Evaluation of the Cyclic Economy Development Based on the Rough Sets and Extension Analysis

Qiang Zhang 1, Jinshou Chen1*, Jia Liu1, Jiaqiong Yuan1

1College of Computer Science & Engineering, Northwest Normal University, Lanzhou, Gansu, 730070, China
*Corresponding author’s e-mail: 1598450080@qq.com

Abstract. Because of the subjectivity of the current index system of the cyclic economy and the lack of the comprehensive assessment of the trend for the economic development, the present paper proposes a rough-set-based approach to establish the index system for the cyclic economy and sets up the evaluation model for the cyclic economy development with the comprehensive extension evaluation method. The paper begins with the formalizing description and discretization of the initial economy index, establishing the assessment system with the Attribute Reduction method. Then the paper establishes a meta-model for the cyclic economy development and proposes the comprehensive extension evaluation method to assess the cyclic economy development based on the correlation function method. The index system based on the established assessment model is simple but comprehensive enough to assess the current development as well as analyse the trend of the future development of the cyclic economy, which can offer theoretical basis and working approach to development the regional cyclic economy. Finally, taking Gansu as an example, by making an empirical study on the related data in 2013, the paper establishes the index system for the cyclic economy in Gansu, and assesses the development and the trend of the cyclic economy in some areas of the province.

1. Introduction

The development of cyclic economy is an important channel to build a resource-conserving and environment-friendly society and to realize sustainable development. The index system for cyclic economy is the basis of quantitative evaluation of circular economy development, so the key and difficult point of cyclic economy research is to establish a set of reasonably designed and highly operable cyclic economy index system and scientifically evaluate it. The common ways to establish the index system for cyclic economy and to evaluate it currently include material flow analysis, energy analysis, analytical hierarchy process, DEA process, etc [1-4]. The rough sets [5-8], being an effective index reduction model and method, has been applied to the construction of evaluation index system, such as petroleum enterprises sustainability, and enterprise competitiveness [9]. Extension analysis [10] is a dynamic comprehensive analytical method based on extension set and correlation function theory. Taking Gansu province for example, the index system of the cyclic economy has been established, and the evaluation has been given towards the development and the trend of its circular economy so that decision making basis has been provided to develop the cyclic economy in Gansu.

2. The construction of the index system on cyclic economy developmental level

2.1. The construction of the initial cyclic economy index system.
From the research results we can get that the construction of the cyclic economy index system is guided under the principle of “educe-Reuse–Recycle,3R principle” [11]. While the development of the cyclic economy is a dynamic evolution process, it is not comprehensive enough to evaluate the evolution of cyclic economy only based on 3R principle and some theoretical principle. The system combines the instructions launched by related national departments and the experience through establishing the national cyclic economy demonstration area in Gansu. It contains nine subsystems, including development standard of society and economy, resource utilization level, reduction, reuse and recycling, pollution reduction and effect, infrastructure and ecological environment, green consumption, publicity, and assurance condition. To solve problems as numerous initial indexes and information redundancy, rough set theory is applied to the initial cyclic economy Index system by method of the Attribute Reduction.

2.2. Reduction model of cyclic economy index system
The reduction model of cyclic economy index system is based on the attribute reduction\textsuperscript{[12]} theory of rough set. The information system model\textsuperscript{[13]} is applied to make a formal description of the index attribute, which makes the problem change from qualitative to quantitative description. The fuzzy c-means clustering (FCM) algorithm\textsuperscript{[14]} is used to discretize the quantitative indicators and obtain the discrete decision table of the index data. The discernible matrix\textsuperscript{[15]} is established on the basis of the decision table, and the optimal reduced indicator system set is selected in combination with expert opinions. The Bayes discriminant method is used to establish the discriminant criterion and verify the rationality of the model.

