The Study on the 3E system coordination evaluation: Evidence from China

ZHANGLAN WU, JIE TANG, DONG WANG *
School of Urban Planning and Management
Harbin Institute of Technology Shenzhen Graduate School
Shenzhen, Guangdong 518055
CHINA
clayton_wang@163.com

Abstract: - Since the introduction of economic reforms in 1978, China has become the world's fastest-growing major economy. But rapid economic development accelerates the process of urbanization, meanwhile resources and environment problems appear. Now, China has given energy and environment high priority in its economic stimulus package, drawing on goals set for the 12th Five Year Plan. The overall approach to environmental protection should continue to be improved during the next few years of recovery period. All of these goals are based on the development of energy, economy and environment (3E). Under this background, implementing the scientific concept of development, and promoting harmonious development among energy, economy and environment is the only choice for achieving sustainable development. The thesis studies the relationship among energy, economy and environment, and then combining the requirements of harmonious development of 3E system, proposes the concept of the coordinative development of 3E system. It is hoped to analyze the 3E coordination situation of 30 provinces of China to promote the sustainable development of 3E system. For this purpose, basing on the study of relevant indicator systems, following the criteria to select assessment indicator based on the system function and efficiency, the text builds 3E coordination degree indicator system framework including 33 specific indicators. In the next, it establishes a coordination evaluation model for 3E system based on the method of Canonical Correlation analysis and Coupling Coefficient Model in physics and estimates 3E coordination degree of 30 provinces in China, dividing them into three different categories: moderate disorder, mild disorder and barely coordination. Based on above results, the thesis finds a new way to promote the coordinative development of 3E system.

Key-Words: - Energy-Economy-Environment System; 3E; Coordination Degree; Canonical Correlation Analysis; Comprehensive Evaluation; China

1 Introduction

Since initiating market reforms in 1978, China has shifted from a centrally planned to a market based economy and experienced rapid economic and social development. GDP growth averaging about 10 percent a year has lifted more than 500 million people out of poverty. With a population of 1.3 billion, China recently became the second largest economy and is increasingly playing an important and influential role in the global economy. Yet China remains a developing country and its market reforms are incomplete. Rapid economic ascendance has brought on many challenges as well. Now China is the country that emits most CO_2 in the world. Urbanization means population migrates to city and town, which will increase sharply demand for energy and other resource. Considering the energy efficiency and energy structure in China, the situation will be extremely serious [1]. China's 12_{th} Five-Year Plan (2011-2015) forcefully addresses these issues. It highlights the development of services and measures to address environmental and social imbalances, setting targets to reduce pollution, to increase energy efficiency, to improve access to education and healthcare, and to expand social protection. Its annual growth target of 7 percent signals the intention to focus on quality of life, rather than pace of growth. Therefore, it is necessary to examine the relationship of 3E (economy-energy-environment) system.

Many domestic and foreign experts studied how to ensure sustainable development, and they achieved many results. Yu et al (2008) compare with pricing decision of two stages ecological industry chain, which is consisting of manufacturer and retailer, main product buyer and byproduct buyer was considered [2]. Akram Avami et al (2008) find transportation sector has dominant effect in air pollution in Iran, so the efficiency of traffic from the structure of the system should be promoted [3]. Nasser Ayoub et al (2009) pointed out that policy making for sustainable development and public interest involves wicked problems, the problems are characterized with lack of clear and definitive problem formulation, different value judgments and uncertainties [4].

Most studies have focused on the relationship between consumption and economic growth [5][6], and the relationship between energy consumption and the environment [7]. Oliverira et. al (2004) constructed the energy-economy-environment multi-objective model which based on the industrial production of linear structure, investigated the coordination situation between the sustainable energy development strategy, economic growth, social welfare and environmental friendly in detail in order to provide the decision-maker with comprehensive evaluation model of environmental carrying capacity, so as to take corresponding measures [8]. By simulating CGE model, Hanley (2006) found that improving energy efficiency will boost energy production and consumption, thus worsening environment. Therefore, the policy itself guided by improving the energy efficiency is not enough to improve the environment, it also need the policy of guide energy consumption with moderate to supplement [9]. X., Su (2007) conducted GRA of energy consumption and economic development in China [10]. Lin (2007) explored the inter-relationships among economy, energy use, CO_2 emission of 37 industrial sectors in Taiwan based on GRA [11]. Shi et al. (2009) examined the impact of energy consumption structure on environment based on GRA [12]. Some researchers have studied the one-way coupling model based on E3MG model and p-TOMCAT model, and used the model to comparison and analysis the atmospheric concentrations of Mexico under the condition of extensive use of fossil fuels and the low greenhouse effect .The results showed that under the condition of insufficient employment in Mexico, heavy investment on low carbon technology (electric, heat pump) is beneficial for improving the employment rate, maintaining economic growth, reducing the risk of future oil revenues falling [13]. By establishing 3E model of multiple targets and sectors, Carla Oliveira and Carlos Henggeler Antunes (2011) analyzed the influence on environment respectively when the economic structure of energy system is changing, and provide suggestions for policy making [14], what's more, the results of the analysis is very essential to understand the role of carbon reduction technology, energy utilization plan and so on [15][16][17]. There are many qualitative analysis in the system coordination studies, but most studies sorely neglect the energy-economy-environment system.

