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Posted Date: 18 May 2023

doi: 10.20944/preprints202305.1278.v1

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An Evolutionary Game Analysis of Shared Private Charging Piles Behavior in Low-Carbon Urban Traffic

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Abstract: Choosing new energy vehicles for travel, especially electric vehicles, is an important component of building a low-carbon urban transportation system. However, the charging need of electric vehicle users is still constrained by the unreasonable layout and insufficient supply of public charging piles in the city. Private charging pile sharing as an alternative policy tool can play a very good role in solving this problem. But it needs decision-makers in urban transportation to take corresponding measures to promote. This paper constructs an evolutionary game model to study the decision behavior of participants in private piles sharing platform. Through numerical simulation analysis, it is found that under most parameter conditions, the government tends to establish a shared charging pile platform based on public interests. Private charging pile owners are influenced by the relationship between the cost of supply modification and revenue, and they tend to join the shared platform when they expect to recover the modification cost. The research conclusions of this paper will provide support for exploring how participants make decisions to maximize overall benefits in the development of low-carbon urban transportation.

Keywords: shared private charging pile; low-carbon urban transport; evolutionary game; policy making

1. Introduction

With the global environmental concerns and energy crisis growing, many countries have established "double carbon" targets that require cross-border and global collaboration on energy revolution and industrial transformation. In the realm of urban transportation, low-carbon development is a significant trend, and sustainable travel is being encouraged. New energy vehicles, particularly electric vehicles, can be widely adopted to reduce vehicle emissions. The establishment of low-carbon urban transportation systems is crucial for energy conservation and emission reduction.

While more and more owners of new energy vehicles are choosing to install charging stations in their private parking spaces, some do not have their own parking spaces or necessary installation conditions and must use public charging stations. The growing demand for charging infrastructure, particularly charging stations, is being met with accelerated construction. Despite the rapid growth of public charging stations, issues related to their layout and inadequate supply can deter potential electric vehicle purchases due to fears of charging difficulties.

Private charging pile sharing can effectively utilize idle charging resources, enhance the economic efficiency of private charging piles, and facilitate the green and low-carbon development of urban transportation. Private charging piles are typically only utilized 1-2 times per week on average. However, private pile sharing can accommodate an additional 10-15 cars, significantly alleviating the scarcity of charging infrastructure in cities.

To promote the private pile sharing model, decision-makers in the development of low-carbon urban transportation need to involve various stakeholders and formulate policies, along with the construction of sharing platforms, to achieve optimal social benefits. This study uses evolutionary game theory to develop a model that considers the interest relationship between charging pile owners and decision-makers of the sharing platform in the private pile sharing mode. The aim is to analyze the behaviors of both parties and explore how they can make decisions that maximize overall benefits for the development of low-carbon urban transportation. Through this analysis, the study provides insights into how the participants can work together to achieve mutual gains in this emerging market.

2. Literature Review

Private charging pile sharing is an emerging solution to address the insufficient supply of public charging infrastructure for electric vehicles. Many researchers and industrial engineers are currently studying this problem [1–3]. The research can be divided into three main areas based on different aspects.

Firstly, the distribution of shared benefits is an important factor. Wang et al. emphasized the impact of risk on private charging pile owners and the role of service quality in benefit distribution. They proposed an improved Shapley value model that considers contributions and risks of different stakeholders, enhancing multi-party cooperation [4]. However, determining reasonable pricing for charging pile sharing remains unresolved. Zhao et al. adopted a non-cooperative game model to consider the charging behavior of electric vehicle consumers and determine the shared price of charging piles [5]. They also constructed a bilateral bargaining game model based on Rubin's rotating bargaining game to account for information asymmetry among private charging pile owners, electricity retailers, and electric vehicle users [6].

Secondly, the distribution mode of shared charging piles is crucial. Chen et al. proposed a hierarchical scheduling model for electric vehicles with shared charging piles. This model determines the charging time and location of electric vehicles through upper-level and lower-level scheduling, respectively. They utilized a sharing capacity model based on generalized Nash game to determine the sharing scheme of private charging piles [7].

Thirdly, several cities have implemented charging pile services. Fu et al. proposed a peer-to-peer (P2P) private charging pile sharing system based on blockchain technology. They conducted a case study in Shanghai's Lujiazui business district to verify the system's applicability. The study revealed that private EV charging piles were more popular than public charging piles [8].

With the increase in car ownership, finding vacant parking spaces has become increasingly difficult, and shared parking has emerged as a solution. Qy et al. conducted a declarative selection experiment to understand the tendency of parking space owners to participate in shared parking under different conditions. They considered fixed-mode shared parking, flexible mode shared parking, and uninterested shared parking options [12]. Xiao et al. built on parking management research and proposed an auction-based shared parking space market behavior model that considers the impact of expected regret on participants' bids [13].

