Influence of External Parameters on The Dynamic Behavior of New Energy and Carbon Trading System

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***Abstract*—This paper discusses a new type of selective-constrained new energy and carbon trading(NECT) system, including new energy, carbon emission and carbon trading. The dynamic behavior of the system is analyzed by means of Lyapunov exponents and phase diagram. It is found that the NECT system exists chaotic phenomenon, which may cause the system to crash. In order to eliminate the occurrence of this chaotic phenomenon, considering the execution of enterprises during the COVID-19 pandemic, we use the most direct method, that is government control, to control the chaotic system. Based on the nonlinear dynamics theory, the dynamic behavior of the chaotic system is analyzed. The result shows that the chaos can be controlled with the reasonable government control intensity. With the intensity of government control increasing, the system starts with cyclical fluctuations and then gradually become stabilized. However, the system will crash again if the intensity of government control is too large.**

Keywords—New energy; Carbon emission; Carbon trading; Chaos; Government control.

I. INTRODUCTION

Global warming is an unprecedented challenge mankind face today [1]. Mass anthropogenic emissions of greenhouse gases, especially carbon dioxide, have led to increasing atmospheric concentrations, very likely the primary cause of the warming the Earth has experienced [2]. China has been the world's second largest economy for more than a decade, however, the climate problems of China are becoming more pronounced. China's greenhouse gas emissions are expected to rise until at least 2030, even with policies adopted by China [3]. It is necessary to search low-carbon development pathways [4].

The implementation of carbon trading [5] and the usage of new energy [6] are considered as important ways to improve the climate problem. With the target of energy-saving and emission-reduction (ESER), China has been successively established pilot projects for carbon trading since 2013 [7, 8, 9]. In December 2017, China began to build a carbon emissions trading system [10]. While building the national carbon trading scheme, it is important to refer to the experiences of international carbon markets and strengthen the recognition, control, and supervision of carbon market risks. This will contribute to the healthy development of China's national carbon trading scheme [11]. In addition, the development of new energy is another key to control carbon emission [12]. On the one hand, the establishment of carbon market is conducive to curbing carbon emissions [13], on the other hand, carbon trading market has a significant influence on Chinese new energy industry, as carbon trading market increases the demand for new energy [14]. Therefore, both the establishment of carbon trading market and the development of new energy are of great importance to energy-saving and emission-reduction(ESER).

Carbon market and new energy have been widely studied by many scholars. Fang et al. analyzed a novel three-dimensional energy-saving and emission-reduction(ESER) chaotic system [15], analyzing the impact of cost of conserved energy (CCE), government control, low carbon lifestyle and investment in new technology of ESER on energy intensity and economic growth [16]. He et al. built a new energy and carbon trading(NECT) system based on the complex relationship between carbon trading, new energy and carbon emissions, analyzing the driving mechanism of carbon trading for new energy and carbon emissions [17].

Government control is very effective in controlling emergencies. There will be some collapse and chaos in different systems and there are a lot of studies on this. However, during the COVID-19 pandemic, the system affected by the environment and complex conditions can't meet good expectations. Therefore, powerful government control is needed to deal with emergencies. During the COVID-19 pandemic, effective management of emergencies is a meaningful study.

The purpose of this paper is to study whether there is chaos in the NECT system and whether it can be controlled by the government control. Another purpose is to study the impact of the intensity of government control on this system and the dynamic evolution of the three factors (new energy, carbon emission and carbon trading) with government control.

The outline of this paper is organized as follows. Section 2 provides the establishment of this model and the dynamic analysis of the model. The impact of government control on carbon trading, new energy and carbon emissions are analyzed in Section 3. The conclusions and outlook are finally presented in Section 4.

II. ESTABLISHMENT OF THE MODEL

The new energy and carbon trading(NECT) dynamical system includes new energy, carbon emission and carbon trading and many other variables [17]. Excessive carbon emissions from energy consumption will promote the development of new energy, and will also give rise to the carbon trading market. However, the rapid development of new energy will curb carbon emission levels, and the resulting excess carbon allowance may lead to the shrinking carbon market. As key elements of a low-carbon economy, new energy, carbon trading, and carbon emissions are closely related to each other. The system can be described by the following differential equations

$$\begin{cases} \frac{dx}{dt} = a_1 x(y-M) + a_2 z(\frac{z}{N} - 1) \\ \frac{dy}{dt} = -b_1 x + b_2\left(1 - \frac{y}{C}\right) - b_3 z \\ \frac{dz}{dt} = c_1 z\left(\frac{y}{E} - 1\right) - c_2 x \end{cases} \qquad (1)$$

