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Game Analysis of the Evolution of Energy Structure Transition Considering Low-Carbon Sentiment of the Decision-Makers in the Context of Carbon Neutrality

Xinping Wang [1], Zhenghao Guo [1], Ziming Zhang [1], Boying Li [2,*], Chang Su [3], Linhui Sun [1] and Shihui Wang [1]

[1] School of Management, Xi'an University of Science and Technology, Xi'an 710054, China
[2] School of Political Science and International Relations, Tongji University, Shanghai 200092, China
[3] School of Safety Science and Engineering, Xi'an University of Science and Technology, Xi'an 710054, China
* Correspondence: liboying@tongji.edu.cn

Abstract: Countries have started to aggressively undertake energy structure transformation strategies in order to reach the objective of carbon neutrality. Both clean and efficient coal energy use and clean energy use will be crucial to the process of changing the energy structure since the two cannot be totally replaced within a short period of time. In this study, we quantify emotions as an irrational factor, combine them with an evolutionary game using RDEU theory, and build an evolutionary game model between government regulators and energy consumers. We then analyze how low-carbon emotions of decision-makers affect their choice of strategy and the transformation of the energy structure. The findings support that by affecting the relative importance of each strategic choice, emotions have a profound impact on the evolutionary steady state of the system. Appropriate stress and anxiety can increase decision-makers' feelings of responsibility, while pleasant emotions frequently support strategic conduct. The main countermeasures are as follows: Allow government regulators and energy consumers to properly release positive information, with government regulators forming subsidies and energy consumers actively cooperating and promoting low-carbon activities. This will properly guide the low-carbon sentiment of game subjects to keep them realistically pessimistic.

Keywords: carbon neutrality; energy structure transition; low-carbon sentiment; RDEU; evolutionary game

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1. Introduction

More fossil fuels are being used as science and technology improve, which is a factor in the rising number of environmental problems. Achieving carbon neutrality has been suggested as a solution to the issue of industrial emissions caused by the use of fossil fuels [1]. These emissions have led to issues like the greenhouse effect. By 2050, it is expected that hundreds of countries will be carbon neutral [2] and a number of them have already incorporated carbon neutrality targets into their legal systems. Many nations have begun the shift from fossil fuels to alternative energy sources. Supporting the transition of the changing shape with the advancement of clean fossil fuels and new fuel technologies is critical. As China's economy expands and its CO_2 emissions increase, so does its standard of living, which drives up energy consumption [3]. According to data, China utilized primary energy equal to 3512.8 million tons of oil in 2020, making up 26.1% of the entire amount of energy consumed worldwide [4]. To accomplish carbon neutrality goals and to handle the numerous socio-economic and environmental concerns involved, regional energy transition strategies have been created to achieve low-carbon and sustainable development. The phrase "energy transition" has been referred to in a variety of ways by academics, including "sustainable energy transition" [3], "low carbon energy transition" [4], and "green energy transition" [5]. As a result, reducing greenhouse gas emissions is essential to reducing global warming, its impacts, and the ensuing socioeconomic and environmental issues. Alternative energy sources have been suggested, including examples include the construction of numerous hydroelectric power plants in the Iberian Peninsula and the continued improvement of wind energy generation in Xinjiang [6,7], the gradual advancement of solar energy storage [8], alternative technologies using materials, such as graphene as batteries [9], microbial fuel cell technology [10], and nuclear fission power systems [11,12], all of which have gradually matured, leading to an increase in the share of clean energy in all electricity. As China's economy expands and its CO_2 emissions increase, so does its standard of living, which drives up energy consumption [13]. According to data, China utilized primary energy equal to 3512.8 million tons of oil in 2020, making up 26.1% of the entire amount of energy consumed worldwide [14], it is anticipated that the carbon neutrality goal would be attained by 2060.

China is the country under the most pressure to reduce its emissions and use of energy. Despite fluctuations in economic growth due to the COVID-19 epidemic, China's electricity and energy consumption were still increasing significantly in 2020 [15]. As the main source of energy for power generation, half of fossil energy consumption comes from coal, but the share of clean energy generation has grown significantly [16]. In 2020, 64.7% of China's total power generation came from coal-fired power generation, with hydro-power generation ranking second and accounting for only 16.9% [14]. The country's level of urbanization is still rising, and the industrial structure's impact on the environment, which depends heavily on the combustion of fossil fuels in all areas, is becoming progressively worse [17]. In recent years, smart mines have also been developed with government regulation, emergency response capabilities, and clean coal technologies [18–20], which can operate in low-carbon and in a clean manner while achieving energy conservation [21]. Although green energy sources, such as wind, tidal, and biomass fuels, have relatively little environmental impact, they have the drawback of being unstable and intermittent in their supply [7], which raises the possibility of energy security risk events and jeopardizes the security of the energy supply. This indicates that the use of fossil energy, represented by coal resources, currently dominates the whole energy cycle and is unlikely to alter very soon [22]. Due to technology and other circumstances, the development of new energy applications and development in China is uneven. For example, the development of solar energy, hydrogen energy, and other clean energy sources is still at a very early stage. Due to this, clean energy and coal have been in a constant state of competition, with the latter unable to fully replace the former for an extended length of time. However, clean energy research and utilization have allowed for the safe and effective use of coal. Therefore, coordinating the development of both coal energy and clean energy within the framework of carbon neutrality is a key part of the energy structure change that needs to be dealt with.

The rest of the essay is organized as follows: The literature on the subject of this research is reviewed in Section 2, along with a brief description of the innovation points. The concerns related to research theory are presented in Section 3. Based on the RDEU theory, Section 4 creates an evolutionary game model. The game topics are subjected to stability and asset allocation stability analysis in Section 5. Section 6 runs the model's primary simulation. The study's findings, managerial lessons learned, and inadequacies are presented in Section 7.

2. Literature Review

2.1. Progress of Research on Energy Structure Transition

Analysis of energy strategy games has begun. In order to capture the drivers of the energy transition and in order to simulate and discuss the evolutionary process and evolutionary stabilization strategies to support the development of hydrogen-powered vehicles and solar photovoltaic hydrogen production, Wang et al. [23] analyzed a partnership consisting of an investment company, hydrogen-powered vehicle users, and solar photovoltaic power plants. To replicate and explain the evolutionary process, Wang et al. [24] proposed a partnership of carbon exchange, solar power plants, and coal-fired thermal power plants. Hou et al. [25] proposed a new conceptual model, the institutional economic-technical behavioral framework, to synthesize the similarities and differences in energy transitions in various nations. The German energy transition plan is significant as a framework for fostering the growth of renewable energy, as per Gao et al. [26] 's comprehensive analysis of several strategies for boosting renewable energy during the energy transition. In order to investigate whether the relationship between the government and the public can encourage manufacturers to adopt low-carbon technologies by examining the interaction effects between various stakeholders, Chen et al. [27] developed a three-way game model between the government, manufacturers, and the public under carbon taxes and subsidies. In order to study how financial penalties impact players' tactics and the evolutionary process of optimizing financial penalties, Chang et al. [28] developed a mixed strategy game model and an evolutionary game model for regulators and conventional energy corporations. The application of game theory has been well proven in the study of energy transition, and the theory of evolutionary games can explain how different strategic decisions may have an influence on the entire energy transition system.

