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Investigating carbon tax pilot in YRD urban agglomerations—Analysis of a novel ESER system with carbon tax constraints and its application

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HIGHLIGHTS

• Use nonlinear dynamical method to model the YRD urban agglomerations ESER system.
• The YRD urban agglomerations ESER system has stronger capacity to resist concussion.
• Carbon tax is more suited for the development of ESER in YRD urban agglomerations.
• The measures to promote development of carbon tax properly are put forward.

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ABSTRACT

This paper attempts to explore carbon tax pilot in Yangtze River Delta (YRD) urban agglomerations based on a novel energy-saving and emission-reduction (ESER) system with carbon tax constraints, which has not yet been discussed in present literature. A novel carbon tax attractor is achieved through the discussion of the dynamic behavior of the new system. Based on the genetic algorithm-back propagation neural network, the quantitative coefficients of the actual system are identified. The scenario analysis results show that, under the same tax rate and constraint conditions, the ESER system in YRD urban agglomerations is superior to the average case in China, in which the impacts on economic growth are almost the same. The former’s energy intensity is lower and the shock resistance is stronger. It is found that economic property of YRD urban agglomerations is the main cause for the ESER system of YRD urban agglomerations being superior. In the current YRD urban agglomerations’ ESER system, energy intensity cannot be adjusted to an ideal level by commercialization management and government control; however, it is under effective control of carbon tax incentives. Therefore, strengthening the economic property of YRD urban agglomerations and effective utilization of carbon tax incentives could perfectly control energy intensity, without obvious potential negative impact on economic growth.

1. Introduction

Energy-saving and emission-reduction (ESER) is the ideal choice of building a resource conserving and environment-friendly society. With the deterioration of global resource environment, ESER has attracted increasing attention recently [1–4]. ESER system should be constructed. The index to measure the operating condition of ESER system should be made clear [5], and the evolutionary relationship of the variables in the system needs further attention [6,7]. All of the factors mentioned above are the key to promoting the development of ESER system. In addition, the design of ESER policy [8,9], the advocating energy conservation behavior [10], even the ESER of some concrete industries [11–13] or the progress of ESER technology [14,15] will affect the effectiveness of ESER.

Carbon tax is a more efficient economic measure among the policy instruments of ESER system [16], which is helpful to achieve the ESER targets. Under the action of carbon tax, pollution sources could be controlled better and the final consumption of energy will be affected [17,18]. Levying carbon tax at proper time, designing scientific reasonable carbon tax rate [19] and harmonizing the relationship between carbon tax and other variables in the ESER system will boost carbon tax [20]. In turn, the development of carbon tax could accelerate the pace of ESER. Furthermore, ESER could harmonize the contradictions between economic development and
resources-environment [21], with the objectives of industrial restructuring and low carbon economy being able to achieve.

Carbon tax as a hot topic has been attached more importance. Dissou and Siddiqui [22] analyzed the incidence of carbon taxes on inequality comprehensively. They presented two channels in the assessment of carbon taxes on inequality. Altonet al. [23] explored carbon taxes in South Africa, finding that $30 per ton of CO_2 could achieve the targets set for 2025. Stram [24] proposed a new strategic plan for a carbon tax. Allan et al. [25] carried out a research on the economic and environmental impact of a carbon tax in Scotland. They found the target of 37% CO_2 reduction could be achieved when a tax of £50 per ton of CO_2 was imposed. Carbon tax could secure a double dividend when the revenue is recycled through income tax. Nichols and Victor [26] investigated the relationship between CCS and shale gas production under carbon taxes in America, and discussed some measures which could help guide policy making. Fahimnia et al. [27] presented a tactical supply chain planning model, which integrated carbon emission and economic targets under a carbon tax policy scheme. The numerical experiments based on data from an actual organization in Australia, and the numerical results indicated their organizational and policy insights.

Selecting some areas as a pilot before carrying out a policy across large range [28,29] is thoughtful, which could avert some detrimental effects during the implementing of the policy. Carbon trading [30] and low carbon city [31] had been applied with a ser-}


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Selecting some areas as a pilot before carrying out a policy across large range [28,29] is thoughtful, which could avert some detrimental effects during the implementing of the policy. Carbon trading [30] and low carbon city [31] had been applied with a series of pilot projects. Finland, Sweden, on behalf of Nordic country had levied carbon tax earlier; Boulder (American state of Colorado) and Quebec (Canada) had made a good attempt at carbon tax pilot. Their experiences are worthwhile. China will fully implement carbon trading in 2017 (In China, Shenzhen launched the first carbon trading platform on 18 June 2013. Since then, Beijing, Tianjin, Shanghai, Guangdong, Hubei and Chongqing had carried out trials for carbon trading. The carbon trading market rules in the above provinces and cities are being in gradually perfect process). By contrast, European carbon emissions trading system (EUETS), as the largest carbon trading market in the world, no longer enjoy the past glory after the hard hit in 2013 [32]. Which will have a better effect in ESER system, carbon tax or carbon trading? The key is to find suitable measures to reduce carbon emissions according to the actual situation of the corresponding district (city) [33]. For some districts (cities), carbon tax is better suited for the development of ESER to a certain degree. In the practice process, carbon tax is bound to have an effect on economy, employment and social welfare [34–36]; thus we need to know how much the economic areas are influenced by carbon tax, and how to cope with these conundrums. Only through spotting problems and solving them in the carbon tax pilot projects, can we avoid the failures of Australia and European (On July 2012, carbon tax implemented officially in Australia, the levy amount of carbon tax was 24 $A/ton CO_2. Two years later, Australia abolished carbon tax on July 2014, which aimed to lighten the burden of families and small businesses. The resolution of abolishing carbon tax aroused widespread controversy and criticism. In November 2012, European Union had to declare suspension of levying aviation carbon tax on the airlines outside the EU after the widespread objection).

Moreover, chaos analysis and its applications in dynamical systems have been used in many fields [37–40]. We [41] introduced a novel four-dimensional ESER dynamic evolutionary system in accordance with the complicated relationship between ESER, carbon emissions, economic growth and carbon tax, with a series of productive results. This research, based on the previous study, is to establish a Yangtze River Delta (YRD) urban agglomerations ESER system with carbon tax constraints. The novel system demonstrates the economic property of YRD urban agglomerations. Meanwhile, the commercialization management, government control and carbon tax incentives are introduced as constrained variables. The carbon tax pilot in YRD urban agglomerations and consequent influence of carbon tax are discussed. The Yangtze River Delta (YRD) urban agglomerations carbon tax pilot system is put forward for the first time from the perspective of nonlinear dynamics. By observing the dynamical behavior of the system, we obtain the evolutionary trends of energy intensity, economic growth and carbon emissions under various constraint conditions, followed by relative policy advice for carbon tax in YRD urban agglomerations.