The remainder of the study is organized as follows. Section 2 outlines the model descriptions we use in this study. Section 3 describes the empirical study. The conclusion is reported in section 4.

2 Model descriptions

2.1 Energy-Economy-Environment system

The development of energy industry provides the necessary material base for social economy, but energy industry is one of the root causes of environmental pollution. Economic development is an important guarantee to solve the contradiction problem between energy development and environmental protection, promote the coordinated development of energy and environment. If we only care for economic development and utilization of energy but ignore the environmental protection, the environmental pollution would become an obstruction to development. If we look at isolated the environmental pollution and environmental issues, economic development cannot be sustained, energy development will be restricted, thus unable to provide essential material basis for environmental protection. So the interactions among energy, economic, environment are shown in figure 1.

As can be seen in figure 1, there are two kinds of relationships that exist between them. The first one is zero feedback, that is, when lower levels of economic development, then economic activity is less , consumed energy resources is scarce, the extent of damage to the environment is very small, and thus in turn the environment influence on economic activity is also very small ; The second is the negative feedback relationship, when the economy is in rapid development stage, especially when the economic development depends on the sacrifice of energy, environment, energy consumption of economic activity is large, and a large extent of damage to the environment, which in turn the constraints of environment on economic activity also play a great role, that is, negative feedback; The third is the positive feedback relationship, introducing science and technology in the process of economic development, effectively improving energy efficiency, reducing economic production activities on the environment caused by stress, then the environment provide support to economic activity that generates positive feedback.

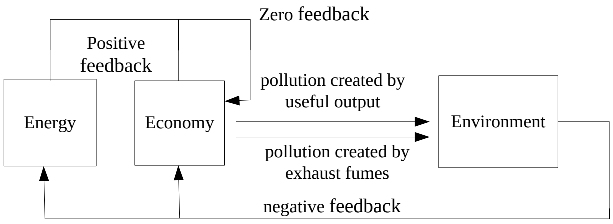

Fig.1 The relationship diagram of 3E

At this stage, Chinese industry has been developing rapidly over the past 60, but the economic performance of industry was poor and the industrial structure was irrational, while extensive economic growth model has not changed in China.

The energy demand is continuously increasing resulting in the ecological environmental issues. So the environment on economic development debilitating side effects, in other words, the relationship among China's current economic development ,energy development and utilization, and environmental protection exists negative feedback, so the sustainable development strategy of 3E system coordinated develop should be designated to promote sustained and healthy economic development, to achieve sustainable economic and social development. Sustainable development refers to a mode of human development in which resource use aims to meet human needs while ensuring the sustainability of natural systems and the environment, so that these needs can be met not only in the present, but also for generations to come. It is become the most often-quoted definition of sustainable development:"development that meets the needs of the present without compromising the ability of future generations to meet their own needs [18][19][20][21][22]. Economic development should effectively coordinate with energy development and environmental protection, which requires play equal attention to economic development, energy conservation and environmental protection both.

2.2. Model

According to the definition of system that is a set of interacting or interdependent components forming an integrated whole or a set of components and relationships which are different from relationships of the set or its elements to other elements or sets. Several factors which are interrelated, interacting and interdependent constitute an organic whole owns a stable structure and specific features in certain circumstances. We could regarded energy - economy, economy - environment, environment - energy as a binary system respectively, and then use the comprehensive evaluation of the coordination function derived from canonical variables to make comprehensive evaluation of the binary system status of each subsystem's coordinate position. By Canonical Correlation Analysis (CCA), it aims to find pairs of canonical variables. It is assumed that in the energy - economic binary system, these canonical variables corresponding to energy is represented by the letters U_l, U_2, corresponding to economic are represented by the letters V_l, V_2. Similarly, in the economic-environment binary system, these canonical variables corresponding to economic are represented by the letters P_l, P_2, corresponding to environment is represented by the letters Q_l, Q_2. In the energy-environment binary system, these canonical variables corresponding to environment are represented by the letters M_l, M_2, corresponding to energy is represented by the letters N_l, N_2. According to the theory of CCA, the original canonical variables can be expressed as a function of indicator variables. So in the energy - economic binary system, canonical variables related with energy and economic subsystems can be expressed as follows:

$$U_1 = a_{1,1}x_1 + a_{1,2}x_2 + ...a_{1,12}x_{12} \tag{1}$$

$$U_2 = a_{2,1}x_1 + a_{2,2}x_2 + ...a_{2,12}x_{12} \tag{2}$$

$$V_1 = b_{1,1}y_1 + b_{1,2}y_2 + ...b_{1,9}y_9 \tag{3}$$

$$V_2 = b_{2,1}y_1 + b_{2,2}y_2 + ...b_{2,9}y_9 \tag{4}$$

In the equation (1) and (2), x_1, x_2, x_3……x_{12} represent each comprehensive evaluation of energy subsystem, equation (3) and (4), y_1, y_2, y_3……y_9 represent each comprehensive evaluation of economic subsystem, and $a_{1,1}$, $a_{2,1}$, $b_{1,1}$, $b_{2,1}$ stand for load factor of other related typical variables on the original index.

According to the principle of canonical correlation analysis, we could find that the typical variable is derived from the weighted sum of the original index.