In recent years, low-carbon technology innovation in power grids has gained significance due to carbon emission reduction goals. Evolutionary game theory has been widely used to study decision-making involving governments and enterprises. Zhao et al. proposed a tripartite evolutionary game theory to investigate the behavior strategies of power grid enterprises, banks, and governments in low-carbon grid technology innovation cooperation [16]. Zou et al. introduced evolutionary game theory and constructed a dynamic evolution tripartite game model with universities as suppliers of low-carbon technologies, enterprises as demanders, and the government as the promoter and regulator. The study revealed the interaction between different actors and the influence of initial participation intentions on government participation [17]. Liao et al. explored effective carbon tax mechanisms in the post-subsidy era and analyzed the evolutionary game between local governments and automakers. They conducted empirical analysis based on China's actual situation [18]. Cao et al. proposed a pricing strategy for electric vehicle charging operators and analyzed the dynamic evolution process between electric vehicle users and charging operators in

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Shanghai. They conducted a sensitivity analysis of factors affecting the system evolution and equilibrium [19]. Zhang et al. applied evolutionary game theory to study policy choices in the waste battery reuse supply chain, considering information asymmetry and limited rationality among government, manufacturer, and consumer participants. They established an evolutionary game model that includes echelon utilization and remanufacturing choices, revealing the balance in government support, echelon utilization, and consumer participation [20].

3. Models

3.1. Model Assumptions and Symbol Definition

The traditional game theory based on the assumption of perfect rationality is difficult to obtain reliable conclusions because of the complex socio-economic environment and decision-making problems. Evolutionary game as the analysis method of finite rational game has become a better tool to deal with the problem of finite rational game. Evolutionary game theory is based on the theory of biological evolution, and it is believed that individuals in a group can achieve a stable dynamic equilibrium through the process of imitation, learning and mutation to form an evolutionary stable strategy.Therefore, this paper constructs an evolutionary game model to study the game phenomenon between the platform party and the charging pile owners under the establishment of the charging pile sharing platform, assuming that the platform is invested and built by the government.

The government decision is divided into two policy making options, active and inactive. In active policy making, two policy perspectives, support and regulation, are considered. For government support, two policy instruments are introduced in the model, namely, the government establishes a sharing platform and gives subsidies to charging pile owners for the platform. Establishing a sharing platform can improve the efficiency of travelers in finding shared charging piles, which is conducive to improving the overall utilization rate of charging piles. On the other hand, direct subsidies are given to the owners of charging piles participating in the sharing platform as support. The government regulation is understood as a "punishment" measure, and a certain management fee is levied on the charging piles that do not participate in the sharing platform. No active policy option to maintain the current situation. The decision of charging pile owners is divided into whether to participate in the sharing platform or not. The following assumptions are made for the game scenario：

(1) Assume that both the government and the owners of charging piles are finite rational, and both can make the evolutionary game of sharing charging piles reach a stable state through self-learning, and assume that the government-led sharing platform can reduce the idle rate of charging piles through optimal resource allocation and bring feedback benefits to the owners of charging piles;

(2) The government has two "active" and "inactive" strategies, and the proportions of choosing the two strategies are x and (1 - x), respectively, $x \in [0,1]$

(3) Charging pile owners have two strategies of "participation" and "non-participation", and the proportions of choosing the two strategies are y and (1-y), respectively,$y \in [0,1]$

R denotes the social revenue enhancement brought by the overall charging pile utilization rate of the society, and G denotes the stable revenue level of the charging pile owner when operating the charging pile normally. Although the charging pile is not saturated in general, the utilization rate of local area is not high, and the idle rate of the charging pile is considered as p, where there exist two high and low idle rates, i.e., P_l， P_h. The loss caused by the complete idleness of the charging pile is L. The investment used for the transformation of the charging pile to access the platform is I. Therefore, the evolutionary game payment matrix is shown in Table 1.

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Table 1.

