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Research on Coordinated Development of Interregional New Energy-Case Study of Jiangsu and Shanxi Province

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Abstract: New energy is the effective power-source to develop low carbon economy. The development and utilization of new energy could solve the problem of energy shortage and environmental pollution. This paper examined the coordinated development of interregional new energy conditions by using the Lyapunov function. The development coefficients of the relevant variables are proposed to perform scenario analysis according to carbon emissions, economic development and the development potential of new energy in Jiangsu province and Shanxi province's energy-saving and emission-reduction (ESER) system. The scenario analysis results show that, the peak value of carbon emissions in ESER system is the critical factor for the simultaneous development of two systems. The coordinated development of new energy between Jiangsu province and Shanxi province could realize by reducing the peak value of carbon emissions appropriately in Jiangsu province and speeding up the development of new energy in Shanxi province.

Keywords: energy-saving and emission-reduction; new energy; coordinated development; energy intensity.

1 Introduction

The environment problem has become the hot issues of current concern [1]. Due to the large amount of greenhouse gas emissions by the massive use of fossil fuel, the environment problems are becoming more and more serious. Energy-saving and emission-reduction (ESER) is the key to solve environmental problems [2], such as a wide range of haze weather, which can make people suffer. During the process of exploring the ESER system, it is found that new energy play a more and more important role. Developing new energy is an important breakthrough to solve the environmental problems, adjust the economic structure and develop low carbon economy. It also an important measure to realize the sustainable development of economy and society [3].

New energy development in different areas is not balanced for its regional attribute [4]. ESER system is a complex nonlinear coupling system under the constraint of the new energy. There are complex evolutionary relationships between different ESER systems. On different aspects of the speed of development, proportion and order in different ESER systems, a reasonable solution, which should be overall and focused, is needed. It can realize the coordinated development between different systems, and it is beneficial to promote the development of the ESER system under the constraints of the new energy [5].

It is a very good attempt to explore the complexity of economic system by using the nonlinear dynamics theory [6-8]. We introduced a novel four-dimensional ESER dynamic evolutionary system in accordance with the complicated relationship between ESER, carbon emissions, economic growth and new energy, with a series of practical proposal [9]. A further study is conducted on the evolution mechanisms of the new energy coordinated development, and the conditions of coordinated development between different regions. According to the measure of energy intensity, we have a study, with a series of practical proposal, on how to realize the coordinated development of regional new energy based on a case analysis of Jiangsu Province, Shanxi Province.

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The outline of this paper is subdivided into the following sections. The model developed for this study is set up and analyzed in Section 2. Section 3 is about the conditions of the coordinated development. A scenario analysis is presented in Section 4. Section 5 provides conclusions and further perspectives.

2 The model

New energy has many advantages such as its abundant reserves, the sustainable utilization and the pollutants generated less (or no) in the process of using it. New energy can not only make up for the fossil energy shortage of vacancies, but also have a little impact on environment. So at present new energy is very suitable for the requirements of ESER. In accordance with the complicated relationship between ESER, carbon emissions, economic growth and new energy, a novel four-dimensional ESER dynamic evolutionary system is introduced [9].

$$\begin{cases} \dot{x} = a_1 x\left(y/M - 1\right) - a_2 y + a_3 z + a_4 u \\ \dot{y} = -b_1 x + b_2 y\left(1 - y/C\right) + b_3 z\left(1 - z/E\right) - b_4 u \\ \dot{z} = c_1 x\left(x/N - 1\right) - c_2 y - c_3 z + c_4 u\left(u/F - 1\right) \\ \dot{u} = d_1 u\left(y - H\right) + d_2 z \end{cases} \tag{1}$$

Where, $x\left(t\right)$ is the time-dependent variable of ESER; $y\left(t\right)$, of carbon emissions; $z\left(t\right)$, of economic growth; $u\left(t\right)$,of development and utilization of new energy. M is the inflexion of $y\left(t\right)$ to $x\left(t\right)$ C is the peak value of $y\left(t\right)$ during a given economic period E, of $z\left(t\right)$ N is the inflexion of $x\left(t\right)$ to $z\left(t\right)F$ is the inflexion of new energy to economic growth; H is the inflexion of carbon emissions to new energy; a_i, b_i, c_i, d_j, (i=1,2,3,4,j=1,2) are the development coefficient or the influence coefficient of the corresponding variables (variables used in the paper are explained clearly on [6,9]).

