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ENGINEERING MANAGEMENT THEORIES AND METHODOLOGIES

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An Evaluation Model for the Coordinated Development of a Circular Economy in China and Its Application to Energy-intensive Industries

Abstract Energy-intensive industries (EIIs) are fundamental to the industrial development of China and are also the key industries of a circular economic infrastructure. It is worth paying attention to the coordinated development of a circular economy using EIIs due to the present interrelationship among EIIs. It is related to the optimization and comprehensive performance improvement of a circular economy. Based on the perspective of order parameter, this study uses economic and environmental subsystems to establish an evaluation model that examines the coordinated development of a circular economy within six main EIIs and an EII cluster from 2006 to 2011 in China. The result shows that the level of coordinated development in a circular economy among six EIIs differs and the level of coordinated development of circular economy among the EII cluster lags behind that of each EII examined. It also shows that the outside coordinated degree of EIIs is lower than the inside coordinated degree of each EII.

Keywords: order parameter, coordinated degree evaluation, energy-intensive industry, circular economy

1 Introduction

Energy-intensive industries (EIIs) are fundamental to industrial and economic development. They have made a huge contribution to economic growth. At the same time, the EII development is followed by massive energy consumption and serious environmental pollution, leading to external diseconomies. EIIs are important in establishing a circular economy. Presently, a circular economy of EIIs has been developed gradually in many regions in China. However, problems in the lack of coordination and imbalanced development have become more apparent.

EII clusters refer to industries, or enterprise groups, having a close relationship when it comes to mineral resource supply and demand, which may form a kind of industrial cluster through a core enterprise supply chain (Zheng & Chen, 2009). The concept of coordinated development of a circular economy of EIIs was proposed in 2010. It studied how waste was treated and reused in a larger industrial network space to improve the utilization efficiency of natural resources and energy.

From a loftier perspective, modern firm, or industry, the competition of modern has entered an era of "network competition". A firm, or an industry, no longer acts alone and supply chains no longer simply compete with other supply chains. The one that can organize, and coordinate, relationships with other members better in a network organization, will become the real winner (Jeffrey, 2000; Christopher, 2000).

Realizing the coordinated development of a circular economy (CDCE) is complicated. It requires a comprehensive evaluation on the level of coordination in a circular economy consisting of EIIs and EII clusters. The evaluation will help find out the uncoordinated situation among different EIIs. It will help provide a scientific basis for improving and systematizing the process of establishing a circular economy in order to get the best economic, environmental and social performance. The dominant principle of synergetic theory requires capturing order parameters during a process of system evolution. This study uses synergetic theory as a guide and selects order parameters that affect the CDCE. It establishes an evaluation model for analyzing the CDCE levels inside and outside EIIs, and provides a reference for facilitating a balanced development of the circular economy in EIIs and in industrial parks.

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2 Concept and literature review

2.1 Literature review on the CDCE of EIIs

EIIs are key fields in the construction and development of a circular economy domestically and abroad. The concept of resource-based industrial clusters or EIIs is a product of a Chinese industry cluster study while the 3R (reduce, reuse, recycle) principle comes from the 3R Manufacturing of DuPont Chemical Company of the United States (US). Cited as the most successful instance of circular economy, Denmark Kalundborg Eco-industrial Park is a coordinated development model of EII cluster based on the eco-industrial chain without waste disposal. The Park is composed of the core firms of a power plant, a refinery, a pharmaceutical factory and a gypsum plate plant. Eco-industrial parks, such as Brownsville, Chattanooga and Choctaw in the US, Fort Saskatchewan, Cornwall and Becancour in Canada, and Kokubo in Japan, are the models for coordinated development of chemical, metallurgical and building materials. Many ecological industrial national and provincial pilot parks in China focus on EIIs such as iron and steel, aluminum, phosphorus chemical and coal chemical industry to carry out the construction of circular economy and have realized a certain degree of coordinated development.

The CDCE of EIIs is not limited to eco-industrial parks. There are many restrictions on the planning and construction of eco-industrial parks, which are still in the pilot phase and involve huge investments. Eco-industrial park construction is not an end in itself, but a means to explore sustainable development for regional economies and to provide an example for the CDCE of regional EIIs. It is necessary to consider the strategic development of regional EIIs using a case in Yunnan Province (Zheng, Chen, W., & Chen, Z., 2008).