where $x(t)$ is the time-dependent variable of new energy, $y(t)$ is the time-dependent variable of carbon emission, $z(t)$ is the time-dependent variable of carbon trading, $t \in I$, I is a given economic period. a_i, b_i , c_i (i = 1, 2, 3), M, N, C, E are positive constants [17]. a_1 is the development coefficient of $x(t)$, a_2 is the influence coefficient of $z(t)$ to $x(t)$, M is the inflexion of $y(t)$ to $x(t)$, N is the inflexion of $z(t)$ to $x(t)$; b_1 is the influence coefficient of $x(t)$ to $y(t)$, b_2 is the development coefficient of y(t), b_3 is the influence coefficient of $z(t)$ to $y(t)$, C is the peak value of $y(t)$ during a given period; c_1 is the development coefficient of $z(t)$, c_2 is the influence coefficient of $x(t)$ to $z(t)$, E is the inflexion of $y(t)$ to $z(t)$.

The dynamic system presented in equation (1) is a complex nonlinear system, in which the evolutionary relationship between the variables is mainly embodied with the coefficients and the corresponding formulas. Take $a_1 x(y-M)$ in equation (1) for example, when $y < M$, the development speed of $x(t)$ becomes slow; when $y > M$, the development speed of $x(t)$ becomes faster. For the description of other relations, see [17].

A. *Equilibrium Analysis*

Equation (1) has real four equilibrium points: $S_0(0,0,0)$, $S_1(x_1,y_1,z_1)$, $S_2(x_2,y_2,z_2)$, $S_3(x_3,y_3,z_3)$.

Linearizing the equation (1) at equilibrium S(x, y, z) the Jacobian matrix is yielded as

$$J = \begin{pmatrix} a_1(y-M) & a_1 x & 2a_2 z/N - a_2 \\ -b_1 & b_2 - 2b_2 y/C & -b_3 \\ -c_2 & c_1 z/E & c_1 y/E - c_1 \end{pmatrix} \qquad (2)$$

The characteristic polynomial of J at the equilibrium point $S_0(0,0,0)$ is :

$$f(\lambda) = |\lambda I - J| = \lambda^3 + p\lambda^2 + q\lambda + r \qquad (3)$$

where I is the three-order unit matrix.
$p = a_1 M + c_1 - b_2$
$q = a_1 c_1 M - a_1 b_2 M - b_2 c_1 - a_2 c_2$
$r = a_2 b_2 c_2 - a_1 b_2 c_1 M$

By the Routh-Hurwitz criterion, all real eigenvalues and all real parts of complex conjugate eigenvalues of equation (3) are negative if and only if the following conditions hold: $p > 0$, $q > 0$, $pq - r > 0$. For certain parameters, the equilibrium $S_0(0,0,0)$ is unstable.

Equation (1) is a complicated dynamic system. When a_i , b_i , c_i , M , N , C , E take different values, equation (1) will have different dynamic behavior, In order to research equation (1) further, parameters are fixed:

$$a_1 = 0.0895, a_2 = 0.0115, b_1 = 0.8548, b_2 = 0.6575, \\ b_3 = 0.0985, c_1 = 0.0786, c_2 = 0.5007, M = 5, \\ N = 10, C = 0.1501, E = 0.0878 \qquad (4)$$

By calculations, the eigenvalues of the Jacobian matrix of equation (1) at $S_0(0,0,0)$ are $\lambda_1 = 0.6575$, $\lambda_2 = -0.4625$, $\lambda_3 = -0.0636$; at $S_1(0,0.1501,0)$ are $\lambda_1 = 0.0673$, $\lambda_2 = -0.6575$, $\lambda_3 = -0.4456$; at $S_2(-0.0006793,0.07325,0.02611)$ are $\lambda_1 = -0.4529$, $\lambda_{2,3} = 0.0073 \pm 0.0411i$. at $S_3(-1104.0,5.185,-121.1)$ are $\lambda_1 = -46.7930$, $\lambda_2 = 1.8690$, $\lambda_3 = 4.7363$; So S_0, S_1, S_2, S_3 are all unstable saddle points.

$$\begin{aligned} \nabla V &= \frac{\partial \dot{x}}{\partial x} + \frac{\partial \dot{y}}{\partial y} + \frac{\partial \dot{z}}{\partial z} \\ &= a_1(y-M) + b_2 - \frac{2b_2}{C} y + \frac{c_1}{E} y - c_1 \\ &= -a_1 M + b_2 - c_1 + (a_1 - \frac{2b_2}{C} + \frac{c_1}{E}) y \end{aligned} \qquad (5)$$

If $-a_1 M + b_2 - c_1 + (a_1 - 2b_2/C + c_1/E)y < 0$, then the dynamic system presented in equation (1) is a dissipative system. Thus there may be chaotic phenomenon.

