Research on the Evolution Mechanism and Enhancement Strategy of Dual Synergy of Energy Innovation System Based on Multi-Agent Win-Win Situation

Jing Gao [1,a], Yang Gao[1,b], Tao Guan [2,*]

[a]jgaohit@163.com, [b]18246575420@163.com,[*]Corresponding author: Tao Guan, hitguan_tao@163.com

[1] School of Economics and Management, Harbin University of Science and Technology, Harbin 150000, China

[2] School of Economics and Management, Harbin Institute of Technology, Harbin 150001, China

Abstract. Digital empowerment for green and low-carbon transformation and green innovation to pull digital leap is an important way for energy companies to realize sustainable development. The dynamic connection between heterogeneous subjects and the environment can accelerate the evolution of the dual synergistic development of digitalization and greening. Therefore, this paper analyzes the mechanism of "dual synergy" of the energy innovation system composed of energy enterprises, academics and researchers, and the government, constructs a three-party evolutionary game model and simulates it with MATLAB software, which shows that: the main body's willingness, the distribution of benefits, the liquidated damages, and the government's governance have different degrees of impacts on the dual synergy of the energy innovation system at different stages of digitization. The degree of influence of dualization synergy is different. Based on this, we propose the evolution strategy of "dualization synergy" for energy innovation system in different stages of digital transformation, in order to realize the high-quality development of energy enterprises.

Keywords: Energy innovation system, Multi-subject, Dual synergy, Evolutionary game

1 Introduction

As a combination of economic growth and environmental protection, green innovation has become a "green engine" for high-quality economic development[1]. Facing ecological constraints and high energy consumption, energy enterprises should promote green transformation on the basis of guaranteeing a sustainable and stable supply of energy in order to realize the improvement of energy efficiency. The digital empowerment of innovation cooperation and resource sharing among multiple actors can improve the efficiency of low-carbon technological innovation and create a favorable digital ecosystem[2]. The need for shared and higher level digital technology for green transformation will in turn lead to digital development[3]. Therefore, accelerating the formation of an energy innovation system that synergizes the development of digitalization and greening is the key to promoting the greening and digital transformation and upgrading of the energy industry under the "dual-carbon" goal[4].

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With the continuous development of digital technology, the bilateral interaction of innovation subjects can no longer meet the needs of innovation and development, and an energy innovation system characterized by multi-subject interaction has emerged[5]. Among them, the government can promote the construction of green, intelligent and ecological civilization in the field of energy through the Environmental Protection Law and other environmental policies[6], not only to improve the value of energy enterprises, but also to take into account the benefits of stakeholders, so as to achieve a win-win situation for the interests of multiple subjects. Based on the win-win situation and environmental constraints, the diversified innovation organization of energy innovation system and the continuous reconstruction and development of digital technology field can help to establish cross-regional green development partnership, joint planning, implementation and monitoring of green development projects, which can realize the optimal synergy effect of digitalization and greening[7]. Therefore, it is necessary to explore the mechanism of "dual synergy" of the energy innovation system composed of energy enterprises, academics and researchers, and the government based on the perspective of win-win situation of multiple actors, and then put forward the evolution strategy of "dual synergy" of the energy innovation system at different stages of the digital transformation. It is necessary to put forward the evolution strategy of "dualization synergy" in different stages of digital transformation.

2 Literature Review

In this regard, scholars have conducted research on energy innovation system from three aspects, namely, participant, driver and research method. In terms of participating subjects, most scholars have studied the dual subjects of manufacturers and suppliers[8], while some scholars have studied the evolution of green innovation system for tripartite subjects of government, enterprises and consumers[9]. Although some scholars have analyzed the law of collaborative innovation among the government, enterprises and academic and research institutes[10], the systematic innovation of government, industry, academia and research has not yet been utilized, and few scholars have studied the heterogeneous nature of green innovation system, which is the key to solve the bottleneck of strategic industry development. Few scholars have analyzed the multiple demands of heterogeneous subjects of green innovation system to realize win-win collaboration among subjects. In terms of driving factors, scholars believe that the internal factors of the energy innovation system mainly include the willingness to innovate[11], knowledge absorption capacity[12], and benefit distribution[13], while the external factors include environmental regulation[14], market demand[15], and digitalization level[16]. Although existing studies have recognized that the evolution of the innovation ecosystem is not only affected by a single type of factors, but also by the interaction, existing studies have not yet formed a unified view on the evolution of the innovation ecosystem's driving force. In terms of effect evaluation, some scholars analyze the synergistic evolution of regional green innovation system under the influence of high-speed rail through linear stability based on the B-Z response model[17]; some scholars use data envelopment analysis to study the efficiency of industry-university-research collaborative innovation in order to enhance the green innovation capacity of the national innovation system[18]; some scholars construct a Logistic model to explore the dynamic synergistic evolution mechanism of green technology innovation system based on the innovation value chain[19].Research has been carried out on the collaborative evolution of the energy innovation system to carry out in-depth discussions, and energy innovation system innovation subjects in the cooperation process is not completely rational, will be based on the scenario of multiple learning and adjustment, and the evolution of the game theory emphasizes the "finite rationality" and the analysis of the dynamic evolution process, although some scholars have used the evolution of the game to analyze the green technological innovation of the Although some scholars have used evolutionary games to analyze the driving role of green technology innovation[20], there are few evolutionary games involving dual-chemical synergy in energy innovation systems.

