

Incentive Management of Power Demand-side Project Construction Considering Environmental Loss Allocation Based on Evolutionary Game Theory

Zhiqiang Zhang, M.Sc

Xin Huang, M.Sc

Jiajia Huan, M.Sc

Xiaohui Zhang, M.Sc

Yuhua Ji, M.Sc

Zhiqiang Zhang, Lecturer, Grid Planning & Research Center, Guangdong Power Grid Co., Ltd, Guangzhou, Guangdong 510080, China. Xin Huang, Lecturer, Grid Planning & Research Center, Guangdong Power Grid Co., Ltd, Guangzhou, Guangdong 510080, China. Jiajia Huan, Lecturer, Grid Planning & Research Center, Guangdong Power Grid Co., Ltd, Guangzhou, Guangdong 510080, China. Xiaohui Zhang, Lecturer, Grid Planning & Research Center, Guangdong Power Grid Co., Ltd, Guangzhou, Guangdong 510080, China. Yuhua Ji, Lecturer, Electric power research institute, CSG, Guangzhou, Guangdong 510663, China.

Correspondence LecHuang; nqiune@163.com

Objectives: Power demand-side construction projects should consider the potential environmental damage and formulate feasible measures to increase the willingness of participants to take the initiative actions. **Methods:** This paper innovatively takes the concept of environmental loss cost into the discussion of the project environmental governance issues, and applies the potential cost expenditures of both principal parts to the study of game strategy equilibrium problems. **Results:** And then, the evolutionary game analysis method is used to discuss the balance of supervision and incentives between government departments and power companies under different strategic choices. Considering the environmental damage cost, the research suggests that taking measures to improve the efficiency of government supervision, reducing supervision costs, or increasing the punishment of power enterprises for delaying responsibility will guide the government's strategy to evolve in the direction of strengthening supervision. **Conclusion:** Increasing the incentives or penalties for power enterprises of taking active responsibility of environmental will also help improve the environmental governance of power demand-side projects. Finally some research perspectives are brought to the attention of readers.

Keywords: environmental loss; evolutionary game analysis; dsm

Tob Regul Sci.™ 2021;7(5-2):4645-4655

DOI: doi.org/10.18001/TRS.7.5.2.29

In the new era of electric power marked by the rapid growth of renewable energy sources such as wind power and photovoltaic power generation, it is becoming more and more important and urgent to further strengthen power demand-side management (DSM)¹. DSM

originated in the United States in the 1970s, which is a customer-participated energy efficiency management technology and energy-saving operation mechanism², meanwhile DSM can optimize the allocation of power resources, coordinate the relationship between energy and

environment, promote advantages of energy saving and emission reduction, which can improve and protect the environment and realize energy-saving and low-cost power services. Generally speaking, power demand-side management requires the construction of feasible power projects to improve power efficiency, change power use methods, optimize resource allocation, reduce power costs, and improve the power environment. From the perspective of industrial ecological environment, the DSM project can help users save electricity and money, and provide users with a clean and convenient electricity environment. Therefore, in order to achieve continuous and effective environmental improvement, the incentive measures for project construction are considered to be important influencing factors. Among them, power enterprises and the government are the main subjects for the effective implementation of DSM projects. Only to ensure that the interests of these two subjects remain undiminished, that the DSM can proceed smoothly³. However, existing studies believe that in the current power market environment, there is a "different oneness" in the implementation of power demand-side management projects, that is, the cost distribution and benefits of project construction are not uniform, which brings certainty to the implementation of new power technologies⁴. The inhibitory effect. Especially in terms of uncertain cost sharing caused by changes in environmental natural factors due to project construction, there is a certain interest game between the government and power enterprises including power construction unit in the DSM projects.

Most of the current research does not consider the cooperation or conflict behavior between the participants⁵, so the construction of the power demand-side management incentive mechanism lacks dynamic and comprehensiveness. In order to accurately analyze the game behavior between the main bodies of the power demand-side management system, focus on the power demand-side management policy operating environment, adopt a dynamic evolution game model to analyze the game behavior in the power demand-side management process, and optimize the design of power demand-side management policy incentive measures, Has become the focus

of current research.