This means canonical correlation variable contains information covered by the original evaluation. So let the characteristic value corresponding to the canonical related variables as weights to weighted aggregated the typical variable, then we can obtain the comprehensive evaluation function of energy subsystems and economic subsystems in energy-economic binary system . Assume that λ_1, λ_2 ..., λ_9 are eigenvalues of canonical correlation coefficient based on energy - economy binary systems canonical correlation analysis, U and V respectively represent comprehensive evaluation coordination function of the subsystem of energy and economy ,then the comprehensive evaluation coordination function of the subsystem of energy and economy based on typical related variables can be expressed as follows:

$$U = (\lambda_1 U_1 + \lambda_2 U_2 + ...\lambda_9 U_9) \Big/ \sum_{i=1}^{9} \lambda_i \quad (5)$$

$$V = (\lambda_1 V_1 + \lambda_2 V_2 + ...\lambda_9 V_9) \Big/ \sum_{i=1}^{9} \lambda_i \quad (6)$$

Similarly, we can obtain the comprehensive evaluation coordination function of economy subsystems and energy subsystems in economy-energy binary system (respectively represent as P and Q) and the comprehensive evaluation coordination function of environment subsystems and energy subsystems in environment-energy binary system (respectively represent as M and N).

In view of energy - economy, economy - environment, environment- energy binary systems are equally important, implementing simple weighted average to the system coordination degree comprehensive evaluation results corresponding to subsystem in system, as coordination degree comprehensive evaluation results of subsystem of energy, economy, and environment in each binary systems 3E system. If the comprehensive evaluation coordination function of subsystem of energy, economy, and environment in 3E could be represent as E_1, E_2 and E_3. The comprehensive evaluation coordination function of subsystem of energy, economy, environment in 3E can be expressed as follows:

$$E_1 = 0.5U + 0.5N \quad (7)$$

$$E_2 = 0.5V + 0.5P \quad (8)$$

$$E_3 = 0.5Q + 0.5M \quad (9)$$

Coupling reflects the degree of interaction and mutual influence between systems, the greater the degree of coupling indicating that the greater the degree of coordination between systems. This paper defined the degree of influence on each other through the respective coupling elements among three subsystems of energy, economy and environment as 3E coordination system. After the evaluation for 3E systems "combined effects" of the three subsystems of energy, economy and environment respectively, learning from the coupling functions in physics to make evaluation for the coordination degree of 3E system. Assume E_1, E_2, E_3 are impact of energy, economy, environment subsystems on the 3E system respectively, then 3E coordination degree indicator system can be expressed as:

$$C = \left\{ \frac{E_1 E_2 E_3}{(E_1 + E_2)^2 (E_1 + E_3)^2 (E_2 + E_3)^2} \right\}^{1/3} \quad (10)$$

In the above, C is a coordination degree statistical measure variable of 3E system. The values are from range of 0 to 1. High values, near one, indicate the higher coordination degree of energy, economy, environment subsystems in 3E energy system. High values, near 0, indicate the lower coordination degree of 3E environment subsystems. We cannot make absolutely affirmation and negative judgement to this. Usually, the coordination state of 3E falls between "coordination" and "lack of coordination", and has dynamic characteristics. Generally speaking, evaluation rank is separated into 4-7 grades. This article divided 3E system coordination degree into 7 levels, namely high-quality coordination, good coordination, moderate coordination, barely coordinated, low offset, moderate disorders, severe disorders. Tables 1 and 2 show the criteria values of 3E system coordination degree evaluation and characteristics analysis of the various levels of coordination.

Table 1 Ranking standard of 3E system coordination degree

Coordination Level	coordination degree
high-quality coordination	(0.8,1]
good coordination	(0.7,0.8]
moderate coordination	(0.6,0.7]
barely coordinated	(0.5,0.6]
low offset	(0.4,0.5]
moderate disorders	(0.3,0.4]
severe disorders	(0,0.3]

Table 2 Features of seven kinds of coordination level evaluation standard

Coordination Level	main level
high-quality coordination	Energy supply and demand is balanced, economic development is at steady speed, energy and environment are affordable, environmental quality improves, and it can be well coordinated development among energy, economy and environmental subsystems.
good coordination	While the subsystem of energy, economy and environment each can well develop, but there is at least a subsystem's coordinated development degree inconsistent with the other two subsystems. People are relatively satisfied with that.
moderate coordination	The subsystem of energy, economy and environment will be in harmonious development, basically. And specific system even can achieve good situation of coordination.
barely coordinated	The development of the system of energy, economy and environment is in initial stage. And there is at least one subsystem even can't reach the level of basic satisfactory. To a certain extent, the two are in conflict in the development process.
low offset	In the course of exploitation and utilization of energy caused destructive disaster for ecological environment, and the growth of economy is using extensive growth pattern, which not only consumed a large amount of energy, but also polluted the environment to some extent. Energy, economy and environment get less coordinated development.
moderate disorders	In the process of economic development, excessive waste of energy resulted in energy supply and demand imbalance, which caused serious environmental pollution. In addition, because the pollution is lack of control over an extended period, the economy cannot get better development.
severe disorders	Economic growth as well as energy exploitation and utilization has caused serious pollution to the environment, and there is no timely treatment of this pollution. Deteriorating environment seriously affects the pace and quality of economic development, which hinder the improvement of people's living standards.

