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The Energy Conservation and Emission Reduction Dynamic Evolution Model Based on Industrial Structure Optimization of the Yangtze River Delta

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Abstract: Based on the economic development of Yangtze River Delta, and considering the status of energy and environment, this paper uses input-output analysis method to establish energy conservation and emission reduction dynamic evolution model (ECER). Calculate the economic output, energy consumption and pollution emission from 2004 to 2008 in Yangtze River Delta using model ECER and then get their evolution rates. This paper studies the evolution rule of energy and environment and the characteristic of industrial structure in Yangtze River Delta, and puts forward a strategy to optimize the industrial structure and to realize the target of energy saving and emission reduction.

Keywords: Yangtze River Delta; energy conservation and emission reduction model (ECER); evolution; industrial structure

1 Introduction

With economic growth, China's industrial structure evolves and optimizes continuously. The industrial structure optimization process of Yangtze River Delta is faster than the national average level. The proportion of output values produced by tertiary industry in GDP is 16.18 percent in 1978 and 42.86 percent in 2008, increasing by 26.68 percent, but the industrial structure of Yangtze River Delta is still the type of "2-3-1", resulting serious energy consumption and environmental pollution. The energy consumption of Yangtze River Delta in 2008 is 76.43 percent of the whole energy consumption, and wastewater emission reaches 5039.78 million tons. The contradiction among energy, environment and economic growth is increasingly sharp.

Presently domestic and overseas scholars have done lots of studies about the problem of energy conservation and emission reduction. Xixin Gu etc. [1-2] study about energy conservation and emission reduction in Yangtze River Delta from the aspects of optimizing energy structure and the relationship between energy and economy. Olutomi I.Adeyemi etc.[3-6] analyze energy consumption considering the energy saving technology, foreign trade, energy intensity and the efficiency of energy utilization, and puts forward related suggestions of energy saving and emission reduction. Beibei Zhang cte.[7] give a new model of energy intensity using the method of nonlinear dynamic systems, and predicts China's energy intensity. Lixin Tian, Jing Liu[8] analyze the relationship between energy prices and energy intensity using the Solow production function model. Honglin Yang etc. [9] suggest an economic growth model with stochastic technology change in which renewable natural resource is introduced and analyzes how economy system is affected by stochastic technology change and renewable rate of resources. Lixin Tian etc. [10] analyze and process the time sequence of carbon emissions from the perspective of the BP neural network, revealing the structure and the law of carbon emissions and describing the dynamic characteristic of carbon emissions system. Lixin Tian etc. [11-13] study the problem of chaos synchronization of the energy resource chaotic system using active control by using Lyapunov stability theory. Jian Yin etc.[14] evaluates FDI's influence on Jiangsu's economic development by quantificational method, and analyzes effects of capital investment on Jiangsu's economic growth. Xuewen Xia[15] puts forward a time series analysis model-building and forecast methods and applies the models to study Xiang river water level.

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2 Model building

2.1 Model assumption

(1) Assume every industry only produces a homogeneous product, and the product made by one industry can not been replaced by another one.
(2) Assume that an industry produces a unit of output needing other industries' fixed investments, and its output invested into other industrial products is also fixed.
(3) Assume the total of several industrial outputs is equal to the total of several industrial investments, which can't be affected by other economic factors.
(4) Assume the input-output direct consumption coefficients and the investment coefficients are relatively stable in a certain period.
(5) Assume the economy of Yangtze River Delta develops stably, which can't be affected by global economic emergencies.
(6)Assume the energy status of Yangtze River Delta is not influenced by global emergencies, and there is not energy shortage or excess phenomenon.
(7) Assume a production cycle is for one year, and the planning period is for five years. The paper studies the data from 2004 to 2008.
(8) Energy includes coal, oil, natural gas, nuclear power, wind power, solar energy and so on, and this paper assumes they have no differences.
(9) This paper does not consider the difference among various pollutants, and divides the pollutants into wastewater, the waste gas and solid waste pollution.
(10) Assume the data of Yangtze River Delta is equal to the total of Jiangsu Province, Zhejiang Province and Shanghai.