Studies believe that the adverse consequences of environmental pollution on human health are not immediately manifested as symptoms of everyone's disease, but have potential impacts on people living in a polluted environment, leading to the deterioration of relevant human indicators to a certain extent, which is harmful to health, causing hidden dangers. Based on the above-mentioned influences, during the construction of electric power construction projects, waste water, waste gas, waste residue, dust, radioactive waste and other pollutants are generated, and due to their discharge volume and discharge method, environmental pollution is caused, which brings certain pollution to the power construction project. Social exclusion and increase the cost of project governance. In the construction of such projects, the responsibility of the government and power grid companies for environmental pollution and the distribution of costs and benefits are important aspects of solving the power demand-side project construction.

From the perspective of cost sharing, the cost of environmental pollution control will generally be included in the cost of the final product and reflected in the price. The environmental pollution control of power construction projects should be provided by the government from the perspective of public goods; but from the perspective of market attributes, the construction unit should bear the environmental control costs of project construction. The division of responsibilities for cost sharing has become one of the main issues between the government and power enterprises in the construction of power demand-side projects. In fact, power products are neither private goods nor pure public goods, but quasi-public goods with some characteristics of public goods. Treatment of environmental pollution usually involves conflicting economic, environmental and social ecological impacts⁶. Power projects are prone to benefit differences between the construction party and government supervision, especially the supervision and cost burden of environmental pollution control, and the construction party is the easiest to profit from it. From the perspective of government supervision, power demand-side construction projects should be able to encourage power

enterprises to take the initiative in environmental governance to maintain the function of the industry and stabilize the foundation of the power industry in the long-term economic construction.

For such problems, the game has become one of the main analytical paradigms. Classical game theory presupposes "economic man", that is, game participants are completely rational. Under the assumption of complete rationality, the game party takes the maximization of its own interests as the decision-making goal, and reacts very rationally to achieve the optimal state. However, in actual economic activities, affected by the external environment, psychological effects, knowledge ability, background ability and other complex factors, the rationality of the game party is restricted, leading to the existence of "bounded rationality" in the game⁷. Under the assumption of "bounded rationality", participants adjust their behaviors through learning and feedback, and play repeatedly until they reach equilibrium. The government is the main promoter and supervisory body of power demand-side project construction. In the implementation of power market reforms, it will direct, guide, guide and regulate the implementation of DSM projects by power enterprises, and support power enterprises in terms of policies and regulations. The purpose of the government is to achieve social benefits such as energy saving and pollutant emission reduction from the perspective of the whole society; power enterprises are the implementers of DSM projects, and they must not only undertake the heavy responsibility of DSM project construction and transformation, but also ensure that corporate benefits do not decline. The various costs in the construction process are generally agreed in the bidding contract; however, it is obviously difficult for both parties to agree on detailed rules for the supervision of potential environmental governance and cost sharing. At the same time, because the government and power enterprises have different interest points in the promotion of DSM work, there will inevitably be fierce games. Both parties will adjust the game strategy according to the other party's behavior, maximize the utility of both parties in the repeated game process, and achieve Nash equilibrium.

METHODS

Evolutionary Game Theory

Game theory was first applied in the field of economics, mainly used to study the interaction between economic individuals⁸. And then, the idea of evolutionary game was proposed by ecologists such as Fisher and Hamilton⁹. Subsequently, some scholars combined the theory of biological evolution with the ideas of evolutionary games, and gradually applied evolutionary games to ecological problems. After 1980, economists began to use evolutionary games to study environmental economic issues¹⁰⁻¹². The emergence of evolutionary game theory expands the research field of game theory and solves the limitations of traditional game theory. Evolutionary game theory abandons the completely rational assumption in traditional game theory. It believes that the participants are economic people with bounded rationality. The optimal strategy of participating groups is not achieved at one time, but through mutual imitation, trial and error, mutation, etc. The process changes dynamically. In addition, evolutionary games do not require participants to have complete information. The participants' information is gradually accumulated during each game. Combining the past strategy choices and gains and losses to make a new strategy choice is a dynamic game process. Evolutionary stable strategy (ESS) and replication dynamic equation are two core concepts in the process of evolutionary game analysis¹³.

