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Research on Warning Model of Circular Economy

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Abstract

Circular economy as an advanced development mode for harmonizing the problems among resource, environment and economy, is destined to be the choice for keeping on developing. It is the sustainable development strategy which based on reducing, reusing, recycling principle and the recommendation of circular economy was proposed to build resource-efficient and environmental-friendly society. How to choose the evaluation index system and correctly evaluation the development trance of circular economy is treated as a decision problem. In this paper, a hybrid warning model using matter-element model, combination weight method and place value method for evaluating the development trance of circular economy is proposed. The matter-element model is used to choose the statistical index system of circular economy. The combination weight method is used to calculate the weight of indicators and the place value method is used to contribute the comprehensive evaluation and warning model of circular economy. Finally a case study demonstrates the application of the proposed model.

Keywords: *Circular economy; Statistical index system; Warning model; Combination weight; Place value method*

1. Introduction

Circular economy focuses on resource productivity and eco-efficiency improvement in a comprehensive way [1]. It is a new concept of sustainable development model of economic development with the objective of making the most effective use of resources and protecting the environment. Also it was seen as a new way to slow down the environmental damage in economies industrializes [2, 3]. However, a series of barriers to the implementation of circular economy was existed [4]. Under this circumstance, some scholars researched the fundamental principles and approaches about circular economy. Joseph Sarkis et al focused on the developing circular economy policy and provided the framework to understand the role circular economy plays in sustainability [5]. Qian Liu et al created a new understanding of public awareness and performance in the promotion of circular economy to increase people's awareness and positive attitude towards circular economy [6].

Quantitative research about the circular economy, Jiuping Xu et al constructed a multi-objective programming model using the theory of SD for analyzing the risk of circular economy [7]. Liu Hai Tao *et al.*, determined the evaluation index system and established the fuzzy model to evaluate the production effect of the circular economy in coal enterprise [8]. Shao-lun Zeng et al applied the DEA model and benchmarking procedure model to ranking the circular economy efficiency in electric power industry [9]. Li Wenbo constructed a comprehensive evaluation index system and evaluation model using ANP for evaluating the performance of circular economy in eco-industrial parks [10]. Hongzhe Sun applied a new algorithm in fuzzy evaluation on the circular economy development of coal mining [11].

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As summarized above, the defect of quantitative study lies in that existing evaluation study stresses macro level while neglects effect of regional difference. Secondly, study on index weight is insufficient, and it lacks of warning on development trend of circular economy. Instead, this paper chooses the statistical index thinking about the effect of regional difference and characteristics, constructs the comprehensive evaluation and warning model for monitoring the development state of circular economy.

The remainder of this paper is organized as follows: in Section 2, the evaluation and warning model for monitoring the development state of circular economy is constructed. In Section 3, a case study is described and finally the conclusion of the paper is given.

2. Establishment on Warning Model of Circular Economy

Establishment process on warning model of circular economy is indicated by Figure 1.

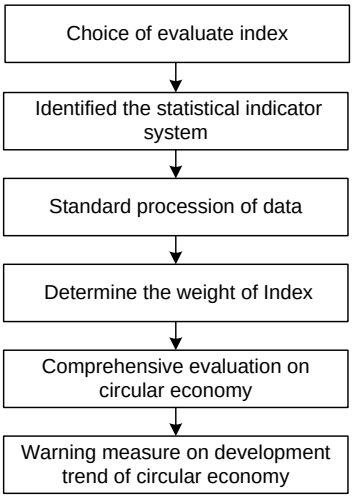

Figure 1. Warning Model System of Circular Economy

2.1. Matter-element Model on Statistics Measure and Index Choice of Circular Economy

2.1.1. Matter-element Model

$$R_0 = (N_0, C_j, V_0) = \begin{bmatrix} N_0 & c_1 & , & \langle v_{01},\ v_{01} \rangle \\ & c_2 & , & \langle v_{02},\ v_{02} \rangle \\ & \cdots & & \cdots \\ & c_n & , & \langle v_{0n},\ v_{0n} \rangle \end{bmatrix}$$

$V_{0j} = \langle v_{0j}\ ,\ v_{0j} \rangle$ is the value range of matter characteristic C_j, R_0 is classical matter-element, N_0 is evaluation target level, C_j is the effect element （ $j = 1, 2, \cdots, n$ ） of determination target level.