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 parameter identification of the actual system based on the statistical data in Yangtze River Delta Urban Agglomerations. A scenario analysis is undertaken in Section 4. Section 5 presents implications of the research for government policy. Conclusions and further perspectives are discussed in Section 6.

2. The model

2.1. Establishment of the model

YRD urban agglomerations are the biggest reform and opening up districts in China. Meanwhile, they are the most promising economic blocks with the fastest developing speed and the biggest economic gross. Smooth development of the ESER system in the area will ensure better development (YRD urban agglomerations’ energy is seriously inadequate and relies on the import for a long period. At present, energy shortages, PM 2.5 and the large scale haze weather have become the new normal, environmental and resource issues have become neck bottle of development in YRD urban agglomerations. ESER is pivotal to solve the problem of environmental emission and resources depletion problem, which could ensure the sustainable development of the socio-economic and ecology). Which one is more suitable for ESER, Carbon tax or carbon trading? There have been different ideas on this problem in the academic field [42,43]. In YRD urban agglomerations, the enterprises are mainly small and medium sized enterprises (SMEs), the private economy being very active. Judging from the present condition in China, carbon trading is more effective for large
enterprise, carbon tax has better incentive and restriction effects on the SMEs. From the status quo of YRD urban agglomeration’s economic development, carbon tax is better suited for the development of ESER in that area.

The development speed of carbon emissions and economic growth may be influenced by carbon tax to a certain extent in the given period of time; but carbon tax will eventually promote the development of ESER. ESER system will be further optimized by taking the advantage of the following measures, such as applying commercialization management to the ESER system, rationally using government control and giving full play of the economic property of YRD urban agglomerations, as well as establishing proper carbon tax incentives. Carbon tax could fulfill its function in the ESER system, forming a virtuous circle. The ESER system could better develop. Based on the four-dimensional ESER system in [41] and the characteristics of YRD urban agglomerations, it is assumed that ESER, carbon emissions, economic growth and carbon tax are restrained by commercialization management, government control, the economic property of YRD urban agglomerations and carbon tax incentives respectively. The corresponding restriction conditions are assumed to be \( F_1(x, y, z, w, t) \), \( F_2(x, y, z, w, t) \), \( F_3(x, y, z, w, t) \) and \( F_4(x, y, z, w, t) \). The novel ESER system with carbon tax constraints can be described by the following differential equations:

\[
\begin{align*}
\dot{x} &= a_1x(y/M - 1) - a_2y + a_3z + a_4w + F_1(x, y, z, w, t) \\
\dot{y} &= -b_1x + b_2y(1 - y/C) + b_3z(1 - z/E) - b_4w + F_2(x, y, z, w, t) \\
\dot{z} &= c_1x(y/N - 1) - c_2y - c_3z - c_4w + F_3(x, y, z, w, t) \\
\dot{w} &= d_1w(y - T) + F_4(x, y, z, w, t)
\end{align*}
\]

(1)

where \( x(t) \) is the time-dependent variable of ESER; \( y(t) \), of carbon emissions; \( z(t) \), of economic growth [41]; \( w(t) \), of carbon tax. \( a_1, a_2, b_1, b_2, b_3, b_4, c_1, c_2, c_3, c_4, d_1, M, C, E, N, T \) are positive constants (\( i = 1, 2, 3, 4, t, l, I \) is a given economic period [see \[41]\]).

The first formula in Eq. (1) indicates that: \( a_1 \) is the development coefficient of \( x(t) \); \( a_2 \) is the suppression coefficient of \( y(t) \) to \( x(t) \); \( a_3 \) is the influence coefficient of \( z(t) \) to \( x(t) \); \( a_4 \) is the influence coefficient of \( w(t) \) to \( x(t) \); \( F_1(x, y, z, w, t) \) is the inflexion of \( y(t) \) to \( x(t) \); \( F_2(x, y, z, w, t) \), \( F_3(x, y, z, w, t) \) and \( F_4(x, y, z, w, t) \) are the system, the parameters in Table 1 are obtained during the early implementation of \( w(t) \); and this stage will continue for a long time; \( i.e. \), \( c_1 > c_2, c_4w = (c_4 - c_2)w \) represents the inhibition effects of \( w(t) \) on economy synthetically. As \( w(t) \) develops, depending on the multiplicative effects of the recycling of the carbon tax revenues into the economy, \( c_1 > c_2 \); \( i.e. \), \( c_4 = c_4 - c_2 < 0 \). The impacts of \( w(t) \) on economy will turn to be positive (just the same, carbon tax has similar impact on \( x \) and \( y \) of \( y(t) \) YRD urban agglomerations have traditionally been a commercial center and the most dynamic region in China. Then the impact of \( F_3(x, y, z, w, t) \) on \( z(t) \) is simplified as the direct effect (−\( c_2z \)).

The fourth formula in Eq. (1) indicates that: \( d_1 \) is the development coefficient of \( w(t) \); \( T \) is the inflexion of \( y(t) \) to \( w(t) \); \( F_4(x, y, z, w, t) = d_2z(y - x) \) is carbon tax incentives; \( d_2 \) is the incentive coefficient. \( dw(t)/dt \) is associated with \( w(t) \) and the share of \( w(t) \) potential \( (y - T) \) simultaneously. When \( y < T, dw(t)/dt \) is slow; when \( y > T, dw(t)/dt \) gets fast. The impact of \( F_4(x, y, z, w, t) \) on \( w(t) \) depends on the development of \( y(t) \) and \( x(t) \).