Regarding the dual-chemical synergy, scholars mainly carry out research from three aspects: research object, function mechanism and evaluation method. The research objects mainly include: corporate[21], and region[22], and other single macro subjects, but a single subject is not a necessary condition for green innovation, and the interaction and combination of multiple subjects can effectively promote green innovation[23], and fewer scholars have explored the impact of synergistic relationship between subjects of energy innovation system on innovation efficiency. From the point of view of the mechanism of action, the existing research mainly focuses on the mechanism of enterprise digital transformation to drive the efficiency of green innovation[24], and further explains that the driving effect of high-intensity environmental regulation on enterprise digital transformation is stronger, but few studies have elucidated the mechanism of green innovation to force enterprises to digitally transform. Overall, the current research on the relationship between digitization and greening is relatively focused on digitization-enabled green innovation, and there are still relatively few studies on green innovation forcing enterprises to digitally transform and the combination of the two. However, the synergistic development of the innovation system is neither determined by a single factor nor a derivative relationship of a single factor, but a whole that is synergistically modulated by a variety of relatively independent subsystems. In terms of research methodology, some scholars use the coupling coordination degree model to measure the level of coupling coordination between the digital economy and green technology innovation[25], or use the evolutionary game model to explore the relationship between traditional enterprises and consumers and the government to explore the evolutionary game under the government's policy[26], but few scholars have used the tripartite evolutionary game model to explore the heterogeneity of the heterogeneity of the subject at different stages of digitalization. The green collaborative innovation strategies of subjects in different digitalization stages. Therefore, it is very important to construct a tripartite evolutionary game model of enterprises, academics and researchers, and the government based on the win-win situation of multiple subjects in order to analyze the mechanism of greening and digitizing synergistic development of the energy innovation system.

In view of this, this paper explores the dual synergy mechanism of the energy innovation system, constructs a tripartite evolutionary game model of enterprises, academics, researchers and the government, and analyzes the influence of the driving factors of the dual synergy of the energy innovation system at different stages of digitization, so as to put forward a targeted strategy of "dual synergy" with a view to promoting the collaborative transformation and development of the digitalization and greening of the energy enterprises, which provides reference for the development of digital greening of the energy enterprises.

3 Dual synergy mechanism of energy innovation system

3.1 Energy innovation system and its composition

Based on the innovation system theory and the characteristics of energy enterprises, this paper defines the energy innovation system as a system in which energy enterprises, in order to satisfy consumers' green demand preferences and achieve the goal of green, low-carbon, and digital innovation, interact and communicate with academics, researchers, government and other innovation organizations through digital platforms, share resources, jointly research and develop low-carbon products and technologies, and industrialize the results of green innovation, so as to realize the win-win situation of multiple subjects. The structure of energy innovation system is shown in Figure 1.

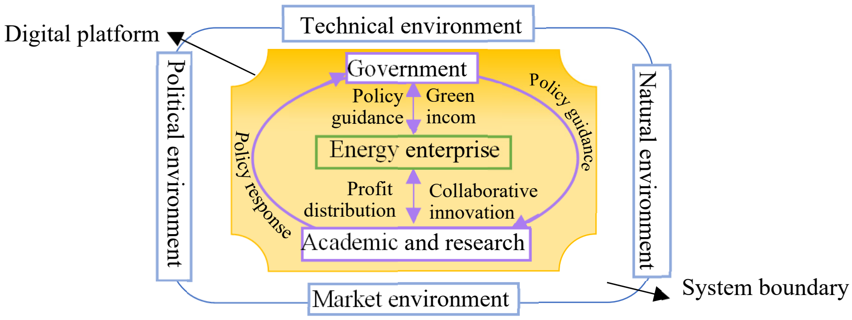


Figure 1. Energy innovation system and its composition

As can be seen in Figure 1, the energy innovation system consists of innovation main body, innovation resources and innovation environment. The main body of innovation includes energy enterprises, academic and research institutions and the government. Innovation resources mainly cover capital, knowledge, talent and technology needed for innovation, while data, as a new production factor, is both an asset and a resource. The innovation environment mainly includes the scientific and technological environment, natural environment, policy environment and market environment, which provide a realistic basis for the research and development of green technologies. The energy innovation system has the following four characteristics:

(1) Heterogeneity of participating subjects. The energy innovation system is composed of energy enterprises, academics and researchers, the government and other interacting subjects. Among them, the main bodies directly involved in green innovation activities include enterprises and researchers; the main body indirectly involved in green innovation activities is the government, which mainly provides policy guidance and financial support and other functions.

