamlining resource distribution, and amplifying consumer demand.

This growth is mirrored in the ratio of workforce engagement relative to the administrative footprint of the industry. (4) Industrialization level (X4): The improvement of the industrialization level promotes the acceleration of technological innovation, providing more technological breakthrough opportunities for the NEV industry. The advancement of core technologies, encompassing energy storage systems, propulsion mechanisms, and smart technologies, serves as fundamental drivers for the emergence and progression of advanced productive capabilities. (5) Government intervention degree (X5): fiscal policies and regulatory measures, particularly as reflected in the proportion of public spending relative to GDP, play a crucial role in enhancing the spatial concentration of the electric vehicle sector and facilitating the diffusion of advanced productive capabilities across regions. Environmental governance mechanisms (6) Environmental regulation (X6) significantly contribute to the establishment and growth of advanced productive systems through multiple channels. These include directing industrial clustering, incentivizing corporate innovation, improving resource utilization efficiency, promoting industrial transformation and upgrading, and facilitating policy and market coordination. This research utilizes the expenditure on environmental protection relative to industrial output as a primary metric [46]. Additionally, green technology innovation (X7) plays a pivotal role in driving industrial transformation and fostering sustainable development. The level of innovation is quantified through green patent applications, reflecting the advancement of eco-friendly technologies [47].

5.3.2 Factor analysis

Employing the optimal parameter discretization (OPGD) method in R, the aforementioned influencing factors were categorized and classified, followed by the application of a geographical detector to assess their impact. Given that both the new energy vehicle (NEV) industry and the new quality productive forces have emerged and developed in recent years, their coupling coordination degree was low before 2016; thus, analyzing the influencing factors prior to this period is of limited significance. As indicated in Table 4, the influencing factors of the coupling coordination degree exhibit significant variations in their intensity of effect across different time nodes. Based on the q-value ranking, the influencing factors are classified into three categories: core influencing factors, including economic development level (X1) and industrial agglomeration (X3); secondary influencing factors, comprising urbanization level (X2), government intervention (X5), and green technology innovation (X7); and general influencing factors, encompassing industrialization level (X4) and environmental regulation (X6).

Table 4. Geographical Detector Results of Influencing Factors on Coupling Coordination Degree in 2016, 2020, and 2023

Influencing factors	2016			2020			2023		
	q	p	Prioritization	q	p	Prioritization	q	p	Prioritization
X_1	0.4763	0.0138	1	0.5277	0.0102	1	0.6976	0.0191	1
X_2	0.3069	0.5589	3	0.5106	0.000	2	0.5354	0.0268	4

X_3	0.3758	0.0266	2	0.4025	0.0118	4	0.6347	0.0150	2
X_4	0.2227	0.4441	5	0.0369	0.8279	7	0.2951	0.8918	7
X_5	0.2462	0.3990	4	0.4031	0.0144	3	0.5616	0.0242	3
X_6	0.0552	0.7663	7	0.1208	0.5407	6	0.3274	0.4442	6
X_7	0.1101	0.4050	6	0.3832	0.0197	5	0.5260	0.0235	5

(1) Regarding core influencing factors, the level of economic development (X1) exhibits strong explanatory power, with its q-value increasing significantly from 0.4763 in 2016 to 0.6976 in 2023, indicating a growing impact on the coupled and coordinated development. The dynamics of economic development play a crucial role in shaping production organization patterns, factor mobility, industrial structure, and technological advancement. These transformative effects substantially influence the synergistic relationship between NEV industrial clusters and new quality productive forces. Notably, the industrial agglomeration index (X3) demonstrates consistent growth, with its value increasing by approximately 69% from 0.3758 in 2016 to 0.6347 in 2023, reflecting its growing contribution to the integrated development of these two systems. As an emerging industry, the NEV industry has broad development prospects and huge market potential. High industrial agglomeration indicates that the region has strong strength and advantages in the NEV industry, this can draw in more enterprises and investors to set foot in the region, thus giving an extra boost to the industry's development and the region's economic expansion. The elevation of regional competitiveness serves as a solid prop for the swift growth of new high - quality productive forces.

(2) Regarding secondary influencing factors, urbanization level (X2), government intervention (X5), and green technology innovation (X7) were not significant in 2016 but became significant from 2020 to 2023, with a marked increase in their influence, indicating a gradual strengthening of their impact on the spatial differentiation of coupled and coordinated development. Initially, as urbanization progresses, the increase in residents' income and living standards provides a broad market demand and consumer base for the new energy vehicle (NEV) industry. The rapid growth of cities creates a fertile ground for universities, research centers, and businesses to work hand in hand, speeding up the process of turning technological breakthroughs into practical solutions. This synergy not only drives innovation but also lays a solid foundation for advancing high-quality productive capabilities. Secondly, government intervention, through the formulation of policy measures, guides NEV-related enterprises to form industrial clusters, this aids in cutting production costs, enhancing production efficiency, and spurring technological innovation as well as industrial upgrading. Through the implementation of strategic industrial policies and the facilitation of corporate modernization initiatives, governmental efforts have significantly propelled the advancement of the electric vehicle sector towards more sophisticated, technologically advanced, and environmentally sustainable practices. These measures have substantially enhanced the industry's competitive edge while providing robust support for the accelerated growth of advanced production capabilities. Concurrently, the progressive evolution of sustainable technological innovation has catalyzed the rapid expansion of

cutting-edge productive capacities. This development has established a mutually reinforcing relationship with the spatial concentration of electric vehicle manufacturing, creating a pattern of interdependent growth between technological advancement and industrial clustering.

