System Dynamics Simulation of China's Electric Vehicle Market Development Trends

Yufei Wang *

School of Statistic, Capital University of Economics and Business, Beijing, China, 100070

* Corresponding Author Email: wangyufei@cueb.edu.cn

Abstract. The global new energy vehicle industry is currently in a phase of rapid development, with the growth of China's new energy electric vehicle sector being dynamically regulated by various factors within the overall market. Consequently, this study considers the competitive relationship with traditional fuel vehicles and the policy and economic factors present in international trade. Utilizing system dynamics models and dynamic simulations based on graph theory, the research analyzes the future development trends of the overall automobile market and China's new energy electric vehicles. The results indicate that electric vehicles globally will have a disruptive impact on the traditional fuel vehicle market. In situations where China's new energy electric vehicles significantly challenge the traditional fuel vehicle market, the market share of electric vehicles is expected to grow at a high rate over the next 30 years, rapidly increasing from 0.4 to 0.87. Different governmental guidance measures can create up to a 17% difference in market share. In foreign markets, under the global context of 'carbon peaking' and other low-carbon initiatives, or in scenarios where Chinese electric vehicles have a competitive advantage, the impact on the development of China's new energy vehicle industry is relatively minor.

Keywords: New Energy Electric Vehicles, Market Size, Policy Factor, System Dynamics.

1. Introduction

New energy electric vehicles are an important means to reduce the consumption of fossil fuels and greenhouse gas emissions. The Chinese government regards the development of electric vehicles as a strategic objective, and China has become the largest electric vehicle market in the world, with sales of electric vehicles continuing to grow rapidly [1].

Khatua A and others have employed panel-corrected standard errors in multiple regression analysis to explore the relationship between the electric vehicle market and institutional theory, using secondary data from 30 countries. They found a positive correlation between institutionally induced isomorphism and the electric vehicle market [2]. Hu Y and colleagues have studied the impact of COVID-19 on China's plug-in electric vehicle industry using a System Dynamics Model (SDM) and provided three feasible and effective measures for the Chinese government [3].SDM, capable of handling continuously changing and interactive scenarios, is widely used in studies related to the dissemination of green vehicles and associated services. Sun S and others have used a System Dynamics (SD) model based on the Lotka-Volterra (LV) species competition model to study the changes in China's new energy vehicles and the overall market, predicting that new energy vehicles will become dominant in China by 2050[4]. Song Q and others, taking Chinese electric vehicles as an example, have researched the interactions among managerial entities behind the policy mix for sustainable development transformation using a social network analysis of political documents. They concluded that accelerating sustainability transformation requires more cross-organizational interaction and coordination for further study [5]. Jadeja N and others have analyzed the impact of public sector intervention policies using System Dynamics (SD) and other systemic approaches, further investigating from an economic efficiency analysis perspective [6].

In recent years, the global new energy electric vehicle market, including the Chinese market, has shown rapid development in exports and market share. However, it also faces challenges from traditional energy vehicle competition and international trade resistance policies from some countries, potentially leading to stagnation or hindrances in China's export market. In this context, this paper focuses on analyzing electric vehicles within the new energy sector, primarily for two reasons: firstly, the transition to electric vehicles is widely considered a key pathway to decarbonizing the transportation sector, which is currently dominated by fossil fuels, making electric vehicles a critical aspect of new energy technology [5]. Secondly, according to a report by the Chinese government in October 2023, pure electric vehicles account for 76.9% of the new energy vehicle fleet, making them the most important type of new energy vehicle.

This paper primarily employs a system dynamics model to analyze the market size changes of electric vehicles within the global and Chinese new energy vehicle markets. Considering the competitive relationship with traditional energy vehicles and the formulation of internal and external environmental policies, it forecasts the impact on the development and export of China's new energy electric vehicles, deriving an overall development trend. This analysis is not only essential and foundational for domestic industry planning, such as charging networks and power grid systems, helping the Chinese government and automobile manufacturers to adjust decisions timely but also can guide the rational and effective layout of China's export new energy electric vehicle industry more efficiently.

2. Materials and Methods

2.1. Data Sources and Scenario Settings

The primary data for this paper is sourced from the annual databases of the National Bureau of Statistics, statistical data from the Automotive Industry Association and the Automotive Market Research Branch of the Automotive Distribution Association, among others, for obtaining relevant historical data. The remaining parameters were set after repeated adjustments to the model. The total simulation period is set for 50 years, with a time step of 1 year (Table 1).