(2) Pluralism of the subject's goal. The goal of energy enterprises is to promote the pace of green and digital transformation of enterprises, and at the same time industrialize green innovation achievements; the goal of academic and research institutions is to improve their own R&D capability, practical ability and academic strength; and the government pursues the long-term development of the society and pays attention to social and ecological benefits.

(3) Stages of system development. The energy innovation system presents the evolutionary characteristics of progressive innovation, with obvious stages. According to the evolutionary stage of energy innovation system is divided into early digital, mid-digital and late digital.

(4) The win-win of collaborative behavior. Under the strategic goal of dual-chemical synergy, the heterogeneous innovation main body takes building a digital low-carbon energy enterprise as the key, takes economic benefits and social effects as the driving force, builds a synergistic and win-win energy innovation system, and jointly promotes the system's greening and digitalization transformation and upgrading

3.2 Dual synergy mechanism of energy innovation system

Under the influence of the external environment, the enterprises, researchers and governments of the energy innovation system will benefit from each other's resources, such as talents, funds and technologies, and eventually realize the "dualization synergy". The dualization synergy mechanism of the energy innovation system is shown in Figure 2.

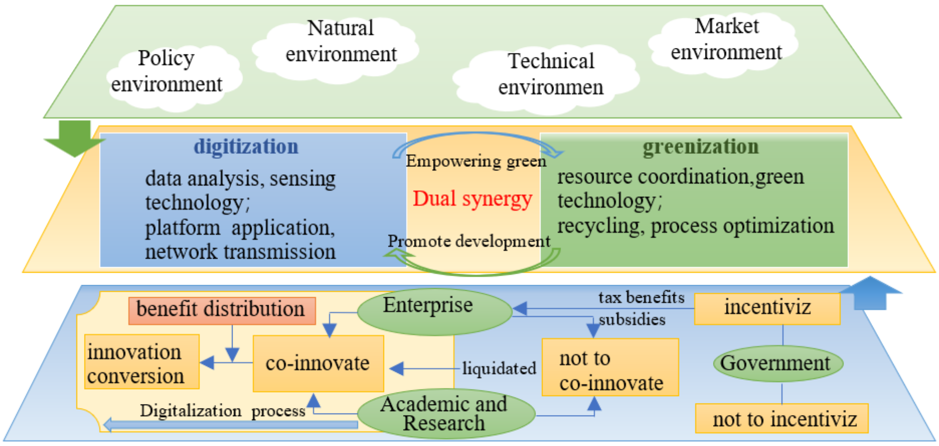


Figure 2. Dual synergistic mechanism of energy innovation system

As shown in Figure 2, the dual synergy mechanisms are mainly as follows:

(1) To meet the green market demand and fulfill the social responsibility of environmental protection, energy enterprises optimize the process flow and strengthen the resource synergy through digital technology, which plays a supporting role in the green transformation of energy enterprises[27]. The high requirements of green innovation on digital acquisition technology and network transmission performance can promote the improvement of enterprise digitalization level, thus realizing the gradual integration of greening and digitalization.

(2) Mechanism of collaborative strategy selection. Collaborative innovation between enterprises and academics and researchers to obtain complementary resources, thus realizing green transformation and technological breakthroughs[28]. The government can improve the R&D intensity of energy enterprises and promote technological innovation through the implementation of two incentive policies, namely subsidies and tax incentives.

(3) Multi-body benefit distribution mechanism. When enterprises and academic and research institutions distribute benefits, they should formulate a reasonable proportion of benefit distribution based on the amount of resource input. In addition, the green and digital transformation of enterprises can accelerate the development of supply chain members, while solving environmental pollution problems for local governments. The tax burden of the transformation of green innovation results can also become a huge fiscal revenue for the government.

(4) Mechanisms for integrating the development stages of dualization. In the early stages of digitization, digital technology plays the role of an accurate insight mechanism, thus realizing high-value potential innovation opportunities. In the middle stage of digitization, digital technology plays the role of promoting and facilitating the continuous iteration of new products, which ultimately enhances the performance of digital technology integration. In the late stage of digitization, digital technology plays the role of supporting optimization mechanism, which enables each entity to quickly and efficiently improve the internal value creation ability and external user value transformation ability.

4. Construction of the game model of energy innovation system

4.1 The theoretical basis and design idea of model construction

Evolutionary game theory to the limited rationality of the subject as the object of study, and will affect the behavior of the subject of the various factors integrated into the model, can be more intuitive examination of energy innovation system synergistic evolution trend. At present, there is little involved in the evolutionary game of energy innovation system dual-chemical synergy, therefore, this paper draws on the basis of existing research, constructs the energy enterprise-academia-research party-government tripartite evolutionary game to analyze the choice of green collaborative innovation strategy of heterogeneous subjects, so as to reveal the key driving factors of "dual-chemical synergy" of heterogeneous subjects of the energy innovation system, and further puts forward digital, green, and green subject behavioral strategies. In order to reveal the key driving factors of "dual-chemical synergy" of heterogeneous subjects in energy innovation system, and to further put forward digitalization and greening synergistic development strategies.