This not only beefs up the overall competitiveness of the industry but also gives a shot in the arm to the sustainable development of the regional economy.

(3) Regarding general influencing factors, the explanatory power of industrialization level (X4) and environmental regulation (X6) on the coupled and coordinated development did not pass the significance test. This is because as the economy continuously develops, the regional industrialization level is rising. This universal improvement makes the differences in industrialization levels in specific industries or industrial clusters relatively small, thus diminishing its ability to elucidate the interconnected and harmonious progression. Environmental regulation may promote technological innovation by enterprises to a certain extent to adapt to stricter environmental protection requirements. However, this technological innovation may focus more on reducing pollution and improving energy efficiency and may not directly promote the coupled and coordinated development of new energy vehicle industry clusters and new quality productive forces. Even if strict environmental regulation policies are formulated, their implementation intensity and effect may vary depending on the region, which in turn leads to insignificant promotion of coupled and coordinated development.

5.3.3 Interaction detection of influencing factors

Further exploration of the interactions among X1 through X7, as depicted in the heatmap in Figure 7, reveals that the interactive effects among the influencing factors of the coupling coordination degree predominantly exhibit a two-factor enhancement relationship. This suggests that the spatiotemporal differentiation pattern of the coupling coordination degree is primarily shaped by the combined influence of multiple factors, rather than a linear impact from a single factor. Moreover, the close interrelationships among these influencing factors indicate that they are not independent of each other.

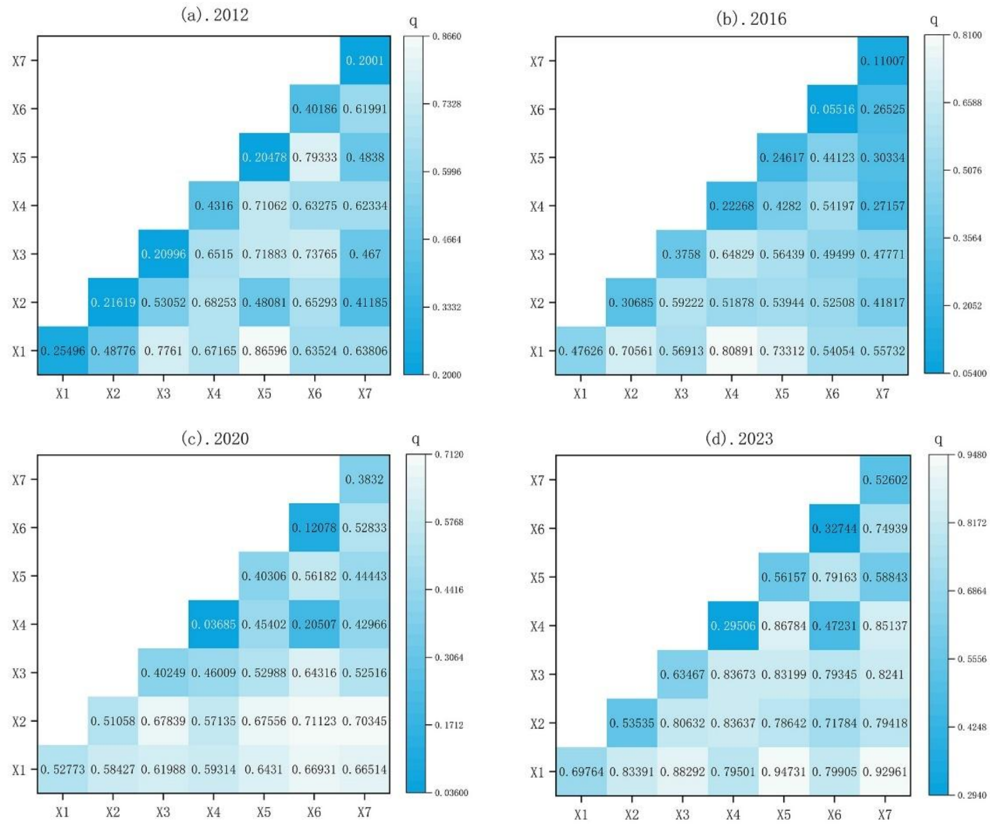


Fig.7. Interaction Detection Results of Influencing Factors on Coupling Coordination Degree in 2016, 2020, and 2023