2.2 Evolution function and evolution rate

Evolution economics theory expands and is applied to the technological changes, institutional changes and industrial evolution, etc. since 1980s. With the rapid development of economy, the global financial crisis happens, which makes evolution become a major means of describing economic activity.

This paper applies evolution economics theory into energy and environment system, taking time for evolutionary variable and taking economic output, energy consumption and pollution emission as dynamic variables, and puts forward the concept of function evolution. The time series is as t_0,t_1,$\cdots$,t_n and the time intervals are same.

The evolution function is expressed as follows:

$$F(t_i) = \frac{G(t_i) - G(t_{i-1})}{\Delta t}(i = 1, 2, \cdots)$$

$G(t_i)$ describes the energy consumption(or pollution emission) at t_i; $F(t_i)$describes the changes of energy consumption(or pollution emission) at t_i compared to at t_{i-1}.

Energy consumption and pollution emission which mainly are studied in this paper have different quantities, so this paper puts forward the concept of evolution rate in order to analyze the evolution processes easily. Its expression is as follows:

$$D(t_i) = \frac{F(t_i)}{G(t_{i-1})}, i.e. D(t_i) = \frac{G(t_i) - G(t_{i-1})}{\Delta t \cdot G(t_{i-1})}$$

$D(t_i)$ is the evolution rate of energy consumption (or pollution emissions) at t_i compared to at t_{i-1}.

2.3 Model building

2.3.1 The objective functions

Based on the present situation of energy and environment in Yangtze River Delta, and considering the features of industrial structure, this paper studies energy saving and pollution emission reduction. We put forward the objective functions from the angles of energy and environment, and at the same time we consider their growth and evolution. The variable, such as $c_i(t)$, describes the amount in stage t, and when t changes the variable also changes.
(1)Industrial energy consumption goal

This paper studies industrial energy consumptions, and puts forward the industrial energy consumption goal: the minimum of total industrial energy consumption growth rate in the planning period.

$$min \qquad f(t) = \sum_{t=1}^{T}\sum_{i=1}^{3}\frac{c_i(t)x_i(t)}{C_0} \tag{1}$$

In (1), $f(t)$ is total energy consumption growth of three industries during the planning period; $x_i(t)$ is the economic output of industry i in stage t; $c_i(t)$ is the energy intensity of industry i; i is industry; t is production cycle; T is planning period($T > 0, T \in Z$).

(2) Evolution trend goal of energy consumption

This paper puts forward the evolution trend goal of energy consumption utilizing evolution theory, which is the minimum of energy consumption evolution rate in each production cycle.

$$min \qquad \Delta f(t) = \sum_{t=2}^{T}\sum_{i=1}^{3}\frac{c_i(t)x_i(t) - c_i(t-1)x_i(t-1)}{\Delta t \cdot c_i(t-1)x_i(t-1)} \tag{2}$$

In (2), $\Delta f(t)$ describes the evolution rate of energy consumption in the planning period.

(3) Pollution control goal

Environment pollution mainly includes wastewater, the waste gas and solid waste pollution. This paper analyzes the industrial pollution emission quantitatively, and separately calculates the pollution emission intensity of wastewater, the waste gas and solid waste pollution, which is the pollution emission per economic output, in order to get the actual pollution emissions. The mathematical expressions are as follows: $E_\alpha(t) = \sum_{i=1}^{3}\alpha_i(t)x_i(t) - \eta_\alpha(t)$; $E_\beta(t) = \sum_{i=1}^{3}\beta_i(t)x_i(t) - \eta_\beta(t)$; $E_\gamma(t) = (\sum_{i=1}^{3}\gamma_i(t)x_i(t)) \cdot (1 - \varepsilon(t))$; Among them,$E_\alpha(t)$, $E_\beta(t)$, $E_\gamma(t)$ respectively describes the actual total emissions of wastewater, the waste gas and solid waste pollution caused by three industries; $\alpha_i(t)$, $\beta_i(t)$, $\gamma_i(t)$ respectively describes the emission intensity of wastewater, the waste gas and solid waste pollution caused by industry i; $\eta_\alpha(t)$ is the removal amount of wastewater; $\eta_\beta(t)$ is the removal amount of the waste gas; $\varepsilon(t)$ is comprehensive utilization rate of the solid waste pollution.