4.2 Research hypothesis

Based on stakeholder theory, this paper integrates enterprises, academic and research parties and government that affect collaborative innovation into the energy innovation system. Any change in the interests of any participant will cause the change of collaborative innovation strategy. Based on this, this paper puts forward the following three hypotheses:

Hypothesis 1: Participant. Without considering other constraints, the government, enterprises and academic and research institutions form a complete energy innovation system, and the three subjects are bounded rational individuals. In the process of the dual-system development of energy innovation system, the government mainly provides policy guidance and governance for the green collaborative innovation process between energy enterprises and the university and research institute; the enterprise is mainly responsible for providing resources and the university and research institute green innovation process; the university and research institute is mainly responsible for collaborative research and development of green and low-carbon technologies to promote the green and digital transformation of energy enterprises.

Hypothesis 2: Engagement strategy. In order to simplify the strategy selection of participants and compare the synergistic innovation effectiveness before and after the selection, both enterprises and academic and research parties can only choose synergistic innovation and non-synergistic innovation according to their own interests. The government can only regulate and not regulate. Strategy set of enterprises: (co-innovate, not to co-innovate), x is the probability of enterprises choosing collaborative innovation; Strategy set of the academic and research parties: (co-innovate, not to co-innovate), y is the probability that the academic and research parties choose collaborative innovation; Government strategy set: (incentivize, not to incentivize), z is the probability that the government chooses to govern industry-university-research collaborative innovation; x, y and $z \in [0,1]$.

Hypothesis 3: Game income. Energy innovation system green innovation has obvious positive externalities[29], green innovation will save resources, reduce environmental pollution, the social benefits of energy innovation system itself, but the main body of green innovation will pay for this higher innovation costs, if the new energy enterprises for the choice of dual synergy, the cost of green technology research and development for C_1; at this time, if the academic and research institutions also choose dual-chemical synergy, the cost paid for C_2. The digitalization level of energy enterprises can affect enterprise performance by empowering green innovation[30]. To simplify the research this paper defines the impact of digital transformation on enterprise performance as a linear form. That is, the energy enterprise counts the original benefit as $(1+b)E_1$; the initial benefit of the academic and research side is E_2; and the original benefit of the government is E_3. when the energy enterprise and the academic and research institutions knowledge, personnel and other complementary synergies, it will create a new knowledge value generated by the benefit of R. If the proportion of the benefit distribution of the academic and research structure is a, the green benefits obtained by the academic and research side are $a(1+b)R$, and the energy enterprise obtains the green benefits as $(1-a)(1+b)R$. In order to ensure the stability of cooperation, the energy enterprise or the academic and research parties to develop if one of the parties choose not to dualization synergy, need to pay compensation for breach of contract F. At the same time, the development of energy enterprises often produce more serious environmental pollution and resource waste, but also need to government to use environmental regulation means to influence the energy innovation system green innovation behavior, there are two main ways, the tax breaks H and the green innovation inputs for the human cost of government incentives is C_3. If the government chooses not to incentivize, it can only obtain its original benefits.

4.3 Payment matrix construction

Based on the above three assumptions, the income matrix is shown in Table 1.

Table 1 The payoff matrix of the double cooperative evolutionary game of energy innovation system

Game player	Academic and research prescriptions	
	co-innovate(y)	not to co-innovate(1−y)

government	incentivize(z)	enterprise	co-innovate(x)	$(1+b)E_1+(1-a)(1+b)R+W-C_1$, $E_2+a(1+b)R-C_2$, $E_3+c(1+b)R-W-C_3$	$(1+b)E_1+F+W-C_1$, E_2-F, E_3-W-C_3
			not to co-innovate(1–x)	$(1+b)E_1-F-H$, E_2+F-C_2, E_3+H-C_3	$(1+b)E_1$, E_2, E_3-C_3
	not to incentivize (1–z)	enterprise	co-innovate(x)	$(1+b)E_1+(1-a)(1+b)R-C_1$, $E_2+a(1+b)R-C_2$, E_3	$(1+b)E_1+F-C_1$, E_2-F, E_3
			not to co-innovate(1–x)	$(1+b)E_1-F$, E_2+F-C_2, E_3	$(1+b)E_1$, E_2, E_3