3 Empirical study

3.1 Data sources

This paper selects 30 provinces and regions (excluding Tibet) in mainland China as an analytical sample. The data arises from China Statistical Yearbook 2011, China Energy Statistical Yearbook 2011, China Environment Statistical Yearbook 2011 and National Research Statistics Database. Due to the uneven distribution of coal resources in our country, the raw coal production data of Shanghai, Guangdong, Hainan is missing. In the absence of such data, we can use the minimum of raw coal production index data. CO_2 emissions data were obtained by extrapolating from other data. First of all, according to the statistical caliber of Chinese statistics yearbook 2011, energy end-use can be divided into coal, coke, crude oil, gasoline, diesel, kerosene, fuel oil, and gas and electricity nine categories. Conversion factor and carbon emission coefficient are shown in

Table 3 Fold of standard coal coefficient and carbon emission coefficient of all kinds of energy

energy	coal	coke	crude oil
Fold of standard coal coefficient	0.7143	0.9714	1.428
Carbon emission coefficient	0.7476	0.1128	0.585
Energy	gasoline	diesel	kerosene
Fold of standard coal coefficient	1.4714	1.4571	1.4714
Carbon emission coefficient	0.5532	0.5913	0.3416
Energy	fuel oil	natural gas	electricity
Fold of standard coal coefficient	1.4286	13.300	1.229
Carbon emission coefficient	0.6176	0.4479	2.2132

Table 3. Due to all kinds of energy end-use in the statistical yearbook are based on physical statistics, conversion factor need to be converted into standard statistics. And then total consumption of these nine kinds of energy multiplied by the carbon emission coefficient comes out the data of CO_2 that this paper uses.

3.2 Methodology

When carrying on the comprehensive evaluation, positive indicators require its index value the bigger the better, and reverse index demands its parameter values as small as possible. Moderate indicators require their index value closer to a certain value, the better the results of the evaluation. During the evaluation, analyzing the original index data directly will introduce bias. Therefore, we need to use mathematical transform to convert reverse index and moderate index into positive indicators, called positive indicators treatment. Since reverse indicators and moderate indicators exist in the evaluation index system of coordination that this paper establishes, the original index data needs positive indicators treatment. Furthermore, each index represents a different physical meaning, and they have the difference in dimension, the dimensional difference will affect the evaluation results. Therefore, this paper use range method while processing original data into positive and dimensionless.

For positive indicators, coal production, electricity generation, natural gas consumption in proportion to total energy consumption, electricity consumption in proportion to total energy consumption, GDP, gross capital formation, total volumes, tertiary industry output value accounted for the ratio of GDP, tertiary industry employment to population ratio, GDP growth, retail sales of social consumer goods growth, per capita GDP, per capita retail sales of social consumer goods, amount of industrial wastewater emission standards, industrial SO_2 removal, industrial soot handling capacity, industrial dust processing capacity, comprehensive utilization rate of industrial solid waste, "three wastes" product output are using the following formula to transform:

$$x' = \frac{x - x_{\min}}{x_{\max} - x_{\min}} \tag{11}$$

For the reverse indicators, thermal power in proportion to the total generation capacity, coal consumption in proportion to total energy consumption, oil consumption in proportion to total energy consumption, elasticity of energy consumption, per unit of GDP energy consumption, per unit of GDP electric consumption, energy consumption for per unit of industrial added value, industrial wastewater emissions, CO_2 emissions, industrial SO_2 emissions, industrial soot emissions, industrial dust emissions, industrial solid waste production are using the following formula to process:

$$x' = \frac{x_{\max} - x}{x_{\max} - x_{\min}} \tag{12}$$

Moderate indicators, per capita energy consumption are using the following formula for processing:

$$x' = \frac{1}{1 + |x - M|} \tag{13}$$

$x_{\max}$ and $x_{\min}$ respectively denote the maximum, minimum. M is the reference values of per capita energy consumption above-mentioned. Using the standard that the total energy consumption is 4 billion tons of standard coal in 2015, which is put forward in "Twelfth Five-Year Plan", can convert the reference values of per capita energy consumption. To illustrate the empirical analysis easily, each index in the evaluation index system of energy subsystem is respectively denoted with x_1, x_2……x_{12}. Each index in the evaluation index system of economic subsystem is respectively denoted with y_1, y_2……y_9. Each index in the evaluation index system of environment subsystem is respectively denoted with z_1, z_2……z_{12}. All data was tested with SAS software. The following table shows the results.

