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The development of ecological environment in China based on the system dynamics method from the society, economy and environment perspective

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Abstract

The harmonious development in society, economy and environment are crucial to regional sustained boom. However, the society, economy and environment are not respectively independent, but both mutually promotes one which, or restrict mutually complex to have the long-enduring overall process. The present study is an attempt to investigate the relationship and interaction of society, economy and environment in China based on the data from 2004 to 2013. The principal component analysis (PCA) model was employed to identify the main factors effecting the society, economy and environment subsystems, and SD (system dynamics) method used to carry out dynamic assessment for future state of sustainability from society, economy and environment perspective with future indicator values. Sustainable development in China was divided in the study into three phase from 2004 to 2013 based competitive values of these three subsystems. According to the results of PCA model, China is in third phase, and the economy growth is faster than the environment development, while the social development still maintained a steady and rapid growth, implying that the next step for sustainable development in China should focus on society development, especially the environment development.

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Introduction

Environmental pollution, rapid population growth and energy consumption are having disaster effects on the global climate challenges and human life. People are more concerned than ever with continues disasters and increased health issues in such technologically advanced economy, which arouse people going a step further taking the sustainable development seriously . However, only a slow and limited switch to sustainable development in some developed countries. So many researchers and politicians argue that human need to introspect upon their behaviors and search for an effective development pathway suitable for economic growth and society development (McMichael *et al.,* 2003; Ostrom, 2009). So many studies have been carried out on sustainable development of the social-economic-environmental complex system.

There are three subsystems in a social-economic-environmental complex system including of society subsystem, economy subsystem and environmental subsystem. The society subsystem refers to necessary human resources and infrastructure, while economy subsystem provides fund support and environment subsystem affords the material foundation. There are complicated interactions and relationships among these three subsystems through exchange of substance, energy and information, so it follows that the related studies regarding the social-economic-environmental system should be viewed as complicated issues with all subsystems rather than any single subsystem, impling that these subsystems are not independent, but both mutually promote each other, or restrict mutually complex to have long-enduring overall process (Bogggia *et al.,* 2010). It is generally known that economic analysis is widely used in contemporary national policy making. However, mainstream economics used for regional or national policy making often focuse on the economy growth rather than the environmental and social dimensions of sustainable development. The whole society must focus its attention on sustainable development of social-economic-environmental complex system including growth of wealth, as well as, comprehensive progress of social, economic, cultural, political and ecological environment (Wu, 2013).

There have been increasing researches focusing on the empirical studies regarding integration of environment, economic growth theories and relationship among series of social, economic and environmental factors (Grossman *et al.,* 1995), which aims to investigate the relationship between economic development and environmental pollution (Henri *et al.,* 2004; Manash *et al.,* 2009; Partha *et al.,* 2004; Luisito *et al.,* 2005; Li *et al.,* 2014).

A several reports in terms of modeling and analyzing in social and economic aspects are available (Ostrom, 2009; Ma *et al.,* 2008; Brock *et al.,* 2010).Grossman single out three main channels through which economic growth may affect environmental quality including scale effects, composition effects and technique effects (Grossman, 1995). Some researchers argue that policy has an important role in relationship of economy growth and environmental quality (Torras *et al.,* 1998). Relationship between the level of per capita income and environment quality in Italian regions was investigated based on the prescription of Environmental Kuznets Curve (EKC), taking into account the contribution of agriculture and rural areas (Carillo *et al.,* 1998). Some studies reveal that policy has an important role in determining the emergence of second part of EKC (Seung *et al.,* 2014). Tan and Lu (2015) analyzed that interaction and relation among society, economy and environment subsystem, provide a framework to conceptualize the influence among their changes and simulates future scenarios in the Bohai Rim region in China. A combined model of system dynamics and geographic information system is employed to explicitly understand the synergic interaction and feedback among variety of influencing factors, and assess sustainability of economy-resource-environment system in China (Guan *et al.,* 2011). However, most of these researches select some reasonable indicators to reflect each subsystem and establish static models for assessments or integration, which is not always practical or possible because of the complexity and dynamics of social-economic-environmental system.

Principal component analysis (PCA) is a statistical method commonly used and well-studied data analysis approach which aims identifing some linear trends and simple patterns in group of samples (Hosseini *et al.,* 2011; Douka *et al.,* 2012), such as sustainable development indicators (Abou-Ali *et al.,* 2013). This methodology can convert multiple indexes to few synthesis and irrelevant indexes from high dimension to low dimension effectively within a given framework, and is provides us with meaningful access to the overall picture of national or local development (Seema *et al.,* 2006).