Owners	**Platform side - Government**	
	Active	**Not Active**
Participation	$(R-\partial A-\beta S,\ G+\Delta G+\beta S-I)$	$(-P_lE,\ G+\Delta G-P_lL-I)$
Non-participation	$(R+\gamma F-\partial A-P_lE,\ G-P_lL-\gamma F)$	$(-E,\ G-P_hL)$

R - Social benefits from increased utilization of charging piles
A - Cost of establishing the sharing platform
S - Cost for platform subsidy
F - The management fee levied by the government
G - Revenue level of charging pile owners' operation
ΔG - Increased revenue from the participation of charging pile owners in the sharing platform
P - Charging pile idle rate, for low idle, for high idle
L - Idle loss of charging pile owners
I - The transformation cost of charging pile access to the platform
E - Social benefit loss of charging pile idleness
α、β、γ - Intensity factor of platform construction, subsidy and management costs

3.2. Replication Dynamic Equation Building

The expected benefits of the two behavioral choices of active and inactive government policies are

$$u^p{}_G = y(R-\partial A-\beta S)+(1-y)(R+\gamma F-\partial A-P_lE)$$
$$u^n{}_G = y(-P_lE)+(1-y)(-E)$$

The average benefit of government decisions is

$$u_G = xu^p{}_G+(1-x)u^n{}_G$$

The expected benefits of the charging pile owner's decision are

$$u^i{}_C = x(G+\Delta G+\beta S-I)+(1-x)(G+\Delta G-P_lL-I)$$
$$u^k{}_C = x(G-P_lL-\gamma F)+(1-x)(G-P_hL)$$

The average benefit of charging pile owner decisions is

$$u_C = yu^i{}_C+(1-y)u^k{}_C$$

The replication dynamic equation for government decision making is

$$F(x,y)=\frac{dx}{dt}=x[u^p{}_G-u_G]=x(1-x)[R+\gamma F-\partial A-P_lE+E+(2P_lE-\beta S-\gamma F-E)y]$$

The replicated dynamic equation for the charging pile owner's decision is

$$G(x,y)=\frac{dy}{dt}=y[u^i{}_C-u_C]=y(1-y)[\Delta G-P_lL-I+P_hL+(2P_lL-P_hL+\beta S+\gamma F)x]$$

3.3. Analysis of Evolutionary Stabilization Strategies

Let $F(x,y)=0$, while $G(x,y)=0$, find the five equilibrium points of the system, respectively: (0,0)、(0,1)、(1,0)、(1,1)、$\left(\frac{P_lL-\Delta G+I-P_hL}{2P_lL-P_hL+\beta S+\gamma F},\frac{P_lE-\gamma F+\partial A-E-R}{2P_lE-\beta S-\gamma F-E}\right)$

According to the replication dynamic equation, the Jacobi matrix J of the system is obtained as

$$J=\begin{bmatrix}(1-2x)[\gamma F-\partial A-P_lE+E+R+(2P_lE-\beta S-\gamma F-E)y] & x(1-x)(2P_lE-\beta S-\gamma F-E)\\ y(1-y)(2P_lL-P_hL+\beta S+\gamma F) & (1-2y)[\Delta G-P_lL-I+P_hL+(2P_lL-P_hL+\beta S+\gamma F)x]\end{bmatrix}$$

According to the stability theorem of differential equations, the evolutionary stabilization strategy is stable to smaller disturbances, and the derivative of $F(x,y)$ must be less than 0, i.e., when the determinant$Det(J)>0$of the matrix J ,the trace $Tr(J)<0$ of the matrix, is a local asymptotically stable immobile point, i.e., the evolutionary stabilization strategy ESS. five equilibrium points are brought into the Jacobi matrix, and the results are shown in Table 2.

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Table 2.

Equilibrium point	DetJ	TrJ
(0,0)	$(\gamma F-\partial A-P_lE+E+R)(\Delta G-P_lL-I+P_hL)$	$(\gamma F-\partial A-P_lE+E+R)+(\Delta G-P_lL-I+P_hL)$
(0,1)	$(\partial A+\beta S-P_lE-R)(\Delta G-P_lL-I+P_hL)$	$P_lE+P_lL+R+I-P_hL-\partial A-\beta S-\Delta G$
(1,0)	$-(\gamma F-\partial A-P_lE+E+R)(\Delta G-I+P_lL+\beta S+\gamma F)$	$\partial A+P_lE+\Delta G+P_lL+\beta S-I-E-R$
(1,1)	$(P_lE+R-\partial A-\beta S)(\Delta G-I+P_lL+\beta S+\gamma F)$	$I-\Delta G-P_lL-P_lE-R-\gamma F+\partial A$
(x^*,y^*)	U	0

$$U=\frac{(\partial A+\beta S-P_lE-R)(\Delta G-I+P_lL+\beta S+\gamma F)(\gamma F-\partial A-P_lE+E+R)(\Delta G-P_lL-I+P_hL)}{(2P_lL-P_hL+\beta S+\gamma F)^2(2P_lE-\beta S-\gamma F-E)}$$

According to Table 2, if we want to determine the determinants and trace values of the five equilibrium points, further discussion on parameter taking is needed.One is whether the choice of the access platform strategy will bring higher benefits than the investment for the charging pile owners, and the other is the question of whether the public cost paid by the government for active decision making can maximize the social benefits from the perspective of the overall social benefits, i.e., the value of $P_lE+R-\partial A-\beta S$.