There are few Western studies of the CDCE of EIIs. Some discussed the issue from the perspective of industrial symbiosis, an idea similar to that of the eco-industrial parks. Van Berkel (2006), Van Beers and Bossilkov et al. (2007) and Van Beers and Corder et al. (2007) used Australia, a resource-rich country, to discuss the concept and the significance of mining industrial symbiosis, regional resource coordination and regional development coordination. Türkay et al. (2004) discussed modeling and quantitative analysis in coordinating enterprises in the chemical industry.

Some representative Chinese studies discussed the mode of cross industry chain development with an EII as the main focus and demonstrated its superiority. Bao et al. (2007) induced the circular economy pattern of iron and steel industry to build up several eco-industrial chains based on integrating cement, power, chemistry and a polymer processing plant. Sun et al. (2007), through a simulation of the circular economic development of a coal group, argued that coal firms may lessen operational risk and increase by 30% of the profit after developing the eco-industrial chains of coal electricity, coal aluminum, coal chemical industry and coal building materials. J. L. Zhang (2012) proposed a low carbon industrial chain mode for the nonferrous metal industry. J. B. Zhang (2012) considered the S growth model and sustainable development path of resource type industrial cluster under the constraints of resource and environment. Zheng et al. (2013) studied the CDCE mode of EIIs based on the building material industry.

After a review of existing literature, the CDCE mode of EIIs can be summarized as follows: ① heat and power cogeneration (power generation using waste heat from high temperature burning or smelting); ② coal, electricity, building materials co-production mode; ③ coal, electricity, chemical industry integration mode; ④ metallurgy, building materials co-production mode; ⑤ chemical industry, building materials co-production mode; ⑥ metallurgy, chemical industry co-production mode (Zheng & Chen, 2010).

The industrial chains of a circular economy among EIIs are increasing becoming explicit now. The mechanism to build and maintain this kind of industrial chain is still in an initial stage. The mechanism comes mainly from the requirement of building up industrial chains of circular economy inside a firm group, and the coordinated mechanism to build up the eco-industrial chain and network in an industrial cluster has not yet formed. The circular economy construction of EIIs is in the situation of lacking coordination and uneven development, and eco-coordinated technology lags behind. The hypothesis of this study is that, the coordinated degree of circular economy among EIIs (outside coordinated degree) is lower than the inside coordinated degree in each EII. This hypothesis will be verified empirically afterwards.

2.2 Literature review of the order parameter principle and its application to coordinated development and evaluation

The basic idea behind synergetics is that when a complex and open system is unstable, the dominant inside parameters (i.e. order parameters) and some outside parameters will affect its subsystems to produce a synergistic, or coordinated, effect through nonlinear interaction. The old systematic structure will change in terms of time, space, property, or function. A new ordered structure will arise. The dominant principle is the basic principle of synergetics. The main idea is that each element affects the system differently. Elements can be divided into fast and slow variables. A fast variable attenuates quickly and does not play a leading evolutionary role in the system. Some parameters attenuate very slowly but dominate and determine the macro order structure, status and order level for the system, and are called slow, or order, parameters.

Recently, synergetic theory and order parameter principles are widely used in researching coordinated development and evaluating industrial systems, industrial cluster systems and regional systems in the following way.

(1) Order parameter identification and coordinated evaluation of an industry, a province, a city, or a special system. Guo et al. (2005) built an industrial ecological system evolution equation using the Haken Model and empirically analyzed it using 21 provinces and cities in China. The result demonstrated that environmental protection productivity, which reflects environmental scientific and technological progress, is the order parameter for industrial ecological system evolution. Cai et al. (2007) examined the physical processes and self-organization mechanisms when a regional enterprise community evolved into an industrial cluster, and argued that the leading regional industry was the order parameter for the system and played a dominant leadership role. Sun et al. (2009) argued that intellectual property advantages were the order parameters for the innovation system of an industrial cluster. Klodt (2000) studied the order parameters and their changes in a logistics system, the mechanism of a logistics synergetic system, and checked the macro method of a coordinated system. Chen et al. (2010) established a compound index system of order parameters for energy, economy and environment, built a model to evaluate the coordinated degree of this system, and made an empirical analysis with an example in Shandong Province. Li et al. (2012) established an evaluation index system of order parameters for industry, scientific research and higher education, building a coordinated evaluation model of industry-university-research (IUR) innovation system, while making an empirical analysis for a five-city group consisting of Beijing, Shanghai, Tianjin, Chongqing and Xi'an.

