Comprehensive analysis and forecast of Chinese NEV industry development from 2012 to 2025.

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Abstract

More and more countries are turning to renewable energy to reduce their dependence on traditional fossil fuels as climate change increases. Electric cars have also become a new trend in energy transformation that is strongly supported by many governments. To answer the research questions, we employ a literature review approach and the TOPSIS method based on entropy. This paper begins with a systematic review of the relevant literature to identify key characteristics of the Chinese market for new energy vehicles (NEVs), providing clear theoretical support. Then, the author chose data from 2012 through 2022 as the primary research object for analysis and chose a total of five first-level indicators and fifteen second-level indicators as the main observation indicators. Using the TOPSIS method, the authors evaluate the entire NEV market in China and make predictions for three years into the future. Based on the results, the NEV composite score ranking is continuing to increase, which indicates a very promising future. However, when a black swan event occurs, such as a car safety incident, it can seriously impede its development. One of the most significant contributions is that based on the evaluation scores from the indicators, the positive and negative future state of NEV is indicated. Since the data has not yet been updated to 2023, it is necessary to continue to verify the new data to make up for the lack of data.
Keywords: Entropy-based TOPSIS, New Energy Vehicle, Energy Transformation, Five-Year Plan, Black Swan Event.
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INTRODUCTION

With the intensification of climate change and the increasing demand for energy supply security, more and more countries are turning to renewable energy to reduce their dependence on traditional fossil fuels. The use of electric cars to replace fuel vehicles has also become a new energy transformation trend strongly supported by many governments. Under the trend of global low-carbon development, countries have regarded promoting the development of new energy vehicles as an important measure to reduce carbon emissions. Since the first five-year plan in 1991, the Chinese government has started to develop the new energy vehicle industry, and now it has achieved large-scale results. This paper takes China's NEV (New Energy Vehicle) industry as the main research object to explore the development forecast of China's new energy vehicles in the next five years.

When we reviewed the literature about the policies, we found that in the research on new energy vehicles, the Chinese government has been promulgating a series of policies to support the development of new energy vehicles from 1991 to 2025, but how effective these policies are, and whether they can achieve the policy goals needs to be evaluated and given feedback. Most of the research conducted was using context analysis as a base to give a forecast of NEV performance. Only a few researchers were using quantitative methods to analyze the relevant topic, but not focusing on the policy. The Entropy-based TOPSIS method is rarely used in current research. This method can objectively reflect the relationship between indicators and results and is a very important method for macroeconomic research and forecasting.

The research questions in this paper are as follows:

1. How is China's new energy vehicle industry developing currently?
2. What has already been achieved in China NEV?
3. What future are the visions for China’s NEV development in the next 5 years under the current political situation?

This paper adopts a literature review approach and the Entropy-based TOPSIS method to conduct research into the above-mentioned questions. First, the authors systematically reviewed the relevant literature to identify the defining characteristics of the new energy vehicle (NEV) industry development for China, providing clear theoretical support for the paper. The author selected five first-level indicators and fifteen second-level indicators as the main observation indicators and selected the data from 2012 to 2022 as the main research object for analysis. Then, the authors use the Entropy-based TOPSIS method to examine the comprehensive evaluation of China’s NEV industry and give future predictions for three years.

In the analysis part, we unfolded alternative futures: the expected and preferred future, as well as a wild card future. Although the current trend of new energy vehicles is good, future development will be affected by unexpected events. Therefore, based on the ranking of the comprehensive competitiveness of new energy vehicles and the analysis of the internal and external environment of electric vehicles, we outline the favorable and unfavorable factors and put forward targeted opinions.

1.1. LITERATURE REVIEW

Energy Development Trends

With the intensification of climate change and the increasing demand for energy supply security, more and more countries are turning to renewable energy to reduce their dependence on traditional fossil fuels.

New energy: Research has found that solar and wind energy are among the most mature and widely used, however, we have unfolded alternative futures: the expected and preferred one as well as a wild card future. Although the current trend of new energy vehicles is good, future development will be affected by unexpected events. The installed capacity of wind and solar photovoltaics is expected to surpass natural gas in 2023 and coal in 2024. (IEA, 2020) By 2025, solar photovoltaics alone will account for 60% of all new renewable energy capacity, while wind energy will account for an additional 30%. Driven by further cost reductions, renewable energy has become the preferred technology, and by 2040, due to cost reductions and government support policies, renewable energy will account for nearly two-thirds of global new capacity. This is changing the global electricity structure, and by 2040, the share of renewable energy in power generation will rise from the current 25% to over 40%. (IEA, 2018)

However, we must acknowledge that although the application of renewable energy is expanding, traditional energy is still essential in some areas. For example, the transportation and industrial sectors in some countries rely on traditional energy such as oil and natural gas, and in some regions, such as the African continent, although there are abundant solar and wind resources, the trend towards the transformation to renewable energy is not obvious due to the lack of infrastructure and funding. (IRENA, 2021)

Energy transformation: According to the Global Commission on the Geopolitics of Energy Transformation and Van de Graaf (2019), three primary aspects underpin energy transformation: energy efficiency, the growth of renewables, and electrification. The application of electricity is considered an essential aspect of the development of new energy, as many new energy technologies involve the generation, transmission, and storage of electricity. Renewable energy sources, such as solar, wind, and hydropower, require conversion to electricity for use in households and industries. The development of new energy technologies has also driven the transformation of the electricity system, from centralized energy production and transmission to decentralized energy production and smart grid-based energy transmission (Biegańska, 2022). The integration of new energy technologies with electricity has also brought environmental protection and emission reduction benefits. The use of renewable energy and electric vehicles can reduce environmental impacts, lower greenhouse gas emissions, and achieve a low-carbon economy. For example, the European Union aims to increase the share of renewable energy in the electricity supply to 50% by 2030 and achieve a 100% renewable energy supply by 2050 (European Commission, 2022).

NEV industry: The use of electric cars to replace fuel vehicles has also become a new energy transformation trend strongly supported by many governments: the Netherlands (Rishi Iyengar. 2016) and Norway (Jess Staufenberg, 2016) plan to ban the sale of fuel vehicles from 2025, Britain (The Guardian, (2017) and France (The Guardian, (2017) the two countries plan to ban the sale of fuel vehicles in 2040. “EU Approves Ban on Sales of Gas-Powered Cars by 2035” (European Parliament, 2022). In 2017, the Ministry of Industry and Information Technology of China stated that it had initiated relevant research on formulating a timetable for the cessation of production and sales of traditional energy vehicles (CNBC, 2017). In January 2019, China's Hainan Province announced that it will gradually ban the sale of fuel vehicles starting from March 1, 2019, and accelerate the construction of supporting infrastructure such as charging piles and charging facilities (Jessie Yeung, Shawn Deng, 2022).

Under the trend of global low-carbon development, countries have regarded promoting the development of new energy vehicles as an important measure to reduce carbon emissions. As the world's factory, China's new energy vehicle market will usher in a broader space for development.