Assuming that the owners of the charging stations can increase their profits by accessing the shared platform, i.e. the overall benefits obtained from cost reductions through management fee reductions, platform subsidies, and supply chain integration are greater than the investment expenditure for supply chain integration, denoted as $\Delta G-I+P_lL+\beta S+\gamma F>0$. At the same time, assuming that proactive decision-making will reduce the idle rate of charging stations and promote the overall improvement of social benefits, denoted as $P_lE+R>\partial A+\beta S$, the equilibrium values of each balance point are shown in Table 3.

Table 3. Stability of each equilibrium point.

Equilibrium point	**DetJ**	**TrJ**	**Stability**
(0,0)	> 0	> 0	unstable
(0,1)	< 0	To be determined	Saddle point
(1,0)	< 0	To be determined	Saddle point
(1,1)	> 0	< 0	ESS
(x^*,y^*)	> 0	0	Center point

4. Numerical Simulation Analysis of 4 Evolutionary Game Model

4.1. Construction of System Dynamics Simulation Model

According to the modeling analysis of the strategy decision of both the government and the owner of the charging pile, the results of each party's evolutionary game under different conditions are given, using System dynamics to depict the evolution of the game between the government and the owners of the charging posts. An evolutionary game System dynamics model of the mixed strategies of the government and the owner of the charging post was developed to characterize the

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long-term dynamic behavior of the game relationship between the two players, it provides a simulation platform for studying the evolution trend under different conditions and formulating practical countermeasures.

To further verify the strategy choices of both parties under different conditions, the system dynamics model is used for simulation analysis. As a powerful tool to study the dynamic problems of complex systems, system dynamics can effectively portray the decision-making behavior of interested parties from a system perspective. In this paper, we use VENSIM software to establish SD model of strategic materials cross-border supply chain decision making, and conduct simulation analysis to explore the evolutionary strategies among the subjects. the SD model is shown in Figure 1.

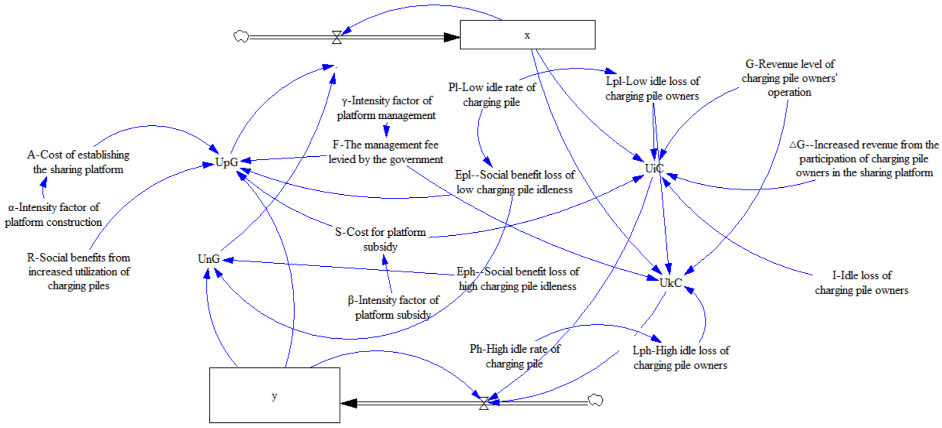

Figure 1. System dynamics model of charging pile sharing platform decision making.

4.2. Simulation Results and Sensitivity Analysis for Different Scenarios

The initial conditions of the model are set as follows: the initial time is 0, the final time is 12, and the time step is 0.0015625. Based on the real situation and the assumptions of the model, the revenue level for the owner-operated charging station is 100 units, the cost of retrofitting for connecting the charging station to the platform for network control and unified settlement is 60 units, the revenue increase for the charging station owner's participation in the sharing platform is 20 units, the idle loss for the charging station owner is 150 units, and the social efficiency loss for the idle charging station is 200 units. The government's cost for building the sharing platform is 80 units, the subsidy cost is 20 units, the management fee charged for charging station operation is 40 units, and the social efficiency gain from the charging station utilization improvement is 150 units. The initial values for α、$\beta$and γ are set to 1, while P_l and P_h are set to 0.1 and 0.7, respectively.

With the initial values input, the simulation results are shown in Figure 2. Under the initial parameter conditions, both the platform operator (government) and the charging station owner take active decisions, and a stable equilibrium point (1,1) is reached, which is consistent with the rough analysis of evolutionary stability. Considering the intensity factors α、$\beta$and γ and the charging station idle rate conditions P_l and P_h set in the model, different game scenarios are discussed, and simulation analyses are conducted with different parameter combinations based on the actual situation.