2.1.2. Confirmation of Matter-element to be Evaluated: It makes evaluation on characteristics value of unit N_i of target level and gets structure of matter-element to be evaluated. It is indicated as follows:

$$R_i = (N_i, C_i, V_i) = \begin{bmatrix} N_i & , & c_1 & , & v_{i1} \\ & & c_2 & , & v_{i2} \\ & & \cdots & & \cdots \\ & & c_n & , & v_{in} \end{bmatrix}$$

N_i is the index to be evaluated of target level on evaluation index system of circular economy, v_i is value of detailed evaluation of index c_i.

2.1.3. Correlation Function: The matter-element correlation function use by this paper is as follows:

$$R_i = f(c_i, v_i) = \frac{f_{v_i}}{\frac{\sum_{i=1}^{n} v_i \cdot f_{v_i}}{\sum_{i=1}^{n} f_{v_i}}}, \quad i = 1, 2, \cdots, n$$

$R_i = f(c_i, v_i)$ is matter-element correlation function, f_{v_i} is the appearance time of index c_i, $\sum_{i=1}^{n} v_i \cdot f_{v_i}$ is the total of statistics frequency of index, $\sum_{i=1}^{n} f_{v_i}$ is total of evaluation index of evaluation set N_i.

2.1.4. Standard of Index Choice: If $R_i > 1$, then keep this index. If $R_i < 1$, then delete this index.

2.2. Standard Procession of Data

$$X_{ij} = \begin{cases} X_{ij} = \dfrac{a_{ij} - \min a_{ij}}{\max a_{ij} - \min a_{ij}}, & a_{ij} \text{ as positive indicators} \\ X_{ij} = \dfrac{\max a_{ij} - a_{ij}}{\max a_{ij} - \min a_{ij}}, & a_{ij} \text{ as negative indicators} \end{cases}$$

a_{ij} ---original data of index, X_{ij} ---data of index after standardization.

2.3. Determination of Combination Weight

$$w_j = \frac{w_j^1 \cdot w_j^2 \cdot w_j^3}{\sum_{j=1}^{n} w_j^1 \cdot w_j^2 \cdot w_j^3}$$

w_j is combination weight, w_j^1 is weight obtained by deviation weight method , w_j^2 is weight from AHP, w_j^3 is weight from literature method.

2.4. Comprehensive Evaluation on Subsystem of Circular Economy

The dada normalization using place value method is as follows:

$$v_{ij} = \begin{cases} 0.01 + 0.99 \times \dfrac{a_{ij} - \min a_{ij}}{\max a_{ij} - \min a_{ij}}, a_{ij} \in v_{ij}^{+} \\ 0.01 + 0.99 \times \dfrac{\max a_{ij} - a_{ij}}{\max a_{ij} - \min a_{ij}}, a_{ij} \in v_{ij}^{-} \end{cases}$$

a_{ij} ---original value of index, v_{ij}^{+} indicates positive index, v_{ij}^{-} indicates negative index.

Comprehensive value of circular economy calculated by using contribution method and linear weight is as follows:

$$f_j = \sum_{j=1}^{n} w_j v_{ij}, i = 1, 2, \cdots, m$$

f_j is comprehensive value of certain subsystem evaluation, v_{ij} is the target fractile of index, w_j is the index weight calculated by combination weight method and:

$$0 < w_j < 1 \text{ and } \sum_{j=1}^{n} w_j = 1, j = 1, 2, \cdots, \text{n}$$

2.5. Comprehensive Evaluation on Circular Economy

The formula is as follows：

$$f = \sum_{j=1}^{n} f_{ij} \cdot w_j \quad , \quad i = 1, 2, \cdots, \text{m}$$

f is the value on comprehensive evaluation of circular economy, f_{ij} is the comprehensive value of subsystem evaluation, w_j is subsystem weight calculated by combination weight method.

2.6. Warning Measure on Development Trend of Circular Economy

The paper divides development state warning of circular economy into 5 kinds such as huge warning, serious warning, medium warning, light warning and no warning [12-13]. The warning division is illustrated in the following Table 1.