4.4 Establishment of replication dynamic equation and solution of equalization strategy

The expected returnU_x^1 for the enterprise choosing " collaborative innovation ", the expected returnU_2^xx for choosing "no collaborative innovation ", the average expected return U^X and the replication dynamic equation $F(x)$ are:

$$U_x^1 = yz((1+b)E_1 + (1-a)(1+b)R + W - C_1) + y(1-z)((1+b)E_1 + (1-a)(1+b)R - C_1) + z(1-y)((1+b)E_1 + F + W - C_1) + (1-y)(1-z)((1+b)E_1 + F - C_1) \quad (1)$$

$$U_2^x = yz((1+b)E_1 - F - H) + y(1-z)((1+b)E_1 - F) + z(1-y)(1+b)E_1 + (1-y)(1-z)(1+b)E_1 \quad (2)$$

$$U^X = xU_x^1 + (1-x)U_2^x = x(yzH + y(1-a)(1+b)R + zW + F - C_1) - yzH - yF + (1+b)E_1 \quad (3)$$

$$F(x) = dx/dt = x(1-x)(yzH + y(1-a)(1+b)R + zW + F - C_1) \quad (4)$$

Similarly, the replication dynamic equation $F(y)$, $F(z)$for the academic and research parties and the government are:

$$F(y) = y(1-y)(xa(1+b)R - xF - zF + F - C_2) \quad (5)$$

$$F(z) = z(1-z)(xyc(1+b)R - xyH - xyW + yH - C_3) \quad (6)$$

Let f(x)=0, f(y)=0, f(z)=0, and solve them to obtain eight local equilibrium points of the system as (0,0,0), (1,0,0), (0,1,0), (0,0,1), (1,0,1), (0,1,1), (1,1,0), (1,1,1), and (1,1,1), respectively. According to the stability criterion of the Jacobi matrix , the stability analysis of the local equilibrium point of the system is performed, and the partial derivatives of equations (4), (5) and (6) are obtained, and the Jacobi matrix J is shown as follows.

$$J = \begin{bmatrix} \frac{\partial f(x)}{\partial x} & \frac{\partial f(x)}{\partial y} & \frac{\partial f(x)}{\partial z} \\ \frac{\partial f(y)}{\partial x} & \frac{\partial f(y)}{\partial y} & \frac{\partial f(y)}{\partial z} \\ \frac{\partial f(x)}{\partial x} & \frac{\partial f(z)}{\partial y} & \frac{\partial f(z)}{\partial z} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix} \text{,Among them}$$

$$A_{11} = (1-2x)(yzH + y(1-a)(1+b)R + zW + F - C_1) \quad (7)$$

$$A_{12} = x(1-x)\ (zH + (1-a)(1+b)R) \quad (8)$$

$$A_{13} = x(1-x)\ (yH + W) \quad (9)$$

$$A_{21} = y(1-y)(a(1+b)R - F) \quad (10)$$

$$A_{22} = (1-2y)(xa(1+b)R - xF - ZF + F - C_2) \quad (11)$$

$$A_{23} = -y(1-y)F \tag{12}$$

$$A_{31} = z(1-z)(yc(1+b)R - yH - yW) \tag{13}$$

$$A_{32} = z(1-z)(xc(1+b)R - xH - xW + H) \tag{14}$$

$$A_{33} = (1-2z)(xyc(1+b)R - xyH - xyW + yH - C_3) \tag{15}$$

8 equilibrium points are substituted into the Jacobian matrix to obtain the corresponding Jacobian eigenvalues, as shown in Table 2.

Table 2 Eigenvalues of Jacobian matrix

Equilibrium point	eigenvalueλ_1	eigenvalueλ_2	eigenvalueλ_3
(0,0,0)	$F-C_1$	$F-C_2$	$-C_3$
(0,1,0)	$(1-a)(1+b)R+F-C_1$	$F-C_2$	$H-C_3$
(0,0,1)	$W+F-C_1$	$-C_2$	C_3
(1,0,0)	C_1-F	$a(1+b)R-C_2$	$-C_3$
(1,1,0)	$-(1-a)(1+b)R-F+C_1$	$C_2-a(1+b)R$	$C(1+b)R-W-C_3$
(1,0,1)	$-W-F+C_1$	$a(1+b)R-F-C_2$	C_3
(0,1,1)	$H+(1-a)(1+b)R+W+F-C_1$	C_2	C_3-H
(1,1,1)	$-H-(1-a)(1+b)R-W-F+C_1$	$C_2-a(1+b)R$	$-c(1+b)R+W+C_3$