The pollution control goal is expressed as follows:

$$min \qquad g(t) = \sum_{t=1}^{T}(\lambda_1\frac{E_\alpha(t)}{W_0} + \lambda_2\frac{E_\beta(t)}{G_0} + \lambda_3\frac{E_\gamma(t)}{S_0}) \tag{3}$$

In (3),$g(t)$ is the total growth rate of pollutants during the planning period; λ_1, λ_2, λ_3 respectively describes the influence coefficient of the wastewater, the waste gas and the solid wastes compared to the total pollutants.

(4)Evolution trend goal of pollution emission

This paper puts forward the evolution trend goal of pollution emission utilizing evolution theory, which is the minimum of pollution emission evolution rate in each production cycle.

$$min \qquad \Delta g(t) = \sum_{t=2}^{T}(\lambda_1\frac{E_\alpha(t) - E_\alpha(t-1)}{\Delta t \cdot E_\alpha(t-1)} + \lambda_2\frac{E_\beta(t) - E_\beta(t-1)}{\Delta t \cdot E_\beta(t-1)} + \lambda_3\frac{E_\gamma(t) - E_\gamma(t-1)}{\Delta t \cdot E_\gamma(t-1)}) \tag{4}$$

In (4), $\Delta g(t)$ describes the evolution rate of pollution emission in the planning period.

2.3.2 Constraints

On the base of the development of industrial structure, this paper studies energy and environment in Yangtze River Delta. By analyzing the present status of energy and environment and applying input-output theory and evolution theory, the paper puts forward following constraints to control industrial economic growth, energy consumption and pollution emission. At last, the paper puts forward constraints to make sure the actual significance of the variables.

(1) The dynamic evolution constraint of input-output balance

Using input-output theory, and analyzing the relationship among the economic output, the capital formation, the economic consumption and economic exports, this paper puts forward the constraint. Its expression is as follows:

$$X(t) = A \cdot X(t) + B \cdot [X(t+1) - X(t)] + XF(t) + CK(t) \tag{5}$$

In (5), $X(t) = [x_1(t), x_2(t), x_3(t)]^T$ is the column vector of economic output produced by three industries; $A = (a_{ij})_{n\times n}$ is the input-output direct consumption coefficients matrix, and $a_{ij} = \frac{x_{ij}}{x_j}$ is the direct consumption coefficients, describing the output of industry i used to produce the output of industry j ; $B = (b_{ij})_{n\times n}$ is the investment coefficients matrix, and b_{ij} is the investment coefficients, describing the investment cost supplied by industry i and used to produce the output of industry j ; $B[X(t+1) - X(t)]$ is the column vector of capital formation; $XF(t)$ describes the final economic consumption; $CK(t)$ describes the economic net exports.

(2)The constraint of energy production and consumption

Energy production includes energy net production and energy import, and energy consumption includes energy demands(including industrial energy consumption, energy consumption in life and energy storage) and energy exports (including the energy exported to other areas). The energy sources in Yangtze River Delta are not enough, and energy production is insufficient, so most of the energy resources are from other areas. Therefore, the constraint of energy production and consumption is expressed as:

$$y(t) + \Delta o(t) + \Delta a(t) \geq \sum_{i=1}^{3} c_i(t)x_i(t) + z_1(t) + z_2(t) \tag{6}$$

In (6), $y(t)$ is the energy production; $\Delta o(t) = o_{in}(t) - o_{out}(t)$ describes the net import; $o_{in}(t)$ is energy import and $o_{out}(t)$ is energy export; $\Delta a(t)$ describes the net import from other areas in China; $z_1(t)$ is energy consumption in life and $z_2(t)$ is the energy storage. When $z_2(t) > 0$, it shows energy storage has reduced in stage t , and when $z_2(t) < 0$, it shows energy storage has increased in stage t.