Table 1. Market Demand Simulation Parameters.

Demand Volume	Settings	Growth Rate	Settings	Growth Rate	Settings	Penetration Rate	Settings
GTA	84100000	γ_{GTA}	0.2	γ_{CTA}	0.1	α_{EV}	0.3
CTA	13950000		0.3		0.15		0.4
CEV	7750000						0.5

Among them, GTA stands for Global Traditional Automobile, CTA for China Traditional Automobile, CEV for China’s New Energy Electric Vehicles, γ_{GTA} for the global traditional automobile growth rate, γ_{GEV} for the global growth rate of new energy electric vehicle, γ_{CEV} for China’s new energy electric vehicle growth rate, and α_{EV} for New Energy Vehicle Adoption Rate.

Renewable energy is key to global sustainable development, with new energy use and consumption gradually rising. However, the consumption of traditional fossil fuels still predominates in current society [7]. Given that the global electric vehicle market is in its early stages of development, the overall market is in a state of uneven development, with significant disparities in some countries. Therefore, for the global market, the market crowding factor is set to a fixed scenario, and simulation analysis will be conducted in combination with global policy orientation factors and different scenarios in the Chinese market. The parameter combinations for the market crowding factor are as shown in Table 2. The market share simulation parameters are as shown in Table 3. The parameters for the simulation scenario of international trade market resistance are as shown in Table 4.

Table 2. Market Crowding Factor Parameter Combination.

group	Scenario	
①	β_{GTA}=0.6	β_{GEV}=0.4
②	β_{CTA}=0.4	β_{CEV}=0.6
③	β_{CTA}=0.7	β_{CEV}=0.3

β Represents the market crowding factor.

Table 3. Market Share Simulation Parameters.

Crowding Factor Combination	Market Growth Rate	Policy Factor
group=①③	γ_{GEV}=0.35	P_G=1, 2, 3
group=①②	γ_{GTA}=0.2	
	γ_{CEV}=0.3	P_C=1, 2, 3
	γ_{GTA}=0.1	

Table 4. Parameters for Simulation Scenario of International Trade Market Resistance.

Scenario	Settings
Export Volume	260000
tariff boycott	0.43
stricter boycott	0.02
sales boycott	0.5
government policy	1.5
polict impact	0.3,0.5,0.7
export ratio	0.2,0.5

By combining different scenarios considered in reality, a clearer simulation of the trends in automotive market share can be achieved.

2.2. Method Introduction

(1)System Dynamics Mode (SDM)

To study the sales volume and market share of China's new energy electric vehicles under the interaction of economic factors such as market competition with traditional energy vehicles and international trade resistance measures faced by Chinese electric vehicle exports, a system dynamics approach was applied to simulate different scenarios. The System Dynamics (SD) method, capable of simulating the behavior of complex systems, analyzes the functional relationships between system elements. Regarding policy impact, the system dynamics model enables the participation of all stakeholders throughout the process, ensuring that real-world scenarios are considered to the greatest extent [6]. In recent years, system dynamics models have been widely applied in sustainable development, social and economic fields, and gradually in management science and government public sectors for application and innovation. Therefore, this method is very suitable for solving the development issues of electric vehicles.

The development trend of electric vehicles is influenced by multiple factors. Internally, these include the construction of new energy vehicle infrastructure, the driving range of new energy vehicles, the cost of electricity consumption, and their selling price. With improvements in internal performance, the demand for short-distance travel with electric vehicles has been initially resolved, reducing the anxiety of some consumers. Meanwhile, in the overall market, consumers will only choose electric vehicles when a cost-benefit analysis favors them, making the process ambiguous [8]. External influences mainly include the competitive relationship with traditional fuel vehicles, government policies, and awareness of sustainable development in society, including government subsidies for new energy vehicles and protective policies for domestic energy vehicles. Joint subsidy policies for industry and procurement can promote the development efficiency of the electric vehicle industry [9]. It is also important to note that government subsidy guidance strategies should not only target electric vehicle manufacturers but also consider subsidies for car-sharing companies, as these subsidies could further incentivize residents to use electric vehicles[10].Moreover, the more parameters and subsystems involved in the system dynamics model, the greater the complexity of the model.

Given the above, this paper will study the development trends of China's pure electric vehicles under different market competition pressures in the external environment of the car market and economic factors in the international trade market. The parameter estimates involved are all derived from the settings in Section 2.1.