2.2.1. Information system model of cyclic economy system. It is assumed that there are \( m \) data sources in the circular economy index system and \( n \) initial indicators, and the corresponding information system \( S=<U,A,Y,F> \) is established. To store the original indicator data in the relational database, the information is systematically reduced to a two-dimensional relational table \( T=(U,P) \). The two-dimensional relational expression of information system is shown in table 1.

| U(region names) | P(indexical information) |
|----------------|--------------------------|
|                | \( p_1 \) | \( p_2 \) | ... | \( p_n \) |
| \( u_1 \)      | \( p_{11} \) | \( p_{12} \) | ... | \( p_{1n} \) |
| \( u_2 \)      | \( p_{21} \) | \( p_{22} \) | ... | \( p_{2n} \) |
| ...            | ... | ... | ... | ... |
| \( u_m \)      | \( p_{m1} \) | \( p_{m2} \) | ... | \( p_{mn} \) |

2.2.2. Continuous index attribute discretization. Fuzzy c-means clustering (FCM) algorithm is a kind of clustering algorithm, which uses membership to determine the degree of clustering of each data point. By using the FCM algorithm, the regional \( u_i \) clustering corresponding to each indicator was divided into \( c \) fuzzy groups. The clustering center of each group is calculated to minimize the value function of the non-similarity region. The value function of FCM is constructed as follows:

\[
J(U, c_1, \ldots, c_r) = \sum_{i=1}^{c} \sum_{j=1}^{m} u_{ij}^d d_{ij}^2
\]  
(1)

The new objective function is constructed as follows to obtain the necessary condition to minimize the value function:

\[
J(U, c_1, \ldots, c_r, \lambda_1, \ldots, \lambda_r) = J(U, c_1, \ldots, c_r) + \sum_{i=1}^{c} \lambda_i (\sum_{j=1}^{m} u_{ij} - 1) = \sum_{i=1}^{c} \sum_{j=1}^{m} u_{ij}^d d_{ij}^2 + \sum_{i=1}^{c} \lambda_i (\sum_{j=1}^{m} u_{ij} - 1)
\]  
(2)
2.2.3. Reduction set of the cyclic economy index system. A discernible matrix $D$ with size $m \times m$ is established to determine the reduction set of circular economy index system. The criteria for determining the existence of $P_k$ in $D_{ij}$ is as follows:

$$d_{jk} = \{ \emptyset, \begin{cases} P_k - P_{jk}, & k = 1, 2, \ldots, n \\ P_k + P_{jk}, & \end{cases} \}$$

(3)

2.2.4. Model criterion. In this paper, Bayes discrimination under the equal misjudgment loss is adopted. A priori probability is assigned to a uniform distribution.

$$q = q_i | q_1 = q_2 = \cdots = q_l \quad = 1/q \quad (i = 1, \cdots, g), \sum_{i=1}^{g} q_i = 1, q_i > 0$$

(4)

Discriminant method. Since $\Sigma_1 = \Sigma_2 = \cdots = \Sigma_g = \Sigma$, the generalized square distance function is:

$$D_j^2(x) = D_j^2(x, u_j) = (x-v_j)^T \Sigma^{-1}(x-v_j) - 2 \ln q_j, j=1,2,\ldots,g$$

(5)

Determination of the posterior probability. The posterior probability of region $x$ belongs to $u_j$ is

$$P(u_j | x) = \frac{\exp(-0.5 D_j^2(x))}{\sum_{i=1}^{g} \exp(-0.5 D_i^2(x))}$$

(6)

3. The evaluation model is constructed by using the extension analysis method.

3.1. The classical domain, section domain and evaluation subjects of cyclic economy development.

Suppose that there are $m$ cyclic economic development levels, $N_1, N_2, \ldots, N_m$, and establish corresponding matter-elements:

$$R_j = \begin{pmatrix} N_j \ c_1 \ v_j \ \cdots \ \cdots \ c_{m} \ v_{jm} \end{pmatrix}$$

(7)

$$R_p = \begin{pmatrix} N_p \ c_1 \ v_{pj} \ \cdots \ \cdots \ c_{m} \ v_{pm} \end{pmatrix}$$

(8)

$$R_o = \begin{pmatrix} P_o \ c_1 \ v_o \ \cdots \ \cdots \ c_{m} \ v_{om} \end{pmatrix}$$

(9)

3.2. Calculation of correlation degree and determination of distance.

The correlation degree of each development level of the object to be evaluated is calculated by the correlation function. Number $i^{\text{th}} (i=1, 2, \cdots, n)$ index value domain belongs to the $j^{\text{th}} (j=1, 2, \cdots, m)$ development level, whose correlation function is:
3.3. Calculation of weight coefficient of evaluation index

The index weight of cyclic economy development level is determined by correlation function method:

\[
K_j(v_i) = \begin{cases} 
\frac{\rho(v_i, V_p)}{\rho(v_i, V_p) - \rho(v_i, V_o)} & v_i \not\in V_o \\
-\frac{b_o - a_o}{b_o - a_i} & v_i \in V_o 
\end{cases} 
\] (10)

\[
\rho(x, <a, b>) = |x - \frac{a + b}{2}| - \frac{1}{2}(b-a) 
\] (11)