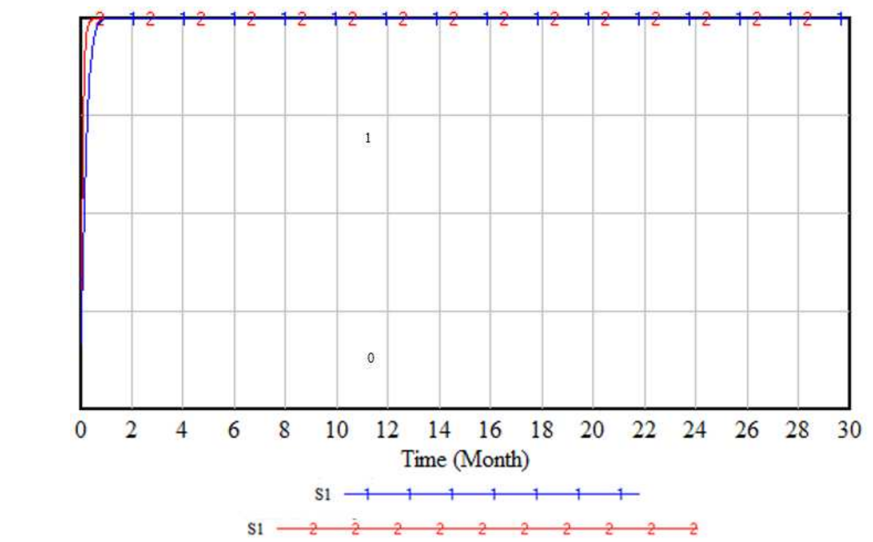

Figure 2. Simulation results under the initial parameters.

(1) Sensitivity simulation for different cost intensity cases.

As the proactive measures taken by the platform (government) require expenditure, such as establishing a sharing platform and providing subsidies to platform users, the cost of policy-making has a significant impact on government decision-making. Only appropriate subsidies can stimulate the enthusiasm of charging station owners to join the platform and not cause excessive financial pressure. Different cost intensities will directly affect the value of . Therefore, it is necessary to discuss the values of the intensity parameter. Situation 1 is the initial parameter and serves as a control. Situation 2 is set to twice the parameter level of Situation 1, where the cost level is higher. Situation 3 is set when the cost level is lower. The value scenarios are shown in Table 4. The simulation results are shown in Figure 3.

Table 4. Values of overhead intensity of the platform party (government) in different scenarios.

parameter	Situation 1	Situation 2	Situation 3
α	1	2	0.5
β	1	2	0.5

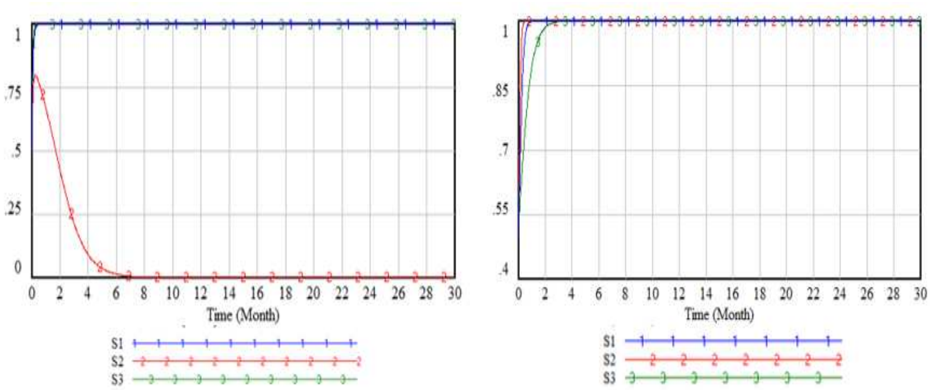

Figure 3. Simulation results of the sensitivity of the system to cost intensity.

As can be seen from the results, when the cost intensity increases significantly, the government's strategy choice changes (indicated by S2), shifting from an active decision to an inactive one. This indicates that cost changes have a significant impact on decision-making, and the formulation of this policy puts significant pressure on the platform party (i.e., the government) finances. On the other hand, changes in cost intensity do not alter the decision outcome for the charging station owners, but a significant increase in cost intensity can accelerate their participation rate in the platform decision-making.