Let \( d_3(z - y) \cdot (d/1 - (1 + d)^{-1}) = a_5, c_4 - c_2 = c_4 \). Then Eq. (1) can be simplified as:

\[
\begin{align*}
\dot{x} &= a_1x(y/M - 1) - a_2y + a_3z + a_4w + a_5(z - y) \\
\dot{y} &= -b_1x + b_2y(1 - y/C) + b_3z(1 - z/E) - b_4w - b_5y \\
\dot{z} &= c_1x(y/N - 1) - c_2y - c_3z - c_4w + c_5z \\
\dot{w} &= d_1w(y - T) + d_2z(y - x)
\end{align*}
\]

(2)

In Eq. (2), integrate \( \dot{y} = dy(t)/dt \) and \( \dot{z} = dz(t)/dt \) with \( t \), the energy consumption and the GDP could be deduced as \( y'(t) = \varphi_1(x, y, z, w, F_1, F_2, F_3, F_4, t) \) (\( k = 1/k_0, k_0 \) is the emission coefficient of the standard coal) and \( z(t) = \varphi_2(x, y, z, w, F_1, F_2, F_3, F_4, t) \). The time-dependent energy intensity during a given period can be depicted as follows:

\[
U(t) = \varphi_1(x, y, z, w, F_1, F_2, F_3, F_4, t)/\varphi_2(x, y, z, w, F_1, F_2, F_3, F_4, t),
\]

(3)

2.2 Dynamic analysis of the model

When the coefficients of Eq. (2) are given different values, the system presented in Eq. (2) will show different dynamic behavior. During the progress of parameter identification in Section 3 (see Parameter identification, \( e < 0.00021 \) in Section 3), it is found that when the parameters of Eq. (2) are given in Table 1, the dynamic system presented in Eq. (2) will display some very interesting dynamic evolution behavior.

Remark 1. In fact, the dynamic system presented in Eq. (2) will have chaotic attractor and the corresponding dynamic evolution behavior when the system has another group of parameters. We find this group of parameters in the research. Based on the data in the system, the parameters in Table 1 are obtained during the
process of parameter identification. These parameters reflect the properties of the system itself, rather than a simple dynamic behavior. From this viewpoint, the parameters in Table 1 make the system closer to the actual one, being more convincing.

Equation (2) has 4 equilibrium points: $S_0(0, 0, 0, 0), S_1(0.1037, -0.0760, 0.2236, 0.1620), S_2(-0.0006, 0.0322, -0.0115, 0.0131), S_3(-0.0399, 0.1303, 0.0755, 0.5973)$. The eigenvalues of the Jacobian matrix of Equation (2) at $S_0$ are $-0.4681 \pm 0.5202i, -1.2217, -0.0529$; at $S_1$ are $0.2959 \pm 0.3675i, -1.2217, -0.0529$; at $S_2$ are $-0.4852 \pm 0.5318i, -0.1161, 0.2443$; at $S_3$ are $-0.6310 \pm 0.7338i, 0.1376 \pm 0.2962i$. $S_0, S_1, S_2, S_3$ are all saddle points.

When the parameters of Equation (2) are given in Table 1 and initials are not the same. The chaotic attractor in Fig. 1 is a new chaotic phenomenon in ESER system of YRD urban agglomerations, which further confirmed the existence of chaotic attractor in ESER system of YRD urban agglomerations with carbon tax constraints. The first discovery of attractor phenomena in Eq. (2) opens a new chapter in the research of YRD urban agglomerations ESER system with carbon tax constraints.

In general, the dynamic system presented in Eq. (2) will have chaotic behavior when the system has another group of parameters. The coefficients of Equation (2) are obtained in the process of parameter identification based on the data of YRD urban agglomerations, which further confirmed the existence of chaotic attractor phenomenon in ESER system of YRD urban agglomerations with carbon tax constraints. The first discovery of attractor phenomena in Eq. (2) opens a new chapter in the research of YRD urban agglomerations ESER system with carbon tax constraints.

We can verify Equation (2) has Smale horseshoes and horseshoes chaos. The existence of chaotic attractor could be proved with theoretical proof.

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| $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $c_1$ |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 0.2874 | 0.5874 | 0.1614 | 0.8372 | 0.0345 | 0.1943 | 0.3926 | 0.4321 | 0.0628 | 0.4613 | 0.4948 |
| $a_6$ | $a_7$ | $a_8$ | $a_9$ | $a_{10}$ | $c_2$ | $c_3$ | $c_4$ | $c_5$ | $d_1$ | $d_2$ |
| 0.3042 | 0.5483 | 0.1041 | 0.2368 | 0.3029 | 0.1269 | 3.7426 | 0.4236 | 0.6857 | 0.0312 | 0.4198 |

Table 1: Parameters of Eq. (2).
3. Parameter identification

Calculation of ESER is mainly referred to the algorithm in Ref. [37]. The source data of carbon emissions and economic growth come from Statistical Yearbook. In a real sense, some cities in Anhui province also belong to YRD urban agglomerations. The economic structures in Jiangsu-Zhejiang-Shanghai are similar, for ease of data statistics, the data origins from the Statistical Yearbook of Jiangsu-Zhejiang-Shanghai. Calculation of carbon tax is mainly referred to the algorithm in Ref. [41]. For comparison with the average situation in China, the levy amount of carbon tax as 15 CNY/ton·CO$_2$ is presented [41]. The data of carbon tax could be obtained from the corresponding carbon tax rate and the carbon emissions data. The carbon tax increases at the annual average rate of 0.2 CNY/year. The data of ESER, carbon emissions, economic growth and carbon tax of YRD urban agglomerations in the years 2000 to 2013 are shown in Table 2.

Where, $x$ is the time-dependent variable of ESER $x(t)$ and abbreviated to $x$; $y$, of carbon emissions; $z$, of economic growth; $w$, of carbon tax. The drop of ESER $x(t)$ value in 2004 and 2009 mainly because the lag effect of SARS (Severe Acute Respiratory Syndrome) and Beijing Olympic Games (2008).

The Genetic Algorithm-Back Propagation (GA-BP) neural network is an effective method to identify the coefficients of a novel system with tiny error [45,46]. Select the previous thirteen sets of data as the input data, and the latter thirteen sets of data as the output data. The input variables and output ones are normalized. Select proper multilayered feed-forward neural network, and let all the adjustable parameters be random. Stop the debugging and running when $e$ reaches the specified precision (such as $10^{-5}$, see [38]). In this paper, let crossover rate be 0.8 and mutation rate be 0.04. When the error $e \leq 8.9635e-005$, the parameters of the actual system are shown in Table 3.

Fix the parameters of Eq. (2) shown in Table 3, select the data of 2000 as the initial condition (0.0000000294, 0.0207, 0.068, 0.000274), the unit being $10^{10}$ ton standard coal. The corresponding phase diagrams of the actual 4D system are observed as shown in Fig. 5. The phase diagram in Fig. 5 is limit cycle, indicating that the actual system is stable, the same with the actual situation.