(2) Order parameter identification, and coordinated, or collaborated, degree evaluation between industries, or between an industry and an area. Anbanandam et al. (2011) built a model to evaluate the degree of collaboration between the retail industry and the manufacturing industry in India. Zhong et al. (2011) selected five order parameters to reflect the status of logistic development in a port and six order parameters to reflect the economic development of a city. They built a model to evaluate the degree of coordination between both parts and made an empirical analysis using Dalian. Zhao (2011) established an index system of order parameter for the manufacturing industry and third party logistic industry from aspects of a running economy, profit capability and industrial work. She built a model to evaluate the degree of coordination between both industries and made an empirical analysis on the degree of coordination between two industries in China. J. Zhang (2012) identified seven order parameters in an automobile industry cluster and regional logistic, building a model to evaluate the degree of coordination between both industries, and making an empirical analysis using, as an example, Guangzhou City. Tang et al. (2012) selected nine indicators of an economic system as order parameters, analyzed the degree of order between resource reproduction and equipment manufacturing development, calculated the coordination coefficient, built a coordinated degree model, and established a referring standard for coordinated development.

In sum, there are no rules about selecting and judging the order of parameters. An index system may be built to evaluate the coordinated degree of a compound system. An order parameter for the evolution of an industrial system is selected and verified using a Haken Model, and in that case, the order parameter obtained is usually a single indicator. There is little written on how to select order parameters or the coordinated evaluation of a circular industrial economy development. To fill the research gap, this paper focuses on selecting order parameters in the circular economic development of EIIs, the establishment and application of evaluation model for CDCE.

3 Establishing an evaluation index system for CDCE of EIIs using order parameters

3.1 Selection principles of order parameters and establishing an index system

(1) Combining science and practicability. Based on the basic characteristics of an EII and circular economy theory, the order parameter indicators selected should be brief and succinct. The difficulty and reliability of the data acquired are to be considered.

(2) Combining system and hierarchy. The index system should reflect structural characteristics and the hierarchical structure of the EII circular economy system.

(3) Combining commonality and key points. The index system should reflect EII commonalities to coordinate the comprehensive performance objectives of circular economic, highlight the key points, and be concise.

3.2 Establishing an evaluation index system for EII CDCE using order parameters

There are many state variables affecting an EII CDCE. They are divided into two subsystems: the economic and the environmental. EII coordination is essentially the co-evolution of the economic subsystem with the environmental subsystem. According to these principles, based on the commonality in EII circular economic construction, the order parameter index system is established to reflect and evaluate the coordination levels of EII CDCE. This is shown in Table 1. In Table 1, the index system is composed of relative indicators, considering the relative indicator showing more characteristics of order parameter.

Table 1

Evaluation Index Systems for EII CDCE Based on Order Parameters

Subsystem	State layer	Indicator layer
Economic subsystem	Development level	Total industrial output value accounted for the proportion of gross domestic product (GDP)
		Ratio of profit to cost
	Development potential	Annual growth rate of gross industrial output value
		Technology investment accounted for the proportion of industrial output value
Environmental subsystem	Resource consumption	Reduction rate of water consumption per million yuan of industrial output value
		Reduction rate of comprehensive energy consumption per million yuan of industrial output value
	Resource reuse	Comprehensive utilization rate of industrial solid waste
		The recycling rate of industrial water
	Waste emission	Emission reduction rate of industrial solid waste
		Emission reduction rate of industrial water
		Emission reduction rate of industrial gas SO_2

4 EII CDCE evaluation models

4.1 Evaluation idea on the CDCE of EIIs

An EII evaluation idea for CDCE is shown in *Figure 1*. An EII system is composed of EII subsystems which have an industrial chain relationship. The evaluation index system is composed of the economic and environmental subsystems. There are three evaluation layers here. The first layer is an evaluation of the coordination of the economic subsystem and environmental subsystem inside each EII and the EII clusters. The second is an evaluation of the coordination between the economic and environmental subsystems for each EII. The third is an evaluation of the coordination between EIIs–called the coordinated degree of EIIs. The evaluation model of CDCE is based on the ordered model.