3.4. Rating the degree of evaluation

The value of correlation function \(K(x)\) indicates the subordinate level of the evaluation object in accordance with the cyclic economy development level:

\[
K_j(R_j) = \sum_{i=1}^n w_i K_j(v_i) 
\] (13)

4. Empirical analysis -- Taking Gansu province as an example

Developing cyclic economy is the objective need for Gansu to give full play to its resource advantages, revitalize old industrial bases and promote economic and social development. It is an inevitable requirement to ensure ecological security, maintain national unity and border stability, and also a realistic choice for provinces based on exploring resources to achieve scientific development.

4.1. Construction of Gansu cyclic economy index system

The construction of Gansu’s cyclic economy index system will select ten regions in the province, including statistics of Jiuquan, Dinxi, Jingyuan, Ningxian, Yumen, Wushan, Linze, Chongxin, Jinchang and Baiyin of the year 2013. The initial data of the initial index from the reduced subsystem are shown in Table 2.

### Table 2. The raw data of initial cyclic economy index system(2013)

| C1  | C2  | C3  | C4  | C5  | C6  | C7  | C8  | C9  | C10 | C11 |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Jiuquan | 42.3 | Yes | 452.75 | 0.834 | 105 | 0.54 | finished | 10.9 | 67.9 | 10.8 | P: 1.3; C: 78 |
| Dinxi | 38.1 | Yes | 186.08 | 1.235 | 115 | 0.48 | finished | 4.51 | 32.3 | 8.7 | P: 1.96; C: 102 |
| Jingyuan | 39.4 | Yes | 139.90 | 1.87 | 48.46 | 0.56 | unfinished | 2.96 | 67 | 8.2 | P: 1.87; C: 96 |
| Ningxian | 36 | Yes | 202.40 | 0.638 | 83.8 | 0.53 | finished | 4.72 | 71 | 9.8 | P: 1.76; C: 98 |
| Yumen | 37.2 | Yes | 200.87 | 1.408 | 109.6 | 0.55 | finished | 3.33 | 51.6 | 7 | P: 2.43; C: 102.15 |
| Wushan | 38.7 | Yes | 163.4 | 1.31 | 78.9 | 0.54 | unfinished | 4.68 | 61.7 | 9.2 | P: 1.86; C: 93 |
| Linze | 38.5 | Yes | 143.7 | 1.22 | 74.2 | 0.56 | finished | 3.14 | 62 | 9.4 | P: 1.88; C: 98 |
| Chongxin | 37.25 | Yes | 217.6 | 0.872 | 88.1 | 0.50 | finished | 4.7 | 61.64 | 9.2 | P: 1.60; C: 87 |
| Jinchang | 39 | Yes | 230.9 | 1.45 | 108.8 | 0.54 | finished | 5.78 | 70 | 10 | P: 1.87; C: 96.3 |
| Baiyin | 38.8 | Yes | 254.3 | 1.18 | 90 | 0.53 | finished | 5.2 | 61.9 | 9.5 | P: 1.83; C: 90 |
In this paper, qualitative indexes were firstly quantified, and pesticide density was selected to represent index $C_{11}$. Fuzzy C-means clustering algorithm is used to discretize the index data and remove duplicate columns to obtain a preliminary simplified table of cyclic economy index system (Table 3). By using the method of discernibility matrix to do Attribute Reduction of Table 3, see Table 4. Obtained the set $\text{CORE}(P)=\{C_1, C_5, C_6, C_7, C_{10}, C_{11}\}$ of index system, and obtained three index system reduction set $\{C_1, C_5, C_6, C_7, C_{10}, C_{11}\}$ or $\{C_1, C_5, C_6, C_8, C_{10}, C_{11}\}$ or $\{C_1, C_5, C_6, C_7, C_8, C_{10}, C_{11}\}$. Select the best index reduction set $\{C_1, C_2, C_5, C_6, C_7, C_{10}, C_{11}\}$ as the cyclic economy index system in Gansu Province at the advice of experts and scholars. Other index reduction results: Repeat the above steps and the index reduction results of the remaining subsystems can be obtained (Table 5).