B. *Numerical simulation results*

When the parameters of equation (1) are given in equation (4), and initials are given as $[0.011,0.4,0.06]$, the phase diagram of equation (1) could be observed as shown in Fig. 1, the corresponding time series of $x(t)$, $y(t)$, $z(t)$ as shown in Fig. 2.

A chaotic attractor is observed for parameters as in equation (4). Fig.1 shows the chaotic relationship between new energy, carbon emission and carbon trading.

Vary a_2 in the interval [0,0.2], and fix parameters as in equation (6) :

$$a_1 = 0.0895, b_1 = 0.8548, b_2 = 0.6575,$$
$$b_3 = 0.0985, c_1 = 0.0786, c_2 = 0.5007, M = 5,$$
$$N = 10, C = 0.1501, E = 0.0878 \tag{6}$$

According to Fig.3, the maximum Lyapunov exponent is positive for a large range of parameters. Thus, there is chaos for some parameter a_2.

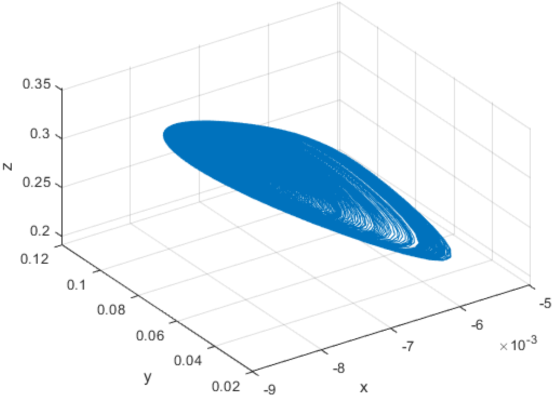


Figure 1: The chaos phase diagram of the NECT system without government control

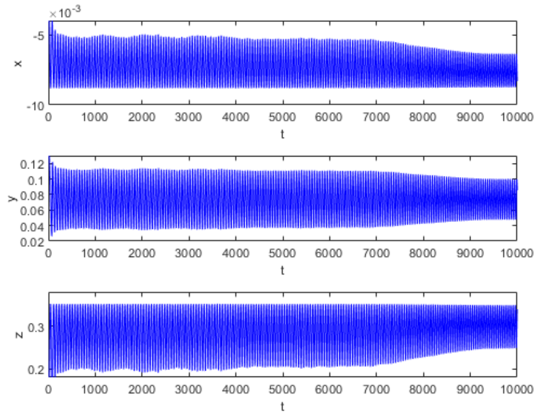


Figure 2: The time series of $x(t)$, $y(t)$, $z(t)$

III. THE MODEL WITH GOVERNMENT CONTROL

The COVID-19 pandemic has caused a large amounts of deaths and brought substantial economic loss to all countries [18]. During such extreme event, the government control is very efficient. So we focus on the impact of government control on the NECT system. For the three factors (new energy, carbon emission and carbon trading), the carbon emission is the only factor that the government control can intervene. In the three-dimensional NECT system, it is assumed that new energy, carbon emission and carbon trading are restrained by government control. government control has direct effects on reducing carbon emission, so the constraint of government control in this model can be simplified as the direct restriction $-b_4 y$. The system can be described by the following differential equations

$$\begin{cases} \frac{dx}{dt} = a_1 x(y-M) + a_2 z(\frac{z}{N}-1) \\ \frac{dy}{dt} = -b_1 x + b_2\left(1-\frac{y}{C}\right) - b_3 z - b_4 y \\ \frac{dz}{dt} = c_1 z\left(\frac{y}{E}-1\right) - c_2 x \end{cases} \tag{7}$$

With the intervention of government control, what will happen to the chaotic phenomenon of the system and whether the system could be controlled deserve further study.

We study the dynamical system equation (7) from Lyapunov exponents. b_4 is taken as the parameter. Vary b_4 in the interval [0,0.5], and fix parameters as in equation (4). The Lyapunov exponent spectrum is shown in Fig.4 with the initial condition [0.011,0.4,0.06].