2.2. The Use of Evolutionary Games in Energy Structure Transformation

Evolutionary game theory offers a reasonable analytical framework, given that energy structural transformation is a gradual and ongoing process rather than a sudden change that occurs only once. Many academics have conducted pertinent studies on energy transitions using this evolutionary game framework. In a three-way evolutionary game model that included regulators, energy companies, and whistleblowers, Yang et al. [29] discovered a substantial association between the likelihood of a whistleblower, the likelihood of active management by energy companies, and the likelihood of rigorous monitoring. Zhao et al. [30] analyzed the behavioral strategies of generators in connection to renewable energy and the influence of important institutional characteristics on the dynamic evolutionary process of generators. According to Qiao and Yin [31], who used an evolutionary game model based on psychological perceptions, strategic choices made by consumers and companies are essential to the effective implementation of the energy transition. In order to study two different types of power generation enterprises, Liu et al. [32] used an evolutionary game approach and a numerical simulation method of scenario analysis to study two different types of power generation enterprises. In order to deal with the complex relationship between the Chinese government, thermal power producers, and grid companies, Shang et al. [33] used a system dynamic (SD)-based evolutionary game. They came to the conclusion that the Chinese government must strictly enforce the renewable portfolio standard in order to promote green and low-carbon upgrading of energy and electricity (RPS). By examining the many actions each decision-maker in the process takes, these studies have concentrated on how the entire decision-making system changes to support the transition in the energy mix. However, are decision-making processes in government agencies and energy users entirely rational? It is unknown if additional factors have any role in their decision-making.

2.3. Progress of Emotions in Related Research

Nevertheless, research has shown that psychological preferences and feelings have an effect on decision-makers' inclinations and decisions, both in terms of long-term direction and contingency influences [34,35]. As an example, negative emotional states can have a direct impact on risk-taking behavior and decision-making [36]. Since decision-makers are limited in their rationality, in their behavioral choices, and have limited access to information, which can reveal different preferences and subsequently different emotions, emotions play a significant role in decision-making [37]. Decision-makers have varied psychological preferences and risk attitudes as a result of their differing values, interests, and contingent emotions [38]. Both government regulators and energy users experience emotions as a result, and these feelings can further affect their choices. The emotional attitudes of the participants in the energy structure transition towards the transition will have a significant impact on policy practices. However, the traditional evolutionary game does not take into account the psychological preferences and emotions of each player, so further improvement and refinement are required. The rank-dependent expected utility (RDEU) theory and evolutionary games have been merged. To create a co-evolutionary game model of shared manufacturing quality innovation with multi-subject involvement and examine how emotions impact quality improvement motivation, Zhang et al. [39] merged the RDEU theory with evolutionary game theory. To create an RDEU game model for various sectors, Ni et al. [40] merged game theory with the RDEU theory. They came to the conclusion that different emotional states and intensities impact evolutionary outcomes and evolutionary speed. Emotions are less often taken into account as an influencing element in research pertaining to the evolution of energy transitions, however. As a result, this article takes the impact of each game subject's low-carbon sentiment into account and builds an evolutionary game model that takes carbon sentiment into account using the RDEU theory. The mutual synergistic development of coal energy and clean energy is translated into the question of the impact of the share of coal and clean energy in the energy structure transformation on the energy structure transformation based on the issue of the share of coal and clean energy in the integrated energy consumption. Government regulators and energy consumers won't always act rationally in the face of energy structural transformation. In order to promote the efficient use of coal energy, the quick development of clean energy, and new advancements in energy structural transformation, we must first understand the effects that various emotions will have on people's decision-making and behavior, as well as on energy structural transformation.

Major research findings and importance of the study:

(1) In the new condition of energy structure transformation, coal energy and clean energy have been in a position of reciprocal gaming with regard to carbon neutrality. This paper discuss the effects of the shift to a cleaner energy mix after analyzing the decisions chosen by energy consumers and government regulators about the usage of efficient and clean coal.
(2) This paper creatively introduces the factor of low-carbon sentiment, where decision-makers are not in a fully rational state, and analyzes the impact of various low-carbon sentiments of government regulators and energy consumers on decision-making behavior and energy structural transformation. This is in contrast to other traditional studies exploring energy structural transformation.
(3) It contributes to the expansion of evolutionary game theory and applications by building a sentiment model that naturally combines evolutionary game theory and the RDEU theory to explain the tactical decisions chosen by government regulators and energy consumers under various sentiments and risk aversions.

3. Theoretical Assumptions

The Rank-Dependent Expected Utility Theory

Government regulators and energy consumers may have different attitudes toward clean energy options due to their dependence on coal and their usage habits, and thus different emotions in their strategy choices, as a result of the limited information available to them in the face of the energy transition process. Their psychological preferences and risk attitudes may also irrationally shift as a result of interest claims and situational emotions. The psychological interests and emotions of decision-makers may be well explained by the RDEU theory [41], which was put out by Quiggin [42]. It can "satisfactorily" explain the real decision-making behavior in a complicated model and accurately portray the great variability of decision-makers' emotions [43]. A real-valued function V defined by a utility function $U(x)$ and a decision weight function $\pi(x)$ is used to express the level of the decision-maker's preference for various options.

The function expression is:

$$V(x, u, \pi) = \sum_{i=1}^{n} \pi(x_i)U(x_i), i = 1, 2, 3, \cdots, n \tag{1}$$

The method's cumulative probability function is $RP_i = P(X \leq x_i) = \sum_{\tau \geq i}^{n} p_i, i = 1, 2, \cdots n$ for the set of strategies $X = \{x_i; i = 1, 2, \cdots n\}$ and $P = \{X = x_i\} = p_i$. Assuming that the methods x_i are ordered according to the amplitude of the utilitarian calculus $U(x)$ and defining $x_1 > x_2 > \cdots > x_n$, the utilitarian rank of the technique x_i is defined as RP_i. The bigger the strategy's utility, the higher its cumulative probability, and as a result, the more importance the strategy utility will have in the choice.

At this stage, the sentiments function, which is an asymptotic growing function fulfilling $\omega(0) = 0, \omega(1) = 1$, is represented by the decision weight function, $\pi(x) = \omega(p_i + 1 - RP_i) - \omega(1 - RP_i)$, where $\omega(\cdot)$ is the function.

The potential of $X \leq x$ being increased or decreased is possible by the function $\omega(\cdot)$. Here are the following three situations:

(1) $\omega(\cdot)$ is a concave function when $\omega(p) < p$. $\omega(\cdot)$ reduces the likelihood of $X \leq x$ for any $p \in [0, 1]$, demonstrating the participants' pessimism.
(2) $\omega(\cdot)$ is a convex function when $\omega(p) > p$. $\omega(\cdot)$ widens the likelihood of $X \leq x$ for any $p \in [0, 1]$, demonstrating the participants' optimism.
(3) The possibility is unchanged when $\omega(p) = p$, a sign that people are in a rational mood.

RDEU theory addresses decision weights by non-linearly altering the utility theory in traditional game theory. As a result, the shortcomings of conventional game theory in the attitude dimension can be partially compensated for by the RDEU theory. Additionally, by incorporating this theory, evolutionary game analysis can more objectively and accurately depict each participant's emotional state in the energy structure conversion and the impact of their psychological response on the structure's conversion.