5. Simulation and analysis of dual-integration collaboration of energy innovation system

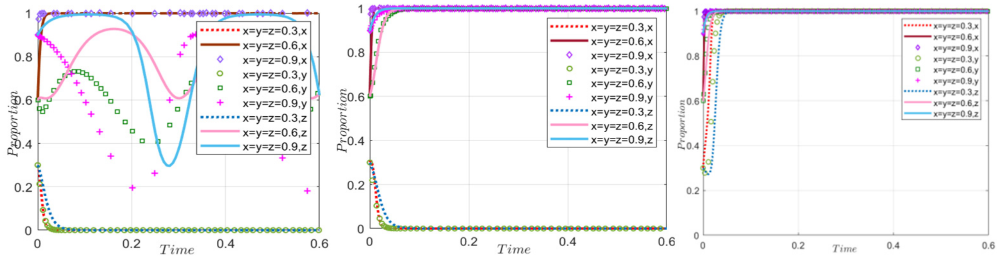
If we only deduce from the theoretical level, it is not possible to intuitively reflect the influence of parameter changes on the evolution of "dual synergy" of energy innovation system under different digitalization stages. In this paper, the digital transformation of the energy innovation system is divided into three stages: early digitalization stage b1 (information transformation of traditional energy enterprises), mid-digitalization stage b2 (digital platform) and late digitalization stage b3 (digital ecology). The parameter assignments are shown in Table 3.

Table 3. Initial assignment of related parameters

Parameter	b_1	b_2	b_3	a	c	R	C_1	C_2	C_3	W	F	H
Assignment	0.1	0.4	0.8	0.3	0.2	1000	400	250	80	80	100	200

(1) The influence of the cooperative willingness on the dual synergy of energy innovation system

It is assumed that the initial willingness of the three parties in the game x=y=z, and other parameters are shown in Table 2. The influence of the initial willingness of the main body o under different digitalization stages is shown in Figure 3.



(a) Early phase of digitization (b) mid-digitization (c) post-digitization

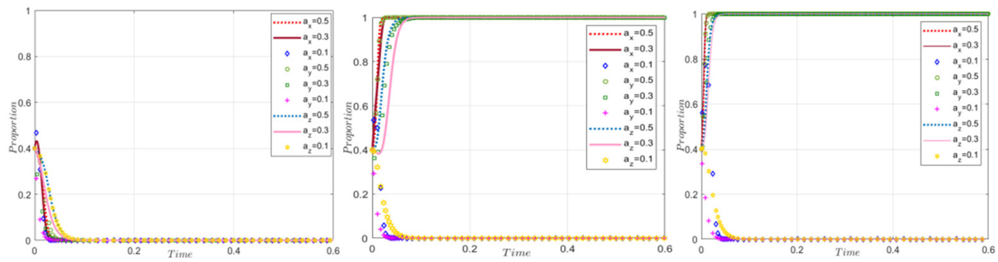
Figure 3. The influence of subject's cooperative willingness on the dual synergy

As can be seen from Figure 6, in the early stage of digitization, when the initial willingness x=y=z=0.3, x, y, z converge to zero; when the initial willingness x=y=z=0.6 or x=y=z=0.9, the evolution of enterprise collaborative innovation tends to be stable, while the willingness to participate of the academic and research institutions and the government rises but appears to be oscillatory. This may be due to the fact that in the early stage of digitization, academic and research institutions and the government have a skeptical attitude towards whether the digital construction of enterprises can meet the demand of green innovation. In the middle stage of digitization, when the initial willingness x=y=z=0.3, x, y, and z still converge to zero; when x=y=z=0.6 or x=y=z=0.9, x, y, and z all converge to 1. In the late stage of digitization, regardless of the initial willingness, the energy enterprises, academic and research institutes, and the government converge to a dualistic and synergetic evolution.

(2) The impact of university-research and enterprise cooperation on the dual synergy

(I) The influence of profit distribution coefficient on the dual synergy

The influence of the profit distribution coefficient of the academic and research parties in different digitalization stages is shown in Figure 4.



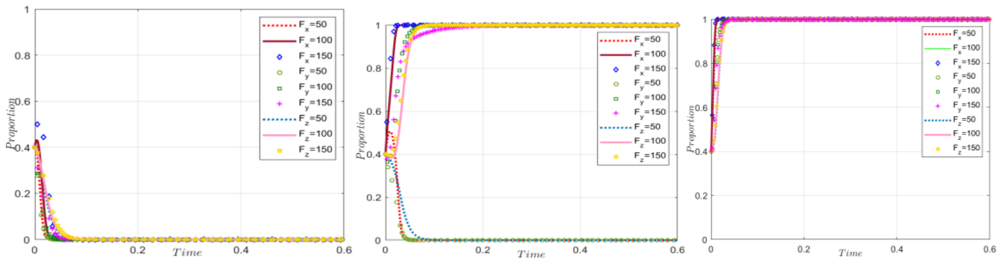
(a) Early phase of digitization (b) mid-digitization (c) post-digitization

Figure 4. Influence of profit distribution coefficient of academic and research parties on dual synergy

From Fig. 4, it can be seen that in the early stage of digitization, x, y, and z converge to 0. In the middle and late stage of digitization, when the coefficient of benefit distribution is 0.1, x, y, and z converge to 0. With the increasing of the coefficient of benefit distribution, x, y, and z converge to 1 and the convergence of y and z increases with the increasing of the coefficient of benefit distribution and accelerates. This is due to the fact that when the distribution of benefits is low, the academic and research institutions may not have a strong willingness to carry out collaborative innovation, and at this time, the willingness of enterprises and the government to collaborate and innovate in order to avoid losses will also decline.