Developing new energy can reduce the dependence on traditional energy sources gradually, improve the efficiency of energy utilization and the level of energy cleanliness, promote rapid, sustainable and comprehensive economic growth. The eastern provinces have paced the whole nation in the development of new energy and the new energy industry in these provinces has become more and more mature. In recent years, wind power and photovoltaic power generation based on the new energy industry is developing rapidly in Shanxi, Inner Mongolia, Ningxia Province etc.which are China's traditional coal power. The new energy industry has become an important way to change the energy consumption structure and improve the ecological environment. However, the new energy development is not balanced between eastern and western China. For example, eastern China has advanced technological capacities; western China has ideal development conditions. If the advantages of developing new energy in eastern and western China can be combined effectively, the coordinated development of new energy will be realized, which will accelerate the China new energy revolution, and help establish a new economic growth pole.

In prosperous Jiangsu province of China, there are not self-sufficient energy, such as oil and coal, for a long time. However, Shanxi, with its vast coal reserves, is the traditional coal power exporting provinces. In the past long period of economic development, the feature of energy demand in Mid-Eastern China, represented by Jiangsu and Shanxi province, is the extensive use of the traditional fossil energy and electric power. In recent years, new energy industry such as Photovoltaic and wind power is developing rapidly in Jiangsu province. The related industries of new energy have begun to present the state of centralization and they will take the commanding heights of the development of economy and science and technology. In Shanxi province, which is full of wind and solar energy, new energy industry including the wind and photovoltaic power has also developed rapidly in recent years. So Shanxi province is walking out of a successful path with the combination of energy conservation and technological advances. Choosing Jiangsu and Shanxi Province as the research object can comprehensively reflect the development of new energy in China. So we can draw promotional conclusions from a case analysis of Jiangsu Province, Shanxi Province about new energy.

We will explore evolutional mechanism of the coordinated new energy development based on Eq. (1). In order to facilitate the analysis and get the accurate conclusions, we assume that development coefficient of $x\left(t\right)$, $y\left(t\right)$, $z\left(t\right)$, $u\left(t\right)$, M, C, E, N, F, H in Jiangsu province are the same as the ones in Shanxi province. We will get the novel ESER system of Jiangsu and Shanxi province with the constraints of the new energy.

The novel ESER system of Jiangsu province with the constraints of the new energy can be described by the following differential equations:

$$\begin{cases} \dot{x_1} = ax_1\left(y_1/M-1\right) - a_2y_1 + a_3z_1 + a_4u_1 \\ \dot{y_1} = -b_1x_1 + by_1\left(1-y_1/C\right) + b_3z_1\left(1-z_1/E\right) - b_4u_1 \\ \dot{z_1} = c_1x_1\left(x_1/N-1\right) - c_2y_1 - cz_1 + c_4u_1\left(u_1/F-1\right) \\ \dot{u_1} = du_1\left(y_1-H\right) + d_2z_1 \end{cases} \tag{2}$$

The novel ESER system of Shanxi province with the constraints of the new energy can be described by the following differential equations:

$$\begin{cases} \dot{x_2} = a^{'}x_2\left(y_2/M-1\right) - a_2y_2 + a_3z_2 + a_4u_2 \\ \dot{y_2} = -b_1x_2 + b^{'}y_2\left(1-y_2/C\right) + b_3z_2\left(1-z_2/E\right) - b_4u_2 \\ \dot{z_2} = c_1x_2\left(x_2/N-1\right) - c_2y_2 - c^{'}z_2 + c_4u_2\left(u_2/F-1\right) \\ \dot{u_2} = d^{'}u_2\left(y_2-H\right) + d_2z_2 \end{cases} \tag{3}$$