Table 3. The first simplify table of the initial cyclic economy index system (2013)

|   | C1 | C2 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | d  |
|---|----|----|----|----|----|----|----|-----|-----|----|
| X1| 2  | 2  | 2  | 2  | 2  | 2  | 2  | 2   | 1   | 2  |
| X2| 1  | 2  | 1  | 2  | 1  | 1  | 1  | 2   | 1   | 2  |
| X3| 1  | 2  | 2  | 2  | 2  | 2  | 1  | 2   | 1   | 2  |
| X4| 1  | 2  | 2  | 2  | 2  | 2  | 1  | 2   | 1   | 2  |
| X5| 1  | 2  | 2  | 2  | 2  | 2  | 1  | 2   | 1   | 2  |
| X6| 1  | 2  | 2  | 2  | 2  | 2  | 1  | 2   | 1   | 2  |
| X7| 1  | 2  | 2  | 2  | 2  | 2  | 1  | 2   | 1   | 2  |
| X8| 1  | 2  | 2  | 2  | 2  | 1  | 1  | 2   | 1   | 1  |
| X9| 1  | 2  | 2  | 2  | 2  | 1  | 1  | 2   | 1   | 2  |
| X10| 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

Table 4. The discernibility matrix

|   | C1 | C2 | C5 | C6 | C8 | C9 | C10 | C11 | C12 |
|---|----|----|----|----|----|----|-----|-----|-----|
| 0  | C1 | C2 | C5 | C6 | C8 | C9 | C10 | C11 | C12 |
| 0  | C1 | C2 | C5 | C6 | C8 | C9 | C10 | C11 | C12 |
| 0  | C1 | C2 | C5 | C6 | C8 | C9 | C10 | C11 | C12 |

Table 5. The cyclic economy index system for Gansu

| First-class index | Second-class index |
|------------------|-------------------|
| development and society | Per capita disposable income level; Per capita disposable fiscal income level; proportion of value added in the first, the second and the third industry; ratio organic, green and pollution-free agricultural area; performance of eliminating backward production capacity |
| Resource level | Resource output rate; energy output rate; water resource output rate |
| Reduction | Clean production audit rate of enterprises above scale; non-resident water use being fully managed under the quota plan; water consumption per unit of industrial added value; effective utilization coefficient of water for agricultural irrigation; performance of annual energy conservation and progress; centralized government office building per capita floor space; the extent of pesticide and fertilizer use below the national average |
| Comprehensive utilization ratio of crop straw; recycling rate of waste agricultural film; large-scale farming manure and sewage utilization; comprehensive utilization rate of industrial solid waste; rural biogas penetration rate; penetration rate of comprehensive utilization of water-saving technology in farmland; reuse of industrial water; utilization rate of regeneration water generated by urban sewage treatment facilities; standardized proportion of recovery stations in built-up areas; the recycling rate of main non-ferrous metals; waste paper recovery; Recycling rate of waste plastics and rubber; waste collection rate of food and beverage enterprises |
| Reuse and recycling | Achieve annual emission reduction targets for COD, ammonia nitrogen, sulfur dioxide and nitrogen oxides; number of days less than or equal to 100 of AQI(or API) annually; percentage of Ivclass and above surface water in urban planning areas |
| Infrastructure and ecological environment | Plans of rain and pollution diversion in new urban areas, renewal in old urban areas; standard rate of urban sewage treatment; the rate of domestic garbage treated harmless; per capita public green area of the built-up area; implementation rate of new green building standards in urban areas; energy saving renovation area of public buildings and public institutions |
| Green consumption | Energy-saving products sales ratio in supermarkets; green lighting product promotion quantity; the proportion of building application of new wall materials in counties; proportion of water-saving appliances popularized in built-up area; proportion of non-fossil energy households in built-up areas; plastic limit ratio on packaging material in supermarkets; governance on over-packaging of market goods; governmental procurement rate of renewable products concerning energy conservation, environmental protection |
Publicity
Carried out propaganda activities of cyclic economy characteristics; produced publicity materials and broadcast cyclic economy public welfare film; construction of circular economy education demonstration base or related facilities; clear after-class-education cyclic economy contents in primary and secondary schools; implementation of creative publicity assurance condition
Relatively complete statistics of circular economy; clear responsibility for superior government to create cyclic economy demonstration county, carry on the work to deploy, and implemented fund support; expenditures for ecological and environmental protection, circular economy, energy conservation and emission reduction.