4. Game Model Construction

4.1. Illustration of Relevant Gaming Concepts

Many academics have taken notice of the RDEU theory because it corrects the flaws in conventional game theory that do not adequately account for actual emotions [44] by taking into account how players' emotions may affect their decision-making behavior. An RDEU eagle-dove game model was created by Li et al. [45] to help resolve trade disputes between nations by taking into account the impact of corporate interests, conflict costs, "emotional variables," and "asymmetric elements" on enterprises' strategic decisions. The RDEU game model was developed by Liu et al. [46] after analyzing the equilibrium tactics of subject nations and stakeholders in the marine pollution industry from various interest vantage points. This model is crucial for researching international relations and environmental protection. A conflict-inducing game mechanism-relative expected utility theory (RDEU) evolutionary game model was created by Hong et al. [47] to investigate the evolution of the strategic behavior of expropriated farmers and local governments when emotions are present. In conclusion, the RDEU-based evolutionary game analysis may efficiently investigate how players' emotions affect their behavior while making decisions and may provide a more plausible depiction of the behavioral development of each game topic.

4.2. Model Hypothesis

Hypothesis 1 (H1). *In this study, the evolutionary game model is used for two finitely rational parties: energy consumers and government regulators. In the course of the game, one side alters their strategy in the energy structure transition, while the other side modifies their options in reaction to the other side's decision-making behavior. Each player in the game makes a tactical decision based on the illogical influence of emotion. Government regulators may play the energy structure transformation game in one of two ways: (1) To put green regulations into effect. The regulator adopts the green and low-carbon guiding philosophy and effective supervision with environmental protection as a prerequisite in the process of energy structure reform and development. (2) The use of traditional monitoring. In the process of developing and transforming the energy structure, supervisory measures are implemented using the notion of conventional management as a guiding* *thought. Additionally, there are two energy consumer strategy choices: (1) Put integrated energy utilization into practice and consumption practices that combine renewable energy with coal as a source. (2) The use of coal in a clean and effective manner and the practice of consuming energy only via the clean and effective use of coal as a fuel. In this paper, wind, hydroelectric, solar, and nuclear energy are examples of clean energy since they are all renewable energy sources with minimal environmental impact.*

Hypothesis 2 (H2). *Single coal energy and integrated energy are two categories that are separated based on the amount of energy used. In contrast to clean energy, which is difficult to store, expensive, and unstable but is a new type of energy whose environmental impact is minimal and difficult to cause, China's coal energy reserves are substantial, cheap, easy to transport, and also have the qualities of easy storage and high stability. The fact is that clean energy cannot, in a short amount of time, replace coal energy as the primary source of energy consumption; nonetheless, clean energy utilization and coal energy clean utilization work in tandem and grow together. In this study,* x_1 *stands for the externalized costs caused by the use of coal, such as high levels of air pollution and a high environmental burden, whereas* x_2 *stands for those caused by the use of clean energy, such as supply instability. Positive externalities, such as a reliable supply from the use of coal, are marked by* y_1*, while positive externalities, such as environmental friendliness from the use of renewable energy are denoted by* y_2*. a and b reflect the respective percentages of coal and clean energy in the total energy consumption. q is the probability of occurrence of potential systemic risks in the process of energy structure transformation, and L is the hazards/damage of potential systemic risks in the process of energy structure transition.*

Hypothesis 3 (H3). *In order to utilize coal and create clean energy efficiently, green regulations will force government regulators to develop appropriate inputs and outputs, and energy consumers will likewise carry out certain inputs and outputs. The government regulators will implement specific measures as part of the energy restructuring process to encourage the use of clean energy and the clean and efficient use of coal, with the number of subsidies being* l_1 *and* l_2*, and to encourage energy consumers to consider the advantages of environmental friendliness. Only when both government regulators and energy consumers make the right policy decision does the energy usage system reach a state that is secure and stable. Both parties' decision-making practices may influence one another, or a systemic risk event may happen as a result. According to the concept of risk sharing, risk is transferred, and the amount of risk transfer is quantified by a risk transfer factor.*

5. Model Optimization Analysis Considering Heterogeneous Emotions

Under the influence of emotional factors, the subjective probability function becomes $\omega(m_i) = mi^r$. When $r = 1$ the subjective probability value is the same as the objective probability value, and the game subject does not have emotions; when ($r < 1$) the subjective probability value is greater than the objective probability value and the game subject is optimistic; when ($r > 1$) the subjective probability value is smaller than the objective probability value, and the game subject is pessimistic.

Based on the assumptions of the underlying model in Section 2 and the relevant principles of RDEU theory, the rank-dependent expected utility models of government regulators and energy consumers under different strategies adopted are constructed, where parameter r_1 denotes the sentiment status of the government regulator, and the emotional intensity of energy consumers is represented by parameter r_2.

5.1. Stability Analysis of Government Regulators' Strategies Considering Low-Carbon Sentiment

Based on the correlation between the dimensions of cost, benefit, reward, and punishment, the utility rating for the government regulators' four strategy options is:

$$\begin{aligned} &a(y_1 - x_1 - S + l_1) + b(y_2 - x_2 - T + l_2) - c_1 > y_1 - x_1 - S + l_1 - c_1 - \beta\eta Lq \\ &> a(y_1 - x_1) + b(y_2 - x_2) - \theta Lq > y_1 - x_1 - Lq \end{aligned} \tag{2}$$

As a consequence, the utility, probability, rank, and decision weights applicable to each of the government regulators' strategies are shown in Table 1.

Table 1. Ranking of the expected benefits of government regulators, taking into account sentiment.

the Effectiveness of Government Regulators' Strategies	Probability	Rank	Decision Weights
$a(y_1 - x_1 - S + l_1) + b(y_2 - x_2 - T + l_2) - c_1$	mn	1	$\omega A(mn)$
$y_1 - x_1 - S + l_1 - c_1 - \beta\eta Lq$	$m(1-n)$	$1 - mn$	$\omega A(m) - \omega A(mn)$
$a(y_1 - x_1) + b(y_2 - x_2) - \theta Lq$	$(1-m)n$	$1 - m$	$\omega A(m + n - mn) - \omega A(m)$
$y_1 - x_1 - Lq$	$(1-m)(1-n)$	$1 - m - n + mn$	$1 - \omega A(m + n - mn)$

The expected benefits of "green regulation" and "regular regulation" by government regulators are U_{1m} and U_{2m}. The average expected return for government regulators is $\overline{U_m}$. Government regulators replicated the dynamic equation as $F(m)$. Specific formula content and derivation data is supported by the Equations (S4)–(S6) are provided in the Supplementary Materials Section.

5.2. Stability Analysis of Energy Consumers' Strategies Considering Low-Carbon Sentiment

Based on how the dimensions of costs, benefits, incentives, and penalties relate to one another, the utility score for the energy consumers' four strategy options is as follows:

$$\begin{aligned} & a(-c_2 + w_1 + S) + b(-c_3 + w_2 + T) > -c_2 + w_1 + S - \eta Lq \\ & > a(-c_2 + w_1) + b(-c_3 + w_2) - \beta\theta Lq > -c_2 + w_1 - Lq \end{aligned} \tag{3}$$

As a consequence, the utility, probability, rank, and decision weights applied to each of the energy consumers' strategies are shown in Table 2.

Table 2. Expected utility of energy consumers' rank dependence considering emotions.

Energy Consumers Strategy Utility	Probability	Rank	Decision Weights
$a(-c_2 + w_1 + S) + b(-c_3 + w_2 + T)$	mn	1	$\omega B(mn)$
$-c_2 + w_1 + R - \eta Lq$	$m(1-n)$	$1 - mn$	$\omega B(m) - \omega B(mn)$
$a(-c_2 + w_1) + b(-c_3 + w_2) - \beta\theta Lq$	$(1-m)n$	$1 - m$	$\omega B(m + n - mn) - \omega B(m)$
$-c_2 + w_1 - Lq$	$(1-m)(1-n)$	$1 - m - n + mn$	$1 - \omega B(m + n - mn)$

The expected benefits of "integrated energy use" and "clean and efficient use of coal" for energy consumers are U_{1n} and U_{2n}. The average expected return for energy consumers is $\overline{U_n}$. The energy consumers replicated the dynamic equation for $F(n)$. Specific formula content and derivation data is supported by the Equations (S7)–(S10) are provided in the Supplementary Materials Section.