In Eq. (2) and (3), a and $a^{'}$ are the development coefficients of $x_1(t)$ and $x_2(t)$. The development coefficients are different due to the gap of ESER investment, development and relevant policies between Jiangsu and Shanxi province. b and $b^{'}$ are the development coefficients of $y_1(t)$ and $y_2(t)$. The elasticity coefficients b , $b^{'}$ are different due to the differences between the industrial structures, the proportion of energy consumption etc. in Jiangsu and Shanxi province. c and $c^{'}$ are the suppression coefficient of the ESER investment to economic growth respectively. The suppression coefficients are different due to the differences between the speed of economic development, economic scale and ESER investment etc. in Jiangsu and Shanxi province. d and $d^{'}$ are the development coefficients of $u_1(t)$ and $u_2(t)$. The development coefficients are different due to the differences between the potential of new energy development in Jiangsu and Shanxi province. We consider that the other coefficients, which are reflected in the interaction between variables, are basically the same.

3 The coordinated development conditions

Adaptive synchronization method is widely used to the problem of the synchronization between two systems with different unknown parameters [10]. We assume that the new energy ESER system of Jiangsu province is a driving system and the new energy ESER system of Shanxi province is a response system. In Eq. (3), we apply the appropriate control value, which is controlled by $u_1(t)$, $u_2(t)$, $u_3(t)$, $u_4(t)$. $u_1(t)$, which is relevant to the ESER capacity, carbon emissions, Economic growth and the development and utilization of new energy capacity, is a control of the ESER rate in Shanxi province. So $u_1(t)$ is a complicated multi element function. Similarly, $u_2(t)$, $u_3(t)$, $u_4(t)$ which are respectively relevant to the Carbon emission development speed, the economic development speed and the development and utilization speed of new energy development, are the control of the other corresponding variables. So $u_2(t)$, $u_3(t)$, $u_4(t)$ are influenced by many variables and they are complicated nonlinear functions.

The driving system is a novel ESER system of Jiangsu province with the constraints of the new energy-The Eq. (2). After applied the appropriate control value, the novel ESER system of Shanxi province with the constraints of the new energy can be described by the following differential equations-The Eq. (4):

$$\begin{cases} \dot{x_2} = a^{'}x_2\left(y_2/M-1\right) - a_2y_2 + a_3z_2 + a_4u_2 + u_1(t) \\ \dot{y_2} = -b_1x_2 + b^{'}y_2\left(1-y_2/C\right) + b_3z_2\left(1-z_2/E\right) - b_4u_2 + u_2(t) \\ \dot{z_2} = c_1x_2\left(x_2/N-1\right) - c_2y_2 - c^{'}z_2 + c_4u_2\left(u_2/F-1\right) + u_3(t) \\ \dot{u_2} = d^{'}u_2\left(y_2-H\right) + d_2z_2 + u_4(t) \end{cases} \tag{4}$$

In Eq. (4), $a^{'} = a + \gamma_1 a$, $b^{'} = b + \gamma_2 b$, $c^{'} = c + \gamma_3 c$, $d^{'} = d + \gamma_4 d$, γ_i $(i = 1, 2, 3, 4)$ indicates the relationship between the corresponding unknown parameters.