(2) Simulation of sensitivity to the intensity of overhead costs of the platform party (government)

In the model design, in the game scenario where the platform (government) takes an active decision but the charging station owner chooses not to, the management fee for charging station operation is not exempted. γ is the intensity parameter for implementing this decision, with $\gamma = 2$ representing high management fee level and $\gamma = 0.5$ representing low management fee level, corresponding to scenarios 4 and 5 in Table 5, respectively. The simulation results are shown in Figure 3, compared with the initial scenario 1. The influence of different management fee levels on government policy choices is relatively small. The main impact of government decisions is still the social benefits of the policy, and the financial revenue generated by the management fee has limited impact on decision-making. The increase in management fee intensity will accelerate the rate of charging station owners joining the sharing platform decision-making, reflecting the sensitivity of charging station owner decisions to costs.

Table 5. Values of overhead intensity of the platform party (government) in different scenarios.

parameter	Situation 1	Situation 4	Situation 5
γ	1	2	0.5

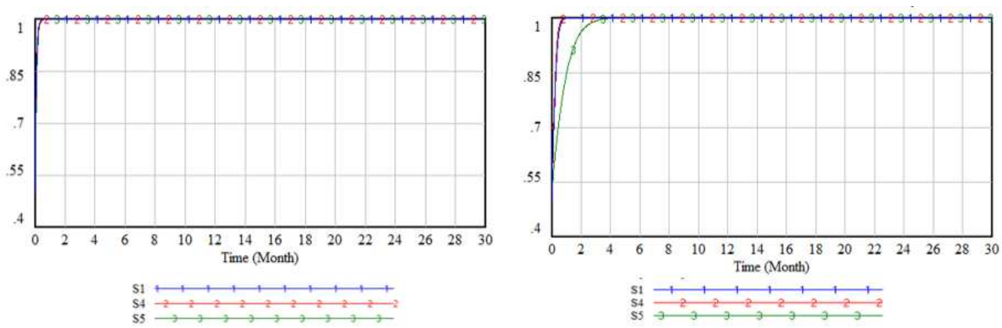

Figure 4. Simulation results of the sensitivity of the system to cost intensity.

(3) Simulation of sensitivity to the idle rate of charging piles

The idle rate of charging piles reflects the actual usage of charging piles. Personal charging piles are often used 1-2 times a week and have a high idle rate. The overall idle rate of charging piles in the urban area reflects the adaptation level of the overall charging infrastructure configuration, and reducing the overall idle rate is also an important goal for the charging pile platform operation to solve the uneven distribution of charging piles. Setting scenario 6 as the high idle rate scenario and scenario 7 as the low idle rate scenario, the idle rates are shown in Table 6, and the simulation results are shown in Figure 5. The decrease in idle rate will also reduce the rate at which the government and charging pile owners make joint decisions on platform sharing.

Table 6. Idle rate values for different scenarios.

parameter	Situation 1	Situation 6	Situation 7
P_l	0.1	0.3	0.1
P_h	0.7	0.9	0.3

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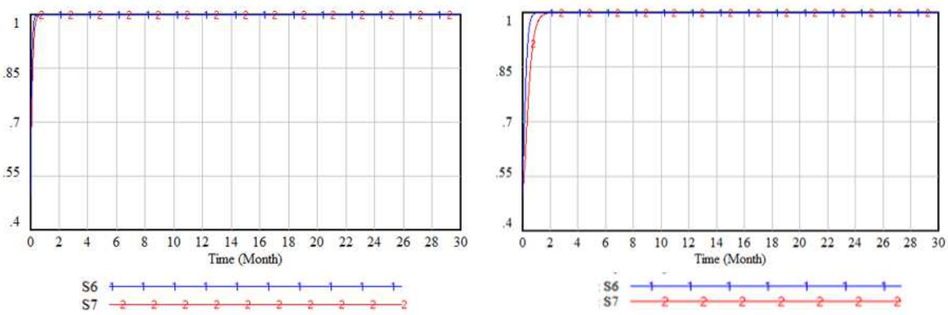

Figure 5. Simulation results of the sensitivity of the system to the risk factor.

(4) Simulation of sensitivity to market development stages

As many cities have already launched related shared charging station construction, the cost of charging station transformation will continue to change with the continuous maturity and progress of technology. Therefore, Scenario 8 is designed for the later stage of the market, where the idle rate of charging stations enters the normal range, the shared charging station market tends to be saturated, and the cost of charging station operation and maintenance increases significantly. Scenario 9 represents the mature stage of the market, where the idle rate of charging stations enters the normal range, and the transformation cost gradually decreases to a certain level as the market size expands. Scenario 10 represents the initial stage of the market, where personal charging stations grow rapidly, resulting in a rise in the overall idle rate of charging stations, and the shared charging station market is just starting, with high transformation prices. The coefficient values under each scenario are shown in Table 7.