Replication dynamic thinking is to describe the evolutionary trend of behavior of bounded rational individuals in a large group by simulating the process of natural selection. The replication dynamic equation is a differential equation that describes the dynamic change of the frequency of a certain strategic behavior in the population with time. The replication dynamic equation of a single population can be expressed as :

$$F(x) = \frac{dx_i}{dt} = x_i[f_i(x) - \bar{f}(x)] \quad (1)$$

x_i represents the frequency of strategy \boxtimes selected; $f_i(x)$ represents the expected return of strategy \boxtimes selected; $\bar{f}(x)$ represents the average

expected return when the whole group chooses different strategies.

Participants of the Evolutionary Game

Traditional game theory has been widely used in the research of incentive mechanism of power projects^{14,15}. However, traditional game theory is based on the assumption that the participants are completely rational and complete information, which is contrary to the reality. In addition, traditional game theory lacks the analysis and explanation of how the participants reach equilibrium in the process of the game, and cannot explain the dynamic process of the game. The evolutionary game theory breaks through the limitations of traditional game theory¹⁶. It believes that the participants are not completely rational, and their decisions are dynamically changed through mutual learning and imitating between groups over time. Therefore, the evolutionary game theory is more suitable for studying the conflict of interest analysis of power demand-side project construction, that is, the study of incentive mechanism and establishment^{17,18}.

It is assumed that the government and power enterprises will participate in the construction period of the power demand-side project. According to the current policy, the government is responsible for the policy formulation and subsequent supervision and management of power demand-side project construction. Its ultimate goal is to maximize social welfare, ensure the orderly progress of project construction as much as possible, and continuously improve environmental safety; at the same time, timely investigate the environmental impact during the construction and duration of the project, and order the power company to make timely rectification. As a limitedly rational economic man, electric power enterprises follow the principle of maximum utility in their behavior decisions, that is, from the perspective of individual interests, there may be problems of poor environmental supervision or neglect of environmental governance. The government and power enterprises are different interest groups and have different interest demands. According to the assumption of a bounded rational economic man, the two parties

cannot fully understand each other's behavior; the supervision and governance caused by the environmental ignorance of power enterprises can be regarded as the dynamic process of mutual learning and imitation among groups.

The Strategic Choice of the Game Participants and Game Process Analysis

When power enterprises produce environmental problems, they need to manage environmental pollution in a timely manner; however, they may also choose to ignore some of the environmental impacts in consideration of their own economic interests and the impact of various subjective and objective factors. Therefore, power enterprises may choose the strategic choice as "take the initiative to take responsibility, delay taking responsibility". However, in reality, government supervision can't fully grasp the environmental damage of construction projects, and therefore can't determine the cost of governance in time. It is necessary to conduct supervision and review of the construction activities of power enterprises through a certain form, taking into account the cost of supervision and review. For factors such as strength and efficiency, the government will adopt a sample survey method, so the government department's strategy choice space is "supervise, not supervise".

From the perspective of the game process under the static reward and punishment mechanism. The main purpose of government supervision is that power enterprises take the initiative to undertake the environmental pollution control of construction projects. It is assumed that the government provides certain policy incentives to actively undertake environmental governance, such as more accurate environmental assessment before construction, or certain subsidies for governance of environmental damage that may occur during construction and operation. For companies that ignore environmental damage issues, additional economic penalties are imposed, and it is assumed that the revenue from fines is used for environmental damage governance. At the same time, it is assumed that for the government departments that discover environmental damage, especially the grassroots management departments, the higher-level departments will give certain rewards; in addition,

the environmental damage that may occur due to the construction of power demand-side projects is related to the government’s Prestige; therefore, when government supervision fails to find environmental damage, it will not only cause pollution caused by environmental damage, but also cause the public to lower the evaluation of government supervision and reduce the government’s prestige.