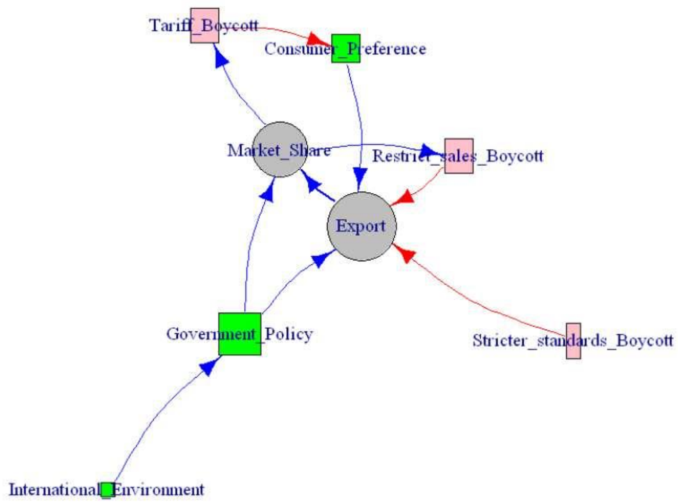

Figure 1. Network Structure Diagram.

Figure 1 is a network structure diagram of China's electric vehicle export market, reflecting the direct impact relationships between various economic variables. Chinese electric vehicle exports will lead to changes in market share and face interactions of various trade market impact factors, including different types of international market trade resistance policies, government policies on new energy vehicles, consumer preferences, and the global economic environment. Through the iterative and feedback mechanisms of the directed network structure diagram, the status of influencing factors is updated to simulate the dynamic changes in export volume under different economic policies and market conditions. The simulation introduces randomness to address consumer preference uncertainties and international environmental uncertainties, simulating random fluctuations caused by other factors. In Figure 1, red arrows represent negative feedback, while blue arrows represent positive feedback. The size of the graph reflects the degree of the nodes, that is, the number of edges connected to the node.

Three types of international market trade resistance policies considered for Chinese electric vehicle exports are: (1) imposing high tariffs, leading to higher selling prices and reduced consumer willingness to buy; (2) adopting stricter safety standards and import certifications, increasing the difficulty of exporting goods and reducing export quantities; (3) restricting the sale of Chinese new energy electric vehicles in the market. Additionally, consumer preferences and the international environment are introduced to consider the competition of products in the international market.

3. Model Establishment and Solution

3.1. Electric Vehicle Development Trend

As one of the largest new energy vehicle markets globally, China's development trend has a significant impact on both the global new energy vehicle market and the traditional energy vehicle market. The following uses system dynamics methods to study the development trend of China's pure electric vehicles and their impact on the global traditional energy vehicle market. During the simulation process, for the two subsystems of traditional fuel vehicles and new energy electric vehicles, the penetration rate of electric vehicles affects the fluctuations of the two markets, and the growth rate of their own market is also affected by the adoption rate of electric vehicles. As the penetration rate of electric vehicles increases, the growth rate of market sales for traditional fuel vehicles is negatively affected, thereby slowing the growth rate of traditional fuel vehicles. In the analysis process of market share changes, a policy orientation factor is introduced, which has a positive feedback effect on electric vehicles. Taking into account market saturation, as the market share approaches saturation, the rate of share growth slows down. The combination of market crowding-out factors is traversed to simulate the global situation and the Chinese market scenario.

Trends in Automobile Market Sales Changes

Figure 2 includes scenarios and sensitivity cases for global traditional automobiles, Chinese traditional fuel vehicles, and Chinese new energy vehicles under different market growth rates and electric vehicle penetration rates. As shown in Figure 2, with the increase in the penetration rate of electric vehicles from 0.3 to 0.5, the sales volume of traditional fuel vehicles will significantly decrease in the next 30 years under the same competitive pressure due to the penetration rate of new energy electric vehicles. When the growth rates for global (γ_{GTA})and Chinese(γ_{CTA})traditional fuel vehicles maintain a higher level of development at 0.3 and 0.15, respectively, an increase in the electric vehicle penetration rate from 0.3 to 0.5 would lead to a significant decline in sales by about 64% and 62%, respectively. Due to the higher frequency of updates and replacements for new energy electric vehicles and their technology being in a rapid development stage, they will have a relatively larger market impact on traditional fuel vehicles in the future. That is, within the next 30 to 50 years, if the development level of electric vehicle technology stabilizes, the market demand for traditional fuel vehicles will significantly reduce. Therefore, global and Chinese traditional fuel vehicle manufacturers should formulate appropriate corporate transformation policies, gradually transitioning to the new energy vehicle industry to ensure sustainable development.