Table 7. Coefficient values for different market development stages.

parameter	Situation 8	Situation 9	Situation 10
α	3	2	2
P_h	0.3	0.3	0.5

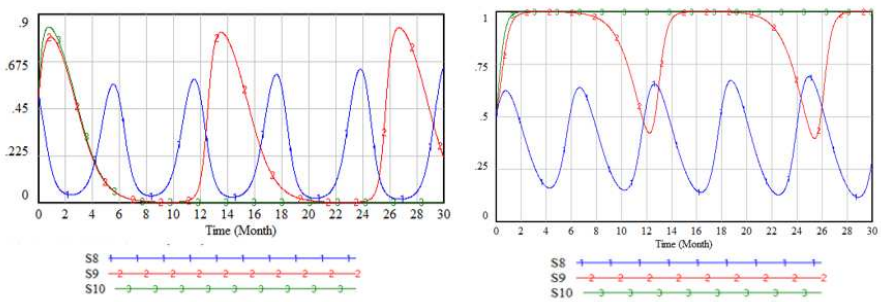

Figure 6. Simulation results of the sensitivity of the system to the international situation.

Under the condition that the idle rate enters the normal range, the adjustment of the decision-making behavior of both parties increases with the increase in retrofitting costs, leading to unstable fluctuations and making the game process difficult to control. It is challenging to obtain an evolutionarily stable strategy.

(5) Sensitivity simulation on the parameters of social benefits and charging post owners' revenue level

The social benefits reflect the improvement of the travel experience of electric vehicle drivers and the carbon reduction benefits brought by some private car owners choosing to purchase or replace their cars with electric vehicles due to the overall increase in the use of charging stations in the city. The quantification of this parameter needs to consider both the overall development of

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electric vehicle travel and the overall social benefits brought by the development of low-carbon transportation in the city. It is challenging to accurately determine and is compared in two scenarios, high and low. Similarly, the normal revenue level of charging station owners is also compared in two scenarios, high and low, with parameter values shown in Table 8. The simulation results, as shown in Figure 7, demonstrate that as the social benefits significantly decrease, the government's decision-making changes from proactive to inactive. Conversely, the improvement of social benefits accelerates the government's decision-making process towards a more proactive approach, reflecting the government's consideration of overall social development. The decision of charging station owners remains unchanged.

Table 8. Parameter values for social benefits and charging stake owners' benefit levels in different scenarios.

parameter	Situation 1	Situation 11	Situation 12
R	150	75	300
G	100	50	200

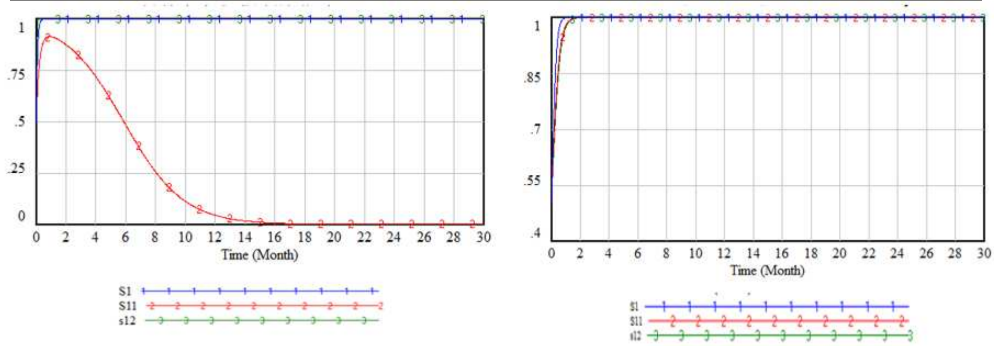

Figure 7. Simulation results of the sensitivity of the system to the level of social benefits and charging post owners' benefits.

(6) Sensitivity simulation of charging stake owners' participation in revenue sharing platform

The costs and benefits of participating in a sharing platform are important considerations for charging station owners in making decisions from a business perspective. In this study, we compared two scenarios: one where the benefits of participation increase while costs remain unchanged (Scenario 13), and another where the benefits remain constant while costs increase (Scenario 14). The parameter values used in the simulation are presented in Table 9, and the simulation results are shown in Figure 8. When the benefits of participation in the sharing platform increase, charging station owners accelerate their decision-making process to participate. However, when the cost of retrofitting the charging stations increases significantly while the benefits remain unchanged, charging station owners switch from a participation strategy to a non-participation strategy. The government's decision remains unchanged, but the speed at which it adopts an active strategy increases when charging station owners switch to a non-participation strategy.