4. A scenario analysis

ESER system research has found that energy intensity constraint is more suitable for the reduction of China’s greenhouse

| year | $x$ | $y$ | $z$ | $w$ | year | $x$ | $y$ | $z$ | $w$ |
|------|-----|-----|-----|-----|------|-----|-----|-----|-----|
| 2000 | 1.8126 | 1.0598 | 1.1232 | 1.0741 | 2007 | 4.4716 | 2.3144 | 3.3044 | 2.5646 |
| 2001 | 2.1497 | 1.1274 | 1.2444 | 1.1578 | 2008 | 4.9285 | 2.4376 | 3.8380 | 2.7341 |
| 2002 | 3.4816 | 1.2375 | 1.4051 | 1.2877 | 2009 | 4.3158 | 2.5451 | 4.1830 | 2.8891 |
| 2003 | 3.6781 | 1.4037 | 1.6642 | 1.4796 | 2010 | 5.2714 | 2.7603 | 4.9805 | 3.1706 |
| 2004 | 4.2483 | 2.0936 | 2.7716 | 2.2917 | 2011 | 5.0847 | 2.9883 | 5.8062 | 3.3775 |
| 2005 | 3.1549 | 1.9187 | 2.3810 | 2.0742 | 2012 | 5.3932 | 2.9883 | 6.2840 | 3.4729 |
| 2006 | 4.2483 | 2.0936 | 2.7716 | 2.2917 | 2013 | 5.5976 | 3.1180 | 6.8280 | 3.6236 |

| Table 3 |
| Parameters of the actual system. |
| $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $b_1$ | $b_2$ | $b_3$ | $b_4$ | $b_5$ | $c_1$ |
| 0.2874 | 0.5874 | 0.1614 | 0.6372 | 0.0345 | 0.0498 | 0.3926 | 0.4321 | 0.0628 | 0.4613 | 0.4948 |
| $c_2$ | $c_3$ | $c_4$ | $c_5$ | $d_1$ | $d_2$ | $M$ | $C$ | $E$ | $N$ | $T$ |
| 0.3042 | 0.5483 | 0.1041 | 0.2368 | 0.3092 | 0.1279 | 3.3672 | 0.2352 | 0.6857 | 0.0312 | 0.2574 |
gas emission targets than overall emissions constraint. Meanwhile, economic growth should be given enough attention in the progress of ESER. Since carbon tax has impact on the overall variables of ESER system, it may cause the system to be in rather complex dynamics behavior. Therefore, this paper sets particular emphasis on the impacts of levying carbon tax on energy intensity and economic growth. From the dynamical evolution behavior of the ESER system with carbon tax constraints, the evolution behavior of energy intensity and economic growth are diagramed. By observing the stable value and evolution trend of energy intensity, the error value and evolution trend of economic growth, a contrastive analysis of carbon tax evolution regulations in YRD urban agglomerations and China as a whole is carried out. The evolution behavior of ESER system with carbon tax constraints in YRD urban agglomerations are further discussed.

4.1. The impact of YRD urban agglomerations’ economic property

With the levying of carbon tax going to work gradually, each variable of the actual system will be affected. The system presented in Eq. (2) is restrained by \( F_1(x, y, z, w, t) \), \( F_2(x, y, z, w, t) \), \( F_3(x, y, z, w, t) \) and \( F_4(x, y, z, w, t) \) and \( F_4(x, y, z, w, t) = 0 \). Fig. 6 in [41] shows the energy intensity when the initial value is 15CNY/ton-CO\(_2\). Select the curve turning point 3 in Fig. 6 (the most ideal curve) as the representative of energy intensity evolution diagram in China’s ESER system with carbon tax constraints, i.e. the blue\(^1\) curve (Stable value 2) in Fig. 6 in this paper. The green curve (Stable value 3) is the energy intensity evolution diagram of YRD urban agglomerations with carbon tax constraints; and the red curve (Stable value 1) is the energy intensity evolution diagram of 3D ESER system [37].

By observing Fig. 6 (see Appendix A), it is found that the blue curve has a slighter fluctuation than the red curve (the time of reaching the first stable value is shorter). The energy intensity is always smaller than that of the red curve. The energy intensity starts with a precipitous decline after the turning point. The above analyses indicate that the 4D ESER system with carbon tax constraints is superior to the 3D ESER system, in that it is easier to control, and the final stable value is far smaller than the former one in 3D ESER system. The green curve has a slighter fluctuation than the blue curve, with smaller stable value. It is clear that, with the same carbon tax rate and constraint conditions, the energy intensity in YRD urban agglomerations’ ESER system with carbon tax constraints has a more gentle decline than the one in the 4D ESER system with carbon tax constraints [41]. The descent speed is faster, and the stable value is smaller. Interestingly enough, the energy intensity in YRD urban agglomerations’ ESER system with carbon tax constraints has no turning point under the same constraint conditions.

The levying of carbon tax exerts a better effect on controlling energy intensity. Moreover, carbon tax will take an inhibitory action on economic growth (the impact on economic growth shows inhibition in the early implementation of carbon tax) [41]. Fig. 7 shows the comparison diagram of error value of economic growth under the same carbon tax rate and constraint conditions. The diagrams in Fig. 7 are not very acute, thus the method in Fig. 6 is not adopted. Case 1 (the difference of \( z(t) \) between the 4D ESER system presented in [41] and the 3D ESER system presented in [37]) shows the evolution diagram of economic growth’s error value when the levy amount of carbon tax is 15CNY/ton-CO\(_2\) in the case of China; Case 2 (the difference of \( z(t) \) between the YRD urban agglomerations’ ESER system presented in Eq. (2) and the 3D ESER system presented in [37]) shows the corresponding diagram in YRD urban agglomerations’ ESER system with carbon tax constraints under \( F_3(x, y, z, w, t) \).

From Fig. 7, it can be observed that levying of carbon tax has inhibitory impact on economic growth. Both the two curves are all below the zone line (red line). There is a vast difference between the blue curve and the green one in the initial stage. During this stage, because of the economic property of YRD urban agglomerations, economic growth of the green curve keeps grow, but the value drops quickly after the apex. The diagram in the rectangular area is the drawing of partial enlargement. In the elliptic region, the absolute value of slope in the second half is remarkably larger than that in the first half. The curve tends to be stable after a short-term fluctuation, with the fluctuation time being shorter than case 1. Between elliptic region and the crossover point, the inhibitory impact on economic growth in case 2 is bigger than that in case 1. After the crossover point, the green curve is stabilized, while the blue curve still declines. The stable value of the blue curve is much smaller than that of the green curve. The above analyses indicate that YRD urban agglomerations have shown greater resilience to carbon tax than the average case of China, which has a

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\(^1\) For interpretation of color in Figs. 6–17, the reader is referred to the web version of this article.
shorter time to reach the stable value of energy intensity and error value of economic growth; and there is smaller inhibitory impact on economic growth. This also reveals the reason we choose YRD urban agglomerations to carry out carbon tax pilot in some respects.