Table 4 shows the first eigenvalue is 33.2727, and its contribution rate is 64.52%, which

Table 4 Energy - Economic binary system eigenvalues and contribution rate

number	Eigenvalues	Variance	Contribution rate	Cumulative contribution rate
1	33.2727	26.1913	0.6452	0.6452
2	7.0814	0.6148	0.1373	0.7825
3	6.4665	4.4254	0.1254	0.9078
4	2.0411	0.6165	0.0396	0.9474
5	1.4246	0.565	0.0276	0.975
6	0.8596	0.6623	0.0167	0.9917
7	0.1974	0.0279	0.0038	0.9955
8	0.1694	0.1088	0.0033	0.9988
9	0.0606		0.0012	1

shows the first pair of canonical correlation variables extracts most of the information of the original data. And the second eigenvalue is 7.0814, and its contribution rate is 13.73%, relatively, its explanation about the relationship between energy subsystem and economic subsystem is much smaller. The cumulative contribution rate shows that the former two pairs of canonical correlation variable on the interpretation of the original message reaches 78.25 percent. Meanwhile, in the canonical correlation analysis by testing the correlation coefficient of two pairs of extracted related variables, and in condition of given significance level a=0.10, canonical correlation coefficient is processed with significant test. In general, the calculated canonical correlation coefficient can make adequate explanation about the relationship between energy subsystem and economy subsystem. Similarly, the canonical correlation analysis results of economic - environment, environment - energy binary systems are shown below.

Table 5 Economic - environmental binary systems eigenvalues and contribution rate

number	Eigenvalues	Variance	Contribution rate	Cumulative contribution rate
1	22.0407	16.8872	0.6412	0.6412
2	5.1535	2.0049	0.1499	0.7911
3	3.1487	1.2405	0.0916	0.8827
4	1.9081	0.9451	0.0555	0.9382
5	0.9631	0.2827	0.028	0.9662
6	0.6804	0.4021	0.0198	0.9860
7	0.2783	0.1008	0.0081	0.9941
8	0.1775	0.1553	0.0052	0.9993
9	0.0242		0.0007	1.0000

Table 6 Environment-energy binary systems eigenvalues and contribution rate

number	Eigenvalues	Variance	Contribution rate	Cumulative contribution rate
1	221.635	164.4001	0.7309	0.7309
2	57.2349	42.7179	0.1887	0.9196
3	14.5171	10.4627	0.0479	0.9675
4	4.0544	0.6831	0.0134	0.9809
5	3.3713	2.0861	0.0111	0.9920
6	1.2852	0.8057	0.0042	0.9962
7	0.4795	0.1450	0.0016	0.9978
8	0.3345	0.0754	0.0011	0.9989
9	0.2591	0.1935	0.0009	0.9998
10	0.0656	0.0636	0.0002	1
11	0.0020	0.0018	0	1
12	0.0002		0	1

According to load matrix, canonical correlation variables U_1 and U_2 of energy subsystem in energy-economic environment binary system are computed, expressed as follows:

$$\begin{aligned} U_1 = {} & -0.125x_1 + 0.731x_2 - 0.0892x_3 \\ & + 0.1359x_4 + 0.1119x_5 + 0.4376x_6 \\ & - 0.3107x_7 + 0.1521x_8 + 0.2977x_9 \\ & - 0.0328x_{10} - 0.2264x_{11} - 0.2225x_{12} \end{aligned} \tag{14}$$

$$\begin{aligned} U_2 = 0.0244x_1 - 0.4417x_2 + 0.503x_3 \\ + 0.4206x_4 + 0.640x_5 - 0.3735x_6 \\ + 0.502x_7 + 0.0064x_8 + 0.5406x_9 \\ - 0.0764x_{10} - 0.3613x_{11} + 0.0379x_{12} \end{aligned} \tag{15}$$

According to load matrix, canonical correlation variables V_1 and V_2 of energy subsystem in energy - economic environment binary system are computed, expressed as follows:

$$\begin{aligned} V_1 = 1.1224y_1 - 0.340y_2 - 0.032y_3 \\ - 0.1191y_4 - 0.278y_5 + 0.0476y_6 \\ + 0.1576y_7 - 0.7904y_8 + 1.2569y_9 \end{aligned} \tag{16}$$

$$\begin{aligned} V_2 = 0.6875y_1 - 0.5541y_2 - 0.7829y_3 \\ - 0.4505y_4 - 0.1904y_5 + 0.1018y_6 \\ + 0.0915y_7 - 3.7563y_8 + 4.1629y_9 \end{aligned} \tag{17}$$

Likewise, the typical variable expressions of the Economic-Environment and the Environment–Energy binary system corresponding to each subsystem can be calculated, as follows:

$$\begin{aligned} P_1 = 0.2049y_1 + 0.4187y_2 + 0.2973y_3 \\ + 0.0787y_4 - 0.349y_5 - 0.0154y_6 \\ + 0.0306y_7 - 0.2461y_8 + 0.4361y_9 \end{aligned} \tag{18}$$

$$\begin{aligned} P_2 = 2.8795y_1 - 1.7715y_2 - 0.6714y_3 \\ - 0.0943y_4 + 0.6885y_5 - 0.1102y_6 \\ + 0.3932y_7 + 1.9171y_8 - 2.4977y_9 \end{aligned} \tag{19}$$

$$\begin{aligned} Q_1 = -2.752z_1 + 0.303z_2 - 0.2956z_3 \\ + 0.2315z_4 - 0.0032z_5 + 0.0577z_6 \\ + 2.2978z_7 - 0.0128z_8 + 0.4629z_9 \\ + 0.07z_{10} + 0.0346z_{11} - 0.0215z_{12} \end{aligned} \tag{20}$$