System dynamics (SD) is an effective method to predict the dynamic results of interactions and analyze the effect of different policies (Alexandra *et al.,* 1996; Guo *et al.,* 2001; Evrendilek *et al.,* 2001; Sun *et al.,* 2002; Bald *et al.,* 2006; Berling-Wolff *et al.,* 2004; Arquitt *et al.,* 2008). It is widely used to study the economy, project management and supply chain management since beginning of 1990s. Recently, several studies have focused on sustainable management based on SD model (Costanza *et al.,* 1998; John, 1998; Mohammed *et al.,* 2001; Barredo *et al.,* 2003; Tian *et al.,* 2005; He *et al.,* 2005; He *et al.,* 2006; Li *et al.,* 2006; Sufian *et al.,* 2007). Güneralpa and Seto (2008) identified some environmental challenges during urbanization based on simulation model of dynamic interaction in social-economic-environmental system. Dyson and Chang (2008) forecasted municipal solid-waste generation in a fast growing urban region based on SD model.

Most of the relating from researches have focused on evaluation of the sustainability, identify typical indicators in order to make the assessments (Dong *et al.,* 2003; Steven *et al.,* 2003; Guan *et al.,* 2009; Yan *et al.,* 2009). However, there are limited researches focused on carrying out dynamic assessment for future state of sustainability from the society, economy and environment perspective with future indicator values. In light of the above, the present study was carried out to identify the main factors affecting society, economy and environment subsystems, and investigate the relationship and interaction of these three subsystems in China, as well as, carry out dynamic assessment for future state of sustainability from society, economy and environment perspective with future indicator values.

Materials and Methods

The indicators of social, economic and environmental subsystems in China were identified, based on the research of Tan and Lu (Tan and Lu, 2015) as shown in Table 1. According to their research, there are 33 indicators for social-economic-environment system which are as follows: C1–C12 reflects the current social situation from people's standard of living (C1-C5), social equity (C6) and society development level (C7-C12); C13–C22 outlines the scale or size of economies, economic structure and economic benefits in the economic subsystem; C23-C33 consider resources, ecological index, environment pollution and environmental pollution state in the environmental subsystem.

Then the PCA model is applied by the following equations: Let $n \times p$ matrix represents n sets of data, and p variables in every set in order to identify linear orthogonal transformation matrix,

$$X = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} \dots x_{1p} \\ x_{21} & x_{22} \dots x_{2p} \\ \vdots & \vdots \quad \vdots \quad \vdots \\ x_{n1} & x_{n2} \dots x_{np} \end{bmatrix}$$

Table 1 : The indicators of the social, economic and environmental subsystems in China

Subsystems	Names of indicators
Social subsystem	C1Unemployment rate
	C2Engel coefficient in whole society
	C3Adult literacy rate
	C4Per capita disposable income in whole society
	C5Natural population growth rate
	C6Rate of per capita income of peasant and urban residents
	C7Urbanization rate
	C8Per capita living space of rural residents
	C9Hospital beds per ten thousand people
	C10Number of students in colleges and universities
	C11Per capita throughput of post and telecommunications
	C12 Per capita highway mileage
Economic subsystem	C13Per capita GDPC
	14Economy density
	C15Per capita fiscal revenue
	C16Per capita exports
	C17Per capita fixed asset investment
	C18Per capita retail sale of consumer goods
	C19Proportion of primary industry output
	C20Proportion of tertiary industry output
	C21Average wages of staff and workers
	C22Social labor productivity
Environmental subsystem	C23Per capita water resource
	C24GDP energy consumption per ten thousand yuan
	C25Per capita forest stocking volume
	C26Rate of nature reserves to land area
	C27Per capita emissions of SO2
	C28Per capita emissions of COD
	C29Per capita emissions of solid wastes
	C30Rate of environment protection investment to GDP
	C31Industrial solid wastes comprehensive utilization ratio
	C32Per capita emissions of Industrial wastewater
	C33Per capita emissions of Smoke dust

Let $[[x_{11} x_{12} \dots x_{1p}]^T]$ represent data set of p variables, and Y is vector of m principal components (mp£) through linear transformation:

$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} = \begin{bmatrix} l_{11} & l_{12} \dots l_{1p} \\ l_{21} & l_{22} \dots l_{2p} \\ \vdots & \vdots \quad \vdots \quad \vdots \\ l_{n1} & l_{n2} \dots l_{np} \end{bmatrix}^T \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} = Lx$$