Table 1. Warning of Circular Economy

f	0-0.2	0.2-0.4	0.4-0.5	0.5-0.8	0.8-1.0
Warning degree	Huge warning	Serious warning	Medium warning	Light warning	No warning

3. Numerical Analysis

3.1. Data Source

The data source of this statistics is from Liaoning Statistics Annual, Official Journal of Liaoning National Economy and Social Development Statistics (2004-2013), Official Journal of Liaoning Environment Statistics (2004-2013), some individual data is from website such as Liaoning Statistics Bureau, Liaoning Environmental Protection Ministry, Liaoning National Land Bureau etc. Data not be found adopts portable average method to make supplementary and get the final original data.

3.2. Establishment on Statistics Measure Index System of Circular Economy

This paper divides the statistical index system of circular economy into five parts subsystem: subsystem of resources consumption, subsystem of economic development, subsystem of environment pollution, subsystem of environmental protection, subsystem of resources reuse (Figure 2).

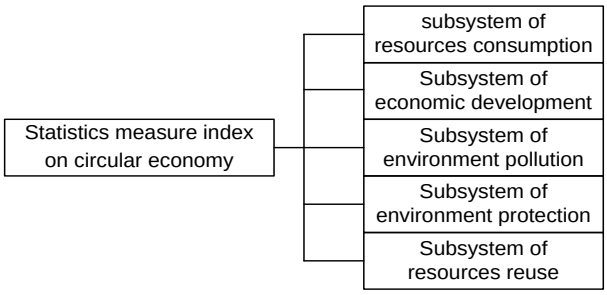

Figure 2. Index System of Circular Economy

Takes the primary index selection of resources reuse subsystem as an example, there are 8 detailed indexes listed. Using the matter-element method choose the statistical index, which is indicated in Table 2.

Table 2. Primary Index of Resources Reuse System

Evaluation set Ni	Evaluation index Ci	Frequency Vi	Matter-element value Ri
Subsystem of resources reuse	Harmless amount of garbage processing	15	1.2
	Comprehensive utilization rate of agricultural straw	9	0.72
	Yield of comprehensive application of three wastes	13	1.04
	Environment management budget	16	1.28
	Target rate of waste water discharge	14	1.12
	Reclamation and utilization rate of nonferrous metal	8	0.64
	Comprehensive utilization rate of solid waste	18	1.44
	Reclamation and utilization rate of waste plastic	7	0.56

So the index of resources reuse subsystem is shown in Figure 3.

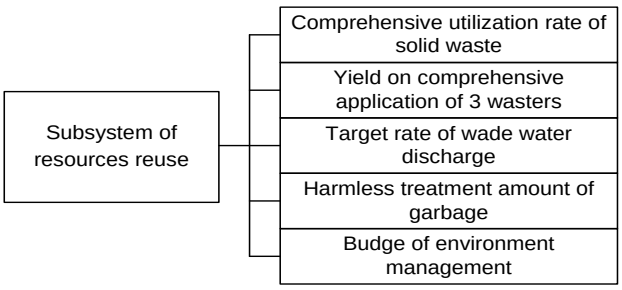

Figure 3. Index of Resources Reuse Subsystem

According to the same methods, it makes choice for the rest 4 primary indexes and gets the index system of statistics measure of Liaoning circular economy. Figure 4 shows the index system and weight using combined weight method. This index system has 5 subsystems and 29 detailed indexes.