Competition in the power industry helps increase consumers’ welfare ¹⁹, but the environmental governance is the foundation. Government’s game behavior as the environmentalist is the inevitable result of Chinese-style decentralization at this stage [20]. Power enterprises are the construction parties of power demand-side projects, and the effective power supply revenue derived from the projects makes them the main beneficiaries. Regardless of

any changes during its construction and operation, its interest appeals always follow the principle of maximizing corporate utility rather than maximizing social public interest. When the environmental damage of the construction project actually occurs, some power enterprises find out in time and assume the responsibility for governance, but another part of the company may have a fluke mentality and choose to ignore it due to insufficient supervision.

RESULTS

Parameters Definition

Evolutionary game model of power construction project with environmental loss sharing include the following parameters indicated in Table 1.

Table 1
Parameters in the Model

Parameters	Meaning
C_1	The supervision cost of government departments on environmental damage of power construction projects
C_2	Project environmental governance costs when power enterprises ignore environmental damage and are not found
C_3	Increased cost of social environmental governance when environmental damage occurs
C_4	Construction costs saved by power enterprises delaying environmental responsibility
M_1	Reward for timely reporting of environmental damage discovered by government agencies
M_2	Rewards for power enterprises taking the initiative to take responsibility for environmental governance
T_1	Penalties for power enterprises for delaying responsibility for environmental damage
T_2	Increased engineering costs caused by power enterprises’ responsibility for environmental damage delays
p	Efficiency of government supervision
G_c	Increased prestige obtained by government agencies in promptly detecting and punishing environmental damage
G_d	Environmental damage occurs and has not been supervised to damage the prestige of government agencies

Model Building

Power enterprises should take the initiative to undertake environmental damage management during project construction and operation. It is assumed that the probability of taking the initiative is x , then, probability of choosing to delay responsibility is $1-x$, which $0 \leq x \leq 1$.

In order to ensure that environmental damage is contained in a timely manner, government agencies will adopt sampling surveys to investigate power demand-side projects, which audit cost is C_1 , but even due diligence, there may be omissions. Therefore, assuming the effective rate of the audit as p . Companies that ignore environmental governance and go undetected will save costs C_4 . If power enterprises are found to be responsible for the delay in environmental damage, they will be punished T_1 , And power enterprises will increase costs T_2 on the basis of the original project. At this time, if the basic government department finds environmental damage and report it in time, it will be rewarded M_1 by the superior department. At the same time gaining public recognition and

increasing government prestige G_c . If power enterprises take the initiative to undertake environmental governance, they will be rewarded M_2 . Power enterprises ignore environmental damage and fail to discover it will cause the project to incur governance costs C_2 , and environmental damage will increase the cost C_3 of governance of the social environment. At the same time, this will also cause the public to lower the evaluation of the government, and the damage to the government's prestige is G_d . Due to the limited administrative resources of government departments, the probability of supervision is y , and the probability of insufficient supervision is $1-y$.

According to the above assumptions, there are 4 types of strategy combinations available for evolutionary game model: (supervision, active responsibility), (non-supervision, active responsibility), (supervision, delayed responsibility), (non-supervision, delayed responsibility). The payment matrix of government departments and power enterprises is shown in Table 2.

**Table 2
Game Payout Matrix**

		Government departments	
		Supervision (x)	non-supervision (1-x)
Power enterprises	Active responsibility (y)	$M_2, -C_1 - M_2$	$M_2, -M_2$
	Delayed responsibility (1-y)	$p(-T_1) + (1-p)C_4,$ $p(M_1 + T_1 + T_2 + G_c - C_1)$ $+ (1-p)(-C_1 - C_2 - C_3 - G_d)$	$C_4, -C_2 - C_3 - G_d$