5.3. Analysis of Strategy Portfolio Stability

Government regulators may attain local stability by pursuing a green regulatory approach when conditions are $m = 0$, $m = 1$, or $m = m^*$. Consumers of energy in phases $n = 0$, $n = 1$, or $n = n^*$ decide on an integrated energy usage plan to promote localized stability. As a result, the evolutionary game model's five partial equilibria are $E_1(0,0)$, $E_2(0,1)$, $E_3(1,0)$, $E_4(1,1)$, and $E_5(m^*, n^*)$.

Among them:

$$m^* = \frac{[(a-1)(-S+l_1)+b(-T+l_2)+\beta\eta Lq+\theta Lq-Lq]n+2(h_1-d_1)-S+l_1-c_1-\beta\eta Lq-Lq}{[(a-1)(-S+l_1)+b(-T+l_2)+\beta\eta Lq+\theta Lq-Lq]n+a(-S+l_1)-c_1-\beta\eta Lq+Lq}$$

$$n^* = \frac{[(a-1)(-c_2+w_1)+(a-2)R+b(-c_3+w_2)+bD+2\eta Lq-2\beta\theta Lq-Lq]m+R-\eta Lq+Lq}{[(a-1)R+bD+\eta Lq+\beta\theta Lq]m+(1-a)(-c_2+w_1)+R-b(-c_3+w_2)+\beta\theta Lq-\eta Lq}$$

Since the Jacobian matrix's value depends on the values of the model parameters, it changes depending on the players' feelings and emotions, which also affects the equilibrium points that are determined. Therefore, based on the various feelings and emotions of the game subjects, this article analyzes the stability of the strategic portfolios of government regulators and energy consumers, which includes four scenarios: (rational, rational), (rational, emotional), (emotional, rational), and (emotional, emotional).

Scenario 1. *Rational government regulators and rational energy consumers.*

The attitude parameters $r_1 = 1, r_2 = 1$ are now applicable when government regulators and energy customers are both sensible. The strategy portfolio's stability analysis at this stage is shown in Table 3 after the sentiment parameter has been included in each replication dynamic equation.

In Table 3, there are two saddle points in the system when government regulators are rational and energy consumers are rational. When condition $(A_1-2A_2-2A_3-A_4+A_5)(B_1-2B_2-B_3+B_4)-(A_1-A_2)(B_1-B_2)>0$ $A_1-2A_2-2A_3-A_4+A_5+B_1-2B_2-B_3+B_4<0$ is fulfilled,$E_4(1,1)$ is a stable point in the system, when the government regulators' strategy choice is stable in green regulation and the energy consumers' strategy choice is stable in integrated energy use; it also becomes a stable point in the system's evolution when certain conditions are met.

Table 3. Stability analysis of the strategy portfolio under rational government regulators' and rational energy consumers' scenarios.

Equilibrium Point	$\frac{\partial F(m)}{\partial m}$	$\frac{\partial F(m)}{\partial n}$	$\frac{\partial F(n)}{\partial m}$	$\frac{\partial F(n)}{\partial n}$	$Det(J)$	$Tr(J)$	Consistency
$E_1(0,0)$	0	0	0	0	0	0	Unstable
$E_2(1,0)$	$-A_3-A_4+A_5$	A_1-A_2	0	0	0	×	Unstable
$E_3(0,1)$	0	0	B_1-B_2	$-2B_3+B_4$	0	×	Unstable
$E_4(1,1)$	$A_1-2A_2-2A_3$ $-A_4+A_5$	A_1-A_2	B_1-B_2	$B_1-2B_2-B_3+B_4$	×	×	Saddle Point
$E_5(m^*,n^*)$	Saddle Point						

Scenario 2. *Government regulators' sentiment and energy consumers' sentiment.*

The sentiment parameters are $r_1 \neq 1, r_2 \neq 1$, the sentiment of government regulators and energy customers. The strategy portfolio stability analysis is displayed in Table 4, after adding the sentiment parameters to each replication dynamic equation.

In Table 4, there is a saddle point in the system at the government regulators' sentiment and energy consumers' sentiment. When condition $r_1(A_1-2A_2-2A_3-A_4+A_5)[r_2(B_1-B_2-B_3+B_4)-r_1B_2]-(r_2A_1-r_1A_2)r_1(B_1-B_2)>0$, $r_1[A_1-2A_2-2A_3-A_4+A_5]+[r_2(B_1-B_2-B_3+B_4)-r_1B_2]<0$ is fulfilled,$E_4(1,1)$ is a stable point in the system, when the government regulators' strategy choice is stable at green regulation and the energy consumers' strategy choice is stable at integrated energy use. The specific value of the sentiment parameters r_1, r_2 cannot be determined, and as a result, the stability of the local equilibrium point $E_5(m^*,n^*)$ is dependent on the specific value and sentiment intensity.

At the same time, the intensity of the sentiment of government regulators and energy consumers is unknown.

Table 4. Analysis of the stability of the strategy portfolio under various scenarios, including the attitudes of regulators and consumers of energy.

Equilibrium Point	$\frac{\partial F(m)}{\partial m}$	$\frac{\partial F(m)}{\partial n}$	$\frac{\partial F(n)}{\partial m}$	$\frac{\partial F(n)}{\partial n}$	$Det(J)$	$Tr(J)$	Consistency
$E_1(0,0)$	0	0	0	0	0	0	Unstable
$E_2(1,0)$	$r_1(-A_3 - A_4 + A_5)$	0	0	0	0	×	Unstable
$E_3(0,1)$	0	0	0	$r_2(-B_3 + B_4)$ $-r_2B_3$	0	×	Unstable
$E_4(1,1)$	$r_1(A_1 - 2A_2 - 2A_3$ $-A_4 + A_5)$	$r_2A_1 - r_1A_2$	$r_1(B_1 - B_2)$	$r_2(B_1 - B_2 - B_3$ $+B_4) - r_1B_2$	×	×	Saddle Point
$E_5(m^*, n^*)$	Specific values and emotional intensity are necessary for stability						

Scenario 3. *Government regulators rational, energy consumers emotional.*

The emotional parameters $r_1 = 1, r_2 \neq 1$ occur when government regulators are rational and energy customers are emotional. The strategy portfolio stability analysis is displayed in Table 5 after adding the sentiment parameters to each replication dynamic equation.

In Table 5, there is a saddle point in the system when the government regulators are rational, and the energy consumers are emotional. When condition $(A_1 - 2A_2 - 2A_3 - A_4 + A_5)[r_2(B_1 - B_2 - B_3 + B_4) - B_2] - (r_2A_1 - A_2)(B_1 - B_2) > 0, r_1[A_1 - 2A_2 - 2A_3 - A_4 + A_5] + [r_2(B_1 - B_2 - B_3 + B_4) - r_1B_2] < 0$ is fulfilled, $E_4(1,1)$ is a stable point in the system, when the government regulators' strategy choice is stable at green regulation and the energy consumers' strategy choice is stable at integrated energy use. However, because the emotional intensity of energy consumers is unknown, the particular value of the emotional parameter r_2 cannot be established, and the stability of the local equilibrium point $E_5(m^*, n^*)$ depends on the specific value and emotional intensity.