Intelligent and new energy vehicles are challenging the traditional automotive industry.

With the worsening of global climate change and environmental pollution, the international community has a growing demand for sustainable development. As mentioned earlier, the transition from traditional energy to new energy is the main trend of sustainable development, and automobiles, as the world's largest energy consumer and source of carbon dioxide emissions, are a key target of attention. Taking Europe as an example, according to a report from the European Environment Agency, transportation was responsible for about a quarter of the EU's total CO2 emissions in 2019, of which 71.7% came from road transportation (European Parliament, 2019). Currently, the automotive industry has formed two main camps: traditional automobile manufacturers and new energy-intelligent automobile manufacturers, and their products have undergone essential differences. Traditional automobile manufacturers have long focused on producing mechanical means of transportation, while the other camp has launched intelligent electric vehicles. The application of autonomous driving, artificial intelligence, and internet technology has made cars smarter, safer, and more comfortable, thereby further enhancing their competitiveness (Biswas, A., & Wang, H.-C., 2023). The emergence of electric and new energy vehicles has made the automotive industry shift towards a more environmentally friendly and sustainable direction, while also promoting the transformation of the energy and automotive supply chains. With the promotion of concepts such as reducing carbon emissions and sustainable development, intelligent electric vehicles have become an industry consensus, and traditional automobile manufacturers have begun to actively transform and promote their products towards intelligent electric vehicles (Cao, J., Chen, X., Qiu, R., & Hou, S., 2021).

In addition to the changes brought about by the automotive industry itself, government and consumer guidance is also one of the reasons for the development of smart and new energy vehicles. Governments around the world have successively introduced subsidy policies and tax incentives to promote the popularization of new energy and smart vehicles, which has promoted the market penetration of these vehicles (IEA, 2021). With the acceleration of urbanization and digitization, people's requirements for travel efficiency and comfort are increasing, which has also promoted the market demand for smart and new energy vehicles (Sanguesa, J. A., Torres-Sanz, V., Garrido, P., Martinez, F. J., & Marquez-Barja, J. M., 2021). In addition, the popularization of smart and new energy vehicles will have many positive impacts on society (Lugano, G., 2017). For example, the application of autonomous driving technology will increase the automation level of the taxi and logistics industries, thereby reducing labor costs and increasing efficiency; and the popularity of new energy vehicles will also lead to a decrease in sales of traditional fuel vehicles. The popularity of smart and new energy vehicles will also bring new market opportunities. For example, the recycling and utilization of new energy vehicle batteries and the construction of electric vehicle charging facilities will become new industries and business opportunities (Alexander. T, Georg. B, Dale. H, 2023).

China's policy guidance toward new energy vehicles

The development of China's energy vehicle industry and market cannot be separated from policy guidance. During the 8th Five-Year Plan period (1991-1995), the government listed electric vehicles as a technology research and development project (State Council General Office,1991). During the 11th Five-Year Plan period (2006-2010), the government gradually established a research and development pattern based on three main vehicle technologies: fuel cells, hybrid power, and pure electric power, as well as three key technologies: multi-energy powertrain systems, driving motors, and power batteries (State Council General Office,2006). During the 12th Five-Year Plan period (2011-2015), China issued many measures, but mainly focused on the technological and market development of new energy vehicles. More policies were introduced to encourage the development of the electric vehicle industry, such as incentives and exemptions, and some management systems. Subsequently, with the global development of technology and industrial innovation, China gradually identified electric vehicles as a key development direction. In June 2012, the State Council issued the "Energy-saving and New Energy Vehicle Industry Development Plan (2012-2020)," which further clarified the direction of pure electric drive as the development of new energy vehicles and the transformation of the automobile industry (State Council General Office,2012.

During the 13th Five-Year Plan period (2016-2020), China proposed three main development directions: the development of green low-carbon technology, the environmental protection and resource recycling industry system, and new energy vehicles. The policy not only covered new energy vehicles themselves but also promoted related industries and sustainable development (State Council General Office,2016). During the 14th Five-Year Plan period (2021-2025), in November 2020, the State Council issued the "New Energy Vehicle Industry Development Plan (2021-2035)," which is a second-level plan development of the new energy vehicle industry based on the existing development achievements since the 2012 new energy vehicle development plan (State Council General Office, 2012). This plan covers more technological innovation, industrial integration, industrial ecology, and infrastructure aspects.

1. **Table The Development Goals and Important Steps in Three Five-Year Plans**

	Development Goals	Important steps
12TH Five-Year Plan (2011-2015)	• *"Significant progress has been made in new energy vehicle power batteries, motors, and electronic control technologies. The specific energy of power battery modules has reached more than 150 Wh/kg, and the power density of electric drive systems has reached more than 2.5 kW/kg."* • *"The cumulative production and sales of pure electric vehicles and plug-in hybrid electric vehicles will strive to reach 500,000 units."* • *"Preliminary formation of a charging facility system and a new energy vehicle business operation model that are compatible with the market size."*	• *"Improve fiscal and tax incentive policies to encourage the consumption and use of new energy vehicles."* • *"Establish a management system for power battery recycling and cascade utilization."*
13TH Five-Year Plan (2016-2020)	• *"Focus on the innovation and application of green and low-carbon technologies, guide green consumption and promote green products."* • *"Significantly increase the proportion of new energy vehicles and new energy applications, and comprehensively promote the construction of high-efficiency energy-saving, advanced environmental protection and resource recycling industrial systems."* • *"Promote green and low-carbon industries such as new energy vehicles, new energy, energy conservation, and environmental protection to become pillar industries. By 2020, the output value will reach more than 10 trillion yuan."*	• *"Realize large-scale application of new energy vehicles, new energy vehicle power battery upgrade project."* • *"Promote the development of the new energy industry and develop projects with a high proportion of new energy."* • *"Vigorously develop high-efficiency and energy-saving industries, energy-saving technology, and equipment development projects."* • *"Accelerate the development of advanced environmental protection industries, green and low-carbon technology comprehensive innovation demonstration projects."*

14TH Five-Year Plan (2021-2025)	• *"The competitiveness of the new energy vehicle market has been significantly enhanced, major breakthroughs have been made in key technologies such as power batteries, drive motors, and vehicle operating systems, and the safety level has been comprehensively improved."* • *"The average power consumption of new pure electric passenger cars has dropped to 12.0 kWh/100 km, and the sales of new energy vehicles have reached about 20% of the total sales of new cars."* • *"The commercial application of highly autonomous vehicles in limited areas and specific scenarios has significantly improved the convenience of charging and swapping services."*	• *"Improve technological innovation capabilities, new energy vehicle core technology research projects."* • *"Build a new industrial ecology, build an eco-system for vehicle operating systems, and build an efficient recycling system for power batteries."* • *"Promoting industrial integration and development, smart city new energy vehicle application demonstration action."* • *"Improve the infrastructure system and build an intelligent infrastructure service platform."*