**Remark 2.** Fig. 7 describes the comparison diagram between the 3D ESER system and the 4D ESER system with carbon tax constraints. As a matter of fact, the total economic amount of YRD urban agglomerations is different from China’s economic gross as a whole. Based on this, it is more reasonable to inspect the influence ratio of economic growth. Since the economic gross of YRD urban agglomerations is smaller, when the curves in case 1 and 2 are divided by the corresponding economic gross, the evolution tendency of the curves almost unchanged. The space between the curves will become greater, but the size relations will not change. Fig. 7 is used to show the error value of economic growth.

There are a lot of differences in the diagram of energy intensity error value of economic growth between Figs. 6 and 7. Apart from the differences in the parameters and the initial condition, the variable $F_3(x, y, z, w, t)$ in YRD urban agglomerations is the main reason. Fig. 8 shows the evolution curve of energy intensity when $c_5$ growing (see Appendix A). The red curve (Stable value 1) corresponds to the curve when $c_5 = 0.2368$. The blue curve (Stable value 2) corresponds to the curve when $c_5 = 0.2568$. The green curve (Stable value 3) corresponds to the curve when $c_5 = 0.2768$. It can be observed that, when $c_5$ becomes bigger, the peak value and stable value of energy intensity become smaller. It shows that, in the current YRD urban agglomerations’ ESER system with carbon tax constraints, the economic property $F_3(x, y, z, w, t)$ is the key to the reduction of energy intensity. The more effectively $F_3(x, y, z, w, t)$ plays the role in the system, the more energy intensity declines.

Levying carbon tax into the system presented in Eq. (2), when the effect of $F_3(x, y, z, w, t)$ gets bigger, it will exert influence on $z(t)$. $z(t)$ then exerts influence on $x(t), y(t)$ and $w(t)$; and reduce $U(t)$ finally. Fig. 9 interprets the reason why the bigger $F_3(x, y, z, w, t)$ ($c_5$) makes smaller $U(t)$. It shows the error value of carbon emissions and economic growth when $c_5$ changing from 0.2368 to 0.2568. The blue curve is the error value of carbon emissions; the green curve is the error value of economic growth. As $c_5$ grows, the blue curve is lower than the red line (zone line) after a short fluctuation, with the error value of carbon emissions being negative, i.e. it has hampered the carbon emissions’ growth. The green curve is higher than the red line except for a short curve below the red line in the early stage. The bigger $c_5$ is, the more evident the trend is, i.e. growing $c_5$ causes further development of the economy. In the time-dependent energy intensity formula $U(t)$, the numerator gets $\phi_3$ small, while the denominator $\phi_2$ gets big, and $U(t)$ gets small.

Along with the development of carbon tax, further maturation of the ESER system, transformation of development patterns and economic structure, carbon abatement cost will reach its inflection point at a certain moment. When the carbon abatement cost declines, the impact of $z(t)$ on $y(t)$ gets bigger, which reflects in Eq. (2) that the coefficient $b_3$ gets bigger. If the policy measures remain unchanged, the effect of ESER will be neutralized, even bringing a fatal shock to the ESER system. Fig. 10 shows the evolution diagram of YRD urban agglomerations and the whole China when the systems crash. The blue curve shows the energy intensity of the 4D China’s ESER system in [41] when $b_3 = 0.4296$; the ESER system will be broken fall when $b_3 \geq 0.4296$. In the YRD urban agglomerations’ ESER system, the system will be broken fall after a brief fluctuation when $b_3 \geq 0.7515$. To make it more clearly, let $b_3 = 0.7815$, the green curve shows its energy intensity when $b_3 = 0.7815$. Comparative observations of the two curves indicate that collapse point 2 is later than collapse point 1, i.e. the collapse time of the green curve is later than that of the blue curve. The
value of $b_1$ in YRD urban agglomerations’ ESER system is actually bigger than $b_3$ in the whole China’s ESER system in [41] (0.7815 > 0.4296). The foregoing analyses show that, compared with the 4D China’s ESER system, the YRD urban agglomerations’ ESER system is more stable, with stronger capacity to resist concussion.

The comprehensive observations of Figs. 6–10 under the same carbon tax rate and constraint conditions elaborate that the YRD urban agglomerations’ ESER system with carbon tax constraints has smaller effect on economic growth with lower energy intensity and stronger capacity to resist concussion. Compared with the 4D China’s ESER system, the carbon tax constraints of the former is superior to that of the latter due to the YRD urban agglomerations’ economic property. Levying carbon tax $w(t)$ into the YRD urban agglomerations, making use of the economic property $F_3(x, y, z, w, t)$ properly, these measures will promote economic growth, control carbon emissions and reduce energy intensity effectively (as shown in Fig. 9). All the above analysis provides convincing evidence for the feasibility and effectiveness of levying carbon tax.

4.2. The scheme of promoting carbon tax pilot in YRD urban agglomerations

Commercialization management of ESER can bring win–win results if it is properly applied. For example, Energy Performance Contracting (EPC) is mature in America, Canada and other countries, which is under rapid development in China in recent years. EPC can promote the social benefit of ESER project and bring economic benefit to both parties. As another example, the well-known carbon trading is widely practiced in the European Union. There are many variables and management styles in the commercialization management of ESER system. In the final analysis, it is restrained by carbon emissions $y(t)$ and economic growth $z(t)$; hence commercialization management $F_1(x, y, z, w, t)$ in this model is simplified as $a_3(z - y); a_5$ being the coefficient of commercialization management. Fig. 11 displays the energy intensity diagram when $a_5$ growing (in the system presented in Eq. (2), let $a_3 = 0$; $d_2 = 0$). The red curve (Stable value 1) is the same as the red curve in Fig. 8, i.e. it is restrained only by $F_3(x, y, z, w, t)$, without $F_1(x, y, z, w, t)$. The blue curve (Stable value 2) corresponds to the curve when $a_5 = 0.001$; the green curve (Stable value 3) corresponds to the curve when $a_5 = 0.0015$.