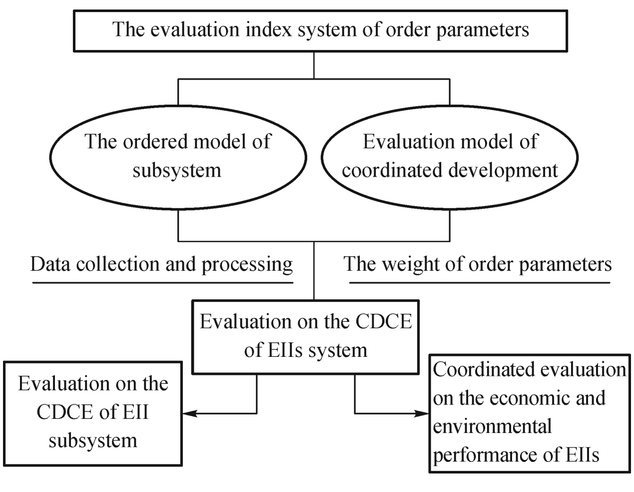

Figure 1. Evaluation model of EII CDCE.

4.2 Analysis of the subsystem order

Set the subsystems of the CDCE of EIIs as S_i, $i \in [1,2]$, the order parameter indicators of a subsystem as $x_i = (x_{i1}, x_{i2}, ..., x_{in})$, in it, $\alpha_{ij} \leqslant x_{ij} \leqslant \beta_{ij}, j \in [1, n]$, α_{ij} and β_{ij} are the upper and lower limit of the indicators at the stable critical point of a system. According to the synergetic theory, there are two parameter ordering effects on systemic order degree. One is a positive effect which means that the order degree of a system increases as an order parameter increases. The other is negative which means the order degree decreases as an order parameter increases. So the contribution of the order parameter x_{ij} to the order degree of the subsystem S_i is defined as:

$$W_i(x_{ij}) = \begin{cases} \dfrac{x_{ij}-\alpha_{ij}}{\beta_{ij}-\alpha_{ij}}, j \in [1,m] & \text{Positive effect} \\ \dfrac{\alpha_{ij}-x_{ij}}{\beta_{ij}-\alpha_{ij}}, j \in [m+1,n] & \text{Negative effect} \end{cases} \tag{1}$$

As seen from equation (1), $W_i(x_{ij}) \in [0,1]$, if the value of $W_i(x_{ij})$ is larger, the contribution of x_{ij} to the ordered evolution of the subsystem will be greater. The total contribution of all order parameters x_i of a subsystem S_i to the ordered evolution is expressed in equation (2).

$$W(S_i) = \sum_{j=1}^{n} \lambda_j W_i(x_{ij}), \ \lambda_j \geqslant 0, \ \sum_{j=1}^{n} \lambda_j = 1 \tag{2}$$

Where λ_j is a composite weight; $W(S_i)$ is the order degree of subsystem S_i, $W_i(x_{ij}) \in [0,1]$. If the value of $W_i(x_{ij})$ is larger, the contribution of x_{ij} to S_i is greater then, the ordered evolution of subsystem S_i will be better.

4.3 Determining the composite weight of an order parameter indicator

The composite weight λ_j is used here as in equation (3), where $\lambda_j^{(a)}$ is the weight through the expert assignment method, $\lambda_j^{(b)}$ is the weight through the entropy method, $\alpha+\beta=1$, j is the number of order parameter indicators in a subsystem, k is the number of time serial of each indicator.