$$\begin{aligned} Q_2 = -23.697z_1 + 0.1363z_2 + 0.6447z_3 \\ + 0.7388z_4 + 0.4502z_5 - 0.7749z_6 \\ + 22.822z_7 + 0.3333z_8 + 0.3589z_9 \\ - 0.81042z_{10} + 0.2751z_{11} - 0.1024z_{12} \end{aligned} \tag{21}$$

$$\begin{aligned} M_1 = 4.4001z_1 + 0.9109Z_2 + 0.\ 0226z_3 \\ + 0.0812z_4 - 0.0453z_5 + 0.2154z_6 \\ - 4.3647z_7 + 0.0354z_8 - 0.3054z_9 \\ + 0.2604z_{10} - 0.2231z_{11} - 0.1237z_{12} \end{aligned} \tag{22}$$

$$\begin{aligned} M_2 = -7.9244z_1 + 0.3184z_2 + 0.2615z_3 \\ + 0.1948z_4 + 0.1326z_5 - 0.2337z_6 \\ + 7.47212z_7 + 0.1203z_8 + 0.7908z_9 \\ - 0.1801z_{10} + 0.3243z_{11} - 0.0645z_{12} \end{aligned} \tag{23}$$

$$\begin{aligned} N_1 = 0.1306x_1 - 0.499x_2 + 0.172x_3 \\ + 0.0166x_4 + 0.1105x_5 + 0.4296x_6 \\ + 0.4116x_7 + 0.1882x_8 + 0.151x_9 \\ - 0.0481x_{10} - 0.1352x_{11} + 0.1591x_{12} \end{aligned} \tag{24}$$

$$\begin{aligned} N_2 = -0.3853x_1 + 0.9267x_2 - 0.4721x_3 \\ - 0.031x_4 - 0.0468x_5 + 0.2577x_6 \\ - 0.1466x_7 - 0.0048x_8 - 0.0425x_9 \\ + 0.0512x_{10} + 0.0637x_{11} - 0.3059x_{12} \end{aligned} \tag{25}$$

According to the step of building 3E system coordination degree evaluation model, the calculation of coordination degree is based on the result of comprehensive evaluation of the energy, economic, environmental subsystems in 3E system. Through weighting summary the canonical correlation variables of energy, economy in the Energy - Economic binary system, we can obtain the energy subsystem and economic subsystem comprehensive evaluation function and the weights are determined by the eigenvalues which are based on the canonical correlation analysis. By the analysis results, we can see that: the eigenvalues of the first and second pair to the canonical correlation variable, respectively are 33.2727 and 7.0814 and normalizing them, we can get that the weights of the first and second pair to the canonical correlation variable, respectively are 0.8245 and 0.1755. So, we can measure the energy subsystem and economic subsystem by the following formula.

$$U = 0.8245U_1 + 0.1755U_2 \tag{26}$$

$$V = 0.8245V_1 + 0.1755V_2 \tag{27}$$

Among them, U represents the comprehensive evaluation results of energy subsystem in the Energy- Economic binary system and V represents the comprehensive evaluation results of economy subsystem in the Energy- Economic binary system.

Similarly, we can obtain the comprehensive evaluation p and Q of economic, environment subsystem in the Economic - Environmental binary system and the comprehensive evaluation M and N of environmental, energy subsystem in the Environment – Energy binary system, seeing the following formulas:：

$$P = 0.8105P_1 + 0.1895P_2 \quad (28)$$

$$Q = 0.8105Q_1 + 0.1895Q_2 \quad (29)$$

$$M = 0.7948M_1 + 0.2052M_2 \quad (30)$$

$$N = 0.7948N_1 + 0.2052N_2 \quad (31)$$

Bring the resultants U, V, P, Q, M, N into the equation (7) (8) (9), we can get the comprehensive evaluation results E_1, E_2, E_3 of energy, economic, environment subsystem in the 3E system, then using the equation (10) coordination degree evaluation model to measure the system coordination of the 3E system.

3.3 Empirical Result

Table 7 shows the evaluation results, specific is as follows:

Table7 3E system coordination degree evaluation results of each region

Region	Coordination degree	Coordinate position	Region	Coordination degree	Coordinate position
Beijing	0.466	mild disorder	Henan	0.458	mild disorder
Tianjin	0.484	mild disorder	Hubei	0.484	mild disorder
Hebei	0.525	barely coordination	Hunan	0.510	barely coordination
Shanxi	0.361	moderate disorder	Guangdong	0.396	moderate disorder
Inner Mongolia	0.405	mild disorder	Guangxi	0.583	barely coordination
Liaoning	0.507	barely coordination	Hainan	0.559	barely coordination
Jilin	0.600	barely coordination	Chongqing	0.543	barely coordination
Heilongjiang	0.509	barely coordination	Sichuan	0.499	mild disorder
Shanghai	0.482	mild disorder	Guizhou	0.593	barely coordination
Jiangsu	0.394	moderate disorder	Yunnan	0.544	barely coordination
Zhejiang	0.432	mild disorder	Shanxi	0.480	mild disorder
Anhui	0.497	mild disorder	Gansu	0.476	mild disorder
Fujian	0.504	barely coordination	Qinghai	0.514	barely coordination
Jiangxi	0.549	barely coordination	Ningxia	0.593	barely coordination
Shandong	0.380	moderate disorder	Xinjiang	0.574	barely coordination

Results analysis：

(1). As a whole, regional coordinated development degree of 3E system were still in the barely coordination level and below in 2010，which conformed to the objective reality.