According to Fig.4, when parameter b_4 is very small, the maximum Lyapunov exponent is still positive. As parameter b_4 increases, the maximum Lyapunov exponent is negative for a large range of parameters, i.e. the system is effectively controlled with government control. However, when parameter b_4 is close to 0.5 the maximum Lyapunov exponent becomes positive again, i.e. the system is out of control again. The change of parameter b_4 indicates that reasonable intensity of government control can stabilize the NECT system, too high or too low intensity of government control will be counterproductive. The above analysis shows that government control can play a role in stabilizing the system by affecting carbon emissions, but policymakers need to control the intensity of government control.

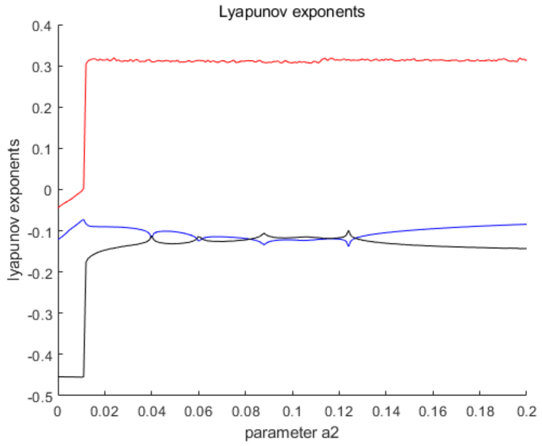


Figure 3: Lyapunov exponents spectrum(a_2) without government control

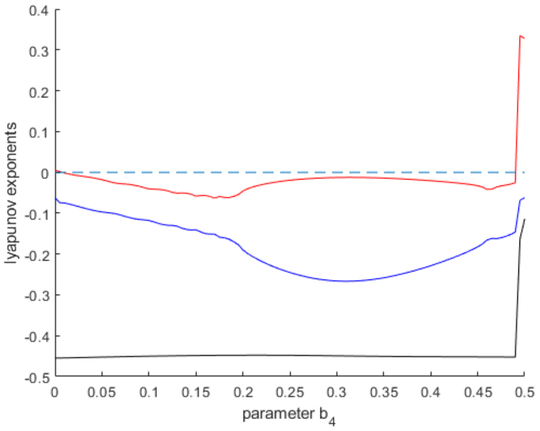


Figure 4: Lyapunov exponents spectrum(b_4) with government control

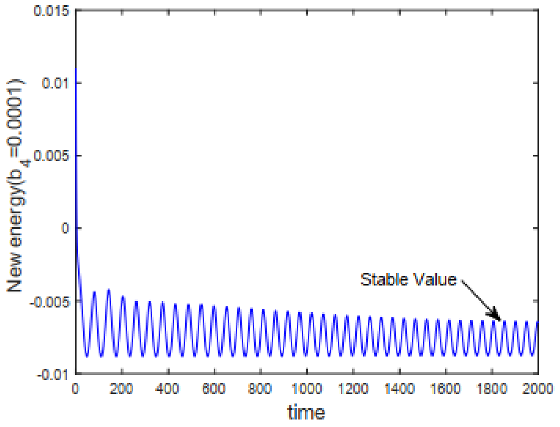
A. The Impact of Government Control on New Energy

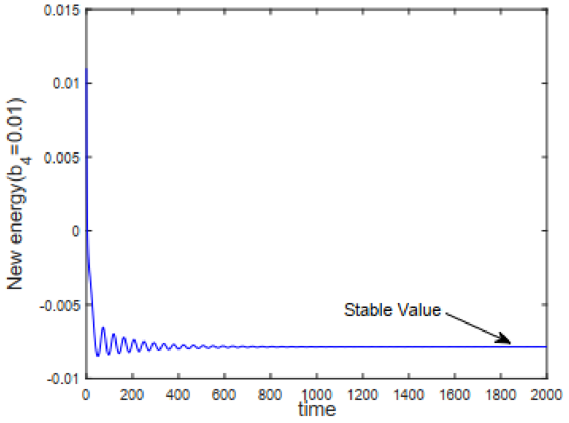
Each parameter has its meaning in the NECT system, and changes in parameters will lead to complex changes in the entire system. b_4 represents the intensity of government control. Fix the parameters as shown in equation (4) with the initial condition $[0.011, 0.4, 0.06]$, let parameter b_4 be varied. According to Fig.5(a) to (d), when b_4 is very small, the new energy is cyclical fluctuating; when b_4 increases to 0.01, the new energy goes toward stability, and the time it takes for the curve to stabilize is shortened. As b_4 continues to increase, the time it takes for the curve to stabilize will continue to decrease. However, when b_4 reaches 0.4948, the curve will suddenly stop evolving. The evolution of all the above curves is consistent with the Lyapunov exponent in Fig.4.