4.2. Evaluation of cyclic economy development level in Gansu

4.2.1. Determination of the index threshold and weight. The evaluation level is divided into five levels according to the development: 1 germination, 2 initial development, 3 moderate development, 4 high development, 5 mature. By referring to the actual situation of the development level of cyclic economy in major cities in China and relevant standards, the index threshold is determined. The weight of each index is calculated by using formula (12),(13), as shown in table 6.

Table 6. The value change interval of index system

| criterion          | Index layer | 1 germination | 2 initial development | 3 moderate development | 4 high development | 5 mature | Index weight |
|--------------------|-------------|---------------|-----------------------|------------------------|-------------------|----------|--------------|
| Clean production audit rate of enterprises above scale | [20,30) | [30,40) | [40,50) | [50,60) | [60,80) | 0.0204 |
| Non-resident water use being fully managed under the quota plan | [0,0.2) | [0.2,0.4) | [0.4,0.6) | [0.6,0.8) | [0.8,1) | 0.0184 |
| Water consumption per unit of industrial added value | [400,322) | [322,244) | [244,166) | [166,88) | [88,10) | 0.0158 |
| Effective utilization coefficient of water for agricultural irrigation | [0.3,0.38) | [0.38,0.46) | [0.46,0.54) | [0.54,0.62) | [0.62,0.7) | 0.0245 |
| Performance of annual energy conservation and progress | [0,0.2) | [0.2,0.4) | [0.4,0.6) | [0.6,0.8) | [0.8,1) | 0.0272 |
| Centralized government office building per capita floor space | [16,14) | [14,12) | [12,10) | [10,8) | [8,6) | 0.0091 |
| The extent of pesticide and fertilizer use below the national average | [3,2.6) | [2.6,2.2) | [2.2,1.8) | [1.8,1.4) | [1.4,1) | 0.0136 |

4.2.2. Evaluation of development level of cyclic economy. Take the data of five areas including Jiuquan, Dingxi, Jingyuan, Ningxian and Yumen in Gansu Province of the year 2013 as an example. Table 6 are used to get the comprehensive evaluation relevance degree under their respective ranks. The results of the development trend of cyclic economy development are shown in table 7.

Table 7. The evaluation results of cyclic economy

| Correlation degree Kj | 1 germination | 2 initial development | 3 moderate development | 4 high development | 5 mature | degree | trend |
|-----------------------|--------------|----------------------|-----------------------|-------------------|---------|--------|-------|
| Kj (Jiuquan)          | -1.5315      | -0.6924              | 0.5457                | -0.5643           | -1.4912 | moderate | Relatively weak |
| Kj (Dingxi)           | -0.6663      | 0.4827               | -0.4675              | -1.6428           | -1.7325 | preliminary | medium |
| Kj (Jingyuan)         | -0.7820      | 0.3406               | -0.7953              | -1.7180           | -1.8447 | preliminary | extreme week |
| Kj (Ningxian)         | -1.4035      | -0.9151              | 0.5121               | -0.9123           | -1.6362 | moderate | very weak |
| Kj (Yumen)            | -1.0268      | -0.8062              | 0.5027               | -0.8404           | -1.6891 | moderate | preliminary week |

we know that the cyclic economy development in Jiuquan in 2013 is of level 3. The level of circular economy development in Ningxian and Yumen in 2013 is in the middle stage, while Dingxi and Jingyuan are in the preliminary stage. And the analysis shows that Ningxian is slowly entering a high development stage, and Dingxi is reaching a moderate development stage. The development level of cyclic economy in Jingyuan and Yumen is basically unchanged, accompanied by a weak downward fluctuation. The evaluation results of this model are basically consistent with the actual situation of these five regions. It shows that the evaluation model can be used to evaluate and forecast the development level of cyclic economy in Gansu Province in the coming years.
5. Conclusion
A cyclic economy index system model is established by using rough set theory, and relevant data of the 10 regions in Gansu province is selected to build a cyclic economy index system of Gansu province. The cyclic economy evaluation model based on extension analysis can not only evaluate the current overall level of cyclic economy, but also make an accurate analysis of its development trend. It is a dynamic evaluation model. The model of the cyclic economy index system and the comprehensive evaluation model constructed in this paper are not only applicable to Gansu province, but also can be used as a reference to other regions. In the following research, a software system will be developed by using the model constructed in this paper, so that the evaluation of cyclic economy development level can be automatically realized, providing convenience for local government departments to formulate scientific cyclic economy development policies.

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