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Government control or low carbon lifestyle? – Analysis and application of a novel selective-constrained energy-saving and emission-reduction dynamic evolution system

Guochang Fang [a,b], Lixin Tian [a,*], Min Fu [a], Mei Sun [a]

[a] Center for Energy Development and Environmental Protection, Jiangsu University, Zhenjiang, Jiangsu 212013, PR China
[b] Department of Basic Courses, Yancheng Institute of Technology, Yancheng, Jiangsu 224051, PR China

HIGHLIGHTS

- Use of nonlinear dynamical method to model the selective-constrained ESER system.
- Monotonic evolution curves of energy intensity and economic growth are obtained.
- Detailed analysis of the game between government control and low carbon life.
- A better plan to control energy intensity with the selective-constrained ESER system.

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ABSTRACT

This paper explores a novel selective-constrained energy-saving and emission-reduction (ESER) dynamic evolution system, 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. Based on artificial neural network, the quantitative coefficients of the actual system are identified. Taking the real situation in China for instance, an empirical study is undertaken by adjusting the parameters of the actual system. The dynamic evolution behavior of energy intensity and economic growth in reality are observed, with the results in perfect agreement with actual situation. The research shows that the introduction of CCE into ESER system will have certain restrictive effect on energy intensity in the earlier period. However, with the further development of the actual system, carbon emissions could be better controlled and energy intensity would decline. In the long run, the impacts of CCE on economic growth are positive. Government control and low carbon lifestyle play a decisive role in controlling ESER system and declining energy intensity. But the influence of government control on economic growth should be considered at the same time and the controlling effect of low carbon lifestyle on energy intensity should be strengthened gradually, while the investment in new technology of ESER can be neglected. Two different cases of ESER are proposed after a comprehensive analysis. The relations between variables and constraint conditions in the ESER system are harmonized remarkably. A better solution to carry out ESER is put forward at last, with numerical simulations being carried out to demonstrate the results.

1. Introduction

Global warming has gained the whole world's close attention. “Global action” is of great necessity in controlling the pace of global warming. Since the approval of the United Nations Framework Convention on Climate Change (UNECCC), the wrangle between nations about the goal and task of carbon emission reduction has never stopped. Despite all the controversy, people have consonant opinions on the big challenge: energy-saving and emission-reduction (ESER) is the key to control carbon emissions and tackle global warming issues. Each country can establish an ESER system in agreement with their actual situation by coordinating variables in ESER system efficiently, according to the country's ESER plan. (Hamit-Haggar, 2012; Bloch et al., 2012; Su and Ang, 2011; Fourcroy et al., 2012). Then carbon emissions could be better controlled and energy intensity would decline to a great extent.

In the process of probing ESER system (Wang and Chen, 2010; Zhang et al., 2011; Rezessy and Bertoldi, 2011; González-Eguino, 2011), the actual ESER system is restrained by many constraint

* Corresponding author. Tel.: +86 511 88797671; fax: +86 511 88791467.
E-mail addresses: fgchang79@163.com (G. Fang), tianlx@ujs.edu.cn (L. Tian).

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conditions. By reasonably adjusting these constraint conditions and refining ESER system, carbon emissions could be controlled more effectively and energy intensity would decline while the economic growth could be guaranteed. Among the constraint conditions in ESER system, cost of conserved energy (CCE) is the restrictive factor of ESER, and the decision-making basis of energy saving measures (Garg et al., 2011; McNeil and Bojda, 2012). Investment in new technology of ESER will have certain effects on economic growth (Aghion et al., 2009). Government control and low carbon lifestyle could decrease carbon emissions directly (Abdelaziz et al., 2011; Zhang, 2011).

Government control and low carbon lifestyle is the key to control carbon emissions and decrease energy intensity, which have naturally enjoyed widespread popularity. Fulfilling the function of government control could control carbon emissions immediately (Mu and Niu, 2011), while these controls have inhibition effects on economic growth most of the time. Low carbon lifestyle has little inhibition effects on economic growth with decreasing carbon emissions; therefore building low carbon economy and advocating low carbon lifestyle (Streimikiene and Volochovic, 2011; Rosas-Flores et al., 2011; Marcos et al., 2011; Foxon, 2011) have attracted many scholars' attention.

Heiskanen et al. (2010) analyzed the actions of different types of low carbon communities in changing individual's behavior, and investigated how these communities offer solutions to reduce carbon emissions by changing individual's behavior. Feliciano and Prosperi (2011) analyzed the central questions of planning low carbon cities using Broward County, Florida, USA as an example. Howell (2013) carried out a deep investigation of UK citizens who have adopted lower carbon lifestyles. The investigation mainly includes social justice, community, frugality and personal integrity. The effects of lower carbon lifestyle on inhabitants were explored. The authors pointed out that the overall planning of the layout of low carbon future should be portrayed, rather than simply providing a 'to do' list to tackle climate change. Liu et al. (2011) investigated Chinese current situation of energy supply, energy structure and units' energy consumption, described some application practices of low carbon, for instance, low carbon traffic, low carbon city and low carbon village. Shen and Zhang (2011) explored the problem of energy, economy and society in the West District of Panzhihua City in China, and pointed out that low carbon economy is the key to sustained development in the West District, actively advocating that low carbon lifestyle could promote the coordinated development of economy and society in the West District. Furthermore, there are some specific low carbon actions, such as low carbon transport (Hickman et al., 2011; Brand et al., 2012) and low carbon tourism (Huang and Deng, 2011).