Fig.5(c) shows the impact on new energy when b_4 is gradually increased. The blue curve corresponds to the curve when $b_4 = 0.15$; the green curve corresponds to the curve when $b_4 = 0.30$; the red curve corresponds to the curve when $b_4 = 0.45$. In observational analyses, when b_4 becomes bigger gradually, the impact on new energy becomes bigger. When b_4 increases with the same range, the spacing between the curves becomes smaller, i.e. the impacts of government control on new energy lessen. The above analysis shows that when government control plays a role in the system, it can promote new energy in a short period of time. However, after a long period time, the impact on the new energy is small.

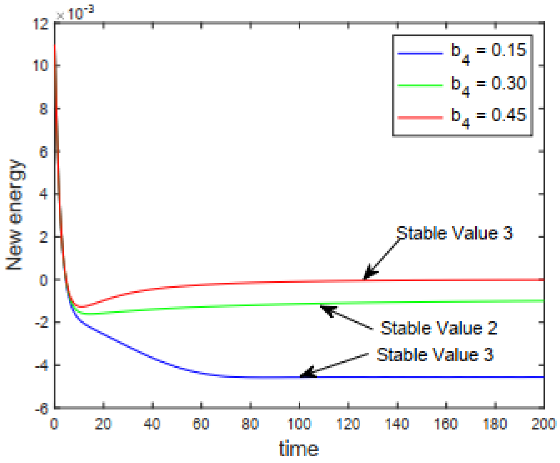
Fig.5(d) shows that the impact on new energy when b_4 reaches the critical point. The blue curve corresponds to the curve when $b_4 = 0.4948$; the green curve corresponds to the curve when $b_4 = 0.5500$; the magenta curve corresponds to the curve when $b_4 = 0.6500$. When $b_4 = 0.4948$, the curve suddenly stopped evolving at time = 80. It indicates that this intensity of government control makes the system lose stability, and as the intensity continues to increase, the time point the system lose stability will be advanced. The above analysis shows that too high intensity of government control is not ideal.

(a) Government control intensity(b_4=0.0001)

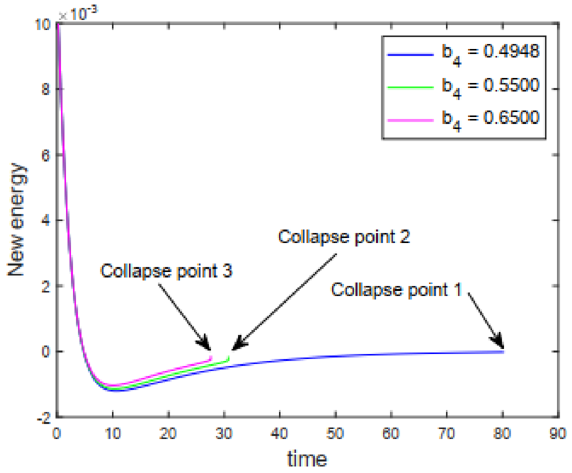




(b) Government control intensity(b_4=0.01)



(c) Government control intensity(b_4=0.15,0.30,0.45)



(d) Government control intensity(b_4=0.4948,0.5500,0.6500)

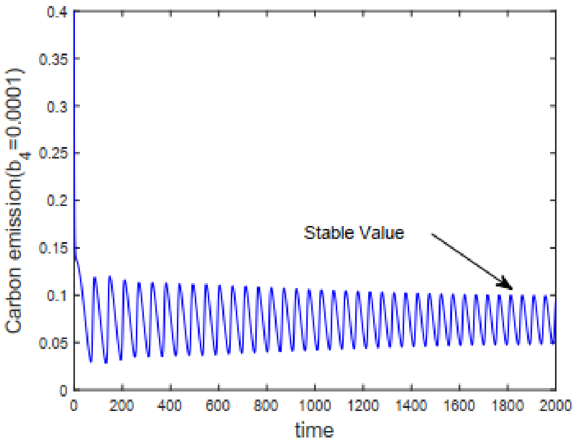
Figure 5: The evolution of new energy with government control