Source: Data is adopted from State Council General Office. (2012). Notice on Printing and Distributing the Development Plan for Energy Saving and New Energy Automobile Industry (2012-2020). Retrieved from http://www.gov.cn/zwgk/2012-07/09/content_2179032.htm; State Council General Office. (2021). Notice on the Issuance of the Development Plan for the New Energy Vehicle Industry (2021-2035). Retrieved from http://www.gov.cn/zhengce/content/2020-11/02/content_5556716.htm; National Development and Reform Commission. (2011). Twelfth Five-Year Plan for National Economic and Social Development of the People's Republic of China (2011-2015). http://www.gov.cn/zhengce/content/2012-07/20/content_3623.htm; National Development and Reform Commission. (2016). Thirteenth Five-Year Plan for Economic and Social Development of the People's Republic of China (2016-2020). http://www.gov.cn/zhengce/content/2016-12/19/content_5150090.htm;National Development and Reform Commission. (2021). Outline of the Fourteenth Five-Year Plan for Economic and Social Development and Long-Range Objectives Through the Year 2035. http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm

From the table, we can see some of the same important factors in different periods of time: technology improvement, marketing exploration, production sustainability, infrastructure, and service preparation. The steps were a step-by-step refinement along with China's economic development. The development of these strategies and measures has been very effective. According to the "Global Electric Vehicle Outlook 2022" published by the International Energy Agency, as of 2021, China has built approximately 677,000 slow charging stations in the public sector, accounting for 56% of the global total, and approximately 470,000 fast charging stations, accounting for 83% of the global total. China's construction of charging infrastructure has kept pace with the growth in sales of new energy vehicles, essentially meeting the needs of the rapid development of new energy vehicles (IEA, 2022).

1.2. METHODOLOGY

1.2.1. RESEARCH QUESTIONS & METHODS

The TOPSIS method and a literature review strategy are used in this work to answer the following research issues. To establish the defining characteristics of the new energy vehicle (NEV) industry development for China and to provide a strong theoretical foundation for the study, the authors first conduct a comprehensive evaluation of the pertinent literature. The authors then examine a thorough assessment of China's NEV business and provide future projections for the next three years using the Entropy-based TOPSIS technique. The research questions in this paper are as follows:

How is China's new energy vehicle industry currently developing?

From the previous literature review, we can see that new energy vehicles have become an industry consensus, and traditional automobile manufacturers in China are actively transforming and promoting their products towards intelligent electric vehicles. By examining the current state of the industry, including production, sales, market share, and technological advancements, this question aims to understand the growth and progress of China's new energy vehicle industry.

What financial policies has the Chinese government implemented to promote the industry, and have they had a positive impact?

This question can be derived from the mention of governments introducing subsidy policies and tax incentives to promote the popularization of new energy and smart vehicles. By investigating the specific financial policies implemented by the Chinese government to support the new energy vehicle industry, as well as their effects on market penetration, sales, and consumer adoption, this question aims to evaluate the impact of these policies on the industry's development.

What are the author's predictions for the industry's future development in the next three years?

This question can be derived from the information stating that the author expects further development and changes in the industry. By analyzing the existing literature and opinions of the author, this question aims to explore the anticipated trends, challenges, and opportunities in the new energy vehicle industry in China over the next three years. It may encompass aspects such as market growth, technology advancements, policy changes, consumer preferences, and potential impacts on the energy and automotive supply chains.

The authors followed the principles of systematic, scientific, and operational approaches to select the indicators for this paper, totaling 15. From the perspective of the industry value chain, the authors established an evaluation system consisting of five primary indicators: environmental competitiveness, research and development competitiveness, production competitiveness, market competitiveness, and service competitiveness, along with 15 related secondary indicators, as shown in Table 2. All initial data were collected by authors from the official website of the General Administration of Customs of the People's Republic of China (http://english.customs.gov.cn/) and China Association of Automobile Manufacturers (CAAM)(http://en.caam.org.cn/).

2. Table Indicator system

Primary Indicators	Secondary Indicators	Code
Environmental Competitiveness	Gross Domestic Product (100 million yuan)	X1
	Per Capita Disposable Income Nationwide(yuan)	X2
	Car Sales in China (10000 units)	X3
R&D Competitiveness	Full-time Equivalent of R&D Personnel (10,000 person-year)	X4
	Expenditure on R&D (CNY 100 million)	X5
	R&D expenditure as a percentage of GDP (%)	X6
	Number of Patents Application Accepted(item)	X7
Production Competitiveness	New energy vehicle production volume (10,000 units)	X8
	New energy vehicle sales volume (10,000 units)	X9
	Number of new energy vehicle-related companies (10,000)	X10
Market Competitiveness	China market share (IMS) (%)	X11
	New energy vehicle export volume (10,000 units)	X12
	New energy vehicle penetration rate (%)	X13
Service Competitiveness	Number of charging infrastructure holdings	X14
	Number of registered power battery recycling companies	X15

Source: All initial data were collected by authors from the official website of the General Administration of Customs of the People's Republic of China (http://english.customs.gov.cn/) and China Association of Automobile Manufacturers (CAAM)(http://en.caam.org.cn/).

These research questions address different aspects of the new energy vehicle industry in China, including its status, government support, and future prospects. By exploring these questions, researchers can gain insights into the industry's dynamics, challenges, and potential avenues for further development.

The selection of indicators for quantitative research in this study was based on the logic of capturing key aspects related to the development and performance of China's new energy vehicle industry. The primary categories were established to provide a comprehensive understanding of various dimensions and factors influencing the industry. To assess the overall economic impact, Gross Domestic Product (GDP) was chosen as an indicator, measured in 100 million yuan. It reflects the financial value of all goods and services produced within a country and provides insights into the industry's contribution to the national economy.

Per Capita Disposable Income Nationwide, measured in yuan, was selected to examine the purchasing power and affordability of individuals across the country. This indicator helps evaluate the potential demand for new energy vehicles among the population. Car Sales in China, measured in 10,000 units, serves as a crucial metric to assess the overall sales performance and market demand for both traditional and new energy vehicles.

The Full-time Equivalent of R&D Personnel, measured in 10,000 person-years, and Expenditure on R&D, measured in CNY 100 million, were chosen to gauge the investment in research and development activities within the industry. These indicators reflect the industry's commitment to innovation and technological advancements. R&D expenditure as a percentage of GDP (%), an additional indicator, allows for a comparison of the industry's research and development investment relative to the overall economic output. It offers insights into the level of emphasis placed on innovation within the sector. The Number of Patents Application Accepted, measured in items, provides an indication of the industry's intellectual property creation and technological progress. It reflects the innovative capabilities and potential for future growth within the industry.

To specifically focus on the new energy vehicle segment, indicators such as New Energy Vehicle Production Volume and New Energy Vehicle Sales Volume, both measured in 10,000 units, were included to track the manufacturing and sales performance of these vehicles. These indicators help monitor the growth and market acceptance of new energy vehicles. The Number of New Energy Vehicle-related Companies, measured in 10,000, provides insights into the number of businesses operating within the sector, reflecting the level of industry competition and market dynamics.

