Applied Energy 211 (2018) 1039–1049

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

How to optimize the development of carbon trading in China—Enlightenment from evolution rules of the EU carbon price

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

[a] School of Economics, Nanjing University of Finance and Economics, Nanjing, Jiangsu 210023, China
[b] Center for Energy Development and Environmental Protection, Jiangsu University, Zhenjiang, Jiangsu 212013, China
[c] School of Mathematical Sciences, Nanjing Normal University, Nanjing, Jiangsu 210023, China

HIGHLIGHTS

- Use nonlinear dynamics theory to model the ESER system with carbon price constraints.
- Carbon price is closely related to demand and supply relationship.
- Excessive government control will deliver opposite even fatal effect on ESER system.
- The optimal road of carbon trading in China is put forward based on EU's experience.

ARTICLE INFO

Keywords:
Carbon price
Energy-saving and emission-reduction
Energy intensity
Economic growth

ABSTRACT

This paper explores the optimization scheme of carbon trading in China based on a novel energy-saving and emission-reduction (ESER) system with carbon price constraints. With the aid of nonlinear dynamics theory, the dynamics behavior of the novel system is discussed. Genetic algorithm and back propagation neural network is used to identify the quantitative coefficients according to the statistical data of the second period in European Union (EU). Taking the actual situation in EU for instance, the variables which are sensitive to carbon trading are detailedly researched. Enlightened by the EU's experience, an optimal road of China's carbon trading is put forward. The results show that carbon emissions could be controlled by carbon trading. The investment to carbon trading hampers economic growth in the near future, and ESER technical progress is negatively correlated with carbon trading in the long run. Demand and supply relationship is closely related to carbon price, both are the important issues in carbon trading system. Excessive government control and extortionate carbon price will deliver the opposite effect and even fatal influence on carbon trading system.

1. Introduction

Carbon trading is one of the most effective measures of controlling carbon emissions under the framework of market economy [1–3]. It is necessary to construct the proper energy-saving and emission-reduction (ESER) system as soon as possible [4–6], considering the serious pollution of the natural resources and the environment. Among the variables affecting ESER, carbon trading plays an important role in ESER system [7–9]. The development of carbon trading is of great significance to tackling climate change, optimizing the energy structure, promoting ESER and accelerating transformation of economic growth [10,11]. Probing into the evolution mechanism of carbon trading, and seeking for the rule of development, would certainly be helpful to grasp the essential of carbon trading [12–14].

The healthy development of carbon trading could be promoted by giving full play to the positive role of carbon price [15–17]. Carbon price can serve as leverage for guiding resource allocation and optimization, which plays a determinative role in carbon trading system [18,19]. A typical example is the trading markets in European Climate Exchange, the optimal profit of manufacturer and retailer will change with varying carbon price, and carbon price will also influence the optimal total emissions and production quantities of product [20]. Making clear the internal factor and external factor that affect carbon price, will contribute to find the reason of the discrepancy between different economies [21,22]. Carbon price are influenced by multiple variables, it is precisely for this reason that it is critical to construct proper ESER system with carbon price constraints [23–25]. This system should include macroeconomic environment, policy measures, supply-

* Corresponding author.
E-mail address: fgchang79@163.com (G. Fang).

https://doi.org/10.1016/j.apenergy.2017.12.001
Received 18 August 2017; Received in revised form 26 November 2017; Accepted 1 December 2017

demand relationship, energy price, market regulations and so on [26–29].

Carbon trading has drawn growing attention [30,31]. Gong and Zhou [32] explored the impact of emissions trading on production planning. To minimize the manufacturer's expected total discounted cost, the optimal emissions trading and production policies were characterized. The trading situations in different countries had been compared. For example, Zhang et al. [33] discussed the cases of emissions trading scheme (ETS) in China, U.S., Europe, Australia, Japan and South Korea. By comparison, most scholars believed that multi-region integrated ETS would optimize the allocation of emissions permit. However, some scholars disagree with this view for the type of technology used and the country's policy in different countries [34]. Taking EU and Kyoto Protocol emissions trading schemes for research objects, Kanamura [35] analyzed the role of carbon swap trading and energy prices in price correlations and volatilities. The leverage effect of price was showed in his study. Meanwhile, carbon price plays an important role on the unified carbon trading market. Li and Lu [36] found that carbon price generated a different degree of impacts in decreasing the energy demand and improving the environmental quality.

In addition, nonlinear dynamics theory in economic field has caused extensive concern and strong interest of some scholars [37–39]. Fang and Tian [40] proposed a novel three-dimensional ESER chaotic system, and presented results in perfect agreement with actual situation, providing sound theoretical basis for the present study. This paper introduces carbon price into the 3D dynamics system [40], which seeks to establish a 4D nonlinear dynamics system with carbon price constraints. Carbon price is firstly introduced into the 4D nonlinear dynamic evolution ESER system. The evolutionary tendency of carbon price in the EU is put forward, and the way to better develop carbon trading in China is investigated further.