Comparative observations confirm that the fluctuation of energy intensity becomes lighter when $a_5$ gets bigger (the time of reaching stable value gets shorter; the space between the peak value and stable value gets smaller), the stable value showing a slightly rise. Results demonstrate that, in the current YRD urban agglomerations ESER system with carbon tax constraints, commercialization management can control energy intensity to the stable value quickly; but it cannot fully meet the requirement of reducing energy intensity. The reason could be explained commendably by Fig. 12. Fig. 12 describes the error value of carbon emissions and economic growth when $a_5$ changing from 0.001 to 0.0015 (the error is very small, but it can still reflect the evolution trend). The blue curve is the error value of carbon emissions; the green curve is the error value of economic growth. Commercialization management checks the trend of over-rapid carbon emissions growth (the blue curve is slightly higher than the red line after stabilization), which has the inhibition effect on economic growth at the same time. The effect is greater than the one on carbon emissions, i.e. the green curve is always under the red line after an infinitesimal fluctuation at the primary stage. The economic property of YRD urban agglomerations, market maturity and civilization degree are among the causes. Therefore, commercialization management does not suit the current YRD urban agglomerations ESER system.

Government control can often control energy intensity quickly, which is demonstrated in the late “12th Five-Year plan”. However, government control has inhibition effect on economic growth during the progress of reducing energy intensity. $F_2(x, y, z, w, t)$ represents government control in the system presented in Eq. (2). When the strength of government control gets bigger, a very interesting phenomenon arises as shown in Fig. 13, the evolution diagram of energy intensity when $b_5$ gets bigger (in the system presented in Eq. (2), $a_5 = 0$; $d_2 = 0$). The red curve (Stable value 1) is the same as the red curve in Fig. 11; the blue curve (Stable value 2) corresponds to the curve when $b_5 = 0.0213$ and the green curve (Stable value 3) $b_5 = 0.0413$. Energy intensity could be better controlled with government’s control work. The peak value decreases rapidly and the fluctuation gets slighter. The blue and green curve are all lower than the red curve before the junction point; while the green curve is bigger than the red curve after the junction point. It is identified that government control could stabilize energy intensity, and an appropriate strength of government control will bring lower energy intensity. Nevertheless, when the strength is above a critical value, the final control effect would be counterproductive, i.e. the green curve has exceeded the value of the case without government control at junction point.

Fig. 11. Energy intensity ($a_5$).

Fig. 12. Error value of carbon emissions and economic growth ($a_5$).
Why the stable value of energy intensity increases as the control strength getting bigger? This is due to the inhibition effect on economic growth surpassing the effect of reducing energy intensity. Fig. 14 presents the error value diagram of carbon emissions and economic growth when $b_5$ changing from 0.0213 to 0.0413. The blue curve is the error value diagram of carbon emissions; the green curve is the error value diagram of economic growth. The blue curve is always under the red line (zone line) when $b_5$ changing, which indicates that government control could reduce energy intensity effectively. The blue curve is also under the red line (except for a slight fluctuation in the enlarged diagram). The distance between them is bigger. Take the stable values of $b_5$ (there is a more detailed explanation in the contrastive analysis of Figs. 14 and 16). With the increasing of $b_5$ (over a critical value), the inhibition effect on economic growth will surpass the control effect on energy intensity; thus energy intensity does not reduce but increase, which suggests that government control should be sensibly used in some way. In conclusion, the energy intensity of YRD urban agglomerations cannot be controlled efficiently by simple government control. Although the energy intensity could be controlled to the stable state quickly by single government control, through which the value of energy intensity in YRD urban agglomerations has not declined finally, other constraint condition engagement is also needed to better control energy intensity.

Carbon tax incentives can guarantee a better and faster development of carbon tax $w(t)$, $F_1(x, y, z, w, t) = d_2(y - x)$ expresses carbon tax incentives; $d_2$ is the incentive coefficient of $F_2(x, y, z, w, t)$. Fig. 15 represents the diagram of energy intensity when $d_2$ changing (in the system presented in Eq. (2), $a_5 = 0, b_5 = 0$). The red curve (Stable value 1) is the same as the red curve in Fig. 11; the blue curve (Stable value 2) corresponds to the curve when $d_2 = 0.0779$ and the green curve (Stable value 3) $d_2 = 0.0879$. When the incentive coefficient gets bigger, i.e. the development of carbon tax gets faster, these changes will have some effect on the system in the early stage. The peak value of energy intensity gets bigger (Peak value 3 > Peak value 2 > Peak value 1) with the fluctuation intensifying. Nevertheless, energy intensity will be better controlled finally. The green curve is lower than the red curve at junction point 2, where carbon tax incentives are having an effect. The green curve is lower than the blue curve at junction point 3. The carbon tax incentives of value is expressed in controlling energy intensity finally, with the stable value 3 smaller than stable value 1 and stable value 2. In summary, the development of carbon tax will speed up when carbon tax incentives getting larger. There are short term fluctuations in the initial stage; but energy intensity could be reduced rapidly and better controlled eventually. Carbon tax incentives work well in promoting the development of YRD urban agglomerations carbon tax system. Fig. 16 shows the error value of carbon emissions and economic growth when $d_2$ changing from 0.0779 to 0.0879, where the blue curve is the error value of carbon emissions, and the green curve is the error value of economic growth. The two curves are both under the zone line except for a very small fluctuation in the initial phase (small parts of the curves are above the red line in the drawing of partial enlargement). Contrasted with Fig. 14, the blue curves and the green curve are all below the red line in Fig. 16. Then why are the results of energy intensity different? Take Fig. 16 for example, energy intensity ($d_2 = 0.0779$) is assumed to be $U(t) = \psi_1 / \psi_2$. When $d_2$ changing from 0.0779 to 0.0879, the value of $\psi_1$ is $a$, and of $\psi_2$ is $b$. At this time, energy intensity ($d_2 = 0.0879$) is $U(t) = \psi_1 / \psi_2 = \psi_1 - a / \psi_2 - b$. With further calculation, it is found that, when $a/b < U(t), U(t) > U(t)$, i.e. energy intensity will increase; when $a/b > U(t), U(t) < U(t)$, i.e. energy intensity will decrease. In Fig. 14, $a/b < U(t)$; in Fig. 16, $a/b > U(t)$.
In YRD urban agglomerations’ ESER system with carbon tax constraints, its economic property $F_1(x, y, z, w, t)$ is the critical factor for the reduction of energy intensity. The bigger $F_1(x, y, z, w, t)$ will reduce more energy intensity. However, it is noted that the fluctuation of energy intensity will become more volatile. In the light of economic property, market maturity and civilization degree in the current case, the effect of commercialization management $F_1(x, y, z, w, t)$ on controlling energy intensity is not obvious. Government control $F_2(x, y, z, w, t)$ could control energy intensity in the short run, which speeds up the energy intensity, reaching a predetermined value rapidly and steadily. At the same time, it has certain inhibition effect on economic growth. It is for this reason that energy intensity will increase when the strength of government control surpasses a value. The carbon tax incentives $F_3(x, y, z, w, t)$ can accelerate the development of carbon tax and promote carbon tax for a bigger role in the ESER system. The fluctuation of energy intensity is relatively large at this point, but energy intensity will be significantly decreased finally.