China Market Share (IMS) (%), an indicator used to evaluate the market dominance of new energy vehicles in China, offers a perspective on the relative market position and competitiveness of these vehicles. New Energy Vehicle Export Volume, measured in 10,000 units, allows for an assessment of the international market demand and export performance of Chinese new energy vehicles. The New Energy Vehicle Penetration Rate (%), another indicator, examines the proportion of new energy vehicles in the overall vehicle market, indicating the level of market adoption and the penetration of these vehicles.

The Number of Charging Infrastructure Holdings indicates the availability and development of charging infrastructure, an essential factor influencing the adoption and usability of new energy vehicles. Lastly, the Number of Registered Power Battery Recycling Companies was included to gauge the emphasis on sustainable practices within the industry, reflecting efforts towards responsible and environmentally friendly disposal and recycling of power batteries.

These selected indicators collectively provide a comprehensive overview of the new energy vehicle industry in China, covering economic, market, innovation, and sustainability aspects. By analyzing these indicators, the study aims to gain insights into the industry's performance, trends, and potential for future development.

1.2.2. ENTROPY-BASED TOPSIS METHOD

The main idea is to determine the weight of each indicator by the entropy method and then use the TOPSIS method to make a comprehensive evaluation. This method uses the objective weighting idea of the entropy method and the TOPSIS method to approximate the ideal solution, which can effectively eliminate the influence of human subjective factors. It is a decision-making technique used in multi-criteria decision analysis. TOPSIS is designed to determine the best alternative among a set of options based on a predetermined set of criteria. It takes into account both the positive and negative aspects of each alternative and ranks them accordingly. The primary process of the model is shown below.

First, the authors use the collected data to build the original matrix. The data is relative to the development of the NEV industry in China from 2012 to 2022. Let a total of n years, and m indicators be selected for each year to build the original matrix.

$$X=\left(x_{ij}\right)nm(i=1,2,3,\ldots,n;j=1,2,3,\ldots,m) \quad (1)$$

The selected indicators were normalized to initially eliminate differences caused by the dimensions of the variables. As all the data selected in this paper are positively oriented indicators, it is unnecessary for either positive or reverse transformation. To clarify, indicators are typically classified as either positive or negative, depending on the direction of the desired outcome or the aspect being measured. For example, a low unemployment rate is considered positive, as it indicates a lower level of unemployment and is generally seen as a favorable outcome. In contrast, a high poverty rate would be considered negative, as it represents a higher prevalence of poverty and is considered undesirable. Therefore, this study adopts the "normalization by mean" method for data processing.

$$Y_{ij}=X/Mean \quad (2)$$

The authors determine the weights for the values of the j_{th} indicator of the i_{th} object followed by the function below.

$$P_{ij}=\frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}} \quad (3)$$

The authors determine the entropy value of the j_{th} indicator followed by the function below, In information theory, entropy refers to the amount of uncertainty or randomness present in a set of data. The entropy value quantifies the average amount of information contained in a random variable or dataset. It measures the level of unpredictability or disorder in the data. A higher entropy value indicates higher uncertainty or a larger number of possible outcomes, while a lower entropy value suggests greater predictability or a smaller number of potential outcomes.

$$e_j=-\frac{1}{\ln(n)}*\sum_{i=1}^{n} P_{ij}\ln(P_{ij}),(i=1,\ldots,n;j=1,\ldots,m) \quad (4)$$

Calculating the information utility value d, Information utility refers to the value or usefulness of the information in aiding decision-making or reducing uncertainty. The information utility value is a measure of how valuable or beneficial certain information is in providing insights, making informed decisions, or reducing the level of uncertainty. It assesses the impact or effectiveness of information in achieving specific goals or objectives. The information utility value can vary depending on the context and the specific decision or problem being addressed. Higher information utility values indicate that the information is more valuable and contributes significantly to the decision-making process.

$$d_j=1-e_j \quad (5)$$

The authors determined the entropy weight of the j_{th} indicator followed by the function below:

$$w_j=\frac{(1-e_j)}{\sum_{j=1}^{m}(1-e_j)},\ 0\leq w_j\leq 1, \sum_{i=1}^{m} w_j=1 \quad (6)$$

Thus, computing scores for individual indicators and overall performance levels.

$$S_{ij}=w_i\times x_{ij},\ S_i=\sum\nolimits_{j}^{n} S_{ij} \quad (7)$$

Then using the TOPSIS method to conduct a comprehensive evaluation. Assuming there are m_{th} object, n_{th} indicators, then the matrix $X=(x_{ij})_{mn}$, Normalize the decision matrix

$$Y=(y_{ij})_{mn}. \quad (8)$$

next, the weighted and normalized decision matrix V should be computed:

$$V=(v_{ij})_{m\times n}=(w_j y_{ij})_{m\times n} \quad (9)$$

First, using the weighted and normalized decision matrix, calculate the positive and negative ideal solutions. Then, note that in the TOPSIS method, monotonicity is usually required. The formulas for positive and negative ideal solutions are as follows:

positive ideal solution: $X^{+}=(v_1^{+},v_2^{+},\ldots,v_n^{+}),\ v_j^{+}=max_{1\leq i\leq m}v_{ij}$ (10)

negative ideal solution: $X^- = \left(v_1^-, v_2^-, \ldots, v_n^- \right)$, $v_j^- = min_{1 \le i \le m} v_{ij}$ (11)

To calculate the distances between each object and its positive and negative ideal solutions, usually, the Euclidean distance is used:

$$S_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+ \right)^2},\ i = 1, 2, \ldots, m$$
$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^- \right)^2},\ i = 1, 2, \ldots, m \quad (12)$$

One important step in the TOPSIS method is computing the relative closeness of each object, which is typically done by comparing the distances between each object and its positive and negative ideal solutions:

$$C_i^+ = S_i^- / \left(S_i^+ + S_i^- \right) \quad (13)$$

The relative closeness measure C_i^+ of each object is its comprehensive score index, with a C_i^+ higher indicating a better object.

1.3. RESULTS ANALYSIS

1.3.1. Analysis between 2012 - 2022

Based on constructing the evaluation index system and measurement model for the development level of China's NEV industry. The information entropy (e_j), weight (w_j), and utility value (d_j) of each evaluation index in China are derived according to the above formula, as shown in Table 2 below. Based on this result, the X15 (Number of registered power battery recycling companies) is the most heavily weighted among the 15 indicators. The second highest weighted indicator is X14 (number of charging infrastructure holdings). Therefore, service competitiveness accounts for a larger share than the other three primary indicators. In contrast, the X6 (R&D expenditure as a percentage of GDP (%)) has the smallest weighting.