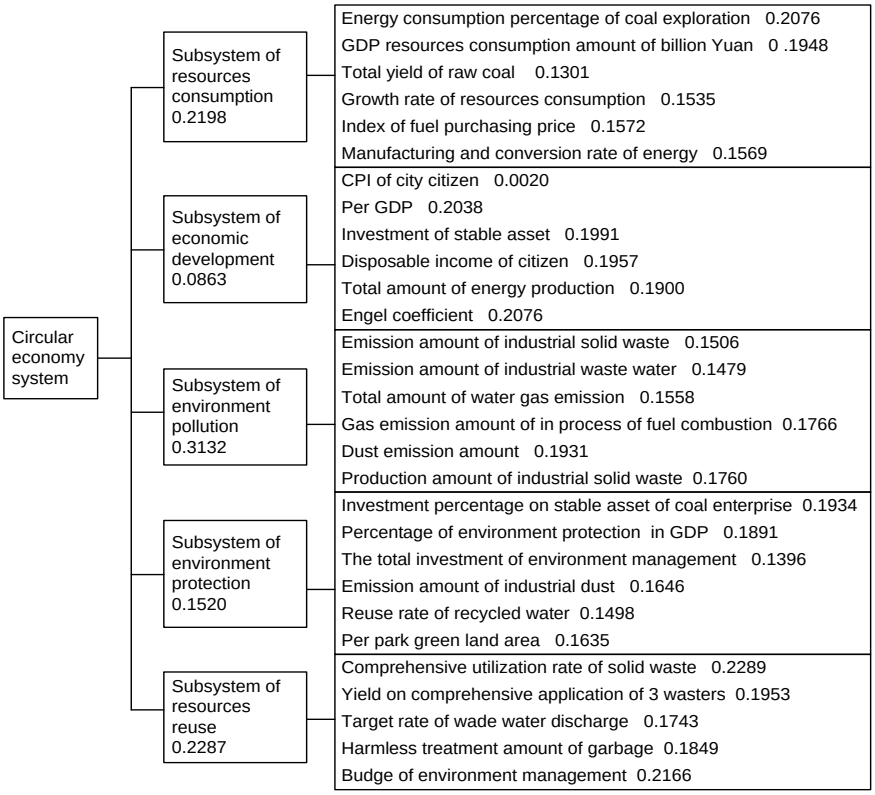

Figure 4. Index of Circular Economy and Index Weight

3.3. Analysis on Development Trend of Liaoning Circular Economy Subsystem

First the dada is normalized by place value method, and then the development trance of circular economy subsystem is calculated by contribution weight method and linear weight method. The result of the development trance of circular economy subsystem is indicated in Table 3 and Figure 5-9.

Table 3. Development Trend on Circular Economy Subsystem of Liaoning

Year	Consumption system of resources	Economic development system	Environment pollution system	Environment protection system	Resources reuse system
2004	0.5186	0.3109	0.8310	0.2698	0.2200
2005	0.2744	0.2756	0.8344	0.4183	0.2849
2006	0.4074	0.3690	0.5748	0.4257	0.3495
2007	0.3879	0.3469	0.2675	0.5259	0.2460
2008	0.4181	0.3965	0.4063	0.4254	0.3410
2009	0.3878	0.5539	0.4182	0.5497	0.5296
2010	0.5447	0.6142	0.5821	0.4836	0.5373
2011	0.4568	0.4372	0.6208	0.4599	0.7669
2012	0.5236	0.5223	0.2820	0.6170	0.6003
2013	0.8254	0.7151	0.2897	0.8388	0.8712