Regulatory Evolution and Stability Strategy of Government Departments

From the above payment matrix, it can be obtained that the expected return of government departments are as follows, when they exercise supervision and non-supervision over power

construction projects

$$U_{Gx} = y(-C_1 - M_2) + (1-y)[p(-C_1 + M_1 + T_1 + T_2 + G_c) + (1-p)(-C_1 - C_2 - C_3 - G_d)]$$

$$U_{G(1-x)} = y(-M_2) + (1-y)(-C_2 - C_3 - G_d)$$

The average expected return of government

departments is:

$$\overline{U}_G = xU_{Gx} + (1-x)U_{G(1-x)} \quad (4)$$

The probability change rate of government

$$\begin{aligned} F_G(x) &= \frac{dx}{dt} = x(U_{Gx} - \overline{U}_G) \\ &= x(1-x)(U_{Gx} - U_{G(1-x)}) \\ &= x(1-x)[p(1-y)(M_1 + T_1 + T_2 + G_C + C_2 + C_3 + G_d) - C_1] \end{aligned} \quad (5)$$

The derivation of the government agency's

supervision and inspection is $\frac{dx}{dt}$, and the dynamic equation for replication of government departments can be abstained as following:

replication dynamic equation is:

$$F_G'(x) = (1-2x)[p(1-y)(M_1 + T_1 + T_2 + G_C + C_2 + C_3 + G_d) - C_1] \quad (6)$$

For further analysis, set $F_G(x) = 0$, then can obtain the equilibrium point that the government departments may reach is $x=0$ or 1, then:

initiative to take the responsibility is higher than y^* , at this time, the government agency chooses not to supervise is its evolutionary stable strategy.

$$y^* = 1 - \frac{C_1}{p(M_1 + T_1 + T_2 + G_C + C_2 + C_3 + G_d)} \quad (7)$$

Whether these three equilibrium points are the evolutionary and stable strategies of government departments, the analysis is as below:

(1) If $y = y^*$, $F_G(x) = F_G'(x) = 0$, and satisfied $0 \leq y \leq 1$

It shows that under the level y^* of power enterprises, all levels of x are the stable state of government departments.

When the probability that the power enterprises choose to take active responsibility is

$y = 1 - \frac{C_1}{p(M_1 + T_1 + T_2 + G_C + C_2 + C_3 + G_d)}$, all the supervision probabilities of government departments are in a stable state.

(2) If $y < y^*$, $F_G'(1) < 0$

Note $x=1$ is the only stabilization strategy for government agencies. That is, when the probability of the power company taking the initiative to take the initiative is less than y^* , at this time, the government agency chooses supervision as its evolutionary stable strategy.

(3) If $y > y^*$, $F_G'(0) < 0$

Note $x=0$ is the only stabilization strategy for government agencies. That is, when the probability of the power company taking the

Evolutionary Stability Strategy of Electric Power Enterprises

From the payment matrix, it can be obtained that the expected return of power enterprises are as follows, when they choose to take the active responsibility and delay the responsibility strategy.

$$U_{Ty} = xM_2 + (1-x)M_2 \quad (8)$$

$$U_{T(1-y)} = x[p(-T_1 - T_2) + (1-p)C_4] + (1-x)C_4 \quad (9)$$

The average expected return of electric power enterprises is:

$$\overline{U}_T = yU_{Ty} + (1-y)U_{T(1-y)} \quad (10)$$

The probability that the power company chooses to take the initiative is $\frac{dy}{dt}$, From this, the replication dynamic equation of the power enterprises is :

$$\begin{aligned} F_T(y) &= \frac{dy}{dt} = y(U_{Ty} - \overline{U}_T) \\ &= y(1-y)(U_{Ty} - U_{T(1-y)}) \\ &= y(1-y)[xp(T_1 + T_2 + C_4) + M_2 - C_4] \end{aligned} \quad (11)$$

The derivation of the replication dynamic equation of the power enterprises is:

$$F_T'(y) = (1-2y)[xp(T_1 + T_2 + C_4) + M_2 - C_4] \quad (12)$$

For further analysis, set $F_T(y) = 0$, then can obtain the equilibrium point that the power enterprises may reach $y=0$ or 1, then :

$$x^* = \frac{C_4 - M_2}{p(C_4 + T_1 + T_2)} \quad (13)$$

The following analyzes the power enterprises' strategic choices when the x have different value ranges.