Table 5. Stability examination of strategy portfolios under scenarios with rational government regulators and optimistic energy consumers.

Equilibrium Point	$\frac{\partial F(m)}{\partial m}$	$\frac{\partial F(m)}{\partial n}$	$\frac{\partial F(n)}{\partial m}$	$\frac{\partial F(n)}{\partial n}$	$Det(J)$	$Tr(J)$	Consistency
$E_1(0,0)$	0	0	0	0	0	0	Unstable
$E_2(1,0)$	$-A_3 - A_4 + A_5$	$-A_2$	0	0	0	×	Unstable
$E_3(0,1)$	0	0	$B_1 - B_2$	$r_2(-B_3 + B_4)$ $-B_3$	0	×	Unstable
$E_4(1,1)$	$A_1 - 2A_2 - 2A_3$ $-A_4 + A_5$	$r_2A_1 - A_2$	$B_1 - B_2$	$r_2(B_1 - B_2 - B_3$ $+B_4) - B_2$	×	×	Saddle Point
$E_5(m^*, n^*)$	Specific values and emotional intensity are necessary for stability						

Scenario 4. *Government regulators' emotions and energy consumers' rationality.*

The rationality of energy consumers, government regulators, and emotional parameters are $r_1 \neq 1, r_2 = 1$. The strategy portfolio stability analysis is displayed in Table 6 after adding the sentiment parameters to each replication dynamic equation.

Table 6. Stability analysis of strategy portfolios under government regulators' sentiment and energy consumers' rationality scenarios.

Equilibrium Point	$\frac{\partial F(m)}{\partial m}$	$\frac{\partial F(m)}{\partial n}$	$\frac{\partial F(n)}{\partial m}$	$\frac{\partial F(n)}{\partial n}$	$Det(J)$	$Tr(J)$	Consistency
$E_1(0,0)$	0	0	0	0	0	0	Unstable
$E_2(1,0)$	$r_1(-A_3-A_4+A_5)$	A_1	0	0	0	×	Unstable
$E_3(0,1)$	0	0	0	$-B_3+B_4$ $-r_1B_3$	0	×	Unstable
$E_4(1,1)$	$r_1(A_1-2A_2-2A_3$ $-A_4+A_5)$	$A_1-r_1A_2$	$r_1(B_1-B_2)$	$B_1-B_2-B_3$ $+B_4-r_1B_2$	×	×	Saddle Point
$E_5(m^*,n^*)$	Specific values and emotional intensity are necessary for stability						

In Table 6, there is a saddle point in the system when the government regulators are emotional and the energy consumers are rational. When condition $r_1(A_1-2A_2-2A_3-A_4+A_5)[(B_1-B_2-B_3+B_4)-r_1B_2]-(A_1-r_1A_2)r_1(B_1-B_2)>0$, $r_1[A_1-2A_2-2A_3-A_4+A_5]+[(B_1-B_2-B_3+B_4)-r_1B_2]<0$ is fulfilled,$E_4(1,1)$ is a stable point in the system, when the government regulators' strategy choice is stable at green regulation and the energy consumers' strategy choice is stable at integrated energy use. In addition, the precise value of the sentiment parameter r_1 cannot be identified, and the stability of the local equilibrium point $E_5(m^*,n^*)$ depends on the specific value and sentiment intensity, which makes it impossible to estimate due to the unknown sentiment intensity of government control.

6. Analysis of Simulation

Based on the various emotional states of government regulators and energy customers, the preceding section examines the stability of the strategy portfolios of both groups, which includes four situations: (rational, rational), (rational, emotional), (emotional, rational), and (emotional, emotional). The game subject's emotional state may be further separated into optimistic and pessimistic states while it is in a certain emotional state, and the precise mechanisms by which optimistic and pessimistic emotional states affect the development of the game subject's behavior are likewise distinct. Therefore, on the basis of the previous four scenarios, this section provides further analysis of the evolutionary stability of the system in the nine specific scenarios (rational, rational), (optimistic, pessimistic), (pessimistic, pessimistic), (pessimistic, rational), (rational, optimistic), (rational, pessimistic), and (optimistic, optimistic).

MATLAB was utilized for the simulation study in order to examine the development of the energy structure transition more intuitively. The analysis of the trend of the system's development is not a change in particular values, and evolutionary game simulation is not a quantitative process, but rather a qualitative one. On the basis of the preceding part, it is appropriate to take values within a specified range, and the approach [39] employed is comparable and reasonable, especially mentioning the rules and framework for setting parameters [48,49]. Table 7 details the precise parameter values.

Table 7. Parameter settings.

Parameters	m	n	c_1	c_2	c_3	R	D	l_1	l_2	x_1	x_2	w_1	w_2	y_1	y_2
Initial Value	0.5	0.5	2	2	3	1.5	1.5	2	2	1.5	1.5	5	3	2	2
Parameters	a	b	q	L	r_1	r_2	θ	η	β						
Initial Value	0.7	0.3	0.5	5	1	1	0.5	0.5	0.2						

6.1. (Rational, Rational) State Analysis

Figure 1 depicts the equilibrium plan where energy users and government regulators are both rational actors, when $r_1 = 1, r_2 = 1$. The game has a mixed strategy Nash equilibrium. The likelihood of green regulation by governing bodies is low, ranging between 0.1 and 0.2, while the likelihood of integrated energy usage by energy customers is high, convergent to a steady one.

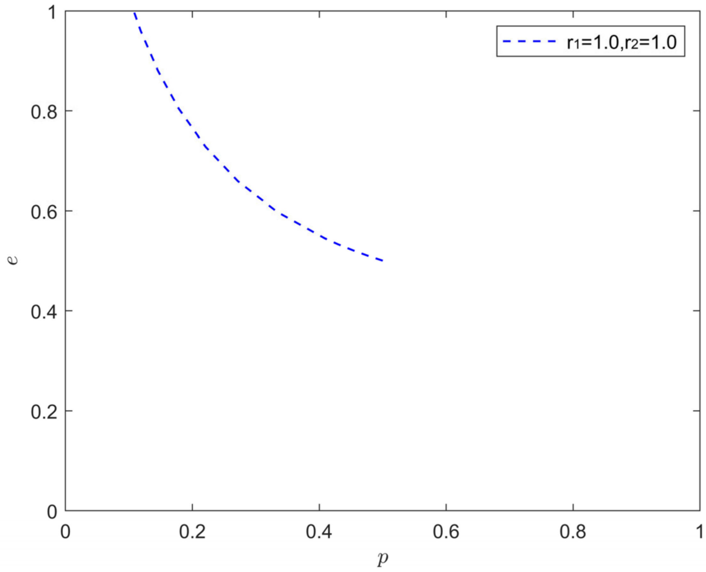

Figure 1. The development of the game's strategy in a (rational, rational) condition.

6.2. (Emotion, Emotion) State Analysis

Figure 2 depicts the optimal approach when both energy users and regulatory agencies are optimistic, i.e., when $r_1 < 1, r_2 < 1$. The likelihood that government regulators would choose green regulation somewhat declines as both government regulators' and energy users' excitement grow. The likelihood that users of energy will choose integrated energy consumption converges and stabilizes at one. The mixed-strategy Nash equilibrium point is moved to the coordinate region's top left corner. According to the aforementioned research, government regulators are more susceptible to optimism than electricity generated, and their regulatory activism lowers when they are unduly enthusiastic about the structural revolution of energy.