$$\lambda_j = \alpha\lambda_j^{(a)} + \beta\lambda_j^{(b)} \tag{3}$$

$$\lambda_j^{(b)} = H_j/\sum_{j=1}^{n} H_j,\ H_j = 1-E_j,$$

$$E_j = \sum_{k=1}^{N} E_{jk} = \sum_{k=1}^{N}\left(-\frac{1}{\ln\ n}P_{jk}\ln P_{jk}\right), P_{jk} = X_{jk}/\sum_{k=1}^{N} X_{jk},$$

$$X_{jk} = \frac{x_{jk}-\overline{x}_{jk}}{\overline{x}_{jk}}.$$

4.4 Coordination evaluation model

Coordination refers to the consistency between elements, or subsystems, of a system. It may be evaluated through coordinated degree. After consulting the literature on coordinated degree models (Tang & Li, 2012; Xu, H., Xu, J., & Kang, 2003), the coordinated degree model below is provided in order to evaluate CDCE levels between the economic and environmental subsystems in an EII or between EIIs in an EII cluster in constructing a circular economy.

Suppose at the initial time t_0, the order degree of a system is $w_i^0(e_i)$; when at the time t_1, the order degree of the system is $w_i^1(e_i)$, then the coordinated degree is expressed as shown in equation (4).

$$U(t) = \delta\sqrt{\sum_{i=1}^{2}\left[\left|w_i^1(x_i)-w_i^0(x_i)\right|\right]} \tag{4}$$

Where i refers to economic system or environmental system; t refers to time serial; $\delta = \begin{cases} 1,\ w_i^1(e_i)-w_i^0(e_i)\geqslant 0 \\ -1,\ \text{otherwise} \end{cases}$; $U\in[-1,1]$, the larger value means the higher coordinated degree. A system's coordinated degree U is determined by the order degree W of subsystems.

5 Application of the CDCE evaluation model

EIIs include many industries. Six main EIIs, in an eco-industrial chain, are chosen for the application of the CDCE evaluation model with two purposes. One is to verify the reasonableness and feasibility of the model. The other is to carry out a comparative analysis on the EII and EII cluster order degree and coordinated degree.

The data of all order parameter indicators in the six EIIs are calculated based on the fundamental or original data, which come from the *Chinese Statistical Year Book*, the *Chinese Environmental Statistics Year Book*, and the *Chinese Energy Statistics Year Book*. On determining the composite weight of each state variable, the coefficient α and β is set at 0.5, respectively.

5.1 Analysis and evaluation on the CDCE level of each industrial subsystem and the EII system

According to the above models, the composite weight of the order parameter indicators and the order degree of each industrial subsystem are calculated as shown in Table 2 and Table 3, respectively. The coordinated degree results for 2006–2011 are calculated in Table 4. The curves of the coordinated degree evolution of each industrial subsystem and the entire EII cluster for 2006–2011 are shown in *Figure 2(a)* and *Figure 2(b)*. All the coordinated degree values rise from *Figure 2(b)* except for a decline falling in 2007–2008 and 2008–2009. The explanation is that a financial crisis broke out in the late 2008 slowing the Chinese economy. The measures such as investing four thousand billion yuan into steel and automobile industries in 2009 had led to an economic increase, while the energy utilization efficiency decreased. The coordinated degree of metallurgy is the highest. There is little difference in the other five industries, and the coordinated degree of thermal power, petroleum and nonferrous in some years was lower than the average of the six industries.

5.2 Analysis and evaluation on the CDCE level of the economic and environmental subsystems and the EII system

The EII CDCE order degrees and coordinated degree levels are calculated using the economic and environmental subsystems which are shown in Table 5, Table 6 and *Figure 3*. We see: ① EII order degrees of economic and environmental subsystems have all risen since 2006; ② most order degrees of environmental subsystem are lower than that of economic subsystem, which is consistent with the reality of the situation; ③ the range of order degrees for the two subsystems is 0.35–0.75, which illustrates that the hard constraint of energy saving and emission reduction called for in the Chinese "Eleventh Five-Year Plan" has produced a positive effect both on the economic and environmental performance, while it points out there are still some spaces to improve; ④ from *Figure 2*, the overall coordinated degree of EII cluster is lower than the average of the six EIIs, which illustrates that the industrial outside coordinated degree is lower than the