B. The Impact of Government Control on Carbon Emission

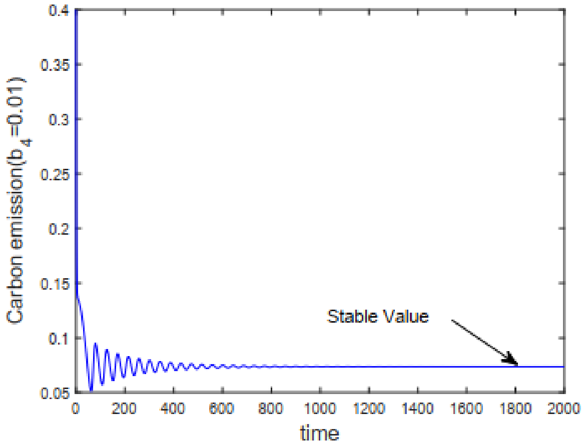
Fix the parameters as shown in equation (4). Let parameter b_4 be varied. According to Fig.6(a) to (d), when b_4 is very small, the carbon emission is cyclical fluctuating; when b_4 increases to 0.01, the carbon emission goes toward stability, and the time it takes for the curve to stabilize is shortened. As b_4 continues to increase, the time it takes for the curve to stabilize will continue to decrease. However, when b_4 reaches 0.4948, the curve will suddenly collapse. The evolution of all the above curves is consistent with the Lyapunov exponent in Fig.4.

Fig.6(c) shows the impact on carbon emission when b_4 is gradually increased. The blue curve corresponds to the curve when $b_4 = 0.15$; the green curve corresponds to the curve when $b_4 = 0.35$; the red curve corresponds to the curve when $b_4 = 0.45$. In observational analyses, when b_4 becomes bigger gradually, the impact of government control on carbon emissions control becomes better. In addition, when b_4 becomes bigger gradually, the curve is easier to reach a steady state.

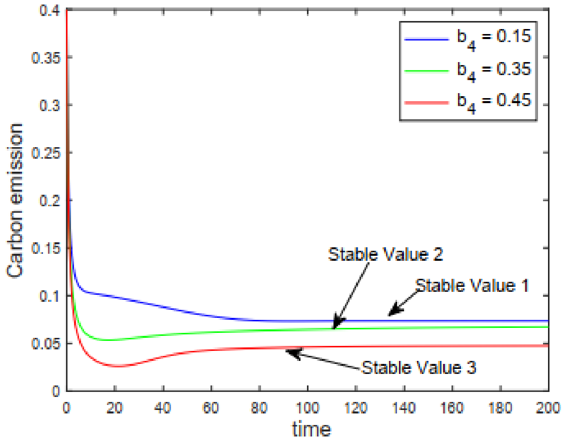
Fig.6(d) shows the impact on carbon emission when b_4 reaches the critical point. The blue curve corresponds to the curve when $b_4 = 0.4948$; the green curve corresponds to the curve when $b_4 = 0.5500$; the magenta curve corresponds to the curve when $b_4 = 0.6500$. It is obvious that when $b_4 = 0.4948$, the system is broken down, which is consistent with the Lyapunov exponent in Fig.4. When b_4 continues to increase, the time point of the system crash will be earlier. The above analysis shows that reasonable government control has a positive effect on curbing carbon emissions. Within a reasonable range, the higher the intensity of government control, the better the effect. However, when the intensity of government control too high, the system will collapse.



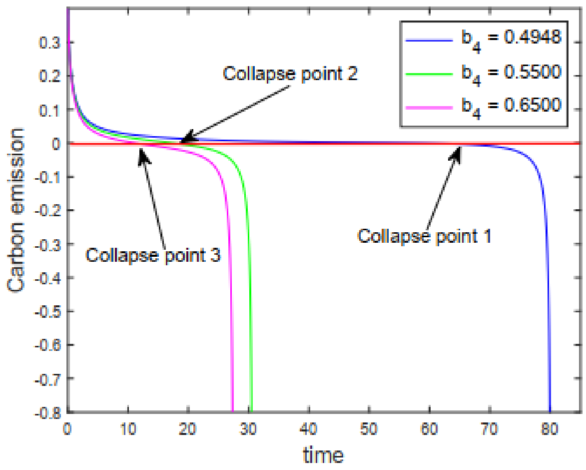
(a) Government control intensity(b_4=0.0001)



(b) Government control intensity(b_4=0.01)



(c) Government control intensity(b_4=0.15,0.35.0.45)



(d) Government control intensity(b_4=0.4948,0.5500.0.6500)

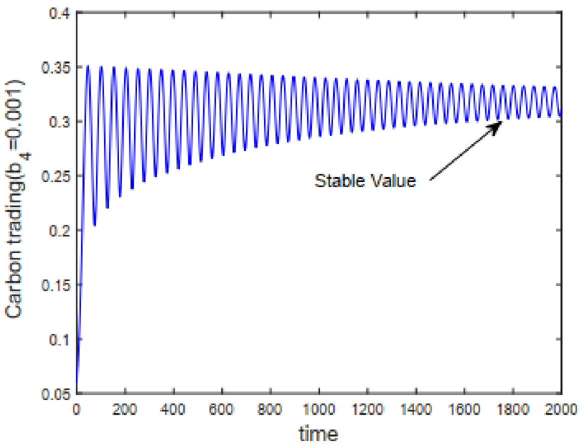
Figure 6: The evolution of carbon emission with government control