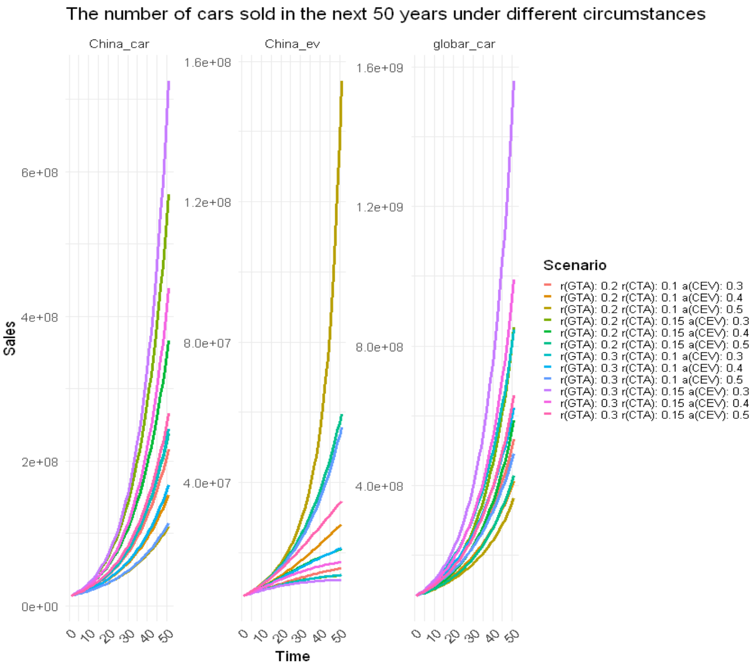

Figure 2. Changes in Automobile Market Sales.

Figure 2 also reveals the market development trend of China's pure electric vehicles. When the electric vehicle penetration rate reaches 0.5, the sales situation of new energy electric vehicles will be less affected by the competition with traditional energy vehicles, showing a higher overall growth rate. It is important to note that a horizontal comparison of the current simulation parameters (0.2-0.1-0.4) reveals an overall upward trend in sales for global traditional automobiles, Chinese traditional automobiles, and Chinese new energy vehicles. However, the growth trends of global traditional automobiles and Chinese traditional automobiles are significantly higher than those of Chinese electric vehicle sales. As the automotive market demand continues to grow, consumer behavior changes need to be gradually adjusted. Although the growth rate of the developing stage of China's new energy electric vehicles is lower compared to the more mature traditional automobile industry, sensitivity analysis results show that with the increase in penetration rate, there is a considerable market potential space of nearly 75%. Therefore, it is crucial for the government to formulate policies actively guiding the development of the new energy industry and building a societal concept of green and sustainable development.

(2) Market Share Trends

Building on the previous discussion, with fixed growth rates for each market, the simulation added different market crowding factorsβand policy orientation factorsPto dynamically simulate the market share trends of traditional fuel vehicles and new energy electric vehicles over the next 50 years under various policy strengths and market competition pressures. The scenario settings are shown in Table 3.

It is important to note that the market crowding factor reflects the competitive pressure one market faces from another, including product competitiveness, market demand, and energy competition. A higherβ_{GTA}value indicates that new energy electric vehicles exert more competitive pressure on traditional fuel vehicles, which may face a reduction in market share in the future.