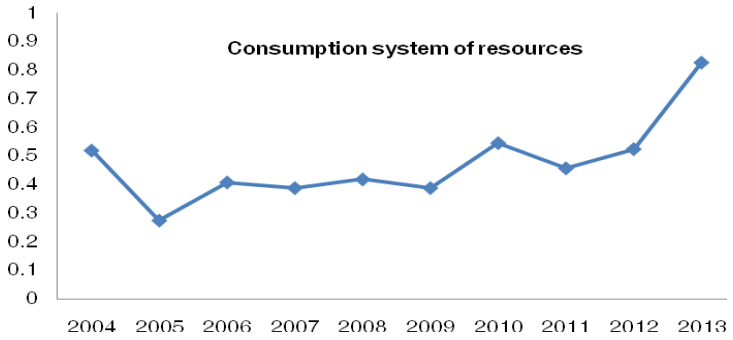

Figure 5. Development Trance of Resources Consumption Subsystem

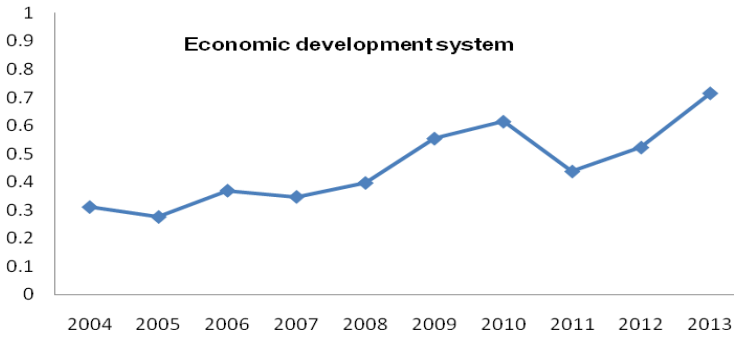

Figure 6. Development Trance of Economic Development Subsystem

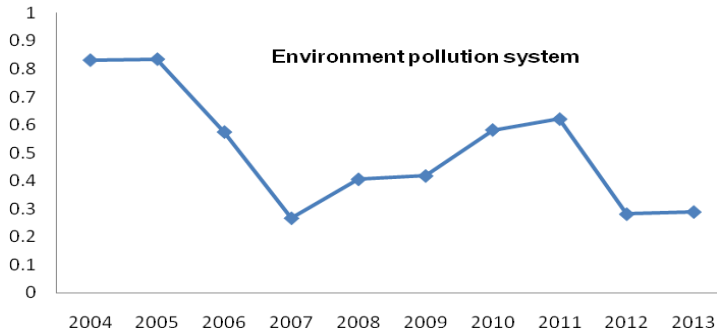

Figure 7. Development Trance of Environment Pollution Subsystem

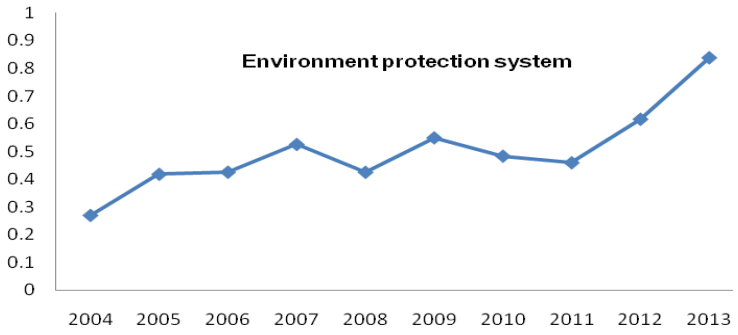

Figure 8. Development Trance of Environment Protection Subsystem

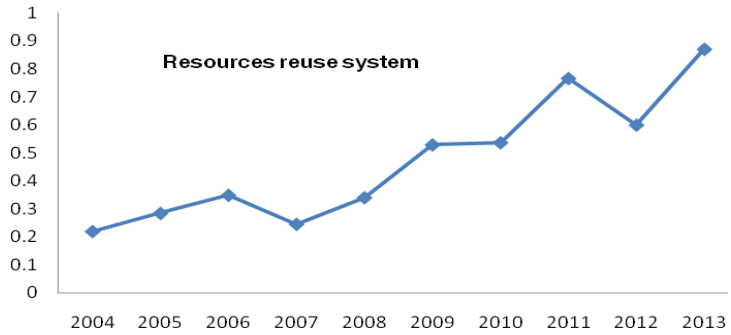

Figure 9. Development Trance of Resources Reuse Subsystem

We can see that the resources consumption subsystem (Figure 5) and the development trend of resources reuse subsystem (Figure 9) of Liaoning from 2004 to 2013 are active and stable. It is the reason that reasonable using resources reduce input and usage amount of resources, which makes sustainable development in economy. There are more than 480 important pollution enterprises developing review of cleaner production and totally implement over 9420 projects about circular economy. Anshan iron and steel factory has already constructed more than 40 circular economy projects, which basically utilized the converter gas and water. Copper and slag produced in that year have been recycled and reused fully.

The overall development state of economic development subsystem (Figure 6) is good, following optimized industrial layout and greatly developed ecological industry by industry combination, the product was updated. On the other hand, enterprises constructed the industrial and ecological chain and recycling network to develop stair application of logistics and energy flow. High energy consumption enterprises were transformed, heavy pollution and bad profit enterprises achieved the new developing point using recycling and circular economy. The economy quality achieved enhancement through adjustment in industrial structure and economic development model.