Since 1978, China's rapid economic growth mainly relies on cheap labour and resources, and funds to promote the denotative and extensive economic growth mode, inevitably lead to the waste of energy resources and ecological environment pollution.

As most development practice shows, developing countries and emerging industrialized countries in economic take-off stage face serious problems of environmental degradation, resource depletion.

In addition, for a long time, our country takes GDP as important evaluation index to assess local officials' achievements，thus many officials instant success, not focus on coordinated development of economic, energy and environment. Under the premise of industrial interests vary greatly, all regions have set their sights on heavy industry which have a good investment returns, ignored the growth of energy consumption, resulting in high energy consumption industry development too fast.

(2). According to the table 7, our country's 30 provinces and municipalities can be divided into three different categories. The first category is moderate disorder whose coordination degree level is in the range of 0.3 to 0.4, including Shanxi, Jiangsu, Shandong, and Guangdong. The second category is mild disorder whose coordination degree level is in the range of 0.4 to 0.5, including Beijing, Tianjin, Inner Mongolia, Shanghai, Zhejiang, Anhui, Henan, Hubei, Sichuan, Shanxi and Gansu. The third category is barely coordination whose coordination degree level is in the range of 0.5 to 0.6, including Hebei, Liaoning, Jilin, Heilongjiang, Fujian, Jiangxi, Hunan, Guangxi, Hainan, Chongqing, Guizhou, Yunnan, Qinghai, Ningxia and Xinjiang.

(3). In the first category moderate disorder regions, most part of Shanxi investment are put into coal, electricity and other energy industries. Meanwhile, most of Shanxi coal enterprises directly belong to the state and all of the revenue turn over to state, resulting in Shanxi local economy lacks the necessary financial support and leading to develop slowly and forming an energy supply-led, single industrial structure. High-strength development of resource-oriented deformed industrial structure also led to the worsening of ecological environment in Shanxi. Due to the ecological environment destruction caused by coal mining and wastes no compensation mechanism to repair. Jiangsu Province, the total amount of machinery industry is the first in our country, and it has a large energy demand, but energy gap between supply and demand is growing and lack of consciousness of environmental protection at the beginning of economic development, caused a lot of pressure on the environment. At this stage, the development of Shandong economy mainly relies on investment and industrial economy. Constituted by the three industries can be seen, industry has been the main driver of economic growth. Heavy industry accounting for the province's proportion of the total industry increases year by year, leading to a rapid increase in energy and resources consumption per unit of GDP energy consumption is higher than other coastal provinces and cities, has become the nation's largest energy consumption in Shandong province, such as SO_2 and industrial dust waste emissions also ranked among the top nationwide. Guangdong is greatly influenced by the traditional economy, such as economy relies mainly on the resource consumption. Affected by the low level of interest contradictions, the second industry is given priority to with industrial structure and Labor-intensive industries dominated. From the point of view of energy consumption, the second industry is the mainly energy consumption and its pollution to the environment is large. Thus 3E system shows moderate disorder.

(4). In the second category mild disorder regions, the industrial structure of Beijing, Shanghai, Tianjin and other places is more reasonable. Among them, the second industry output value accounts for larger, less energy intensive industries; the demand for energy is relatively small and the degree of damage to the environment is relatively low, so the 3E system coordination degree is relatively high. Inner Mongolia economy has developed rapidly in recent years, and rich in resources, but low energy efficiency, a large number of inefficient coal-fired equipment, traditional way of coal and pollution control is not enough, leading to the environment become worsening, so the 3E system coordination degree is relatively low. Lack of funds, the deterioration of ecological environment is an important factor restricting the economic development of Gansu province, thus the 3 E system coordination degree of Gansu province is also low level.

(5).In the third category barely coordination regions, Compared with coastal economic developed area, Liaoning, Jilin, Heilongjiang and north-eastern industrial base, under the guidance and the support of national policy, is looking for a new growth point and the breakthrough point, to implement the new system and new mechanism, promote economic development and at the same time pay attention to save energy and protect the environment, as a result, the 3E system coordination degree presents barely coordination.

4 Conclusions

Achieving 3E system coordinated development put forward from the situation of China is a major strategic decision, is to fully implement and carry out the scientific outlook on development, promote the sustainable development ability, and the urgent requirement of building a harmonious society. "Resource-saving and environment-friendly" is the main value orientation of China's economic and social development, is now included in the government decision-making, planning, legislation, management and evaluation of each link, and penetrated into all sorts of government public services and urban construction. Throughout the current traditional industries in many parts of China, the sustainable development ability is not strong, is restricted by the state policies, resources and environment, and cannot better participate in international competition. Therefore, how to solve resource and environmental constraints on economic effects on the basis of not affecting the speed of economic development is related to the success of China's economic transformation. Based on the above background, from better achieving the coordinated development of the 3E system purpose, according to the demands of the development of 3E system coordination model about 3E system coordinated development of related research, combined with the status quo of China's regional coordinated development of 3E system, this article puts forward the new idea to promote the development of 3E system coordination.