Where, L is projection matrix, and lpn represents loading of the principal component representing weight of p^{th} variable of n^{th} principal component. In the next step, correlation coefficient matrix of X was computed to identify correlation among the variables. Pearson correlation coefficient was used in this research and formulated as following:

Table 2 : The component score coefficient matrix of PCA

Subsystems	Serial No.	Component 1	Component 2
Social subsystem	C1	-0.096	0.034
	C2	0.146	0.124
	C3	-0.105	0.138
	C4	0.104	0.148
	C5	-0.107	0.111
	C6	0.05	0.188
	C7	0.109	0.056
	C8	0.108	0.091
	C9	0.099	0.207
	C10	0.109	0.012
	C11	0.084	0.083
	C12	0.103	0.001
Economic subsystem	C13	0.114	-0.033
	C14	0.114	-0.029
	C15	0.115	-0.009
	C16	0.111	-0.047
	C17	0.114	-0.014
	C18	0.115	0.001
	C19	0.038	0.932
	C20	0.097	-0.14
	C21	0.115	-0.026
	C22	0.113	-0.067
Environmental subsystem	C23	-0.136	0.094
	C24	0.144	0.033
	C25	-0.137	0.02
	C26	-0.117	0.047
	C27	0.11	-0.177
	C28	0.156	0.428
	C29	0.133	0.216
	C30	0.129	0.024
	C31	0.125	-0.139
	C32	0.141	0.126
	C33	0.139	0.143

$$R = \begin{bmatrix} r_{11}\ r_{12} \ldots r_{1p} \\ r_{21}\ r_{22} \ldots r_{2p} \\ \vdots \quad \vdots \quad \vdots \quad \vdots \\ r_{n12} r_n \ \ldots r_{np} \end{bmatrix}$$

Where, r_{ij} represents correlation coefficient between x_i and x_j, and is formulated as

$$r_{ij} = \frac{\sum_{k=1}^{n}(x_{ki}-\bar{x}_i)(x_{kj}-\bar{x}_j)}{\sqrt{\sum_{k=1}^{n}(x_{ki}-\bar{x}_i)^2 \sum_{k=1}^{n}(x_{kj}-\bar{x}_j)^2}}, \bar{x}_i = \frac{1}{n}\sum_{k=1}^{n} x_{ki}.$$

Let *R* represent variance of variables. Then total variance is invariant for both original data and new variables. The variance distribution of principal components in the new coordinate system symmetric matrix *R* was identified based on the eigenvalues and their corresponding eigenvectors. According to the quantities, the eigenvalues of R can be sorted as $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_p \geq 0$ based on the value of principal components, where e_1, e_2, . . ., e_p represent corresponding eigenvectors accordingly. The individual contribution rate of i^{th} principal component C^i is defined as

$$C_i = \frac{\lambda_i}{\sum_{k=1}^{p}\lambda_k},$$

and the accumulative contribution rate of first m principal components was formulated as :

$$D_i = \frac{\sum_{k=1}^{m}\lambda_k}{\sum_{k=1}^{p}\lambda_k}, m = 1,2,...., p.$$

The contribution rate of i^{th} principal component represents significance of data sets. The accumulative contribution rate of *m* principal components reflects integrity of information for characterizing the data sets. Therefore, the purpose of selecting the principal components was to reserve information of data sets as much as possible, as well as, achieve dimensionality reduction of the data sets concurrently.

Let l_{jk} represents contribution weight for k^{th} original variable to j^{th} principal component. l_{jk} was calculated based on the corresponding eigenvalue and eigenvector:

$$l_{jk} = \sqrt{\lambda_j} e_{jk},$$

Where, e_{jk} is the eigen vector e_j of the k^{th} component of e_j. The score of k^{th} principal component of j^{th} data set was as,

$$y_{jk} = l_{k1}x_{j1} + l_{k2}x_{j2} + ... + l_{kp}x_{jp}$$

and the score matrix of principal components is given as below :

$$\hat{Y} = \begin{bmatrix} y_{11} & y_{12} & \cdots & y_{1m} \\ y_{21} & y_{22} & \cdots & y_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ y_{n1} & y_{n2} & \cdots & y_{nm} \end{bmatrix}$$

The component socre coefficient matrix is shown in Table 2.

Results and Discussion

The component score coefficient matrix of PCA is shown in Table 2 and the scatter diagram of component score coefficient matrix of PCA is shown in Fig 1. Table 2 shows that two principal components in each subsystems were identified, and transformation from the original variables to principal components can be seen in Fig.1.