The EU and China have great difference in economic structure and situation of ESER [41,42], and there are still many differences on the background and basic condition of carbon trading. The one thing that the EU and China have in common is that, carbon trading is cost-effective measure to ease environmental crisis and promote ESER. Furthermore, carbon price plays an important role in carbon trading system of both economies [43,44]. China should learn such subject as the EU's allowance mechanism, which is one of the core and sensitive aspects in the design of a carbon emissions trading scheme [45]. The advanced experience of EU carbon trading can help China to enter the carbon trading scheduled track quickly [46,47]. Further, the international cooperation could be strengthened further, and the need for support from developed to developing countries to address climate change could be met [33,48].

The previous research findings about carbon trading (carbon price) are fruitful. The EU [7,9,46,49] and China [8,11,12] are of the major research objects. Carbon trading and carbon tax were compared [1,21], carbon pricing and price forecasting were also studied [22,25]. Further, these studies which highly related to our paper could be classified into three categories: the first is to reveal the role of carbon price (carbon trading); the second is to explore carbon trading pilot programs in China; the last is to analyze carbon trading in diverse economies (countries). For the first category, the impacts of carbon trading on a certain industry (coal-to-materials industry [14], cement industry [17], renewable energy industry [18,23]) and some specific aspects (energy structure [10], energy demand [2]) were discussed. Xu et al. [20] gave a more detailed research about the effects on optimal production decisions and firms' optimal profits. The above studies provide some good modeling ideas. Building on this, more variables are incorporated into our novel system, which is more in line with reality.

Specific pilot emission trading scheme in China was discussed (such as Shenzhen [13], Hubei [29]), analysis and comparison of different pilot areas are mentioned too [19,50]. The financial performance [13], market efficiency [19], economic and environmental impacts [29] and institutional reforms [50] were explored. Some policy suggestions to improve carbon trading market in China were put forward. However, the scope of research should not be only restricted to China. The novel model presented in our paper holds the carbon trading attributes of both China and the EU, which has more convincing results. For the third category, the impacts of carbon price on CCS plant in the EU in comparison with China were discussed [43], and the unique features in allowance mechanism were identified by comparing China's carbon trading pilots with the EU -ETS and California Cap-and-Trade Program [45]. Besides, cooperation emissions trading mechanism was suggested to address climate change [48]. A variety of research methods and models were put forward, such as net present value model, expert interviews and global economy-wide model. The complex and nonlinear relations among the carbon trading system need a more solid theoretical basis. Based on nonlinear dynamics theory, the dynamics behaviors of multiple variables in our novel system are discussed with the aid of simulated images, which has not yet been reported in present literature. The research of this model can better explore the essence and reveal the law of carbon trading, which extends the current research approaches.

The rest of this paper is organized as follows. Section 2 provides a brief description of the model developed for this study. Section 3 is about parameter identification of the actual system based on the statistical data in the EU. Section 4 is about a scenario study of the actual system about the EU and China. Implications of the research for government policy are presented in Section 5. Conclusions and further perspectives are discussed in Section 6.

2. Establishment of the model

Carbon trading as one of the most effective economic measures can really control carbon emissions. Carbon price plays a baton role in the process of carbon trading development. Research into carbon price also reflects the developing law of carbon trading. The rise of carbon price would attract enterprises and individuals to pursuit this profit by various ways. After undergoing the conductional mechanism between the variables, ESER could be promoted, and carbon emissions will be controlled. Economic growth will be affected by carbon price, and the effect is negative in the primary stage of carbon trading. The development of carbon price is closely connected with ESER technical progress, government control (political factors), supply-demand relations and so on. The further research indicates that carbon price has complex and strongly nonlinear coupling relation with the above variables. Based on the complex relationship between these variables, combined with nonlinear dynamics theory, the novel ESER system with carbon price constraints can be described by the following differential equations:

$$\begin{cases} \dot{x} = a_1x(y/M-1)-a_2y + a_3z + a_4u \\ \dot{y} = -b_1x + b_2y(1-y/C) + b_3z(1-z/E)-b_4u \\ \dot{z} = c_1x(x/N-1)-c_2y-c_3z-c_4u \\ \dot{u} = d_1u(y/P-1)-d_2x + d_3z \end{cases} \tag{1}$$

where $x(t)$ is the time-dependent variable of ESER; $y(t)$, of carbon emissions; $z(t)$, of economic growth; $u(t)$, of carbon price. In this paper, a_i,b_i,c_i, d_j, M, C, E, N, P are positive constants. ($i = 1,2,3,4,j = 1,2,3$), $t \in I$, I is a given economic period.

a_1 is the development coefficient of $x(t)$; a_2, a_3, a_4 is the influence coefficient of $y(t)$, $z(t)$, $u(t)$ to $x(t)$, respectively; M is the threshold of $y(t)$ to $x(t)$. b_2 is the development coefficient of $y(t)$; b_1, b_3, b_4 is the influence coefficient of $x(t)$, $z(t)$, $u(t)$ to $y(t)$, respectively. C is the peak value of $y(t)$ during a given period; E, of $z(t)$. c_1, c_2, c_4 is the influence coefficient of $x(t)$, $y(t)$, $u(t)$ to $z(t)$; c_3 is the influence coefficient of ESER's investment to $z(t)$; N is the threshold of $x(t)$ to $z(t)$. d_1 is the development coefficient of $u(t)$ under supply-demand relations, P is the threshold of $y(t)$ to $u(t)$, d_2 is the influence coefficient of ESER technical progress to $u(t)$, d_3 is the influence coefficient of government control to $u(t)$.The coefficient is interpreted as a relation between two