(II) The influence of the change of liquidated damages on the dual synergy

The influence of the change in the amount of liquidated damages of the enterprise and the academic and research party under different digitalization stages is shown in Figure 5.



(a) Early phase of digitization (b) mid-digitization (c) post-digitization

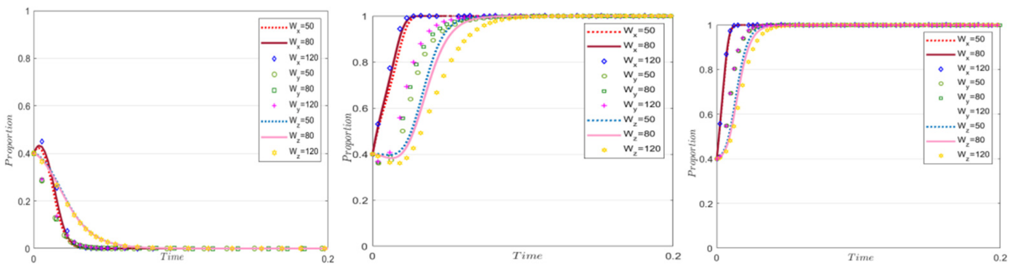
Figure 5. Influence of liquidated damages variation on dual synergy

From Fig. 5, it can be seen that in the early stage of digitization, x, y, and z converge to 0. While in the middle stage of digitization, when the amount of liquidated damages is 150 x, y, and z converge to 0, and as the amount of liquidated damages continues to increase, x, y, and z converge to 1, and the convergence rate of y and z accelerates with the increase of liquidated damages. This is due to the fact that lower liquidated damages are less binding for collaborative innovation between enterprises and academic and research institutions, and enterprises and academic and research institutions may not have a strong willingness to carry out collaborative innovation in order to obtain speculative gains. However, in the late stage of digitization, the instantaneous liquidated damages are 150, and x, y, and z also converge to 1. However, as the liquidated damages F keep increasing, its binding effect on the innovators will gradually become weaker, and the high liquidated damages constraints will become uneconomical.

(3) The influence of government guidance on the dual synergy

(I) The influence of government subsidies on the dual synergy

The influence of government subsidies on the dual synergy of energy innovation system under different digitalization stages is shown in Figure 6.



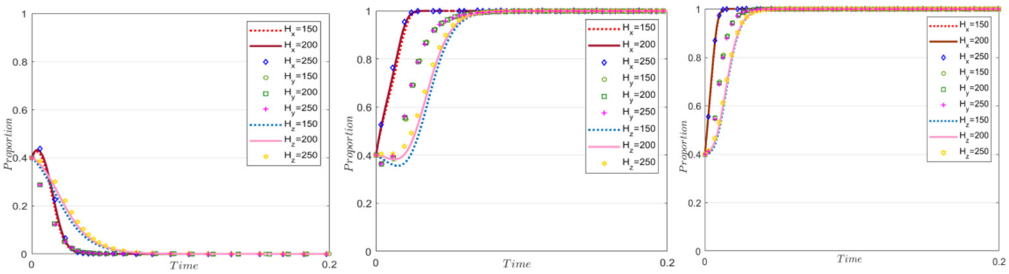
(a) Early phase of digitization (b) mid-digitization (c) post-digitization

Figure 6. Influence of government subsidies on dual synergy

As can be seen from Figure 6, x, y and z converge to 0 at the beginning of digitalization. With the increase of subsidies investment, the convergence rate of x, y and z slows down. However, in the middle and later stages of digitization, x, y and z all converge to 1, and the convergence speed of x, y and z accelerates with the continuous increase of subsidies. This indicates that with the increase of subsidies investment, the intention of collaborative innovation between energy enterprises and academic and research institutions is gradually strong. Through comparison, it can also be found that in the later period of digitalization, the time of the dual collaborative evolution of the main bodies of the energy innovation network is significantly shortened. But high subsidies investment has no significant effect on the incentive of innovation subjects, so it should not be adopted.

(II) The influence of tax incentives on the synergy

The influence of government tax incentives on the dual synergy of energy innovation system at different digitalization stages is shown in Figure7.



(a) Early phase of digitization (b) mid-digitization (c) post-digitization

Figure 7. Influence of government tax reduction and exemption on dual synergy

Figure 7 shows that in the early stage of digitization, x, y, and z converge to 0. In the middle and late stage of digitization, with the increasing tax relief, x, y, and z converge to 1. Tax incentives have an impact in two ways: on the one hand, the increasing tax incentives can cover the innovation costs of enterprises to a greater extent; on the other hand, they release a stronger signal, which can help to amplify the guiding and leveraging effects of the policy. On the other hand, it releases a stronger signal, which helps amplify the guiding and leveraging effects of the policy. However, in the late stage of digitization, the incentive effect of tax incentives on innovation subjects will gradually become weaker, and the continued use of high tax incentives will bring higher costs to the government.