The Eq. (5) is the error system of the Eq. (2)and the Eq. (4).

$$\begin{cases} \dot{e_1} = -a_1e_1 - a_2e_2 + a_3e_3 + a_4e_4 + a/M(x_2y_2 - x_1y_1) + \gamma_1 a\,(x_2y_2/M - x_2) + u_1(t) \\ \dot{e_2} = -b_1e_1 + be_2\,(1 - y_1 + y_2/C) + b_3e_3\,(1 - z_1 + z_2/E) - b_4e_4 + \gamma_2 b\,(y_2 - y_2y_2/C) + u_2(t) \\ \dot{e_3} = c_1e_1\,(x_1 + x_2/N - 1) - c_2e_2 - c_3e_3 - \gamma_3 cz_2 + c_4e_4\,(u_1 + u_2/F - 1) + u_3(t) \\ \dot{e_4} = d_2e_3 - dHe_4 + d(u_2y_2 - u_1y_1) + \gamma_4 du_2\,(y_2 - H) + u_4(t) \end{cases} \tag{5}$$

The problem of Synchronization between two systems has translated into the problem of asymptotic stability at the origin by using the Eq. (5).

Theorem 1: Let the control function of the system be the Eq. (6) and let parameter estimation rate be $\dot{\hat{\gamma_1}}a = (x_2y_2/M - x_2)e_1$, $\dot{\hat{\gamma_2}}b = (y_2 - y_2y_2/C)e_2$, $\dot{\hat{\gamma_3}}c = -z_2e_3$, $\dot{\hat{\gamma_4}}d = (u_2y_2 - u_2H)e_4$. When $y_1 + y_2 > C$, the Eq. (5) is asymptotically stable. For any $[x_1(0), y_1(0), z_1(0), u_1(0)]^T$ and $[x_2(0), y_2(0), z_2(0), u_2(0)]^T$ as the initial condition, there are $\lim_{t\to\infty} \|e\| = 0$ and $e = [e_1, e_2, e_3, e_4]^T$.

$$\begin{cases} \dot{e_1} = a_2e_2 - a_3e_3 - a_4e_4 - a/M(x_2y_2 - x_1y_1) - \hat{\gamma_1} a\,(x_2y_2/M - x_2) \\ \dot{e_2} = b_1e_1 - b_3e_3\,(1 - z_1 + z_2/E) + b_4e_4 - \hat{\gamma_2} b\,(y_2 - y_2y_2/C) \\ \dot{e_3} = -c_1e_1\,(x_1 + x_2/N - 1) + c_2e_2 - c_4e_4\,(u_1 + u_2/F - 1) + \hat{\gamma_3} cz_2 \\ \dot{e_4} = d_2e_3 - d(u_2y_2 - u_1y_1) - \hat{\gamma_4} du_2\,(y_2 - H) \end{cases} \tag{6}$$

$\tilde{\gamma_1} = \gamma_i - \hat{\gamma_i}$, $\hat{\gamma_i}$ is the estimated value of γ_i, $(i = 1, 2, 3, 4)$.
proof. Constructing Lyapunov function as

$$V = \frac{1}{2}(e_1^2 + e_2^2 + e_3^2 + e_4^2) + \frac{1}{2}(\tilde{\gamma_1}^2 a^2 + \tilde{\gamma_2}^2 b^2 + \tilde{\gamma_3}^2 c^2 + \tilde{\gamma_4}^2 d^2)$$

substitute Eq. (6) and Eq. (7) into Eq. (5), then we can get:

$$\dot{V} = -ae_1^2 + b\,(1 - y_1 + y_2/C)\,e_2^2 - ce_3^2 - dHe_4^2$$

When V are positive definite and $\dot{V}$ are negative definite, the asymptotic stability can be judged.a, b, c, d are all positive in the original system. If $\dot{V} < 0$, then $(1 - y_1 + y_2/C) < 0$. That is to say if $y_1 + y_2 > C$, the Eq. (5). will be asymptotic stability at the origin.

So Theorem 1 is proved.

According to the actual situation of the development of the system, it should be that $C < y_1 + y_2 < 2C$. The peak value C from different equation is not the same. In view of these realities, the synchronous conditions as narrated above should be $(C_1 + C_2)/2 < y_1 + y_2 < C_1 + C_2$. are the peak value of the carbon emission in the corresponding equations.