The first principal component in society subsystem including of original index C1, C3 and C5, which are all indexes in terms of intrinsic properties of population, is called "direct social index". And the second principal component which can be regarded as component related to population from the aspect of career, life, health and service is called "indirect social index". In the economic subsystem, proportion of tertiary industry output is the first principal component and is called "Industrialization index", while rest of the indexes in the economic subsystem compose of second principal component, and is called as "traditional economic index". In the environmental subsystem, the first principal component include C23, C25 and C26, which are all index related to resource, and called as "resource index", and other indexes are related with the environmental protection, so it was called as second principal component "environmental protection index".

The results of PCA can be seen more clearly in Fig 2, and the sustainable development in China from 2004 to 2013 was divided into three phase. The first phase was from 2004 to 2007. The sustainable development level in this phase was relatively slow, and the development of economy fell behind the social development and environment development. The second phase from 2008 to 2010 was called "bottleneck phase" because of slow development of all the subsystems and was mainly affected by the global financial crisis. The third phase was from 2011 to 2013, and the economy growth was faster than the environment development, while social development still maintained a steady and rapid growth.

The competitive values of these three subsystems in China can be derived by PCA model, and from the results of

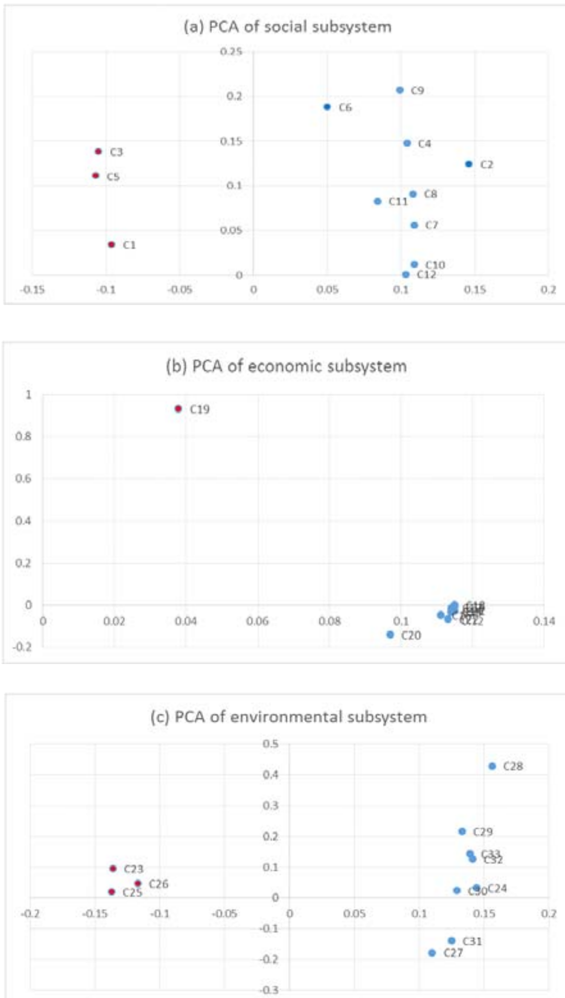

Fig. 1 : The scatter diagram of component score coefficient matrix of PCA

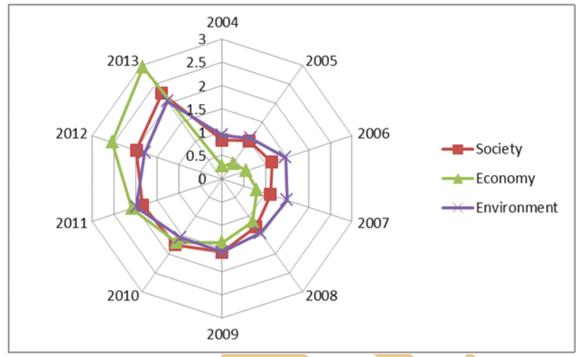

Fig. 2 : Comparison of three subsystems development level of China in different years