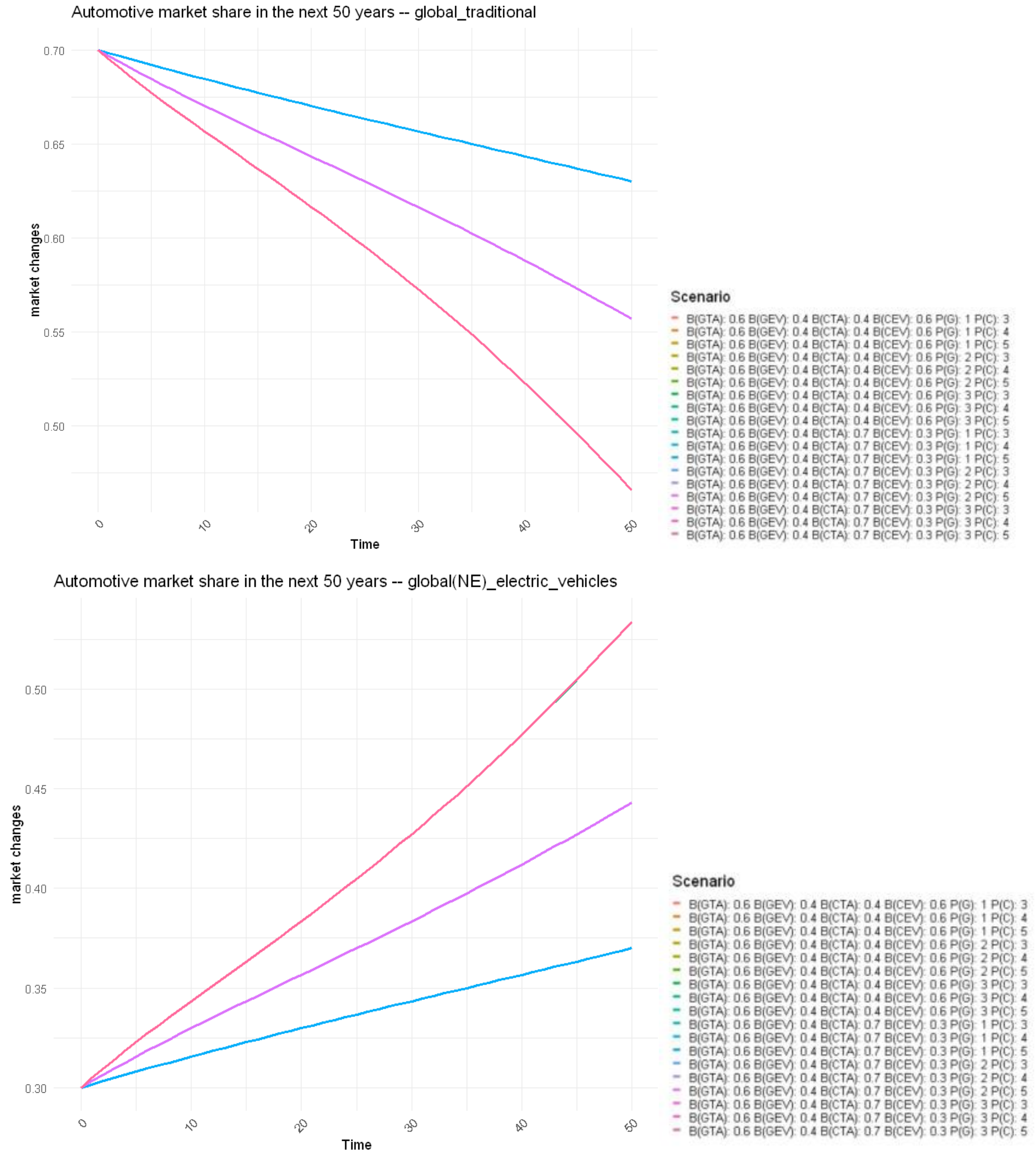

Figure 3. Global Automotive Market Share Changes.

Figure 3 is a market share simulation scenario under different policies and competitive pressures. In the current global automotive market, which encourages "low carbon" and sustainable development, traditional fuel vehicles have a higher market crowding factor and face greater market competition pressure, leading to a gradual decrease in their market share. However, since traditional fuel vehicles have been in the market longer and have a higher initial market share, the lowest it could drop to is around 45%. If the technology level of new energy electric vehicles develops faster, leading to greater market competition pressure, the rate of decline in market share will be quicker. For the electric vehicle market, the share will steadily rise. With the enhancement of various governments' guidance measures for new energy, the market share of electric vehicles could increase to 53% in the next 50 years, nearly 16% higher than under lower levels of government guidance measures.