For different new energy systems, the control value $u_i(t)(i = 1, 2, 3, 4)$ in the response system, such as the Eq. (4), correspond to the specific policies. Whatever the specific policies, and no matter how to apply the control, if $(C_1 + C_2)/2 < y_1 + y_2 < C_1 + C_2$, the system can achieve synchronization. If $y_1 + y_2 < (C_1 + C_2)/2$ or $y_1 + y_2 > C_1 + C_2$, the system cannot achieve synchronization. It also shows the importance of controlling the peak value of carbon emissions from a point of view.

4 Ascenario analysis

A novel four-dimensional ESER dynamic evolutionary system is established based on the complicated relationship between ESER, carbon emissions, economic growth and new energy. Parameter identification is very important for the analysis in the actual system. The ESER data is processed and handled referred to the International algorithm. The source data of carbon emissionseconomic growth and new energy come from China Statistical Yearbook and Statistical Yearbook of Jiangsu-Shanxi. The parameters $a, a^{'}, b, b^{'}, c, c^{'}, d, d^{'}$ which are assumed in Section 3-the conditions of the coordinated development, are different. However, the other parameters in Eq. (2) and Eq. (3) are substantially the same. Considering accessibility of the data and simplicity of the analysis, let parameters in Eq. (2) and Eq. (3) be the parameters under the constraints of the new energy. Considering the status of ESER, carbon emissions, economic growth and the development of new energy, the other parameters in Eq. (2) and Eq. (3) can be described by the following Table 2.

Table 1: Parameters of the actual system.

a_2	a_3	a_4	b_1	b_3	b_4	c_1	c_2
0.1983	0.2065	0.4563	0.1695	0.1032	0.1327	0.4358	0.3326
c_4	d_2	M	C	E	N	F	H
0.2213	0.1092	0.6175	0.4714	0.6452	0.5527	3.5021	0.4852

Table 2: Other parameters in Eq. (2) and Eq. (3).

a	$a^{'}$	b	$b^{'}$	c	$c^{'}$	d	$d^{'}$
0.1372	0.1038	0.3925	0.4792	0.7249	0.5832	0.2845	0.2341

Take the data in 2000 as the initial value. The initial value to the corresponding system of Jiangsu Province (the system (2) are given with [0.0000012, 0.357, 1.496, 0.037].And the initial value to the corresponding system of Shanxi Province (the system (2) are given with [0.00000063, 0.262, 0.29, 0.021], the unit all being ton standard coal. Phase diagrams of the actual system under the constraints of new energy can be described by the following Fig. 1 and Fig. 2. The phase diagrams in Fig. 1 and Fig. 2 indicate that the actual system is steady development, the same with the actual situation.

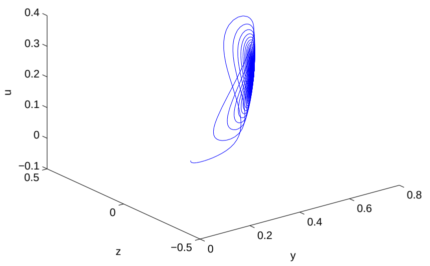

Figure 1: Phase diagram of the actual system of Jiangsu.

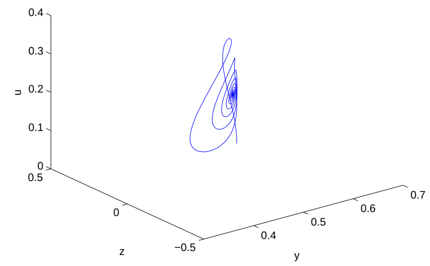

Figure 2: Phase diagram of the actual system of Shanxi.

Energy intensity evolution diagram of the driving system and the responding system can be described by Fig. 3 when coefficients are equal to the figure in Table 2.The solid line in Fig. 3 represents energy intensity evolution diagram of Jiangsu. The dashed lines in Fig. 3 represents energy intensity evolution diagram of Shanxi. Fig 3 indicates that the energy intensity is much differences between the two system. But the energy intensity fluctuating of Shanxi is smooth. Serious energy intensity fluctuating of Jiangsu is reasonable, due to huge energy consumption, relatively large total economy and the rapid development of new energy in Jiangsu Province. Energy intensity fluctuations accurately reflect the situation of the development of the system. In this case, it is not possible for the two systems of Jiangsu and Shanxi to achieve synchronous development of the new energy development and the development of new energy will not be able to realize coordinated development.

