Chapter 36
Evaluation of Recycle Level of Qaidam Salt Lake Circular Economy with Intuitionistic Fuzzy Entropy Measures

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Abstract The purpose of this paper is to build the evaluation index system of Qaidam salt lake circular economy and sorting the programs according to the weights with the intuitionistic fuzzy sets conception. Intuitionistic fuzzy sets conception takes into account the objective and subjective weights comprehensive to determine weight, and then get the more accurately weight. This paper plays a referenced role for assessing the circular level of circulation in the Qaidam region.

Keywords Circular economy · Evaluation index system · Intuitionistic fuzzy entropy · Qaidam salt lake

36.1 Introduction

Circular economy is a completely new kind of ecological economy about human development raised by western countries. It is the economic model based on the reducing, reusing and recycling principles (known as the 3R principle) (Huang 2004). The real terms to develop circular economy is minimal resource consumption and the smallest environmental costs, to get maximize the development benefits, so as to unify economic, environmental and social benefits, and achieve the goal of sustainable development (Xiao 2007). Germany put forward the recycle economic Law in October 1996, and have done quite well in this regard.

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China was first reported circular economy in 1997 (Min 1997), it shows that Chinese late start in the circular economy.

Zhong et al. (2006) summed up in the present on recycle economic, China's mainly research recycle economic is concentrated in the following areas: firstly, the connotation and principle of recycle economics; Secondly, the role of the recycling economy and the impact on socio-economic; Thirdly, the discussion of the pattern of the recycle economic; Fourthly, the supporting conditions to achieve recycle economic. So, in the circulating levels of evaluation have not done enough, and some of them based steel. For example, Wenjie and Ma (2007) build a set of index system about ecological steel industry, include positive benefit and negative benefits, and use them evaluate the Chinese level of ecological steel industry in 2003; Cui et al. (2008) base on the present index system of circular economy and the evaluation index system of steel and iron industry clean production, and build evaluation index system of steel and iron industry based on circular economy. Ma et al. (2007) build index system and evaluation system of steel and iron industry by green manufacturing, and use DEA evaluate the green degree of Chinese eighteen steel and iron companies. But, now there is few people evaluate the level of salt lake circular economy, and it mainly still locate theory research phase. This paper analysis present salt lake resource situation and reference to the index system of steel and iron circular economy and Chinese index and evaluation system, and combine the feature of salt lake to build index and evaluation system, then use the intuitionistic fuzzy(IF) sets and empower weight algorithm to evaluation.

36.2 The Theory of Intuitionistic Fuzzy Sets and Aggregation Operators

Zhang (2006) pointed that there is gap of data in index system of recycle economic, so some index are fuzzy when statistical investigation. Hong and Choi (2000) and Li (2005) used to do useful exploration of decision problems based on the intuitionistic fuzzy sets. And intuitionistic fuzzy sets is characterized by taking into account the element of non-empty set degree of membership and non-membership information, and which makes the ability to express, more flexible, and more suitable to deal with the reality of the practical problems (Wang and Yang 2010).

36.2.1 Intuitionistic Fuzzy Sets

Intuitionistic fuzzy sets constitute a generalization of the notion of a fuzzy set and were introduced by Atanassov in 1983 (Atanassov 1986).

Definition Set X is a not empty classic set, and an intuitionistic fuzzy set A in a universe X is an object of the form $A = \{<x, \mu_A(x), v_A(x) > |x \in X\}$, where, for all $x \in X$, $\mu_A(x) \in [0,1]$ and $v_A(x) \in [0,1]$ are called the membership degree and the

non-membership degree, respectively, of x in A, and furthermore satisfy $0 \leq \mu_A(x) + v_A(x) \leq 1$ (Xu 2008). For example, $[\mu_A(x), v_A(x)] = [0.5, 0.3]$ in voting model meaning that 10 people, including five members in favor, three against and two abstained. The class of intuitionistic fuzzy sets in X is denoted by IFS[X]. For each A-IFS in, if $\pi_A(x) = 1\text{-}\mu_A(x)\text{-}v_A(x)$, then $\pi_A(x)$ is called the degree of indeterminacy of x to A.