In conclusion, the costs and benefits of participating in a sharing platform are critical factors for charging station owners in making business decisions. As shown in our simulation results, charging station owners are more likely to participate when the benefits increase. However, if the costs increase significantly, they may choose to opt-out of the sharing platform. These findings have important implications for policymakers and charging station owners in promoting the adoption of electric vehicles and developing sustainable transportation systems.

Table 9. Parameter values of cost and benefits for charging station owners participating in the sharing platform under different scenarios.

parameter	Situation 1	Situation 13	Situation 14
ΔG	20	100	20
I	60	60	100

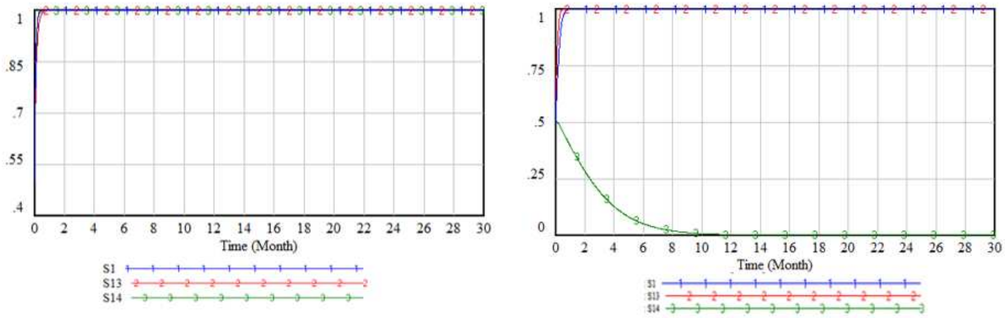

Figure 8. Simulation results of the sensitivity of the system to the cost and benefits of charging station owners participating in the sharing platform.

5. Conclusions

As urban transportation develops towards green and low-carbon solutions, the popularity of electric private cars is increasing. However, the problem of unreasonable distribution and low utilization of charging piles has affected the choice of green travel for residents. To alleviate this problem, it is necessary to promote the "private pile sharing" mode. In this article, a game theory model and a system dynamics-based evolutionary simulation model are constructed to analyze the decision-making benefits of both sides in the private pile sharing mode, involving the charging pile owner and the platform builder (government). The operational mechanism of government and charging pile owners' decisions and the evolutionary process of game stability are analyzed, leading to the following conclusions:

(1) Shared charging piles are a feasible solution to alleviate the imbalance of vehicle pile configuration, promote the low-carbon development of urban transportation, reduce the idle rate of existing charging piles, and provide more convenient charging services for urban electric vehicle users, which meets the interests of both the government and charging pile owners. Both sides will weigh the benefits (including social benefits) and costs of implementing the charging pile sharing strategy to make decisions. A shift from a proactive strategy to a non-proactive strategy by either side will accelerate the decision of the other party.

(2) When$\Delta G - I + P_l L + \beta S + \gamma F > 0$，$P_l E + R > \partial A + \beta S$occur, that is, the comprehensive benefits of the charging pile owner joining the sharing platform strategy, such as management fee reduction, financial subsidies, and idle rate reduction, exceed the charging pile modification expenses, and the social benefits brought by the government's proactive decision-making are greater than the investment in building the sharing platform, the system obtains one evolutionary stable strategy. Under this circumstance, both parties have the driving force to actively engage in charging sharing platforms, which conforms to the pursuit of benefits by charging pile owners and the maintenance of social public interests by the government.

(3) Policy decisions to improve the controllability of the strategic material cross-border supply chain are affected by external factors such as international market prices and international geopolitical situations. When the cost intensity increases significantly, the government tends to adopt a non-proactive policy, but charging pile owners will accelerate the decision to carry out supply chain integration. When the risk increases significantly, it will also accelerate the rate at which the government and charging pile owners carry out supply chain integration decisions. However, simultaneous significant fluctuations in price and risk will make the decision-making behavior

of both parties unstable and difficult to control, and it is difficult to obtain an evolutionary stable strategy during the game process.

(4) The government's ability to bear the financial expenditure required for policy formulation determines the direction of government decision-making. When the government tends to adopt a non-proactive decision, charging pile owners will adopt a supply chain integration strategy to avoid the huge losses that may be caused by supply chain interruptions. When the international market price of strategic materials is in a stable operating state, it is the best time window for the government to implement relevant policies.

Author Contributions: Conceptualization, Lequn Zhu; Data curation, Xiaojun Li; Methodology, Lequn Zhu and Linlin Zhang; Writing – original draft, Lequn Zhu; Writing – review & editing, Ran Zhou and Xiaojun Li. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Key Research and Development Program, grant number 2022YFE0113500 and the Tianjin Key Research and Development Program, grant number 22YFZCSN00030.

Conflicts of Interest: The authors declare no conflict of interest.

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