Adjusting parameters of the system appropriately, and imposing policy factors on the system, can promote the system to realize the coordinated development of two systems. Fig. 4 indicates energy intensity evolution diagram of Jiangsu and Shanxi under the condition of the control values. Just like Fig. 3, the solid line in Fig. 4 represents energy intensity evolution diagram of Jiangsu. The dashed lines in Fig. 4 represents energy intensity evolution diagram of Shanxi. Parameter c of new energy system in Jiangsu changes from 0.4714 to 0.4604. Parameter d of new energy system in Shanxi changes from 0.2341 to 0.5141. After the simple adjustment of parameters c and d, energy intensity evolution trend of the two systems is highly consistent. The analysis shows that coordinated development of the new energy system can be achieved

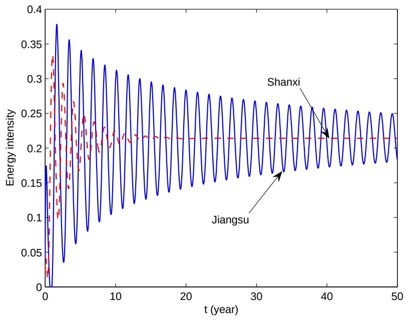

Figure 3: The comparison diagram of energy intensity between Jiangsu and Shanxi.

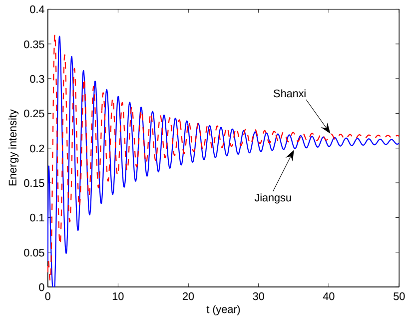

Figure 4: The comparison diagram of energy intensity between Jiangsu and Shanxi.

when the relative high energy consumption provinces reduce energy consumption appropriately to delay the peak value of carbon emission and accelerating the development in backward new energy development province at the same time.

By observing Fig. 3 and Fig. 4, after a simple adjustment the trend of the two systems is becoming more and more relevant (shown in Fig. 4) from the large difference (shown in Fig. 3) at the beginning. Technically, Fig. 4 indicates that the synchronous development of the two systems is not meant to be achieved. After the appropriate adjustment of the related parameters in the two corresponding systems and applying more perfect policies and measures on the two systems, which means fully exerting the function of control value $u_i(t)(i = 1, 2, 3, 4)$, the synchronous development can be truly achieved.

5 Conclusions

Based on the ESER system under the constraint of the new energy, the paper constructed ESER system of Jiangsu province and Shanxi Province and examined the regional coordinated development of new energy. By using the Lyapunov function, we explore the two coordinated development of new energy system conditions. According to ESER, carbon emissions, economic growth and the development potential of new energy in Jiangsu and Shanxi Province, we assume development coefficients of related variables and make scenario analysis. At last some practical policies and measures are presented.

The results of this paper reveal that the peak value of carbon emissions in the system is the key factor for the simultaneous development of two systems. Achieving synchronous development between the two systems will be possible only when the sum of carbon emission fall within a reasonable range. Reducing the peak value of carbon emissions in Jiangsu Province appropriately and accelerating the development of new energy in Shanxi Province can achieve the coordinated development of new energy in Jiangsu and Shanxi Province.

This paper explored the coordinated development of new energy in Jiangsu province and Shanxi Province. Analysis results may be affected due to the limited statistical data and some of the system parameters, which are assumed. This paper examined the evolution trend of energy intensity, and the impact on other variables will be given in the future. Based on the statistical data from other regions, more areas of new energy development evolution could be studied.

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