Table 2

The Weight of Circular Economic Order Parameter Indicators of Six EIIs

Objective layer	Indicator layer	Composite weight ($\alpha = \beta = 0.5$)					
		Metallurgy	Chemical	Thermal power	Building material	Petroleum	Nonferrous
Economy	Total industrial output value accounted for the proportion of GDP	0.08805	0.09377	0.09301	0.08694	0.09557	0.09187
	Ratio of profit to cost	0.09386	0.08374	0.08733	0.08422	0.08090	0.09538
	Annual growth rate of gross industrial output value	0.08784	0.09016	0.08683	0.08632	0.09468	0.08487
	Technology investment accounted for the proportion of industrial output value	0.08790	0.08777	0.09251	0.08941	0.09476	0.09321
Environment	Reduction rate of water consumption per million yuan of industrial output value	0.09542	0.08994	0.08712	0.08960	0.08725	0.08959
	Reduction rate of comprehensive energy consumption per million yuan of industrial output value	0.08555	0.09002	0.09482	0.09089	0.09008	0.10141
	Comprehensive utilization rate of industrial solid waste	0.09648	0.08841	0.08928	0.10193	0.08843	0.08725
	The recycling rate of industrial water	0.09159	0.09612	0.08839	0.09531	0.09059	0.08704
	Emission reduction rate of industrial solid waste	0.08683	0.09443	0.08480	0.10243	0.09292	0.09879
	Emission reduction rate of industrial water	0.09397	0.10032	0.09320	0.09159	0.08477	0.08397
	Emission reduction rate of industrial gas SO_2	0.09251	0.08532	0.10272	0.08136	0.10004	0.08662

Table 3

The Order Degree of Each EII Subsystem in 2006–2011

Industry	Subsystem	2006	2007	2008	2009	2010	2011
Metallurgy	Economic subsystem	0.49079	0.57972	0.59662	0.65938	0.68832	0.73109
	Environmental subsystem	0.35732	0.49337	0.55395	0.53929	0.64435	0.69279
Chemical	Economic subsystem	0.46328	0.50300	0.60551	0.56572	0.65013	0.70331
	Environmental subsystem	0.40905	0.50985	0.55711	0.58542	0.65083	0.69252
Thermal power	Economic subsystem	0.47125	0.54139	0.57752	0.62108	0.65877	0.67941
	Environmental subsystem	0.44421	0.52573	0.59477	0.55943	0.63424	0.65206
Building material	Economic subsystem	0.45017	0.56194	0.59381	0.57945	0.69854	0.71704
	Environmental subsystem	0.44214	0.50769	0.55914	0.54039	0.59814	0.67522
Petroleum	Economic subsystem	0.48850	0.54660	0.62175	0.59616	0.68811	0.72987
	Environmental subsystem	0.43134	0.50714	0.56323	0.56306	0.60687	0.66807
Nonferrous	Economic subsystem	0.46657	0.52948	0.63798	0.56797	0.67573	0.69951
	Environmental subsystem	0.43679	0.49160	0.52480	0.56383	0.66122	0.67477

average of industrial inside coordinated degree, and that the outside coordinated degree between industries falls behind the industrial inside coordinated degree, and it is also consistent with the reality of the situation.

6 Conclusions

The order and coordinated degree models to evaluate the CDCE EIIs are first built up based on synergetic theory and

Table 4

The Inside Coordinated Degree Change of the Six EIIs in 2006–2011

Industry	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011
Metallurgy	0.47432	0.54996	0.59208	0.69611	0.75879
Chemical	0.37486	0.53878	0.52802	0.65470	0.72354
Thermal power	0.38944	0.50679	0.51483	0.61445	0.64499
Building material	0.42108	0.51052	0.47699	0.63589	0.70707
Petroleum	0.36592	0.51491	0.48926	0.61249	0.69144
Nonferrous	0.34312	0.50933	0.47795	0.65847	0.68623