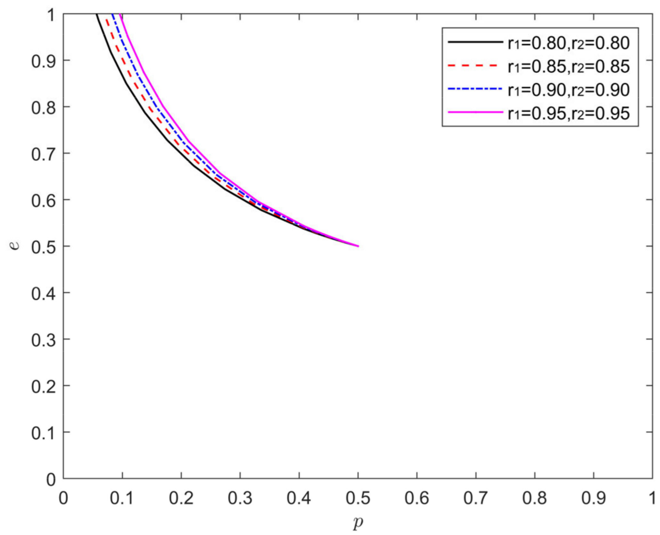

Figure 2. The development of the game's strategy in a (optimistic, optimistic) condition.

Figure 3 depicts the equilibrium plan when both energy users and regulatory agencies are pessimistic, i.e., when $r_1 > 1, r_2 > 1$. The likelihood that government regulators will choose green regulation rises as pessimism among government regulators and energy consumers intensifies. The mixed strategy Nash equilibrium point shifts to the upper right of the coordinate region as the probability of the energy consumers choosing integrated energy use converges to 1, but the probability of the energy consumers choosing integrated energy use declines when the pessimism of government regulators and energy consumers is too great. According to the aforementioned findings, a healthy dose of pessimism can maintain energy consumers' high levels of willingness to integrate energy use and boost government regulators' willingness to enact green regulations, but an excessive amount of pessimism deters both government regulators and energy consumers from making strategic decisions.

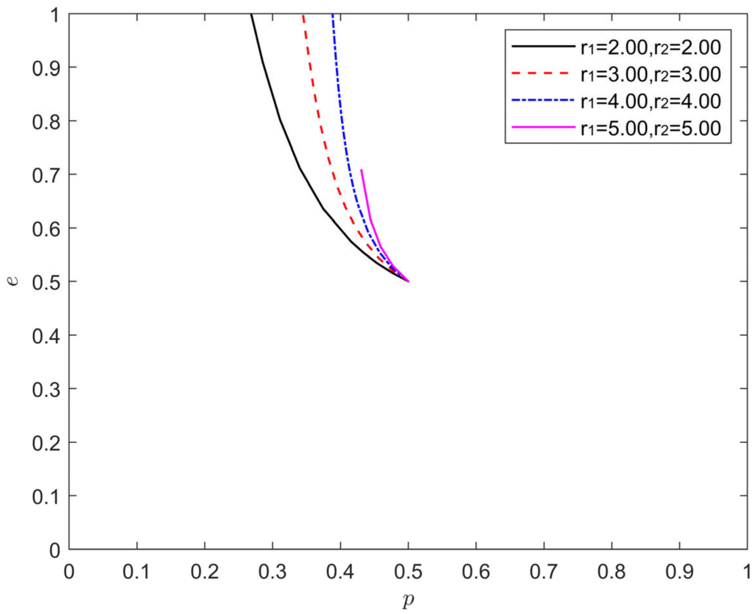

Figure 3. The development of the game's strategy in a (pessimistic, pessimistic) condition.

Figure 4 depicts the optimum approach when energy users are apprehensive and government regulators are optimistic, i.e., when $r_1 < 1, r_2 > 1$. As shown in Figure 4, when watchdogs are optimistic for a period of time, the likelihood that they will choose green regulation continues to decline as the pessimism of electricity generated deepens and the convergence speed of the system's evolution to the stability point (1,0) significantly increases. Further analysis in Figure 4a–c reveal that when the optimism of government regulators increases, the Nash equilibrium point moves to the top left corner of the coordinate area. According to the data above, combinations of (optimistic, pessimistic) diverse sentiments are not the best options for systematic Pareto optimization.

Figure 5 depicts the equilibrium approach when energy users are optimistic and government agencies are pessimistic, i.e., when $r_1 > 1, r_2 < 1$. Figure 5 shows that when there is certainty regarding the optimism of energy consumers, the probability of green regulation by government regulators keeps rising as the pessimism of the government agencies keeps deepening and the mixed strategic plan Nash equilibrium point wants to keep leveling off in the upper right corner of the coordinate region. As demonstrated in Figure 5a–c, the trajectory of strategy development for each game subject is essentially constant, and the growing optimism of the energy consumers has less of an influence on the system's evolution. According to the aforementioned results, the strategy chosen by each game subject is greatly influenced by their pessimism and optimism, with pessimism having a greater impact.

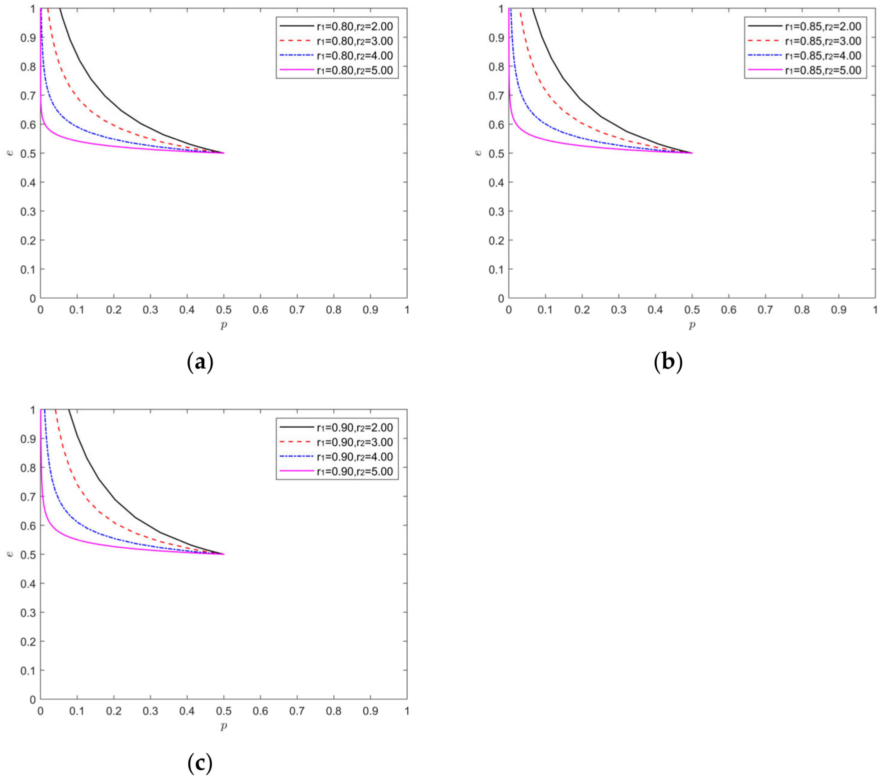

Figure 4. The development of the game's strategy in a (optimistic, pessimistic) condition. (**a**–**c**) represent the results of different parameter values.