6. Conclusions and recommendations

6.1 Conclusion

The "dual synergy" of digitalization enabling greening and greening pulling digitalization is an inevitable choice for energy innovation enterprises to realize high-quality development through digitalization and green transformation and upgrading. To this end, this paper takes the energy innovation system tripartite subjects: energy enterprises, research and government as the research object, analyzes the mechanism of "dual synergy" of the energy innovation system and constructs the tripartite evolution game model of enterprise-learning and research-government, and analyzes the influence of each factor on the evolution of dual synergy of the system at different stages of digitization by using the simulation of MATLAB software, according to which, the target is to analyze the impacts of each factor on the evolution of dual synergy. We also use MATLAB software to simulate and analyze the influence of each factor on the evolution of system dualization synergy at different stages of digitization, and accordingly put forward the strategy of "dualization synergy" for energy enterprises. The main work and conclusions of the study are as follows:

(1) Analyzing the mechanism of "dualization synergy" in energy innovation system. Based on defining the concept of energy innovation system and systematically analyzing its composition and characteristics, this paper analyzes the mechanism of "dual synergy" of energy innovation system. The study shows that: the interactive symbiosis mechanism of digitalization and greening; the mechanism of selecting the main synergistic strategy; the mechanism of distributing the benefits of multiple main bodies and the mechanism of coordinating the stages of dual development support the dual synergistic development of the energy system.

(2) Constructing a game model of energy innovation system evolution. Based on the existing research, this paper constructs a tripartite evolutionary game model of energy enterprise-academic research party-government to analyze the choice of green collaborative innovation strategy of heterogeneous subjects. The study shows that when the sum of government support, default amount and co-innovation benefit is greater than cost, enterprises will choose co-innovation; co-innovation benefit is greater than the sum of default amount and cost and academic and research institutions will choose active innovation; when the government's benefit is greater than the sum of its subsidies and governance costs, the government will choose to regulate.

(3) Simulation analysis of the influence factors of dualization synergy of energy innovation system. This paper uses MATLAB software to simulate and analyze the influence of internal and external factors on the evolution of system dualization synergy at different stages of digitization. The study shows that: heterogeneous subject willingness to collaborate, benefit distribution coefficient, the amount of liquidated damages, government R & D investment and tax relief and other factors in different stages of digitization on the evolution of energy innovation system "dualization synergy" has a certain degree of variability in the impact of factors.

6.2 Recommendations

(1) Initial digitization strategy: Strengthening government orientation. Clarify the overall goal of "dual-chemistry synergy" in the energy sector, and design stage-by-stage tasks accordingly. Local governments should give support to key projects, so as to promote the implementation of energy enterprises' "dualization synergy" on the ground. Second, improve the construction of enterprise digital facilities. The overall architecture of digital transformation should be developed to provide support for the interconnection of the innovation process of each main body. In addition, the use of digital technology for online monitoring of energy consumption data effectively reduces resource waste and carbon emissions. Third, improve the sense of synergy between enterprises and academic and research institutions. Led by the energy industry, leading enterprises and research institutes will participate in the formulation of the "dual-

chemical synergy" implementation guide, which will provide reference for the construction of the innovation system and the implementation of the "dual-chemical synergy" path.

(2) Medium-term digitalization strategy First, increase government support. Provide R&D subsidies and tax incentives for innovative applications that utilize digital technologies to achieve energy conservation and carbon reduction. The second is to adopt smart contracts and other digital technologies to help form a long-term effective benefit distribution mechanism, so as to better serve the interconnection and synergistic development between the main bodies of the energy innovation system. Third, increase the amount of liquidated damages between enterprises and academic and research institutions. In the green technology collaborative R & D agreement clearly agreed on the responsibility of breach of contract and set a high amount of liquidated damages, to avoid opportunism and "free-riding" behavior.

(3) Post-digitalization strategies First, the government should change the incentive model. Government incentives are no longer appropriate to take a "wide net" "one-size-fits-all" subsidy model, can be taken to lower subsidies and tax incentives to save government incentive costs. However, there is still a need to strengthen the supportive policy measures to support the publicity. Secondly, enterprises should adopt a medium level of benefit distribution. The distribution of benefits from green innovation should be based on a reasonable assessment of the continuous contribution of the innovator in the innovation process and the total benefits created.

Of course, this study has some limitations. In this paper, the dualization synergy is based on the traditional green innovation synergy evolution game, the introduction of digitization level parameters, and then analyze the dualization synergy strategy of energy innovation system at different stages of digitization, and in the future, we can try to incorporate the dualization synergy strategy and benefits directly into the analysis of the game model.

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