3. Table The results of the calculation of various indicators

Index	e_j	d_j	w_j
X1	0.9865	0.0135	0.44
X2	0.987	0.013	0.42
X3	0.9975	0.0025	0.08
X4	0.9524	0.0476	1.55
X5	0.976	0.024	0.78
X6	0.9984	0.0016	0.05
X7	0.9423	0.0577	1.88
X8	0.7025	0.2975	9.68
X9	0.7005	0.2995	9.75
X10	0.5806	0.4194	13.65
X11	0.7075	0.2925	9.52
X12	0.7025	0.2975	9.68
X13	0.6908	0.3092	10.06
X14	0.5874	0.4126	13.43
X15	0.415	0.585	19.03

Source: All initial data were collected by authors from the official website of the General Administration of Customs of the People's Republic of China (http://english.customs.gov.cn/) and China Association of Automobile Manufacturers (CAAM)(http://en.caam.org.cn/).

Additionally, based on the TOPSIS evaluation model above for the development level of China's NEV industry. The data results of positive (S_i^+), negative (S_i^-)ideal solutions, the relative closeness of each object (C_i^+) and its rank are shown in Table 3 below.

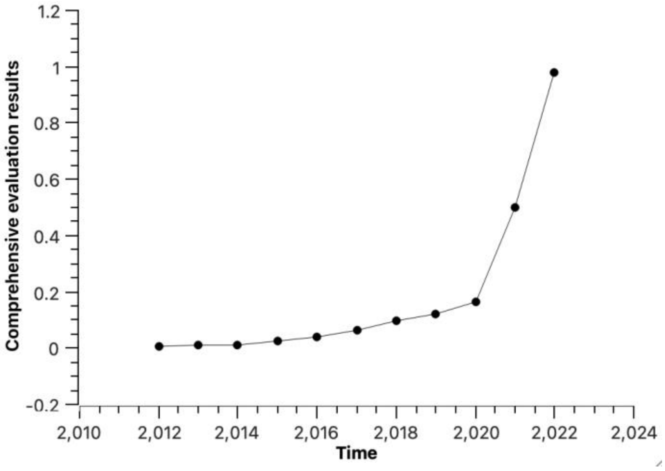
4. Table Comprehensive Evaluation Results of Chinese NEV industry's development level

Time	S_i^+	S_i^-	C_i^+	ScoreC_i^+
2012	1.947	0.016	0.008	11
2013	1.944	0.019	0.010	10
2014	1.936	0.023	0.012	9
2015	1.914	0.053	0.027	8
2016	1.891	0.078	0.040	7
2017	1.858	0.127	0.064	6
2018	1.811	0.194	0.097	5
2019	1.779	0.245	0.121	4
2020	1.670	0.327	0.164	3
2021	1.001	1.004	0.501	2
2022	0.038	1.947	0.981	1

Source: All initial data were collected by authors from the official website of the General Administration of Customs of the People's Republic of China (http://english.customs.gov.cn/) and China Association of Automobile Manufacturers (CAAM)(http://en.caam.org.cn/).

In order to visualize the changes in the development of the Chinese NEV industry development level between 2012 and 2022, the authors have made a visual chart based on the above data, as shown in Figure 1 below. From the figure, the level of NEV industry development in China has gradually increased from 2012 to 2022, showing a good growth trend of continuous strengthening. The speed of NEV industry development in China accelerated significantly after 2020.

1. Figure Comprehensive Evaluation Results of NEV Industry Development Level in China from 2012 to 2022



Source: All initial data were collected by authors from the official website of the General Administration of Customs of the People's Republic of China (http://english.customs.gov.cn/) and China Association of Automobile Manufacturers (CAAM)(http://en.caam.org.cn/).

1.3.2. FUTURE CONSIDERATIONS

Based on the previous calculations, the authors forecast the industry trends in China over the next three years. The authors have used compound annual growth rates in their forecasts. The authors have employed compound annual growth rates (CAGR) in their forecasts to comprehensively depict and interpret growth trends within a specific time period. By utilizing CAGR, they ensure consistent and reliable measurement and evaluation of growth rates, especially in cases where significant fluctuations or variations in the data exist.

CAGR offers several advantages that make it a commonly used approach in forecasting. Firstly, CAGR provides a smoothed representation of growth by calculating the average annual growth rate over a defined timeframe. This smoothing process eliminates short-term volatility or irregularities in the data, resulting in a more dependable and stable measure of growth. Secondly, CAGR takes into account the compounding effect of growth over time. By considering the cumulative impact of year-on-year growth, it becomes particularly relevant when analyzing long-term trends or evaluating investment performance.

Furthermore, CAGR facilitates easy and meaningful comparisons between different time periods or data sets. By calculating growth rates on an annual basis, comparisons can be made across various timeframes, industries, or geographical regions, allowing for valuable insights and assessments. Lastly, CAGR can be employed for future projections by leveraging historical trends. By assuming a consistent growth rate, it serves as a foundation for estimating potential future outcomes or making forecasts.

In summary, the utilization of CAGR in the authors' forecasts ensures a comprehensive and reliable representation of growth trends. This approach accounts for compounding effects, enables meaningful comparisons, and facilitates future projections based on historical patterns.

5. Table The results of the calculation of various indicators for positive prediction

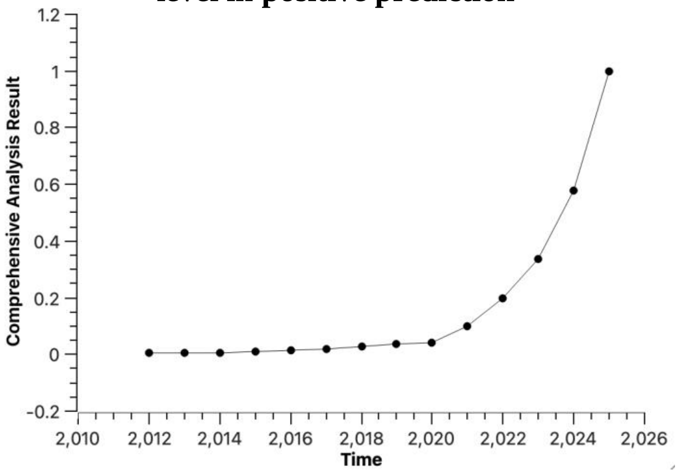
Index	e_j	d_j	w_j
X1	0.9817	0.0183	0.55
X2	0.9828	0.0172	0.51
X3	0.9978	0.0022	0.07
X4	0.9596	0.0404	1.2
X5	0.9661	0.0339	1.01
X6	0.9973	0.0027	0.08
X7	0.9484	0.0516	1.54
X8	0.5943	0.4057	12.09
X9	0.5999	0.4001	11.92
X10	0.5926	0.4074	12.14
X11	0.6221	0.3779	11.26
X12	0.6779	0.3221	9.6
X13	0.6151	0.3849	11.47
X14	0.5779	0.4221	12.58
X15	0.5307	0.4693	13.99

Source: All initial data were collected by authors from the official website of the General Administration of Customs of the People's Republic of China (http://english.customs.gov.cn/) and China Association of Automobile Manufacturers (CAAM)(http://en.caam.org.cn/).