(3) The evolution constraint of energy consumption

This paper controls energy consumption by controlling the growth rate of industrial energy consumption, and the constraint is expressed as:

$$k_1 \leq \sum_{i=1}^{3} \frac{c_i(t)x_i(t)}{C(t-1)} \leq k_2 \tag{7}$$

In (7), $C(t-1)$ is the actual energy consumption in stage $t-1$; k_1 , k_2 respectively describes the minimum and the maximum growth rate of energy consumption.

(4) The evolution constraint of economic growth

The premise of energy saving and emission reduction in Yangtze River Delta is developing economy, so the constraint of economic growth is expressed as:

$$\frac{e^T[X(t) - A\cdot X(t)]}{e^T[X(t-1) - A\cdot X(t-1)]} \geq \rho \tag{8}$$

In (8), $e = (1,1,1)^T$ is unit column; ρ is the growth rate of output produced by three industries in stage t compared to in stage $t-1$.

(5) Pollution control constraints

Control the total of pollution emission, and the expression is as follows:

$$E_\alpha(t) \leq W(t), E_\beta(t) \leq G(t), E_\gamma(t) \leq S(t) \tag{9}$$

In (9), $W(t)$, $G(t)$, $S(t)$ respectively describes the maximum emission of wastewater, the waste gas and solid waste pollution.

(6)Non-negative constraint

In order to ensure that the variables have practical significance, this paper sets them non-negative, such as $x_i(t)$, $y(t)$ and z_1.

$$x_i(t), y(t), z_1(t) \geq 0 (i = 1,2,3; t = 1,\cdots,T) \tag{10}$$

2.3.3 Model building

In 2.3.1, the paper puts forward a model of four objective functions, which belongs to programming problem of multiple goals. In order to calculate the model easily, the paper transforms multiple goals into single goal using the evaluation function method. The multi-infrastructures are θ_1 , θ_2 , θ_3, θ_4 , and $\sum_{i=1}^{4} \theta_i = 1(\theta_i \geq 0)$. The evaluation function is expressed as:

$$u = \theta_1 \cdot f(t) + \theta_2 \cdot \Delta f(t) + \theta_3 \cdot g(t) + \theta_4 \cdot \Delta g(t)$$

The final objective function is as follows:

$$min \quad \theta_1 \cdot \sum_{t=1}^{T}\sum_{i=1}^{3}\frac{c_i(t)x_i(t)}{C_0} + \theta_2 \cdot \sum_{t=2}^{T}\sum_{i=1}^{3}\frac{c_i(t)x_i(t) - c_i(t-1)x_i(t-1)}{\Delta t \cdot c_i(t-1)x_i(t-1)} + \theta_3 \cdot \sum_{t=1}^{T}(\lambda_1 \frac{E_\alpha(t)}{W_0} + \lambda_2 \frac{E_\beta(t)}{G_0} + \lambda_3 \frac{E_\gamma(t)}{S_0})$$

$$+\theta_4 \cdot \sum_{t=2}^{T}(\lambda_1 \frac{E_\alpha(t) - E_\alpha(t-1)}{\Delta t \cdot E_\alpha(t-1)} + \lambda_2 \frac{E_\beta(t) - E_\beta(t-1)}{\Delta t \cdot E_\beta(t-1)} + \lambda_3 \frac{E_\gamma(t) - E_\gamma(t-1)}{\Delta t \cdot E_\gamma(t-1)}) \tag{11}$$