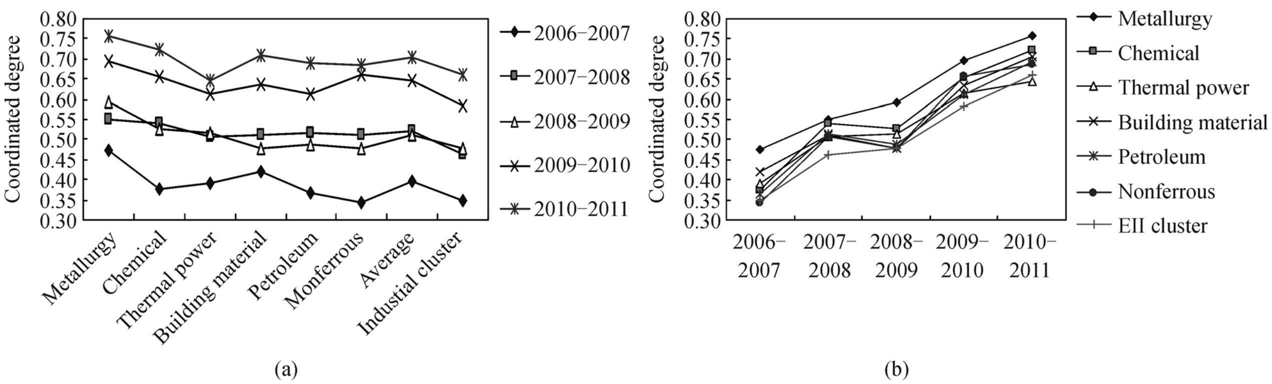

Figure 2. The change of the coordinated degree evolution of six EIIs and the EII cluster.

Table 5

The Order Degree of Subsystem of EII in 2006–2011

Subsystem	2006	2007	2008	2009	2010	2011
Economic subsystem	0.49835	0.56386	0.61591	0.60643	0.63797	0.71063
Environmental subsystem	0.42824	0.48474	0.52500	0.54887	0.62752	0.65413

Table 6

The Coordinated Degree of Circular Economy System of EIIs in 2006–2011

Year	2006–2007	2007–2008	2008–2009	2009–2010	2010–2011
Coordinated degree	0.34930	0.46295	0.47824	0.58215	0.66195

the principle of order parameters. The models have proven to be reasonable and the application values are demonstrated through evaluating the CDCE for six EIIs and the EII cluster made up of the six EIIs in 2006–2011. From the above evaluation results, some conclusions can be drawn. First, the EII CDCE levels differ. The coordinated values for each EII in 2011 show that metallurgy is the highest, followed by chemical, building materials, petroleum, nonferrous, and finally thermal power. Second, the coordinated level of the entire EII cluster is lower than the average of the six EIIs. This supports the forementioned hypothesis of this study related to the coordinated development mechanism of EII circular economy lagged behind. For this reason, this paper calls for future studies focusing on the coordinated development mechanisms of EII circular economy because it is an important issue for the sustainable development of the entire EIIs. It is important for government to promote the construction of a coordinated development mechanism among EIIs and improve coordinated development level of circular economy via coordinated regulation. The CDCE in EIIs is a complicated task. The model and application illustrated here is only a preliminary one due to the lack of data about circular economies in China. An in-depth

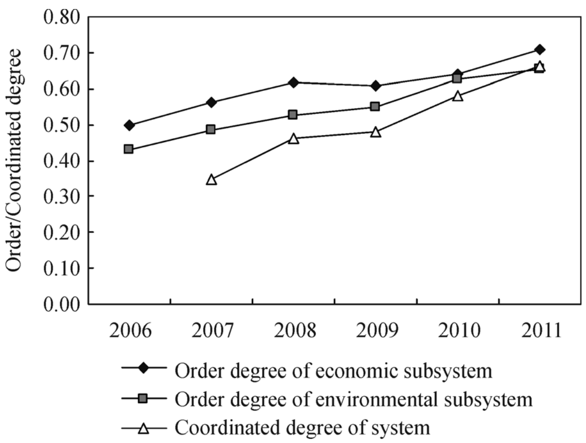

Figure 3. The change of the order degree of subsystem and the coordinated degree of circular economy system of EIIs in 2006–2011.

research will be conducted based on data collection and methodologies in future.