Regarding the optimistic forecast, the results of the calculation of various indicators are shown in table 5 above. The Indicator X15 (Number of registered power battery recycling companies) is still the most heavily weighted among the 15 indicators. So, service competitiveness still accounts for a larger share than the other three primary indicators in the positive prediction. But the X3 (Car Sales in China (10000 units)) replaced the X6's position, which has the smallest weighting.

The Comprehensive evaluation results of the Chinese NEV industry's development level in positive prediction show in Figure 2 below. Without unexpected changes, the trend of the entire industry is still maintaining an upward growth.

2. Figure Comprehensive evaluation results of Chinese NEV industry's development level in positive prediction



Source: All initial data were collected by authors from the official website of the General Administration of Customs of the People's Republic of China (http://english.customs.gov.cn/) and China Association of Automobile Manufacturers (CAAM)(http://en.caam.org.cn/).

Regarding the pessimistic forecast, the results of the calculation of various indicators show in table 5 below. The Indicator X15 (Number of registered power battery recycling companies) is still the most heavily weighted among the 15 indicators. But the X6 (R&D expenditure as a percentage of GDP (%)) has the smallest weighting. In general, the weighting of individual indicators within the indicator system has not changed much.

6. Table The results of the calculation of various indicators for negative prediction

Index	e_j	d_j	w_j
X1	0.9892	0.0108	0.42
X2	0.9898	0.0102	0.4
X3	0.9982	0.0018	0.07
X4	0.9657	0.0343	1.33
X5	0.9809	0.0191	0.74
X6	0.9985	0.0015	0.06
X7	0.9586	0.0414	1.61
X8	0.7247	0.2753	10.7
X9	0.7226	0.2774	10.78
X10	0.7013	0.2987	11.61
X11	0.7381	0.2619	10.18
X12	0.7678	0.2322	9.02
X13	0.7304	0.2696	10.48
X14	0.6539	0.3461	13.45
X15	0.5069	0.4931	19.16

All initial data were collected by authors from the official website of the General Administration of Customs of the People's Republic of China (http://english.customs.gov.cn/) and China Association of Automobile Manufacturers (CAAM)(http://en.caam.org.cn/).

However, the ranking of China's NEV industry development level comprehensive evaluation results from 2012-2025 has changed. The year 2022 became a turning point and the following three years saw a downward trend in the industry. What’s more, Moreover, the industry's ranking for development in 2024 is only seventh, and its ranking for development in 2025 is even lower, at tenth.

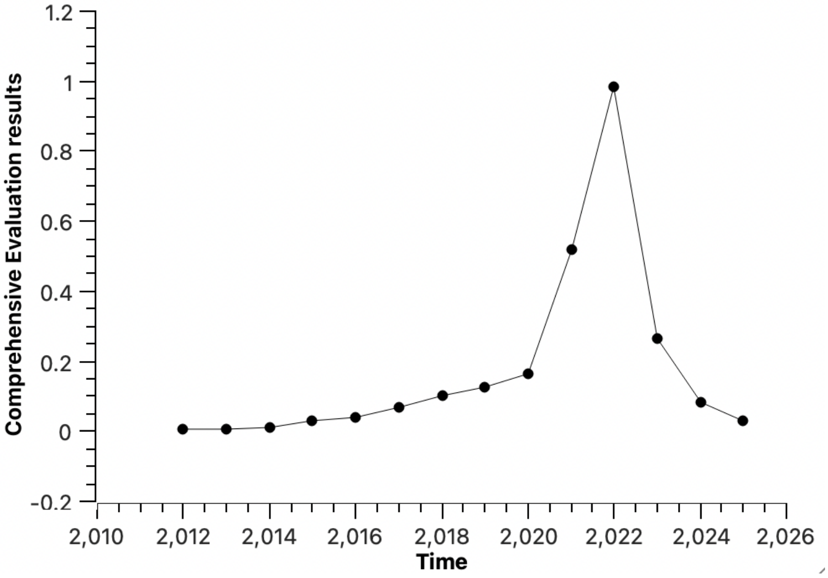
7. Table Comprehensive Evaluation Results of Chinese NEV industry's development level

Time	S_i^+	S_i^-	C_i^+	$ScoreC_i^+$
2012	2.072	0.013	0.006	14
2013	2.069	0.015	0.007	13
2014	2.06	0.021	0.01	12
2015	2.033	0.06	0.029	11
2016	2.009	0.088	0.042	9
2017	1.971	0.142	0.067	8
2018	1.918	0.219	0.102	6
2019	1.885	0.266	0.124	5
2020	1.773	0.352	0.166	4
2021	1.017	1.101	0.52	2
2022	0.031	2.072	0.985	1
2023	1.545	0.555	0.264	3
2024	1.929	0.175	0.083	7
2025	2.031	0.066	0.031	10

All initial data were collected by authors from the official website of the General Administration of Customs of the People's Republic of China (http://english.customs.gov.cn/) and China Association of Automobile Manufacturers (CAAM)(http://en.caam.org.cn/).

For the purpose of visualizing the changes in the level of development of China's NEV industry between 2012 and 2025, the authors have created a visual chart based on the above data, as shown in Figure 3 below.

3. Figure 3 Visual chart of comprehensive evaluation results of the Chinese NEV industry's development level in negative prediction

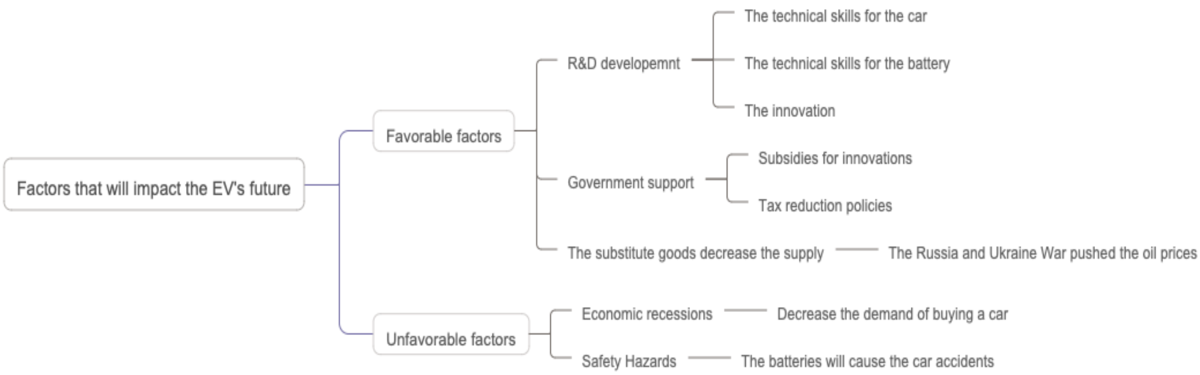


All initial data were collected by authors from the official website of the General Administration of Customs of the People's Republic of China (http://english.customs.gov.cn/) and China Association of Automobile Manufacturers (CAAM)(http://en.caam.org.cn/).

1.4. DISCUSSION

Based on the comprehensive competitiveness ranking of new energy vehicles, we used the environmental scan to analyze the internal and external environment of electric vehicles to identify favorable and unfavorable factors, to make a forecast for the future development status of the new energy vehicle market.