The transformation has not changed the evolution of the original model, and the final energy conversation and emission reduction dynamic evolution model(ECER) is as follows:

$$\begin{cases} \min & \theta_1 \cdot \sum_{t=1}^{T}\sum_{i=1}^{3}\frac{c_i(t)x_i(t)}{C_0} + \theta_2 \cdot \sum_{t=2}^{T}\sum_{i=1}^{3}\frac{c_i(t)x_i(t)-c_i(t-1)x_i(t-1)}{\Delta t \cdot c_i(t-1)x_i(t-1)} \\ & + \theta_3 \cdot \sum_{t=1}^{T}(\lambda_1 \frac{E_\alpha(t)}{W_0} + \lambda_2 \frac{E_\beta(t)}{G_0} + \lambda_3 \frac{E_\gamma(t)}{S_0}) \\ & + \theta_4 \cdot \sum_{t=2}^{T}(\lambda_1 \frac{E_\alpha(t)-E_\alpha(t-1)}{\Delta t \cdot E_\alpha(t-1)} + \lambda_2 \frac{E_\beta(t)-E_\beta(t-1)}{\Delta t \cdot E_\beta(t-1)} + \lambda_3 \frac{E_\gamma(t)-E_\gamma(t-1)}{\Delta t \cdot E_\gamma(t-1)}) \\ s.t. & X(t) = A \cdot X(t) + B \cdot [X(t+1) - X(t)] + XF(t) + CK(t) \\ & y(t) + \Delta o(t) + \Delta a(t) \geq \sum_{i=1}^{3} c_i(t)x_i(t) + z_1(t) + z_2(t) \\ & k_1 \leq \sum_{i=1}^{3}\frac{c_i(t)x_i(t)}{C(t-1)} \leq k_2 \\ & \frac{e^T[X(t)-A\cdot X(t)]}{e^T[X(t-1)-A\cdot X(t-1)]} \geq \rho \\ & E_\alpha(t) \leq W(t), E_\beta(t) \leq G(t), E_\gamma(t) \leq S(t) \\ & x_i(t), y(t), z_1(t) \geq 0 (i = 1, 2, 3; t = 1, \cdots, T) \end{cases}$$

Model ECER is a dynamic evolution model of multiple goals. This paper puts forward the objective functions using dynamic evolution theory, and especially the two evolution trend goals of energy consumption and pollution emission, which describe the evolution process of decreasing energy consumption and pollution emission. Besides, we also apply the dynamic evolution theory to put forward constraints.

3 Empirical analysis

3.1 Processing data

In order to calculate the industrial economic output, energy consumption and pollution emission of Yangtze River Delta from 2004 to 2008 using the model ECER, this paper deals with the coefficients and does reasonable setting. Firstly, four goals in the paper are equal for each other, so we set $\theta_1 = \theta_2 = \theta_3 = \theta_4 = 0.25$. Secondly, set $\lambda_1 = 0.898$, $\lambda_2 = 0.082$ and $\lambda_3 = 0.02$ according to their different influences to the total pollution emission. Thirdly, set $k_1 = 1.0$ and $k_2 = 1.2857$ by simulating data using the model ECER. Finally, set $\rho = 1.12$ according to the actual situation of economic growth in China.

3.2 Empirical analysis

3.2.1 Evolution process analysis

This paper calculates the industrial economic output, energy consumption and pollution emission of Yangtze River Delta from 2004 to 2008 using the model ECER, and gets their evolution rates, which are showed in Table 1.

Table 1: The evolution rate of economic output, energy consumption and pollution emission

t	$D_X(t)$	$D_X^1(t)$	$D_C(t)$	$D_C^1(t)$	$D_E(t)$	$D_E^1(t)$
2005	0.19964	0.14599	0.29322	0.09165	0.14419	0.09277
2006	0.16745	0.15668	0.01025	0.08399	0.01603	-0.03549
2007	0.18751	0.21414	0.17141	0.08030	-0.00866	0.06072
2008	0.18088	0.16853	0.22894	0.07475	-0.78205	-0.01432

In Table 1, $D_X(t)$, $D_C(t)$, $D_E(t)$ respectively shows the evolution rate of the economic output, energy consumption and pollution emission in Yangtze River Delta; $D_X^1(t)$, $D_C^1(t)$, $D_E^1(t)$ respectively shows the evolution rate of the national economic output, energy consumption and pollution emission in China.