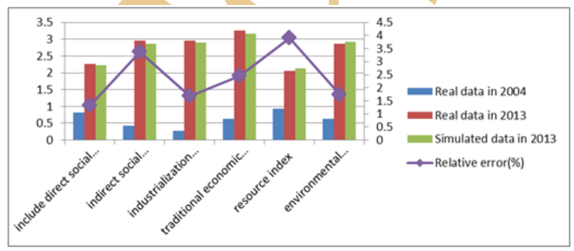

Fig. 3 : Verification result of historical data with the established SD model

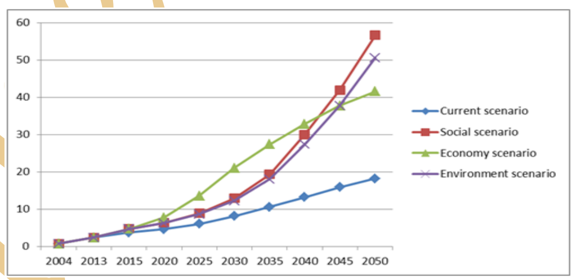

Fig. 4 : Simulated results of economy-social-environment system under different scenarios

PCA, it can be seen that sustainability in China increased from 2004 to 2013 (Table 3), especially for the economy subsystems (from 0.27 to 2.96). However, development of the society or environment is not as fast as economy, implying that the next step for sustainable development in China should focus on society development, especially the environment development.

There were three subsystems in social-economic-environmental complex system including the society subsystem, economy subsystem and environmental subsystem. These subsystems were interrelated and mutually affected each other. The performance of one subsystem not only depends on internal structure, but also the external environment which was represented by the outputs of other subsystems. AHP was employed to identify the weights of the indexes. Twenty experts were selected to decide the AHP weight of each principal component, and the results passed the consistency test. The weight for each subsystem and whole system were derived based on the linear weighted method as shown in Table 4.

Six principal components were identified as validation. In order to validate the SD model, real data in 2004 was compared, as well as, simulated value in 2013 with the real data in 2013 respectively. The testing result are shown in Fig. 3. It can be seen from Fig. 3 that the simulated values of variables in 2013 were close to real values in 2013. The simulated values of variables in 2013 was as low as ±5% error comparing with real values in 2013, which indicated validity of this model. So SD model is reliable to elucidate the causal feedback relationship, and predict the dynamic change

Table 3 : Results of compositive value of three subsystems in China

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Society	0.82	0.99	1.15	1.12	1.27	1.58	1.75	1.84	1.98	2.26
Economy	0.27	0.41	0.56	0.80	1.14	1.37	1.70	2.09	2.54	2.96
Environment	0.93	1.07	1.46	1.49	1.44	1.58	1.56	1.98	1.78	2.05

Table 4 : Weight of assessment indexes of social-economic-environmental system

System	Subsystem	Weight	Principal component	Weight
Social-economic-environmentalsystem	Society system	0.3712	direct social population index	0.4179
			indirect social population index	0.5821
	Economy system	0.3024	industrialization index	0.3716
			traditional economic index	0.6284
	Environment system	0.3264	resource index	0.4957
			environmental protection index	0.5043

Table 5 : Parameter setting of different scenario simulation

Parameter	Current scenario	Social scenario	Economy scenario	Environment scenario
Elastic coefficient of natural population growth rate	0.2	0.25	0.2	0.2
Elastic coefficient of social labor productivity	0.1	0.1	0.2	0.1
Elastic coefficient of Rate of environment protection investment to GDP	0.3	0.3	0.3	0.4

of social-economic-environmental system in China.

Four scenarios setting are shown in Table 5. Different from the scenarios setting (current scenario, environment scenario, resource scenario and technology scenario) in the research of Guna *et al.* (2011), four scenarios including current scenario, social scenario, economy scenario and environmental scenario is presented in the study. Simulated results of future in economy-social-environment system under different scenarios is shown in Fig. 5.

Fig. 4 shows that growth of final evaluation value was relatively slow in the economy-social-environment system under the current scenario, and this finding is similar to the previous researches (Guan *et al.,* 2011; Gibbs *et al.,* 1996; Güneralpa and Seto, 2008) However, the present study shows that the growth trend of final evaluation value in social scenario and environment scenario were similar, while growth of final evaluation value of economy scenario was relatively fast in the early period from 2015-2040 (before 2040). So medium-term promoting effect was more obvious for the economy, but in the long run, the effect of social and the environment is more apparent.

Conclusions : According to the results of the PCA model, six principal components are identified for the sustainable development in China. The next step should focused on the society development, especially the environment development. The suggestions for the future sustainable development for China are: (1) maintain the reasonable economic growth rate, (2) adjust the industrial structure by the local authorities (Gibbs, et al., 1996; Carillo and Maietta,2014) (3) increase the environmental investment, and (4) promote clean production.

The PCA-SD model can be applied in the analysis of other systems, such as population, resource or other systems, which can also be the supplement for future research.

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