4. Figure The favorable and unfavorable factors



All data are collected by the authors.

1.4.1. MARKET COMPETITIVENESS ANALYSIS

By using the TOPSIS method, we describe the international competitiveness of new energy based on the data on environmental competitiveness, R&D competitiveness, production competitiveness, market competitiveness, and service competitiveness. The comprehensive competitiveness of China's new energy vehicles was constructed and ranked for the past 11 years, and its first ranking in 2022 shows that its comprehensive competitiveness is increasing year by year, and overall, the development of new energy vehicles is a positive one.

Horizontal analysis of the current external environment is conducive to the development of new energy vehicles:

The Russia-Ukraine war has created an increased demand for alternative products:

The traditional view is that oil and automobiles are complementary, i.e., the use of automobiles means that the consumption of oil is inevitable. However, the emergence of new energy vehicles has upset this ecological balance. New energy vehicles and traditional old cars form a substitute for each other. As a result, the escalation of the Russia-Ukraine conflict has increased the price of oil and gas, which has shifted the consumer market's preference to new energy vehicles. While the Russia-Ukraine conflict has had a huge impact on the world economy and energy markets, it has had a positive effect on new energy vehicles.

Maturity of new energy technologies:

Current battery technology has been further improved. In the early stage of the development of new energy vehicles, the constraints of slow charging speed, short range, low battery energy, and insufficient popularity of charging piles made consumers fearful of new energy vehicles. Currently, most electric vehicles use nickel-metal hydride (Ni-MH) batteries and lithium-ion batteries as the power source, which is an improvement over previous battery technology. These two types of batteries have a long life, high capacity and low cost. In terms of technology, new energy vehicles can be classified as pure electric vehicles, hybrid electric vehicles, and plug-in hybrid electric vehicles. Diversified electric solutions meet the needs and preferences of different users.

Intelligence also further enhances the competitiveness of electric vehicles. The accelerated integration of new energy vehicles with the Internet, big data, artificial intelligence and other emerging technologies, and the rising popularity of intelligent and autonomous driving technologies for new energy vehicle products will make people's driving experience feel richer.

In addition, traditional fuel car companies are also promoting the research and development of new energy technologies. These new cars appear to give consumers more choices but also drive the transformation and upgrading of the traditional fuel car industry. The top-ranking new energy car sales in the current market are still mainly dominated by traditional fuel car companies. On the one hand, they have the operation of traditional car manufacturing, on the other hand, strong financial support and technology guarantee, making it faster to occupy an important position in the new energy market.

Government policy stimulation:

The new energy vehicle explosion is based on the government's incentive policy for rapid development and layout. The government's stimulus for it is mainly reflected in three aspects: government subsidies, purchase tax exemptions, and the disappearance of consumption tax.

The government has been actively promoting the new energy vehicle market and has given strong policy subsidies. in January 2009, the State Council considered and adopted in principle the Revitalization Plan for the Automobile Industry, which elevated the development of the new energy vehicle industry to a strategic level and allocated 10 billion yuan to support the industrialization of new energy vehicles and key components. In the same year, the Development and Reform Commission, the Ministry of Industry and Information Technology, the Ministry of Finance, the Ministry of Science and Technology, and other ministries released the "Ten Cities and Thousands of Vehicles Project". It is planned that within three years, 10 cities will be developed each year, and 1,000 new energy vehicles will be launched in each city to carry out demonstration operations, and the vehicles will be tried as public transportation, government vehicles, postal sanitation, and other fields. The government's massive subsidies are to help the industry's rapid development in the early years, to achieve the green economic transformation, and to accomplish the goal of carbon neutrality. This is in line with China's future economic development plan. To support the development of the new energy vehicle industry and promote auto consumption, the Ministry of Finance 2022 issued a continued exemption from vehicle purchase tax in 2023. Consumption tax is paid according to the engine displacement, because electric vehicles do not have engines, so they do not need to pay the corresponding consumption tax.

In addition to the policy aspect, the government also vigorously promotes the investment and construction of new energy vehicle charging infrastructure. It can promote further industrial upgrading and drive the development of supporting industries. In 2021, the total number of China's high-speed intercity fast charging facilities exceeded 10,000 units, highway coverage exceeded 35%, covering 27 provincial-level administrative regions, and Beijing, Tianjin, Hebei, Yangtze River Delta, and Pearl River Delta key regional highways had achieved full coverage.

Vertical analysis of the internal market environment of the new energy vehicles is also booming state.

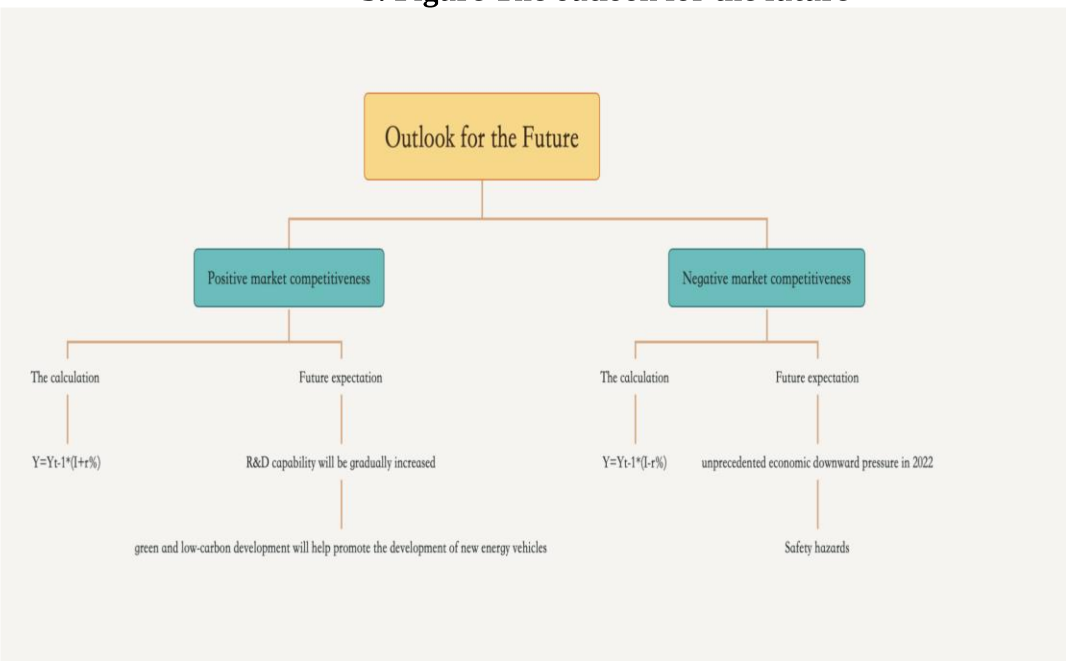
- 2009-2015 initial growth period, the government's subsidy policy to promote the new energy vehicle market. A comprehensive policy system was established. China launched a series of support policies for new energy vehicles, the development, and implementation of systematic standards, and local governments were involved with the actual introduction of the corresponding supporting policies. In 2014, the private purchase of new energy vehicles in China began to appear, which also opened the first year of China's new energy vehicles. 2015, the country entered a high growth year in the new energy vehicle industry, China also became the world's largest new energy vehicle market.