Firstly, the data in Table 1 shows that the average evolution rate of economic output is about 18.39 percent, which illustrates that the economic growth rate of Yangtze River Delta keeps high. Though the evolution rate in 2006 decreased, it increased in the following years, so the whole level of economic evolution is stable. Besides, the economic evolution of Yangtze River Delta is faster than the national average by 1.26 percent. The national economic evolution rate is 21.41 percent in 2007, and it is about 15 percent in other years, which is lower than the average level of Yangtze River Delta by 3 percent. It is a characteristic of economic evolution in Yangtze River Delta. Secondly, the average evolution rate of energy consumption is about 17.60 percent, especially it exceeds 20 percent in 2004 and in 2008, which shows the energy demand and consumption in Yangtze River Delta are large and the evolution of energy consumption is fast. But energy consumption in Yangtze River Delta is also greater than the national level. Thirdly, the evolution rate of pollution emission is decreasing year by year, and it is negative in 2007 and in 2008, which shows the pollution emission has reduced compared to the last year, realizing the goal of pollution emission reduction. What's more, the evolution of pollution emission in Yangtze River Delta is much faster than the national level.

3.2.2 Industrial structure analysis

This paper calculates the industrial economic output of Yangtze River Delta from 2004 to 2008 using the model ECER, and gets their effect rates to the total economic output, showed in Table 2.

Table 2: The actual effect rates and the effect rates gotten by model ECER

t	$\alpha_1(t)$	$\alpha_1^1(t)$	$\alpha_2(t)$	$\alpha_2^1(t)$	$\alpha_3(t)$	$\alpha_3^1(t)$
2004	0.0668	0.0666	0.5418	0.5369	0.3914	0.3965
2005	0.0598	0.0610	0.5372	0.5339	0.4030	0.4051
2006	0.0537	0.0574	0.5400	0.5174	0.4063	0.4252
2007	0.0512	0.0531	0.5314	0.5081	0.4174	0.4388
2008	0.0502	0.0495	0.5212	0.4953	0.4286	0.4552

$\alpha_i(t)$ is the actual effect rate and $\alpha_i^1(t)$ is the effect rate gotten by the model ECER. Firstly, comparing the actual effect rates, the effect rate caused by secondary industry is greater than others, which is about 53.43 percent. Next is the effect rate caused by tertiary industry, 40.94 percent, and the effect rate caused by primary industry is only 5.63 percent. It shows secondary industry is in leading position, which results in plenty of energy consumption and pollution emission. Secondly, comparing the effect rates gotten by the model, the effect rate caused by secondary industry is about 51.83 percent, decreasing by 1.6 percent compared to the actual effect rate. The effect rate caused by tertiary industry is about 42.41 percent, increasing 1.47 percent. And the effect rate caused by primary industry has not any changes. The result gotten by the model makes the economic output of secondary industry decrease, but makes the economic output produced by tertiary industry increase. The result shows that promoting the development of tertiary industry and optimizing the industrial structure is an important strategy to save energy and reduce pollution emission.

4 Conclusions

Considering the situation of economic development, energy and environment, and using input-output analysis method, this paper establishes a dynamic evolution model of energy conversation and emission reduction, called ECER model. Calculate the model using Lingo9.0 and we get evolution rates of economic output, energy consumption and pollution emission in Yangtze River Delta. Based on the empirical analysis about them, this paper puts forward a scheme of optimizing the industrial structure. We should properly reduce the economic output produced by secondary industry and pay attention to developing tertiary industry, which is also an important strategy to save energy and reduce pollution emission. This paper studies the problem from two aspects: energy conservation and emission reduction and industrial structure, which influences each other. We analyze the characteristic of industrial structure through building model ECER and realize the target of saving energy and reducing pollution emission by optimizing the industrial structure. At the same time, the paper testifies the rationality and validity of model ECER by calculating the model and offering empirical analysis, which provides theoretical basis for optimizing industrial structure and provides a new perspective for energy conversation and emission reduction and realizing the sustainable development of economy, energy and environment in Yangtze River Delta.

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