In addition, chaos analyses have been conducted for the extensive applications in dynamical systems. (Sun et al., 2011; Gilli et al., 2012). Fang et al. (2012) proposed a novel three dimensional ESER chaotic system, deducing the time-varying energy intensity calculation formula from the ESER system. An empirical study is undertaken with the real situation in China as an instance. The variables which have significant impact on ESER and energy intensity were figured out. A series of results in perfect agreement with the actual situation of China were presented.

The previous research findings about ESER and corresponding constraint conditions are fruitful, while the constraint conditions were not incorporated into a monolithic system to carry integrated dissections. The actual ESER system should be a complex system, which includes many variables and corresponding constraint conditions. This paper develops a selective-constrained ESER dynamic evolution system further, introducing cost of conserved energy, government control, low carbon lifestyle and investment in new technology of ESER into ESER system (Fang et al., 2012), which act as restriction conditions. By analyzing the effects of these restriction conditions on energy intensity and economic growth, a better restriction condition is put forward. It is confirmed that the selective-constrained ESER dynamic evolution system is more similar to the reality and easier to control, with the final stable value of energy intensity being far smaller than the former one.

The outline of this paper is organized as follows. The model is set up and analyzed in Section 2. Section 3 is the empirical study of the actual system based on China's statistics data. Implications of the research for government policy are analyzed in Section 4. Conclusions and outlook are finally presented in Section 5.

2. The model

The ESER system includes carbon emissions, economic growth, energy intensity, energy efficiency and many other variables. Each variable in the actual ESER system has many restriction conditions. The variable of ESER during a given period has much to do with CCE. Government control and low carbon lifestyle will affect carbon emissions to a large degree, while investment in new technology of ESER and low carbon lifestyle will have certain impacts on economic growth. In the three dimensional ESER system (Fang et al., 2012), it is postulated that ESER, carbon emissions and economic growth are restrained by CCE, government control and low carbon lifestyle and investment in new technology of ESER respectively. The restriction conditions are assumed to be $F_1(x,y,z,t)$, $F_2(x,y,z,t)$ and $F_3(x,y,z,t)$. The selective-constrained ESER system can be described by the following differential equations:

$$\begin{cases} \dot{x} = a_1 x(y/M-1) - a_2 y + a_3 z + F_1(x,y,z,t) \\ \dot{y} = -b_1 x + b_2 y(1-y/C) + b_3 z(1-z/E) + F_2(x,y,z,t) \\ \dot{z} = c_1 x(x/N-) - c_2 y - c_3 z + F_3(x,y,z,t) \end{cases} \tag{1}$$

where $x(t)$ is the time-dependent variable of ESER, $y(t)$, of carbon emissions, $z(t)$, of economic growth (GDP) (Fang et al., 2013). $t \in I$, I is a given economic period (The given economic period I in this paper refers to the period from the past to 2050). a_i, b_i, c_i, $(i=1,2,3)$ are the influence coefficients of the corresponding variables and between these variables (Fang et al., 2012). a_1 is the development coefficient of ESER, a_2 is the influence coefficient of carbon emissions to ESER, a_3 is the influence coefficient of economic growth to ESER; b_1 is the influence coefficient of ESER to carbon emissions, b_2 is the development coefficient of carbon emissions, b_3 is the influence coefficient of economic growth to carbon emissions; c_1 is the influence coefficient of ESER to economic growth, c_2 is the influence coefficient of carbon emissions to economic growth, c_3 is the influence coefficient of investment (investment to ESER) to economic growth; M is the inflexion of carbon emissions to ESER, C is the peak value of carbon emissions, E is the peak value of economic growth, N is the inflexion of ESER to economic growth. (M, C, E, N are all the values during the given period).

The dynamic system presented in Eq. (1) is a complex nonlinear system, in which the evolutionary relationship between the variables is mainly embodied with the coefficients and the corresponding formulas (Fang et al., 2012). Take $a_1 x(y/M-1)$ in Eq. (1) for example, when $y<M$, $y/M-1<0$, the development of ESER becomes slower; when $y>M$, $y/M-1>0$, the development becomes faster. The economy input will facilitate the development of ESER $(+a_3 z)$, while the accession of carbon emissions will counteract the change rate of ESER $(-a_2 y)$. $F_1(x,y,z,t)$ is the time-dependent variable of CCE. Allocate energy saving investment equally in the life cycle of investment. The investment profit is the annual energy saving. CCE is computed by dividing annual energy saving investment by annual energy saving. In $F_1(x,y,z,t) = -(k_{11}z/k_{12}y)\cdot(d/1-(1+d)^{-t})$, the sign "$-$" on the right side of F_1 indicates that CCE is the restricting factor of $x(t)$;