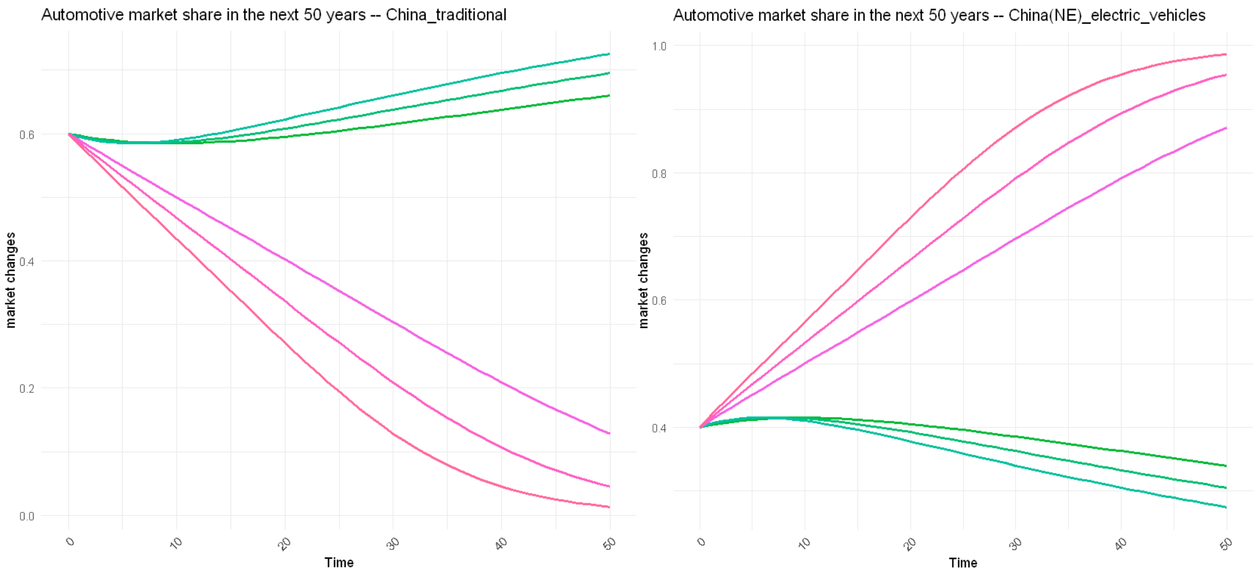

Figure 4. China Automotive Market Share Changes.

The market share simulation scenario for the Chinese automotive market is shown in Figure 4. It is observed that when $\beta_{CEV}$is higher thanβ_{CTA}, the market share of China's traditional fuel vehicles shows a slight decline in the next 10 years, decreasing by 2%, and from the 14th year onwards, it will exceed the original market share, showing rapid development. Government orientation factors will slow the growth rate of traditional energy vehicle market share. When β_{CTA} is higher than β_{CEV},meaning electric vehicles exert more competitive pressure on traditional fuel vehicles, placing them at a disadvantage, the market share change is completely reversed, showing a significant declining trend for China's traditional energy vehicle market share, slowly approaching 1% in the next 50 years. For China's new energy electric vehicle market share, under lower market competition pressure and faster technology iteration, with a smaller crowding factor, the market share will grow at a high rate over the next 30 years, rapidly increasing from 0.4 to 0.87. In the simulation of the next 40-50 years affected by market saturation, the growth rate will gradually slow down. The effects of Chinese government guidance measures can create a gap of nearly 17% in the market share of new energy vehicles. Therefore, the formulation of policies by the Chinese government, such as subsidies for purchasing new energy vehicles, strengthening infrastructure construction, and encouraging technological research by new energy vehicle companies, will significantly impact the development of the automotive market.

The rapid development of the new energy vehicle market will lead to changes in the competitive landscape of the automotive market. The competition in the new energy vehicle market will become more intense, providing new challenges and opportunities for traditional automotive companies. In summary, the impact of new energy vehicles on the global traditional automotive industry is profound, potentially driving the upgrade and transformation of traditional vehicles, reshaping the industrial chain, accelerating the impact of environmental and policy changes, and altering the market competition landscape.

3.2. China's Electric Vehicle Export Situation

Given the sustainable development transition in the global automotive market, the Chinese new energy electric vehicle market still has significant room for growth overseas. The following establishes a dynamic simulation based on graph theory and a system dynamics model to analyze the trends in China's export volume and market share under the influence of economic and policy factors in the international trade context. The network structure of the dynamic simulation based on graph theory is shown in Figure 1. Export volume and market share are the main objects of simulation. Due to the introduction of randomness in consumer preferences and the international market environment, multiple simulations are conducted and the average is taken. For the simulation of market shares involving international trade, the model established in section 3.1 is expanded to include the potential impact factors of resistance due to international trade policies, and simulations of different degrees of export proportions in the Chinese electric vehicle market are conducted, considering scenarios from 20% to 50%.

(1) System Dynamics Simulation of Export Volume Trends Based on Graph Theory

The simulation results of China's new energy electric vehicle export trends under the impact of international trade resistance policies and other economic factors are shown in Figure 5. It can be observed that, with the interplay of China's electric vehicle market share and the intensity of international trade resistance policies, the export situation of China's new energy electric vehicles will first decline and then fluctuate upwards. The development of China's export market is somewhat affected by trade policies.