C. The Impact of Government Control on Carbon Trading

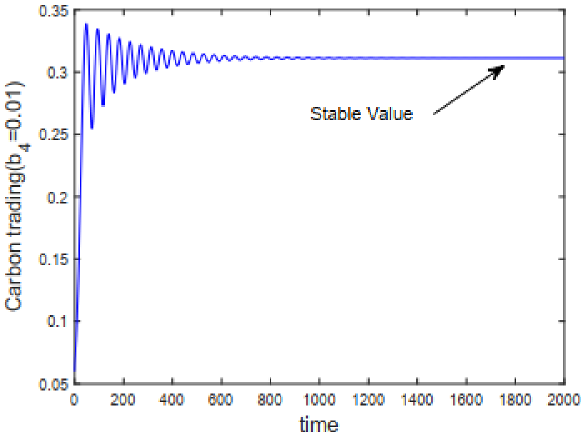
Fix the parameters as shown in equation (4). Let parameter b_4 be varied. According to Fig.7(a) to (d), when b_4 is very small, the carbon trading is cyclical fluctuating; when b_4 increases to 0.01, the carbon trading goes toward stability, and the time it takes for the curve to stabilize is shortened. As b_4 continues to increase, the time it takes for the curve to stabilize will continue to decrease. However, when b_4 reaches 0.4948, the value of the curve finally stopped at zero and stopped evolving. The evolution of all the above curves is consistent with the Lyapunov exponent in Fig.4.

Fig.7(c) shows the impact on carbon trading when b_4 is gradually increased. The blue curve corresponds to the curve when $b_4 = 0.10$; the green curve corresponds to the curve when $b_4 = 0.15$; the red curve corresponds to the curve when $b_4 = 0.20$. In observational analyses, when b_4 becomes bigger gradually, inhibiting effect of carbon trading is more obvious. In addition, when b_4 increases, the time for the curve to stabilize will be shorter. The above analysis shows that government control will indirectly affect carbon trading and the time for carbon trading to reach stability. Thus, the development of the carbon market depends on the intensity of government control.

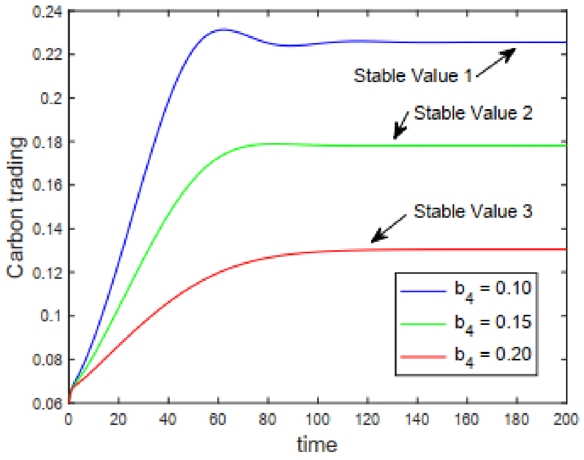
Fig.7(d) shows the impact on carbon trading when b_4 reaches the critical point. The blue curve corresponds to the curve when $b_4 = 0.4948$; the green curve corresponds to the curve when $b_4 = 0.5500$; the magenta curve corresponds to the curve when $b_4 = 0.6500$. When $b_4 = 0.4948$, the value of the curve stopped at zero. It indicates that carbon trading stopped developing. As b_4 continues to increase, the point when carbon trading stops developing will come sooner. Government control is not a panacea, too much intervention does not work well.



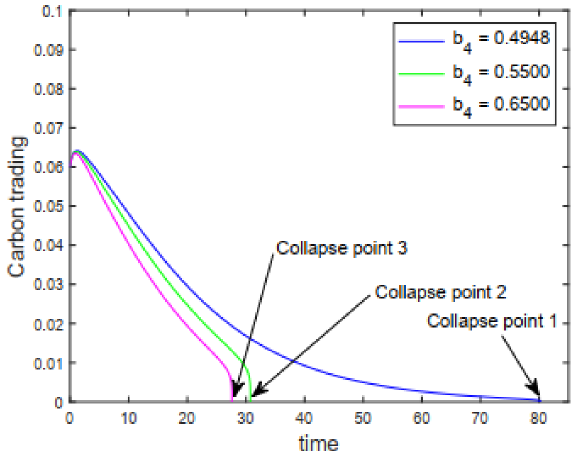
(a) Government control intensity(b_4=0.001)