From a temporal perspective, the explanatory power of each dual-factor interaction on coupling coordination degree varies, exhibiting fluctuating trends over time. Specifically, in 2012, the interaction between economic development level (X1) and government intervention (X5) significantly promoted the coupling coordination degree, with the explanatory power of X1 ∩ X5 exceeding 0.8. This indicates that the combined effect of economic development and government intervention played a dominant role in the spatial differentiation of the coupling coordination degree in 2012. The analysis reveals distinct temporal patterns in factor interactions. In 2016, the synergistic effect between economic development (X1) and industrialization (X4) emerged as the primary driver of spatial variations in coupling coordination. By 2020, while all two-factor interactions showed enhanced explanatory power, none demonstrated particularly dominant influence. A notable shift occurred in 2023, where seven key factor pairs (X1∩X2, X1∩X3, X1∩X7, X2∩X3, X3∩X4, X3∩X5, and X4∩X5) exhibited substantial explanatory power, each exceeding 0.8 and marking a significant improvement from earlier periods. These findings align with the single-factor detection results, confirming the growing importance of comprehensive factor interactions in shaping coupling coordination patterns. The dominant factors of coupling coordination degree are economic development level and industrial agglomeration, followed by urbanization level, government intervention, and green technology innovation. Industrialization level and environmental regulation need to be combined with other factors to affect the coupling coordination degree.

6. Conclusions and discussion

6.1 Research findings

The analysis reveals several key findings regarding the development of China's NEV industry and new quality productive forces. Initially, the study period witnessed most provinces maintaining a low to moderate level of NEV industry concentration, though a positive growth trajectory was evident across regions. Regional disparities in industrial agglomeration gradually diminished, with a noticeable spatial gradient from the eastern and western areas towards the central region. Concurrently, the evolution of new quality productive forces displayed vigorous expansion, accompanied by widening regional discrepancies. Geographically, a distinct east-to-west declining pattern emerged, with the eastern provinces demonstrating pronounced economic advantages. Regarding the relationship between these two systems, their interactive coordination followed an "M"-shaped developmental curve, progressing from initial mild imbalance to approaching equilibrium, though substantial improvements are still required to achieve optimal coordination. This pattern was consistently observed across the eastern, central, and western regions, aligning with national trends. The spatial distribution of coordination development indicated that while the eastern and western areas maintained leading positions, the central region showed signs of accelerated convergence.From a factor analysis perspective, economic development and industrial concentration emerged as primary determinants of system coordination. Urbanization progress, governmental involvement, and advancements in green technology constituted secondary influences. Interestingly, industrialization intensity and environmental regulatory measures showed limited impact on coordination development. Notably, the combined effect of multiple factors demonstrated greater explanatory power than individual elements alone in understanding coordination dynamics.

6.2 Policy recommendations

Firstly, we must intensify technological research and innovation to foster industrial agglomeration. This involves increasing investment in the research and development of core technologies for new energy vehicles, such as batteries, electric motors, and electronic control systems. By attracting and cultivating high-end technical talent and promoting collaboration between enterprises, universities, and research institutions, we can overcome technological bottlenecks and further advance the development of scientific and technological productivity. Simultaneously, it is crucial to formulate and refine the technical standards system for new energy vehicles to ensure product quality and safety, thereby promoting the standardized and regulated development of the new energy vehicle industry. Either by making use of existing industrial parks or by setting up new industrial clusters, we ought to direct the upstream and downstream enterprises in the new - energy vehicle industry chain to gather. This will require improving the infrastructure and public service systems within these industrial agglomeration areas to provide convenient and efficient services for the enterprises that establish operations there. Secondly, we must improve infrastructure construction and supporting services while strengthening policy support and market guidance. This includes integrating the construction of charging facilities into the development plans for new energy vehicles and urban development plans, accelerating the layout and construction of charging stations, and promoting the establishment of a battery recycling and disposal system for new energy vehicles. This will ensure the standardized recycling and safe disposal of waste batteries, thereby promoting the development of digital productivity. We should provide preferential policies, such as tax reductions, to new energy vehicle manufacturers and offer purchase subsidies to consumers to increase their willingness to buy, thereby expanding the new energy vehicle market. To ensure the sustainable growth of the new energy vehicle (NEV) sector, several strategic measures should be implemented. First, enhancing the regulatory framework for the NEV market is crucial. This involves intensifying oversight of product quality and safety standards while advancing the development and refinement of pertinent legal statutes to safeguard the industry's robust growth. Additionally, fostering the intelligent and environmentally friendly evolution of the NEV sector is imperative. Enterprises should be encouraged to integrate cutting-edge technologies like big data, cloud computing, and artificial intelligence to facilitate the industry's digital transformation. These technological advancements can significantly boost production efficiency, lower operational costs, and elevate both product quality and service standards. Promoting eco-friendly production techniques and sustainable consumption practices is equally important to expedite the industry's shift towards low-carbon operations. It is also vital to implement rigorous monitoring and evaluation systems for carbon emissions throughout the lifecycle of NEVs. Such measures will not only support the industry's sustainable development but also contribute to the advancement of green productivity.

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