Initially, facing international trade resistance measures, the export of Chinese electric vehicles will be hindered due to the relatively low demand for new energy vehicles in the international market, thereby reducing export volumes. However, as the concept of global sustainable development takes hold and issues such as the consumption of non-renewable resources intensify, the demand for new energy vehicles in the international market surges. As one of the major exporting countries of new energy electric vehicles, the recognition of Chinese new energy vehicles by other countries will cause the export volume to trend upwards in fluctuations. In the current simulation scenario, influenced by sustainable concepts, the pace of trade resistance policies slows down later, having a relatively minor impact on China's export volume.

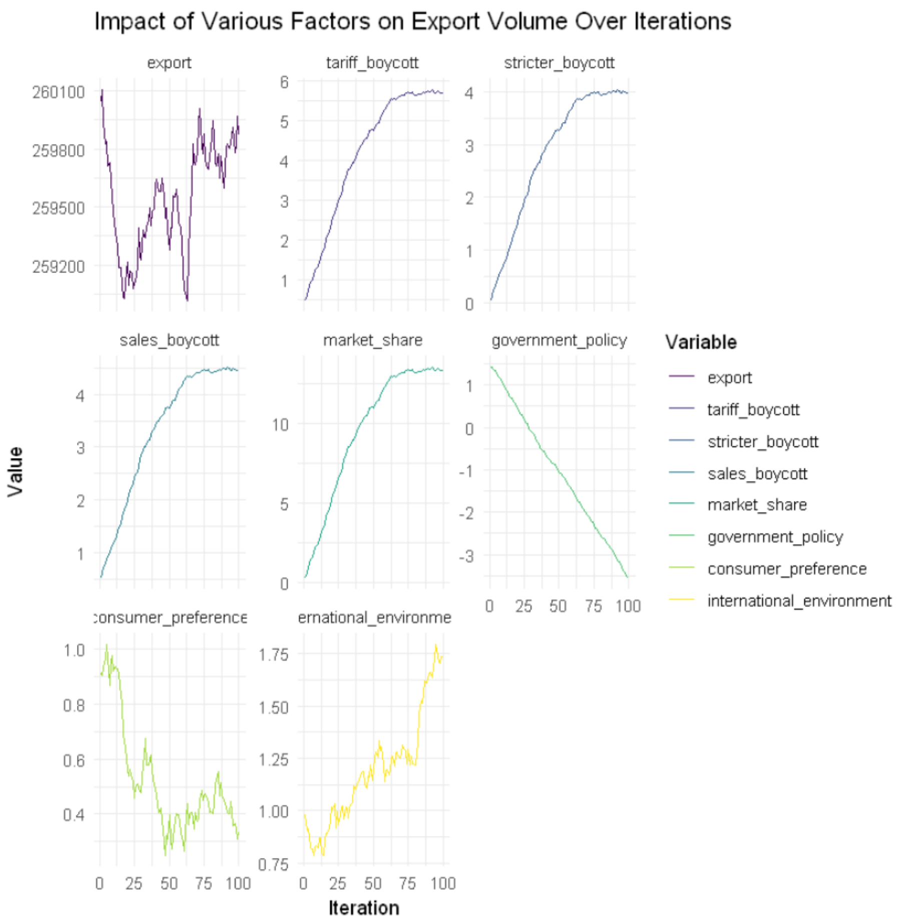

Figure 5. Changes in Factors Influencing China's Export Market

(2) Market Share Changes under International Trade Conditions

Based on the simulation scenario of market share established in section 3.1, an additional factor for trade restriction policies on exports is simulated. Currently, the main sales situation of China's new energy electric vehicles is primarily within the domestic market. However, with the global initiative for "carbon peaking and carbon neutrality" and many places announcing bans on the sale of fuel vehicles, the global new energy vehicle industry is developing rapidly. Post-2050, China may face the issue of gradually saturating its domestic market. Therefore, Chinese automotive enterprises need to continuously update technology and improve global recognition while also timely expanding into overseas markets to increase market share.