- 2016-2021 rapid growth period, technological innovation active new energy vehicle market. 2021 as the first year of the 14th Five-Year Plan, China's new energy vehicle market achieved rapid growth in production and sales scale, rapid improvement in quality brand, rapid growth in product exports, and an outbreak of strong market momentum. The power battery level had been significantly improved, and the industry's competitiveness was leading globally. The electric consumption of mainstream pure electric passenger cars had been reduced to 12.5kWh/100km, the range was increased to over 400km, and the system energy density reached 194.12Wh/kg, reaching the international advanced level.
- 2022-2025 Mature period, consumers change their consumption concept. The external impact of the Russia-Ukraine conflict has further stimulated the demand for the new energy vehicle market, coupled with the continuous technological update and the change of people's consumption concept. Due to the technological updates, the original battery range problem has been solved, policy subsidies have made EVs more affordable, and the government's construction of infrastructure such as charging piles has provided a more friendly charging environment for EVs. As a result, people have changed from fear of new energy vehicles to acceptance.

1.4.2. OUTLOOK FOR THE FUTURE

According to the results above, the competitiveness ranking of new energy vehicles is continuously rising when all indicators are moving towards positive growth. This implies a gradual rise in environmental competitiveness, increased technological R&D capabilities, product updates, market shifts and increased demand, and better infrastructure. But when all indicators are moving in a negative direction, it means that the competitiveness of new energy vehicles is rapidly declining and will be less competitive in 2026 than it was in 2010.

5. Figure The outlook for the future



Source: All figures are made by the authors

Positive market competitiveness forecast analysis.

By calculating the compound annual growth rate, we give the future overall competitiveness of new energy vehicles in a state of active development, which can be observed to be gradually strengthened with the growth of years. This is in line with the current expectation:

- Its R&D capability will be gradually increased with the increase of R&D funds to build and optimize the platform of electric vehicles. The technology will be updated and upgraded for its powertrain, chassis system, and body system. To achieve low cost, high performance and long life of the battery to ensure that the car has sufficient power.
- The goal of green and low-carbon development will help promote the development of new energy vehicles. China is now in a period of economic transition, changing from its original sloppy to an intensive mode of economic development, thus achieving green economic transformation. As a major consumer of energy, automobiles cause a certain degree of environmental pollution every year. Therefore, the emergence of new energy vehicles helps the case of low-carbon automotive energy and promotes carbon neutrality in the whole industry chain and life cycle.
- Most cities have made plans to electrify vehicles in the public sector. Public service vehicles, net cars, cabs, buses, logistics vehicles, etc. have different charging and switching methods, which vary from city to city, and should be combined with the operating characteristics of the vehicles to consider appropriate methods, such as slow charging, fast charging, rapid power exchange, high-power charging, and online charging, like the so-called dual-source trackless in Beijing.
- The competitiveness of the new energy vehicle market is gradually increasing along with its product updates and iterations. 2022 China's new energy vehicles continued to grow explosively, with production and sales completing 7.058 million and 6.887 million units respectively, up 96.9% and 93.4% year-on-year, remaining the world's number one for eight consecutive years. Market share increased to 25.6%, 12.1 percentage points higher than the previous year, and global sales accounted for more than 60%. Among them, 5.365 million units of pure electric vehicles were sold, up 81.6% year-on-year; 1.518 million units of plug-in hybrid vehicles were sold, up 1.5 times year-on-year.

Negative market competitiveness forecast analysis.

Although many positive factors are currently driving the development of new energy vehicles, there is still a big problem with new energy vehicles - safety hazards. Therefore, we constructed the worst scenario analysis of the impact of too many explosive events on the new energy vehicle market. By negative scenario setting, it is believed that the overall competitiveness of new energy vehicles is rapidly declining when all indicators are moving in the direction of negative growth, even falling to the 10th place in 2025. Therefore, the devastating impact on the new energy vehicle industry due to the outbreak of a black swan event cannot be ignored.

- The automotive industry faces unprecedented downward pressure in 2022 under the impact of multiple negative factors such as the domestic macroeconomic downturn, recurring epidemic, continuation of international chip shortage, and high oil and raw material prices. The downward pressure on the macro economy has reduced the overall consumer demand for automobiles. After a period of rapid economic development, most Chinese families already have small cars, and people's demand for cars has reached saturation. The total number of car sales fell back after the epidemic due to people's lower income and excessive economic pressure during the epidemic. As a result, the overall scale of market demand dropped, which will hurt the demand for new energy vehicles.

- Safety hazards are still not properly addressed, increasing consumer concerns about safety. 2021 saw a total of about 3,000 new energy vehicle fire accidents nationwide, and the overall fire risk of new energy vehicles is higher than that of traditional vehicles. In terms of the state of the car that caught fire, 35% were in charging, 40% in driving, and 25% in a stationary state. Seasonally, the probability of fire is much higher in the hot period than in winter and other seasons.

SUMMARY AND POLICY RECOMMENDATIONS

This paper analyzes the comprehensive competitiveness of new energy vehicles and conducts an alternative future situation analysis to analyze positive and negative situations for the future of new energy vehicles. The following conclusions were drawn:

- The future outlook for new energy vehicles is good and in line with China's 14th Five-Year Plan's goal of economic transformation.
- Continuing to strengthen the new energy vehicle battery safety is the key. Prevent new energy vehicles from exploding and other similar black swan events for the negative impact of new energy vehicles.
- The government should continue to strengthen infrastructure development to help create a favorable environment for the development of new energy vehicles.

Based on the current state of development, the government can continue to encourage the EV market by the following measures:

- Exemption from purchase tax, and vehicle purchase subsidy: Individuals and enterprises that purchase new energy vehicles are exempt from purchase tax and can receive a certain vehicle purchase subsidy, which is conducive to reducing the purchase cost of new energy vehicles and increasing the motivation of users to purchase vehicles.
- Promoting new energy vehicle buses, cabs and logistics vehicles: The government has given strong support to the promotion of new energy vehicles in the fields of buses, cabs and logistics, such as giving preferential taxes and government procurement preferences, which is conducive to increasing the market demand and sales of new energy vehicles.
- Building charging infrastructure: The government has increased the construction of charging infrastructure to improve the coverage rate and charging speed of charging facilities in order to better meet the changing needs of new energy vehicle users.
- The biggest contribution of this paper is to give a competitive evaluation of new energy vehicles and to forecast the comprehensive competitiveness of the market for new energy vehicles based on the current situation. However, since the current data on electric vehicles are not comprehensive enough, there is still room for improvement in data collection. Therefore, future research will continue to add data indicators to make the comprehensive competitiveness evaluation more comprehensive and effective.

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