(b) Government control intensity(b_4=0.01)



(c) Government control intensity(b_4=0.10,0.15,0.20)



(d) Government control intensity(b_4=0.4948,0.5500,0.6500)

Figure 7: The evolution of carbon trading with government control

IV. CONCLUSION

This paper further analyses the chaotic phenomenon of the NECT system and chaotic dynamics characteristics of the system. In addition, this paper introduces government control into NECT system, which acts as restriction conditions, to control the chaotic phenomenon. The results prove that government control plays a role in stabilizing the chaotic system.

In detail, we analyze the impact of government control on new energy, carbon emission and carbon trading through Lyapunov exponent spectrum. In the selective constrained NECT dynamic evolution system, when government control plays a role in the system, it can promote new energy in a short period of time. However, such regulation will inhibit the development of the carbon market. If the intensity of government control is too high, the system will collapse. Therefore, when developing new energy and carbon markets, it is necessary to adjust the intensity of government control. This paper is just a theoretical analysis, the results of the theoretical analysis of data may be different from the real situation.

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REFERENCES

[1] R. An, M. Ji, S. Zhang, Global warming and obesity: a systematic review, Obesity Reviews 19 (2) (2018) 150–163.

[2] F. Princiotta, Global climate change and the mitigation challenge, Journal of the Air & Waste Management Association 59 (10) (2009) 1194–1211.

[3] H. Tang, X. Yang, Y. Zhang, Effort at constructing big data sensor networks for monitoring greenhouse gas emission, International Journal of Distributed Sensor Networks 10 (7) (2014) 619608.

[4] X. Yang, X.-C. Wang, Z.-Y. Zhou, Development path of chinese low-carbon cities based on index evaluation, Advances in Climate Change Research 9 (2) (2018) 144–153.

[5] A.-G. Hu, The five-year plan: A new tool for energy saving and emissions reduction in china, Advances in Climate Change Research 7 (4) (2016) 222–228.

[6] B. Jiang, Z. Sun, M. Liu, China's energy development strategy under the low-carbon economy, Energy 35 (11) (2010) 4257–4264.

[7] S. Qi, B. Wang, J. Zhang, Policy design of the hubei ets pilot in china, Energy Policy 75 (2014) 31–38.

[8] F. Jotzo, A. Löschel, Emissions trading in china: Emerging experiences and international lessons (2014).

[9] J. J. Jiang, B. Ye, X. M. Ma, The construction of shenzhen's carbon emission tradingscheme, Energy Policy 75 (2014) 17–21.

[10] Y. Hua, F. Dong, China?s carbon market development and carbon market connection: A literature review, Energies 12 (9) (2019) 1663.

[11] M.-Z. DENG, W.-X. ZHANG, Recognition and analysis of potential risks in china's carbon emission trading markets, Advances in Climate Change Research 10 (1) (2019) 30–46.

[12] J. Liu, H. Xu, Y. Liu, Y. Xu, The study of relationship and strategy between new energy and economic development based on decoupling theory, in: Proceedings of the 2015 International Conference on Applied Mechanics, Mechatronics and Intelligent Systems (AMMIS2015), World Scientific, 2016, pp. 909–914.

[13] L. Liu, C. Chen, Y. Zhao, E. Zhao, China's carbon-emissions trading: Overview, challenges and future, Renewable and Sustainable Energy Reviews 49 (2015) 254–266.

[14] J. Gong, J. Zhou, X. Wang, The current situation and correlation analysis of the new energy industry in chinese carbon trading market, in: 2019 IEEE Asia Power and Energy Engineering Conference (APEEC), IEEE, 2019, pp. 341–346.

[15] G. Fang, L. Tian, M. Sun, M. Fu, Analysis and application of a novel three-dimensional energy-saving and emission-reduction dynamic evolution system, Energy 40 (1) (2012) 291– 299.

[16] G. Fang, L. Tian, M. Fu, M. Sun, Government control or low carbon lifestyle?–analysis and application of a novel selective-constrained energy-saving and emission-reduction dynamic evolution system, Energy Policy 68 (2014) 498–507.

[17] F. Guochang, H. Yu, Z. Yue, Research on carbon trading driving mechanism and regional synergy path, Coal Economic Research (6) (2020).

[18] Q. Wang, M. Su, A preliminary assessment of the impact of covid-19 on environment–a case study of china, Science of the total environment 728 (2020) 138915.