(1) If $x = x^*$, then $F_T(y) = F_T'(y) = 0$ and $x \in [0, 1]$

Any probability choice of power enterprises is in a stable state. When the government department supervises and inspects power enterprises with a probability of $x = \frac{C_4 - M_2}{p(C_4 + T_1 + T_2)}$, the benefits of power enterprises choosing any strategy are the same, so the probability of power enterprises choosing to take the initiative is stable.

(2) If $x < x^*$, $F_T'(0) < 0$

Note $y = 0$ is the only stable strategy for power enterprises. That is, when the probability of government departments conducting supervision and inspection is less than x^* choosing delayed responsibility will be the evolutionary and stable strategy of power enterprises.

(3) If $x > x^*$, $F_T'(1) < 0$

At this time, $y = 1$ is the only stable strategy for

$$\begin{pmatrix} (1-2x)[p(1-y)(M_1 + T_1 + T_2 + G_c + C_2 + C_3 + G_d) - C_1] \\ y(1-y)p(T_1 + T_2 + C_4) \end{pmatrix}$$

From the above matrix, the corresponding

$$TrJ = (1-2x)[p(1-y)(M_1 + T_1 + T_2 + G_c + C_2 + C_3 + G_d) - C_1] + (1-2y)[xp(T_1 + T_2 + G_c + C_4) + M_2 - C_4] \quad (15)$$

Compared with actively spending funds for environmental remediation, ignoring environmental damage is profitable for power enterprises. In addition, due to certain implementation obstacles to supervision, power enterprises will have to spend a lot of governance costs after they choose to take the initiative. Although in the long run, it is achievable that the government's incentives M_2 to actively take

power enterprises. That is, when the probability that the government chooses supervision and inspection is higher than x^* , the electric power company will choose to delay responsibility as its evolutionary stability strategy.

Analysis of System Partial Equilibrium

It is generally believed that the local stability of the equilibrium point of the evolutionary game system can be judged by Jacobi matrix composed of the partial derivatives of the dynamic equation system.

If the determinant value of the Jacobi matrix $DetJ$ is greater than zero and the trace value TrJ is less than zero, the replication dynamic system has an evolutionary stability strategy (ESS). The evolutionary game system has five local equilibrium points, namely $A(0,0)$, $B(1,0)$, $C(0,1)$, $D(1,1)$ and $E(x^*, y^*)$.

The Jacobi matrix of the system is:

$$J = \begin{pmatrix} \frac{\partial F_G(x)}{\partial x} & \frac{\partial F_G(x)}{\partial y} \\ \frac{\partial F_T(y)}{\partial x} & \frac{\partial F_T(y)}{\partial y} \end{pmatrix} = \begin{pmatrix} -x(1-x)p(M_1 + T_1 + T_2 + G_c + C_2 + C_3 + G_d) & (1-2x)p(M_1 + T_1 + T_2 + G_c + C_2 + C_3 + G_d) - C_1 \\ (1-2y)[xp(T_1 + T_2 + C_4) + M_2 - C_4] & y(1-y)p(T_1 + T_2 + C_4) \end{pmatrix}$$

determinant and trace can be obtained as:

$$DetJ = |J| = (1-2x)(1-2y)[p(1-y)(M_1 + T_1 + T_2 + G_c + C_2 + C_3 + G_d) - C_1][xp(T_1 + T_2 + C_4) + M_2 - C_4] + yx(1-x)(1-y)p^2(T_1 + T_2 + C_4)(M_1 + T_1 + T_2 + G_c + C_2 + C_3 + G_d) \quad (14)$$

responsibility for power enterprises are greater than the cost of power enterprises' delay in taking responsibility C_4 . But $C_4 < M_2$ is unrealistic in the short term, so in a certain period of time, $C_4 > M_2$ will always exist.