It is worthwhile concerning that the warning of environment pollution subsystem (Figure 7) is increasing, which indicates that with the development of economy, environment pollution still exists. For problem resolution, firstly the framework of law and regulation system of accelerating development of circular economy should be established. Also enterprises should be encouraged to reuse resources and private investment into field of ecological environment should be noticed. Government should give support to develop circular economy in aspects such as fund, tax policy, green purchasing of government, purchasing of environmental protection product by government, fees on waste disposal from individual by government, issue of circular economy security etc. Secondly, venous industry development of circular economy should be greatly promoted. On one hand, the framework of developing venous industry should be established; the obligation and responsibility of waste discharger, collector and disposer should be classified correctly. Enterprise of waste reclamation and transportation should be strict managed so as to the waste collection in order to avoid secondary pollution.

Development in environmental protection subsystem (Figure 8) is good. It benefits from propaganda and education in circular economy, which increases participation awareness of public people and acknowledgement in important meanings of developing circular economy of all society. All society established the correct consumption view, which benefits from vast propaganda of media, strengthens awareness of unexpected development in resources for all society. In addition, implementation of circular economy reduces effect on environment.

3.4. Warning of Circular Economy in Liaoning

The warning result on circular economy from 2004 to 2013 in Liaoning is indicated in Table 4 and Figure 10.

Table 4. Warning on Circular Economy from 2004 to 2013 in Liaoning

Year	2004	2005	2006	2007	2008
Warning degree	0.4924	0.4742	0.4361	0.3352	0.3960
Year	2009	2010	2011	2012	2013
Warning degree	0.4687	0.5514	0.5779	0.4796	0.6606

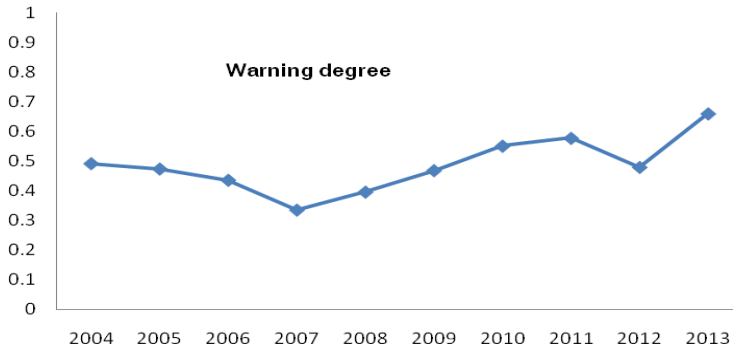

Figure 10. Warning Degree Curve on Circular Economy from 2004 to 2013 in Liaoing

The overall development trend of circular economy in Liaoning is stable. From 2007 to 2009, the trend is serious warning, it is because the traditional economy was transforming to circular economy at this periods, two kinds of development models lack of effective connection and couples with imperfection in policy and regulation as well as insufficient strength of propaganda on circular economy idea. The warning on circular economy after 2009 was reduced and circular economy gradually was normal. The reason is that circular economy was greatly implemented in the whole province; meanwhile government strengthened monitoring on circular economy and promoted circular economy as strategic planning. The established warning model of circular economy by this paper is accord with real conditions and the choice method of statistical index is reasonable .The establishment on warning model is scientific and calculation method is reliable.

4. Conclusion

Economy of Liaoning is in quick growth in recent years, construction gets big achievement, but economic development is restricted by resources shortage, environment pollution and ecology destruction. Reasonably choosing statistical measure index system of circular economy and establishing the evaluation and warning model of circular economy can correctly evaluate development trend of circular economy. This paper designed the statistical index system according with real conditions and characteristics in Liaoning and established comprehensive warning model of circular economy through combination weight method and place value method. The numerical analysis result indicated that the development trance of circular economy in Liaoning from 2004 to 2013 was in the state of light warning and each subsystem of circular economy was in good operation, but stability of environment pollution subsystem was worse. On one hand, law system of circular economy should be improved. On the other hand, venous industry of circular economy should be greatly developed to reduce the effect of economic development on environment.

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