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References

Anbanandam, R., Banwet, D.K., & Shankar, R. (2011). Evaluation of supply chain collaboration: a case of apparel retail industry in India. *International Journal of Productivity and Performance Management*, 60(2), 82–98

Bao, J., & Zhu, S. (2007). Study on the circular economy development mode for iron and steel industry in China. *Science Technology and Industry*, 7(10), 1–4, 12

Cai, S., Wang, J., Xu, H., & Yao, M. (2007). The organization and conjunction mechanism that the district business enterprises evolve from enterprises group to industry cluster. *Inquiry into Economic Issues*, (3), 69–73

Chen, Y., & Zhao, L. (2010). On the coordination degree of the energy-environment-economy compound system of Shandong. *Journal of Shandong Administration Institute and Shandong Economic Management Personnel Institute*, (4), 53–56

Christopher, M. (2000). The agile supply chain: competing in volatile markets. *Industrial Marketing Management*, 29(1), 37–44

Guo, L., Su, J., & Xu, D. (2005). Study on the evolvement mechanism of industrial ecosystem based on Haken model. *China Soft Science*, (11), 156–160

Jeffrey, H. D. (2000). *Collaborative Advantage: Winning through Extended Enterprise Supplier Networks*. New York: Oxford University Press

Klodt, H. (2000). The evolution mechanism of logistics synergetic system. Birmingham: University of Birmingham

Li, Y., & Guo, P. (2012). Comparative analysis on the coordinated degree of regional IUR cooperative innovation system. *Journal of Commercial Era*, (25), 133–135

Sun, B., & Zheng, C. (2009). The order parameter of the industrial cluster innovation system. *Statistics and Decision*, (6), 140–142

Sun, J., Xi, Y., Wang, J., & Fu, Y. (2007). System simulation method for circular economy pattern–case study from coal industry. *Engineering Sciences*, 9(5), 62–71

Tang, Y., & Li, J. (2012). Research on the economic synergistic degree between renewable resources industry and equipment manufacturing industry in industrial city. *Economic Geography*, 32(4), 90–96

Türkay, M., Oruç, C., Fujita, K., & Asakura, T. (2004). Multi-company collaborative supply chain management with economical and environmental considerations. *Computers & Chemical Engineering*, 28(6/7), 985–992

Van Beers, D., Bossilkov, A., Corder, G., & Van Berkel, R. (2007). Industrial symbiosis in the Australian minerals industry: the cases of kwinana and gladstone. *Journal of Industrial Ecology*, 11(1), 55–72

Van Beers, D., Corder, G. D., Bossilkov, A., & Van Berkel, R. (2007). Regional synergies in the Australian minerals industry: case-studies and enabling tools. *Minerals Engineering*, 20(9), 830–841

Van Berkel, R. (2006). Regional resource synergies for sustainable development in heavy industrial areas: an overview of opportunities and experiences. Perth, Australia: Curtin University of Technology

Xu, H., Xu, J., & Kang, S. (2003). Collaborative model and empirical analysis on organization system of China state-owned pharmaceutical manufacturing industry. *China Technology Forum*, (1), 113–117

Zhang, J. B. (2012). The path selection of sustainable development of resource based industry cluster. *Science and Technology Progress and Policy*, 29(19), 51–54

Zhang, J. L. (2012). Industry chain model of ecological and low-carbon economy in non-ferrous metal industry. *China Nonferrous Metallurgy*, 41(2), 79–83

Zhang, J. (2012). Research on collaborative development of Guangzhou automobile industry cluster and regional logistics (Master's degree thesis). Guangzhou: South China University of Technology

Zhao, Y. (2011). Research on collaborative development of manufacturing industry and the third party logistics (Master's degree thesis). Changsha: Central South University

Zheng, J., & Chen, W. (2009). On the development of energy-intensive industrial cluster based on circular economy. *Science and Technology Management Research*, 29(9), 271–273

Zheng, J., & Chen, W. (2010). Discuss on the circular economy coordination development of energy intensive industries. *Science and Technology Progress and Policy*, 27(1), 53–56

Zheng, J., Chen, W., & Chen, Z. (2008). Analysis on the circular economy development strategy of energy-intensive industry in Yunnan Province. *Science and Technology Management Research*, 28(8), 92–94

Zheng, J., & Li, J. (2013). The circular economy coordination development mode of energy intensive industries based on building material. *2013 China Engineering Management Forum Proceedings*, 35–38

Zhong, M., Wu, Y., & Luan, W. (2011). Model of synergy degree between port logistics and urban economy. *Journal of Dalian Maritime University*, 37(1), 80–82