According to the values of $DetJ$ and TrJ , in order to determine the determinants and trace values of the 5 equilibrium points, the value range of x^* and y^* need to further discuss, which means whether

$p(M_1 + T_1 + T_2 + G_c + C_2 + C_3 + G_d) - C_1$ is bigger than 0 and the relationship between C_4 and

$$p(T_1 + T_2 + C_4) + M_2.$$

Based on this, the local stability of each

equilibrium point is discussed under 4 different scenarios. The results are shown in Table 3.

scenarios		Local equilibrium points	D etJ	TrJ	Balanced result
scenario 1	$0 < x^* < 1$ $0 < y^* < 1$	A (0 , 0)	-	Δ	*
		B (1 , 0)	-	Δ	*
		C (0 , 1)	-	Δ	*
		D (1 , 1)	-	Δ	*
		E (x^* , y^*)	+	0	Center point
scenario 2	$x^* > 1$ $0 < y^* < 1$	A (0 , 0)	-	Δ	*
		B (1 , 0)	+	-	ESS
		C (0 , 1)	-	Δ	*
		D (1 , 1)	+	+	**
		E (x^* , y^*)	-	0	Non-equilibrium point
scenario 3	$0 < x^* < 1$ $y^* < 0$	A (0 , 0)	+	-	ESS
		B (1 , 0)	+	+	**
		C (0 , 1)	-	Δ	*
		D (1 , 1)	-	Δ	*
		E (x^* , y^*)	-	0	Non-equilibrium point
scenario 4	$x^* > 1$ $y^* < 0$	A (0 , 0)	+	-	ESS
		B (1 , 0)	-	Δ	*
		C (0 , 1)	-	Δ	*
		D (1 , 1)	+	+	**
		E (x^* , v^*)	+	0	Center point

*: Saddle point; **: Unstable point; Δ : Uncertain

It can be seen that scenario2, scenario3 and scenario4 have the evolutionary stable strategy

(ESS). It is a common strategy for power companies to delay taking responsibility. Simulation by assignment (omitted) shows in the scenario 2 and scenario 4, measures such as improving the efficiency of government supervision, reducing the cost of supervision, or increasing the penalty for delaying responsibility can be used to guide the government's strategy to evolve in the direction of supervision. Meanwhile, in the scenario 1 and scenario 2, when other conditions remain unchanged, the cost saved by the power enterprises' delay in assuming responsibility is a key factor affecting its decision-making. Therefore, in order to effectively guide electric power enterprises to take the active responsibility, it can choose increasing the rewards and punishments for taking the initiative responsibility, and improving the efficiency of government supervision to realize the enterprises' initiative to take responsibility for the construction of power demand-side projects.

DISCUSSION

Environmental governance consumes huge costs. Power enterprises and governments have a complicated game relationship in environmental governance during project construction. The evolutionary game model in this paper reflects the cost and benefit between the two participants and the game relationship to a certain extent. In the game relationship of environmental governance cost sharing, the continuous fluctuations and shocks of the strategies of the two sides of the game may prevent government departments from adopting specific strategies to control the behavior of enterprises, which may result in more environmental governance costs. In addition, it can be seen to a certain extent that the strategic choice of power companies to delay responsibility is of great significance, and it also brings great challenges to government supervision.

The game system does not have an ideal evolutionary stable strategy in scenario1, that is, the strategic choice of power enterprises will not evolve in the direction of active responsibility. Therefore, in order to achieve the goal of controlling the stability of the strategy selection

probability of both parties in the game and improving the probability of the game party choosing the ideal strategy, how to introduce effective policy tools will be the focus of subsequent research later.

Human Subjects Approval Statement

This paper did not include human subjects.

Conflict of Interest Disclosure Statement

None declared.