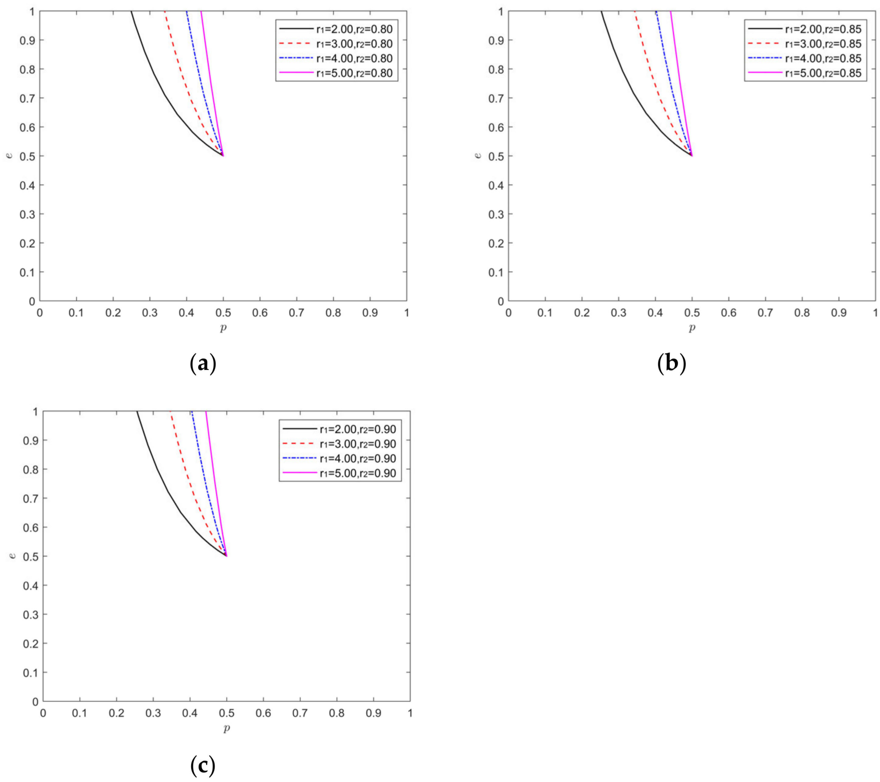

Figure 5. The development of the game's strategy in a (pessimistic, optimistic) condition. (**a**–**c**) represent the results of different parameter values.

6.3. (Emotional, Rational) State Analysis

Figure 6 depicts the equilibrium approach with an optimistic regulatory environment and rational energy users, i.e., when $r_1 < 1, r_2 = 1$. Figure 6 illustrates how the chance of government regulators adopting green regulation continues to decline as their optimism grows, and how the mixed strategy Nash market equilibrium begins to move horizontally toward the top left corner of the coordinate area.

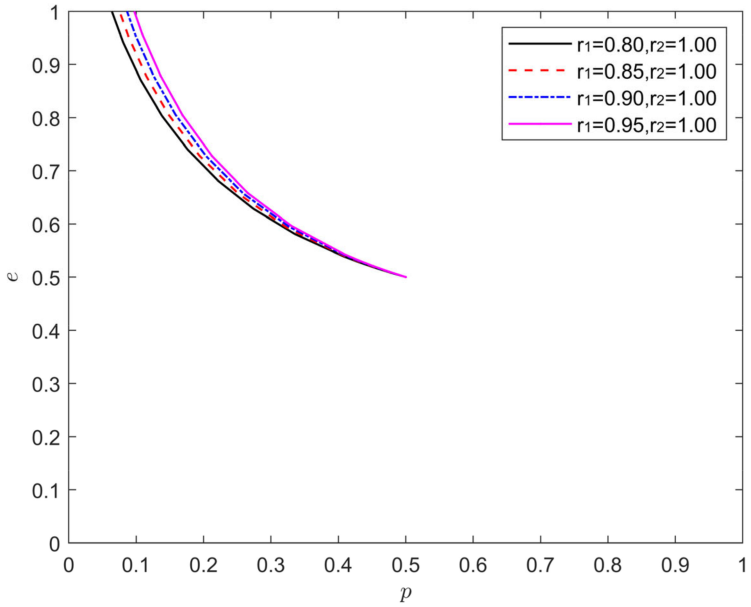

Figure 6. The development of the game's strategy in a (optimistic, rational) condition.

Figure 7 depicts the equilibrium approach where energy customers are rational and government regulators are pessimistic, i.e., when $r_1 > 1, r_2 = 1$. From Figure 7, as government regulators' pessimism deepens, the likelihood that they will choose green regulation rises, and the mixed strategy Nash equilibrium point continues to move horizontally toward the coordinate region's top right corner. According to the facts above, optimism and pessimism have opposing impacts on the technique that government regulators use. Pessimism has a positive impact and may increase the likelihood of green regulation by government regulators. Optimism, on the other hand, has a negative impact and can decrease the likelihood of green regulation by government regulators.

6.4. (Rational, Emotional) State Analysis

Figure 8 depicts the equilibrium plan where energy customers are enthusiastic and government regulators are sensible, when $r_1 = 1, r_2 < 1$. Figure 8 shows that the system's development is less affected by government regulators' growing confidence, and that the general trend of strategy evolution for each game subject is essentially unaltered.

Figure 9 depicts the equilibrium approach where energy consumers are pessimistic and government regulators are sensible, when $r_1 = 1, r_2 > 1$. As energy consumers' pessimism continues to grow, as seen in Figure 9, the pace at which the system's evolution converges to the stability point (0,1) grows noticeably. According to the aforementioned data, a slight increase in the energy of consumers' pessimism may retain the likelihood that they will choose integrated energy usage at a high level.

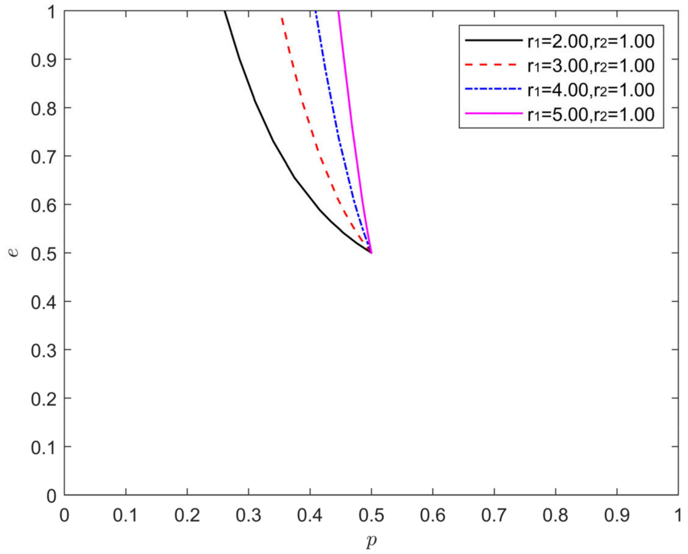

Figure 7. The development of the game's strategy in a (pessimistic, rational) condition.

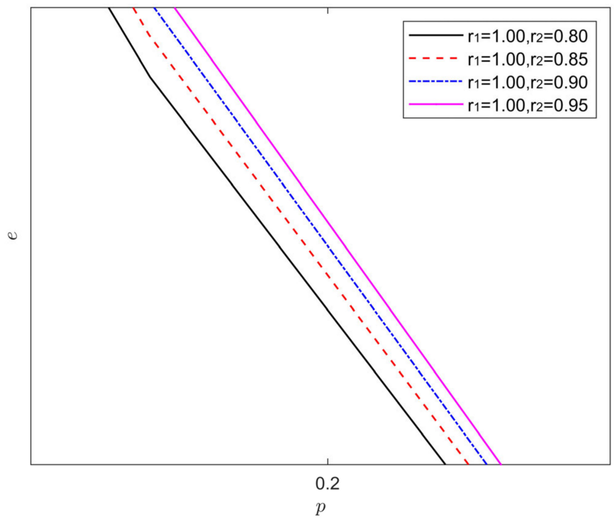

Figure 8. The development of the game's strategy in a (rational, optimistic) condition.