The YRD urban agglomerations’ ESER system with carbon tax constraints is a complicated system. For a better development of carbon tax pilot, the proper constrained control plan can be formulated according to its ESER actual situation and economic development situation. From the analysis above arises a fact that $F_2(x, y, z, w, t)$ and $F_3(x, y, z, w, t)$ could better control the value of energy intensity; $F_1(x, y, z, w, t)$ and $F_2(x, y, z, w, t)$ could control the oscillation of energy intensity steadily and rapidly. In the YRD urban agglomerations carbon tax system, sustainable and healthy economic growth should keep developing all the time. Thus, the economic property of YRD urban agglomerations is the essential differences between YRD urban agglomerations system and other systems. Meanwhile, developing proper carbon tax incentives policy strategies will promote faster and better development of carbon tax. During the development of YRD urban agglomerations ESER system, energy intensity has to be reduced quickly in a certain period of time. Government control is vital at this moment, with appropriate control strength and control time.

5. Implications of the research for government policy

The YRD urban agglomerations as one of the six world-class urban agglomerations are internationally recognized. Levying carbon tax in YRD urban agglomerations, the most developed urban agglomerations in China, will accelerate the developing process of carbon tax in China, accumulating necessary experience of levying carbon tax for other areas. Generally speaking, the development of economy will result in more carbon emissions and higher energy intensity in the current economic system [47–49]. By Contrast, YRD urban agglomerations with carbon tax constraints is different. In YRD urban agglomerations, private economy is active, small and medium enterprises accounting for the majority of enterprises. When levy carbon tax, these enterprises will actively seek method to reduce their own carbon emissions. With the development of economy, the carbon emissions descend after brief fluctuation, and the energy intensity gets lower, as shown in Fig. 9. The development of economy doesn’t necessarily go with more carbon emissions. The levying of carbon tax in YRD urban agglomerations plays a major role in controlling carbon emissions. The YRD urban agglomerations’ ESER system has stronger capacity to resist concussions. Therefore, levying carbon tax in YRD urban agglomerations is necessary, feasible and effective.

Commercialization management of ESER needs mature industry and economic structure, completed rules and laws and strong public support (strong low carbon awareness) [50]. As for the current YRD urban agglomerations, the low carbon awareness of enterprises and the public are not strong enough. There are no appropriate laws and regulations. The current economic character and economic reality has ordained that commercialization management does not suit YRD urban agglomerations’ ESER system. China will carry out comprehensive carbon trading programs in 2017, while the results of this paper reveal that carbon tax is more suited for the development of YRD urban agglomerations’ ESER system (Figs. 11, 12, 15 and 16). It is necessary to cover these issues in depth before the full implementation of carbon trading all over China. Of course, along with the evolution and gradually mature of the YRD urban agglomerations’ ESER system, levying commercialization management can be considered at proper time.

With the aid of economic policy, economic statutes, program teaches, administrative management and certain conduction mechanism, government control could reach the expected objective of reducing energy intensity. The fact has proved that China’s government control is effective in energy intensity control; however it would be detrimental to the local economy, bringing some inconvenience to the public life at the same time. When the strength of the government control is too large, energy intensity could be controlled effectively in the early stages, but energy intensity will increase finally after a certain period, just as shown in Fig. 13. In late “12th Five-Year plan”, some local governments temporarily closed some high energy-consumption enterprises, e.g. some power plants, for the purpose of reducing energy intensity rapidly in a very limited time. Energy intensity had been controlled to the predetermined value, but it had bigger inhibition effect on economic growth, energy intensity going by contrary finally. Therefore, an early warning regulation mechanism of ESER system should be established. Government control should be used at the right time and with a proper strength. In a certain period of YRD urban agglomerations ESER system, the rapid deceleration of energy intensity is urgently demanded, and economic growth could be held up temporarily. In this case, government control should come timely as to reduce energy intensity rapidly. But it should be noticed that, the control strength should not be too large, control time should not be too long to safeguard against much inconvenience for public life and negative effects on economic growth.

The design of carbon tax should be an incentive mechanism [51]. The levying of carbon tax cannot be performed mechanically, which needs the adjustment of carbon tax incentives. Carbon tax incentives could ensure the development of carbon tax, press ahead with carbon tax steadily, and then control energy intensity to a desirable value (Fig. 15). In YRD urban agglomerations, the government may sign carbon emission reduction incentive
contracts with high energy-consuming enterprises (most enterprises in YRD urban agglomerations are open-minded, good at grasping the business opportunities). Under these incentive mechanisms, these enterprises will reduce fossil energy consumption per unit of output automatically by structuring a reasonable energy management system, purchasing and using more environmentally-friendly equipment or technological innovation, to avoid much carbon tax, which will be of good help for environmental pollution and the enhancement of social productivity and natural resource utilization rate, which will promote a win-win objective of economy development and ecological environmental conservation. Relatively speaking, reasonable tax payment is easier than the limit use of energy to be accepted by the public. Carbon tax rate should be drawn up properly in YRD urban agglomerations. The internal impetus of high energy-consuming enterprises in the implementation of carbon emission reduction should be enhanced, helping them to get the economical energy by low carbon means and realize the transition to low carbon development pattern.