Acknowledgements

This paper is supported by the Guangdong Power Grid Corporation Power Planning Special Research Project (No. 031000QQ00190001)

References

1. Babu S, Mohan U. An integrated approach to evaluating sustainability in supply chains using evolutionary game theory. *Computers & Operations Research*, 2018, 89: 269-283.
2. CHEN Mingzhao, MAO Jian, DU Zonglin, et al. Analysis on demand-side management scheme of industrial enterprise based on clustering method. *Power System Protection and Control*, 2017, 45(7): 84-89.
3. Cheng, S. C., CW; Huang, GH. "An integrated multi-criteria decision analysis and inexact mixed integer linear programming approach for solid waste management." *Engineering Applications of Artificial Intelligence* 2003, 16(5): 543-554.
4. Chu Zhaopeng, Bian Chen, Liu Changxin, Zhu Jing. Evolutionary game analysis on haze governance in Beijing-Tianjin-Hebei: based on a simulation tool for proposed environmental regulation policies. *China Population, Resources and Environment*, 2018, 28(12): 63-75.
5. Ding Yi, Hui Hongxun, Lin Zhenzhi, Zheng Menglian, Qu Xinyao, Cui Wenqi. Densin Of Business Model and Market Framework Oriented to Active Demand Response of Power Demand-side. 2017, 41(14):2-9+189.
6. Guo Kunjian, Gao Ciwei, Lin Guoying, Lu Shixiang, Feng Xiaofeng. Optimization Strategy of Incentive Based Demand Response for Electricity Retailer in Spot Market Environment. *Automation of Electric Power Systems*, 2020, 44(15): 28-37.
7. Hamilton W D. Extraordinary Sex Ratios. *Science*, 1967, 156(3774): 477.
8. Li D. Linear programming approach to solve interval-valued matrix games. *Omega-international Journal of Management Science*, 2011, 39(6): 655-666.

9. Li Junlin, CUI Lin, YAO Dongmin. Reinhard selten exploration of bounded rationality and experimental economics. *Economic Perspectives*, 2017(2): 148–158.
10. Luan Tianhong, Wang Shun, Xu Zhenchao. Design of Project Financing Risk Sharing Mechanism: A Study Based on Electricity Infrastructure Projects. *On Economic Problems*, 2019(05): 67-74.
11. NIU Wenqi, SHI Anna. Study on DSM Based on Evolutionary Game Theory. *On Economic Problems*, 2011(11): 61-64.
12. PACHECO J M, SANTOS F C, DINGLI D. The ecology of cancer from an evolutionary game theory perspective. *Interface Focus*, 2014, 4(4): 1–9.
13. Song Zongyun, ZHANG Jian, Zheng Zedong, Xiao Xinli, He Yuankang. Power Demand-side Management Policy Incentive Process Dynamic Evolutionary Game Analysis. *Electric Power*, 2019, 52(10): 54-64.
14. Wang Zhixuan. China's power demand-side management reform. *Energy Outlook*, 2018, (09): 27-34.
15. Wang, C., Shi, F. An Evolutionary Game Model for Industrial Pollution Management under Two Punishment Mechanisms. *Int. J. Environ. Res. Public Health*, 2019, 16, 2775.
16. Wang, Shanyong, Fan, J., Zhao, D.T., Wu, Y.R. The impact of government subsidies or penalties for new-energy vehicles a static and evolutionary game model analysis. *Journal of Transport Economics And Policy*, 2015, 49, 98–114.
17. Wu Guangdong, Yang Huilin. An Evolutionary Game Model for Contractor's Moral Hazard and Prevention Mechanism in Construction Project. *Science & Technology Progress and Policy*, 2018, 35(24): 56-63.
18. Wu, T., Ma, L., Mao, Z., Ou, X. Setting up charging electric stations within residential communities in current China: Gaming of government agencies and property management companies. *Energy Policy*, 2015, 77, 216–226.
19. YANG Taihua, LI Zhixiang, QIN Jin. Game Model Analysis of Safety Cost Sharing in Power Investment Project along "The Belt and Road". *Journal of East China University of Science and Technology (Social Science Edition)*, 2019, 34(03):43-50.
20. Yu Liangchun, Liu Yanbo. Consumers' Welfare in China's Electric Power Industry Competition. *Research on Economics and Management*, 2017, 38(08): 55-64.