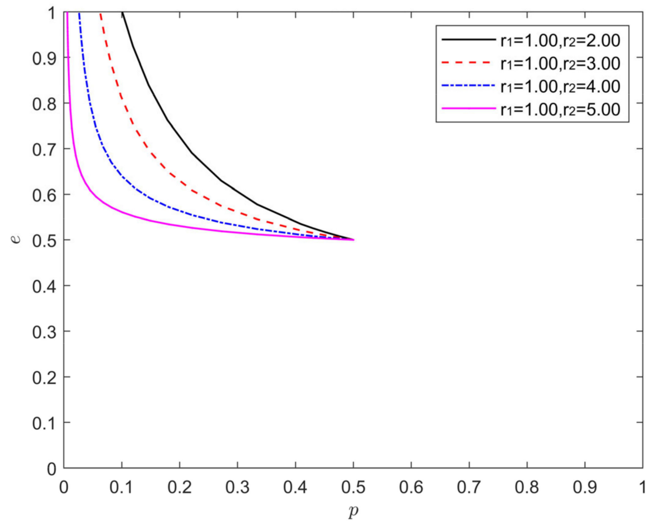

Figure 9. The development of the game's strategy in a (rational, pessimistic) condition.

7. Summary

This essay seeks to examine how various emotions affect the choices and actions of game subjects, as well as how the energy structure transitions. In order to achieve this, given that clean energy cannot quickly replace coal energy, our model quantifies emotions as an irrational element using the RDEU theory and builds an emotion model by fusing the RDEU theory with evolutionary games. The examination of how various emotions affect decision-makers' behavior and the modification of energy structures during strategy decision-making show that incorporating emotions into evolutionary games is feasible. Additionally, in the reality of energy restructuring, government regulators and energy users make irrational decisions. This study serves as a guide for decision-makers' preferred choices when it comes to the clean and effective use of coal energy and the quickening of the development and use of clean energy. China, the greatest developing nation, is a resource-intensive nation with a national situation of "rich in coal, poor in oil, and poor in gas," and it should not aim to "reduce coal," let alone "remove coal." As a result, it is crucial for emerging nations and nations with large coal reserves to understand how China's energy system has changed.

7.1. Conclusions

(1) Emotions have an irrational impact on decision-makers' psychological preferences, which in turn affects their choice of behavioral approach and materially alters the equilibrium state of the model. Government regulators and energy consumers are influenced by emotional and risky attitudes that cause them to make utterly irrational behavioral decisions because they feel dependent on or are unwilling to shift their energy sources too much and too early in favor of coal. The eventual evolution of the system can be impacted by changes in the psychological preferences and feelings of government regulators and energy customers using the same objective decision-making framework.

(2) In terms of the individual consequences of different emotional attitudes, pessimism may raise the decision-maker's psychological preference for the strategy selection process, while optimism can lower this desire. Decision-makers can avoid making judgments with significant mistakes that differ from the system's outcomes by controlling their rational emotions. Pessimism affects decision-makers, increases the likelihood that they will take action, and makes them more likely to choose effective strategies by avoiding acts of omission, but too much pessimism will have a negative impact on the motivation behind decision-making. Appropriate optimism will enable decision-makers to actively adjust to the energy structure transition and intentionally increase the likelihood of attaining the best possible allocation of societal resources. However, overly optimistic decision-makers are prone to arrogance, which can result in motivation loss and inactive behavior.

(3) The interaction of different emotional attitudes results in a more complicated and dynamic synergistic relationship than a simple addition. The effect of pessimism is stronger than that of optimism in this process of synergistic relationships. One of the two sides of the energy structure transformation game displays a rational state, while the other side, regardless of melancholy or optimism, exhibits a state that simply impacts the system's equilibrium state and evolutionary pace rather than the strategy's direction of development. The deepening pessimism of one side will change the evolution rate and equilibrium state of the system as a whole in a relatively positive direction if the optimism of the other side remains unchanged; the deepening optimism of the other side will change the evolution rate and equilibrium state of the system as a whole in a relatively negative direction if the optimism of the other side remains unchanged.

7.2. Revelation

Based on the findings in the previous section, in the context of carbon neutrality, both pessimism and optimism can affect how government regulators and energy consumers make decisions in the face of clean energy and coal energy. However, as compared to optimism, suitable pessimism has a greater impact on government regulators and energy customers. The pessimism of government regulators and energy customers may, thus, be adequately pushed in the context of the reality of the energy structure transition so that both parties can take more proactive steps. The specific recommendations are as follows:

(1) Guiding the appropriate decision-makers to generate appropriate emotional attitudes for decision-makers and regulating the degree of performance of different emotional attitudes to prevent excessive emotions from influencing decision-makers and to strengthen the role of emotions as an irrational factor to support energy structure transformation. Decision-makers are in rational emotions while making judgments about energy structure transformation, and psychological preferences and emotions can influence those decisions in either a positive or a negative way. This is a fact that does exist, and we cannot ignore it. Therefore, we need to take the irrational factor of emotion into full consideration in the overall planning when formulating energy structure transformation strategies and transformation paths. Given that government regulators and energy consumers are adequate at uplifting emotional counseling, preventing the influence of excessive emotions through social monitoring, establishing suitable energy cleanliness standards, etc., they may play a good role.
(2) Increase the pressure, responsibility, and anxiety of both parties appropriately in the energy structure transition in the context of carbon neutrality, so that the pessimism of government regulators and energy consumers gives them the option to take a more proactive approach to opportunities and challenges from all directions. The system for regulating CO_2 emissions can be properly opened up to the public, the relevant data can be made public and clear, the public can be encouraged to get involved, and the public can be asked for their opinions. All stakeholders will naturally cooperate and actively participate in innovation as a result of being made to feel more stressed, anxious, and responsible. This will result in a more reasonable and effective change to the energy system.
(3) Government regulators and energy consumers can release appropriate favorable information to the outside world. As a long-term goal of China's high-quality development, carbon neutrality is not a restriction on energy development, but a strategic goal to achieve carbon neutrality through the transformation and development of the energy structure. Government regulators should, thus, implement relevant regulations, together with subsidies and incentives, during the process of energy structure transition in order to encourage support for the change. Additionally, energy consumers should actively promote low-carbon innovation, actively demonstrate support for pertinent transition policies in regards to implementation and effectiveness, and consistently fortify the linkages and collaboration between various organizations.

7.3. Shortcomings and Prospects

This study creates an evolutionary game model with government regulators and energy customers and creatively incorporates low carbon sentiment into the game of changing the energy structure. This article replicates the various attitudes of government regulators and energy consumers on the reality of energy consumption after determining the Nash equilibrium point and the evolutionary stabilization approach. However, potential game topics, such as whistleblowers, were not considered, and a three-way game could have been played between government regulators, energy customers, and whistleblowers. In the future, a three-way game analysis could be conducted, considering the low carbon sentiment of policymakers. In the upcoming year, we will also consider the possibility that the atypical factor of emotion may have a different salience in the legislative environment than in the social or economic environment. Therefore, it could be interesting to take these various saliences into account in a study session.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/pr10081650/s1, Formulas S4–S10.

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