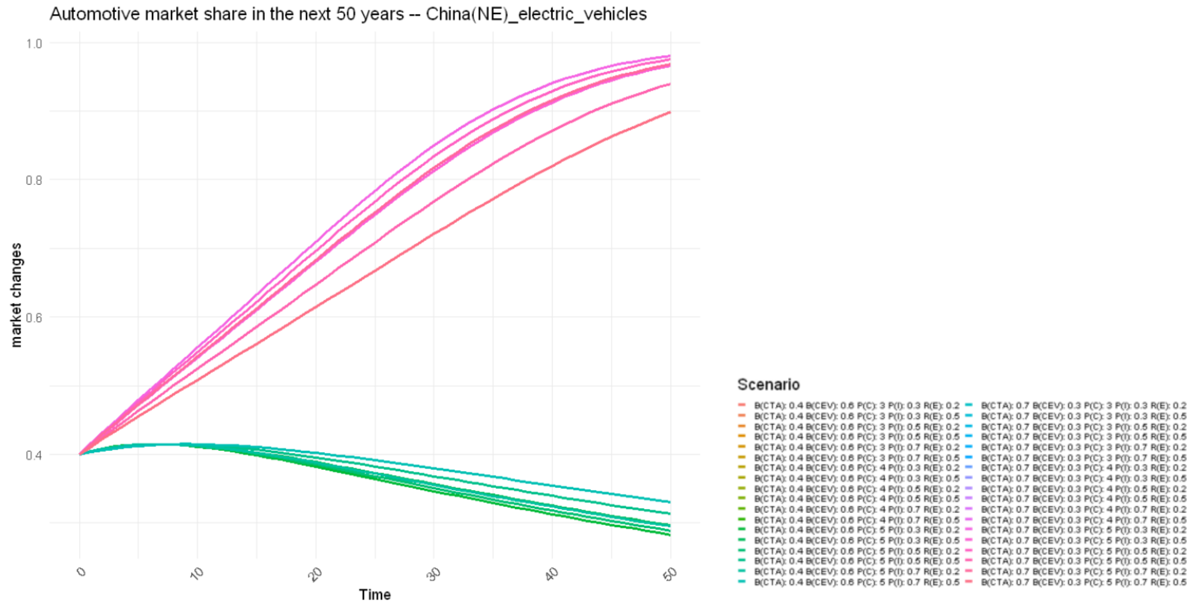

Figure 6. Trends in Market Share of Chinese Electric Vehicles.

The simulation scenario results are shown in Figure 6. In scenarios where β_{CTA} is high, indicating a significant competitive advantage for new energy electric vehicles, the overall market share of China's new energy electric vehicles will continue to rise steadily. When the overseas electric vehicle market share accounts for 50% of China's total and trade resistance measures are severe, the growth rate slows down, differing by nearly 10% from the ideal market share scenario. When β_{CTA} is close to β_{CEV} but β_{CTA} is lower, indicating electric vehicles are at a competitive disadvantage, the market share of Chinese electric vehicles may show a trend of rising and then rapidly declining, impacted by the technological updates and maintenance costs of traditional fuel vehicles. Hence, maintaining the relative competitiveness of electric vehicles is paramount. With the rapid development of the global new energy vehicle market, China's automotive technology level needs to maintain a high development level to continue expanding the market steadily in the face of different trade resistance measures.

4. Discussion

This study establishes a system dynamics model and a dynamic simulation based on graph theory, focusing on analyzing and predicting the development trends of China's electric vehicle industry, considering factors such as market competition, government support, and economic elements in international trade. This approach aids research into the domestic and overseas markets for China's electric vehicle industry.

Assuming that the penetration rate of electric vehicles directly affects the sales of traditional fuel vehicles, the paper discusses the impact of different market competition pressures, various levels of government support policies for new energy electric vehicles, different electric vehicle penetration rates, and economic and political factors that may be encountered in various international trade scenarios on the development of the electric vehicle market. The system dynamics model only considers the impact of government policy factors and market competition pressure on the electric vehicle industry without further considering their interactions. The influence of industry internal factors such as the frequency of technological updates and maintenance costs on electric vehicles requires further research during the modeling process.

5. Conclusion

Maintaining a high level of electric vehicle technology is a necessary condition for industry development, and favorable government guidance measures are important driving factors for promoting industry growth. This paper establishes a system dynamics model composed of government factors, market factors, and other factors. The dynamic simulation based on graph theory focuses on the development changes in China's electric vehicle industry under the influence of consumer preferences and the international market environment. The results show that improving industry internal factors, such as optimizing range and reducing maintenance costs, can enhance the competitive advantage of the electric vehicle market and significantly promote the development of China's electric vehicle industry in both domestic and overseas markets. Positive government guidance measures, the improvement of new energy infrastructure, and overall market attention to sustainable development can promote the development rate of the market.

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