The goal of ESER would be much more easily achieved by carbon tax to a certain extent; but the effect of carbon tax is uncertain in the short term, thus this situation is crying for intervention from various auxiliary constraints. The sustained and healthy development of YRD urban agglomerations' economy is the presupposition of trying to carry out carbon tax pilot in YRD urban agglomerations ESER system. Economic growth will boost ESER under the effect of carbon tax. In view of YRD urban agglomerations' current economic character, inadequate laws and regulations and weak low carbon awareness, commercialization management doesn't suit for the development of YRD urban agglomerations ESER system. Government control could control energy intensity immediately. An excellent warning control system is required, the appropriate time and strength of government control could better control energy intensity, considering the impact of government control on economy growth and public life. The carbon tax incentives should be utilized reasonably, the public low-carbon awareness should be cultivated and enterprises' enthusiasm for ESER should be fully encouraged through various means. All of these will be profitable to the development of carbon tax pilot and ESER in YRD urban agglomerations. It might also be noted that, the current carbon tax rate needs continuous readjustment in order to achieve a reasonable level.

6. Conclusions and further perspectives

On the basis of a novel ESER system with carbon tax constraints, this paper has undertaken explorations on the evolutionary behavior of YRD urban agglomerations' ESER carbon tax system with multiple variable constraints. The carbon tax attractor of YRD urban agglomerations is obtained, followed by the analysis of the nonlinear dynamics behavior of the system. The quantitative coefficients of the actual system are achieved based on the GA-BP network. We take the time-dependent energy intensity calculation formula and the evolution tendency of economic growth as measurements to compare the differences between YRD urban agglomerations' carbon tax system and that of the whole China, putting forward the effect of commercialization management, economic property of YRD urban agglomerations, government control and carbon tax incentives on energy intensity. Energy intensity changes during the varying of constraint conditions. The deep reason is revealed by analyzing the error value of carbon emissions and economic growth. The plan of using carbon tax to properly control energy intensity is presented.

Carbon tax is better suited for YRD urban agglomerations, compared with carbon trading and other commercialization management. Government control could control energy intensity quickly, while the measure has inhibition effect on economic growth. Energy intensity increases when the strength of government control is too large. Hence, a sophisticated warning control system is required, and government control should be used with an appropriate strength at the proper time. The economic property of YRD urban agglomerations is the main reason for its superiority in China's carbon tax system. The healthy and sustained development of YRD urban agglomerations' economy is the precondition of carrying out carbon tax pilot in that area. The development of ESER will be promoted under combined carbon tax and the economic property of YRD urban agglomerations. Designing reasonable carbon tax rate and making good use of carbon tax incentives are helpful to promote the development of carbon tax and ESER.

Existing literatures on carbon tax studies mainly use dynamic Computable General Equilibrium (CGE) model [20,25], dynamic economy wide model [23], modified Cross-Entropy solution method [27], TIMES (The Integrated MARKAL-EFOM System) model [52], simplified system dynamics model [53] and so on. The research contents are multifarious, while there is little literature on carbon tax pilot. Based on the 4D ESER system [41], this paper initiates the exploration of carbon tax pilot in YRD urban agglomerations, with a potential attempt of levying carbon tax in YRD urban agglomerations. The conclusion presents a view on the focus of the current debate, that carbon tax is superior to carbon trading and other commercialization management in YRD urban agglomerations. The effect of government control on controlling carbon emissions is displayed by evolution diagrams. The importance of appropriate government control is suggested at the same time. The economic property of YRD urban agglomerations and carbon tax incentives are the key factors to the control of energy intensity. The dynamic method is an innovation research method for carbon tax pilot. Compared with the previous researches, evolution analysis and theoretical basis in this paper are more persuasive. The findings of this study are more consistent with the reality of YRD urban agglomerations.

Piloting carbon tax in the area is a very good program. Carbon tax could be fanned out across the country gradually after accumulating necessary experience. Levying carbon tax in YRD urban agglomerations can take the best advantages of that region as a benchmark for economic development. The accumulated experience and policies in the progress of levying carbon tax could be applied to other regions and even the whole country. With this model (the model presented in Eq. (2)), the carbon tax pilot of other similar cities or districts could be investigated on the basis of obtaining the corresponding data. In future studies, the contrastive analysis between YRD urban agglomerations and other districts could be carried out.

This paper mainly examines the evolution behavior of ESER, carbon emissions, economic growth, carbon tax and their corresponding constraint conditions. However, more variables should be included in the actual YRD urban agglomerations' ESER system, such as public acceptance, low carbon awareness and so on. Further research on the dynamic behavior of the system is necessary. In addition, the lack of statistical data might have some influence on the output parameters in parameter identification. Furthermore, the data of carbon tax is mainly based on hypothesis, surrogate data could be sought out by some more scientific methods. Besides, the effect of carbon tax is characterized by the evolution trend of energy intensity, carbon emissions and economic growth. Other measurable indicators will be analyzed in the future research.

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Fig. 17 shows the evolution curve of energy intensity. The evolution curve is oscillatory. The red curve (Stable value 1) is the energy intensity evolution diagram of 3D ESER system in [37], the blue curve (Stable value 2) is the curve of turning point 3 in Fig. 6 in [41], and the green curve (Stable value 3) is the energy intensity evolution diagram of YRD urban agglomerations with carbon tax constraints. In order to reflect the evolution tendency of energy intensity more articulately, a optimization method is adopted as follows: the time axis t of evolution curve is divided equally; the maximum of evolution curve in every small range is singled out, and these maximum values are connected by a curve which is as smooth as possible; repeat the previous steps until the evolution curve is monotonic. Using above mentioned method, the monotonic curve is depicted as Fig. 6 shows. With the same method, Figs. 8, 11, 13 and 15 are obtained too.

From Fig. 17, it can be observed that the fluctuation range of the red curve (Stable value 1) is greater than the blue one (Stable value 2), and the fluctuation range of the blue curve (Stable value 2) is greater than the green one (Stable value 3). From the red curve to the green one, the time of reaching stable value gets shorter, and the space between the peak value and stable value gets smaller. The fluctuation of energy intensity becomes lighter. Fig. 6 is the monotonic curve of Fig. 17, Fig. 6 still has the same evolvement trend as Fig. 17. When the initial value and the corresponding constrained conditions are given, the system will keep on developing until the emergence of stable value, and then the system continues to develop with this stable value. In fact, the energy intensity of the system in Fig. 17 (Fig. 6) is constantly changing. During the development of the system, the results of former time point are the initial values of the next time point. In this paper, the evolution trends of the ESER system with different constrained conditions are analyzed. Through comparative analyses, the results for the guidance to practice are carried out. Based on this, initial value and the corresponding constrained conditions are fixed.
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