Acknowledgement
We thank anonymous referees for helpful comments on this paper. The authors are grateful for financial support from the National Natural Science Foundation of China (71103050); China Postdoctoral Science Foundation (20100480988).

References:

[1] W. Zhou, H. Mi, Systems Dynamics of Future Urbanization and Energy-related CO_2 Emissions in China, *WSEAS Transaction on Systems*, Vol. 8, No. 10, 2009, pp. 1145-1154.

[2] H. J. Yu, X. Y. Li, Y. X. Wang, Pricing Strategy of Ecological Industry Chain Based on Game Theory, *WSEAS Transaction on Systems,* Vol. 7, No. 2, 2008, pp. 71-80.

[3] Akram Avami, Bahare Farahm and pour, Analysis of Environmental Emissions and Greenhouse Gases in Islamic Republic of Iran, *WSEAS Transaction on Environment and Development*, Vol. 4, No. 4,2008, pp.303-312.

[4] Nasser Ayoub, Rafael Batres, Yuji Naka, An Approach to Wicked Problems in Environmental Policy Making, *WSEAS Transaction on Environment and Development*, Vol. 5, No. 3, 2009, pp. 229-239.

[5] Z. Han, Y. Wei, and J. Jiao, On the Cointegration and Causality between Chinese GDP and Energy Consumption, *Systems Engineering,* Vol. 2, No. 12, 2004, pp.17-21.

[6] X. Yan and X. Du, Empirical Study on the Relationship of China's Energy Consumption and Industrial Structure Change, *Asia-Pacific Power and Energy Engineering Conferenc*e (APPEEC), 4918330, 2009.pp. 1-5.

[7] N. Wang, The Energy Development and the Environmental Protection in China, *Fusion Engineering and Design*, Vol. 54, 2001, pp.135-140.

[8] Carla Oliveira, Carlos Henggeler Antunes. A Multiple Objective Model to Deal with Economy-Energy-Environment Interactions. *European Journal of Operational Research*, Vol.153, 2004, pp.370-385.

[9] Nick D. Hanley, Peter G. McGregor, J. Kim Swales, Karen Turner. The Impact of A Stimulus to Energy Efficiency on the Economy and the Environment: A Regional Computable General Equilibrium Analysis, *Renewable Energy*, Vol. 31, 2006, PP.161-171.

[10] X. Su, E. Liang, P. Wang and H. Mu, Gray Relative Analysis of Energy Consumption and Economic Development in China, *Energy for Metall. Indus*., Vol. 26, No. 6, 2007, pp. 8-10.

[11] S. J. Lin, I. J. Lu, and C. Lewis, Grey Relation Performance Correlations among Economics, Energy Use and Carbon Dioxide Emission in Taiwan, *Energy Policy*, Vol. 35, No. 3, 2007, pp. 1948-1955.

[12] Y. Shi, N. Pang and Y. Ding, Environment Effects of Energy Consumption Structure Based on Comprehensive Grey Correlation Degree: from 1998 to 2006 in China, *Asia-Pacific Power and Energy Engineering Conference (APPEEC),*. 4918336, 2009, pp. 1-4.

[13] Lei Shen，Sheng kui Cheng，Aaron James Gunson. Urbanization, Sustainability and the Utilization of Energy and Mineral Resources in China. *Cities*. Vol. 22, No. 4, 2005, pp.287-302.

[14] Carla Oliveira, Carlos Henggeler Antunes. A Multiobjective Multispectral Economy-Energy-Environment Model: Application to Portugal. *Energy*, Vol. 8, No. 36, 2011, pp.2856-2866.

[15] Martin de Jong, Dong Wang & Chang Yu, Exploring the Relevance of the Eco-City Concept in China: The Case of Shenzhen Sino-Dutch Low Carbon City, *Journal of Urban Technology*, Vol. 20, No.1, 2013, pp. 95-113.

[16] Dong Wang, Zhanglan Wu, The Effect of FDI on Host Country's Environmental Pollution Evidence from Chinese Cities. *Advanced Materials Research*, Vol. 2, No. 13, 2012, pp.524-527.

[17] Dong Wang, Zhanglan Wu, Yan Li, The eco-knowledge city theory and its practice in Shenzhen of China. *International Journal of Asian Business and Information Management*. Vol. 3, No. 3, 2012, pp. 42-55.

[18] Filippo Neri. Quantitative Estimation of Market Sentiment: a Discussion of Two Alternatives. *WSEAS Transactions on Systems,* Vol. 11, No. 12, 2012, pp. 691-702.

[19] Ming Zhang, Hailin Mu, Yadong Ning, Yongchen Song. Accounting for Energy-Related CO_2 Emission in China (1991–2006), *Energy Policy* Vol. 37, 2009, pp.767–773.

[20] Kong Yigang, Wang Zhixin, Optimal Power Capturing of Multi-MW Wind Generation System, *WSEAS Transaction on Systems*, Vol. 7, No.3, 2008, pp.125-132.

[21] F. Urban, R. M. J, Benders, H. C, Moll. Modeling Energy Systems for Developing Countries，*Energy Policy*. Vol. 35, 2007, pp. 3473-3482.

[22] Filippo Neri. Learning and Predicting Financial Time Series by Combining Evolutionary Computation and Agent Simulation, *Applications of Evolutionary Computation*,2011, pp. 111-119.