36.2.2 Intuitionistic Fuzzy Weighted Averaging (IFWA) Operator

In generally multi-attribute decision-making (MADM) program need be empowered weight, the weight reflect the relative importance of each attribute. The method to determine weight usually divide into two types: the one is subjective method, weight is determined by the decision makers' preferences and experience, the common methods are expert scoring method and Analytic Hierarchy Process (AHP), the shortcomings of such methods have greater subjective arbitrariness in the decision-making. Another is objective method, it basis for attributive information and using the mathematical theory to empower, so it avoid subjective and arbitrary, but the disadvantage is to ignore the preferences of decision makers'. Therefore, this paper used intuitionistic fuzzy intuitionistic fuzzy sets in dealing with uncertainty information than the traditional fuzzy sets have stronger entropy to determine the weights, and then based on expert scoring to correct weights, and to determine the weight integrated.

Set $Y = (y_1, y_2, y_3, \ldots, y_m)$ is sets for the evaluation programs, set $G = (g_1, g_2, g_3, \ldots, g_n)$ is set for attribution, $\lambda = (\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_n)$ is decision makers' preference for all of attribution, and $\sum_{j=1}^{n} \lambda j = 1$. So, the formula of Y about decision information of G is as follows:

$$E_{Gj} = \frac{1}{2m} \sum_{i=1}^{m} \left(\pi_{ij} + \theta_{ij}\right) \tag{36.1}$$

The E_{Gj} reflect the program sets based on the decision-making information of attribution G_j ambiguity and uncertainty, and the higher values indicate that the degree of fuzzy and degree of uncertainty higher,and it meaning that the degree it rely on attribution G_j less. Let D_{Gj} is the degree of deviation of decision-making information of attribution G_j, where, $D_{Gj} = 1 - E_{Gj}$, j = 1,2,…,n. Then the formula of subjective weights of attribution G_j is as follows:

$$r_j = \frac{DG_j}{\sum_{i=1}^{n} DG_j}, \; j = 1, 2, 3, \ldots, n \tag{36.2}$$

Moreover, taking into account the decision makers' preferences and experiences, we according to the subjective weights $\lambda = (\lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_n)$ for correction, the formula is as follows:

$$w_j = \frac{\lambda_j r_j}{\sum_{i=1}^{n} \lambda_j r_j} \tag{36.3}$$

The weighted averaging operator is a common operator in multi-attribute decision making with integrating data and information.

Definition Let WA: Rn → R, if

$$\mathrm{WA}_{\omega} = \omega 1\, \alpha 1 \oplus \omega 2\, \alpha 2 \oplus \cdots \oplus \omega_n\, \alpha_n. \tag{36.4}$$

Then WA is called a weighted averaging operator, where $\omega = (\omega_1,\omega_2,\omega_3,\ldots, \omega_n)^{\mathrm{T}}$ is the weight vector of α_j(j = 1,2,3,…,n), with $\omega_j \in [0,1]$ and $\sum_{j=1}^{n} \omega_j = 1$, R is the set of all real numbers, and "⊕" is the symbol for the addition of intuitionistic fuzzy sets (Harsanyi 1955).

Amended weights apply to formula (36.4) can get each attributive information about sets of programs Y_i (i = 1,2,…,m), then use the formula of intuitionistic fuzzy weighted averaging (IFWA) operator, it is as follows (Qin 2012):

$$\mathrm{IFWA}(Y_i) = \left(1 - \prod_{j=1}^{n} \left(1 - \mu_{ij}\right)^{wj}, \prod_{j=1}^{n} v_{ij}^{wj}\right), \mathrm{i} = 1, 2, \ldots, \mathrm{m} \tag{36.5}$$

Then we can get the value of decision-making programs Y_i (i = 1,2,…m) based on the sets of attribution G_j. Finally, we use formula (36.6) sort based on S (IFWA (Y_i)) and select the maximum score value for the optimal solution. The formula (36.6) is as follows:

$$\mathrm{S}(\mathrm{IFWA}(Y_i)) = 1 - \prod_{j=1}^{n} \left(1 - \mu_{ij}\right)^{wj} - \prod_{j=1}^{n} v_{ij}^{wj}, \mathrm{i} = 1, 2, \ldots, \mathrm{m} \tag{36.6}$$

36.3 Building Evaluation System of Qaidam Salt Lake Circular Economy

36.3.1 The Resource of Qaidam Salt Lake Recycle Economic Development and Situation

There are 33 salt lakes in Qaidam, and the salt lake resources are the unique advantaged resources, and it play an important position and role in Chinese national economic construction, moreover, the lithium mine, and chemical fertilizer and asbestos are ranking first in China, in Table 36.1.

At present, the main developed salt lake includes the Chaka, Keke Lake, Chaerhan Lake, and small Qaidam Lake. The main production includes salt, potassium salt, magnesium salt and boron salt (Yu and Tan 2000). However, the development of Qinghai salt lake resources, in the past 50 years, always had been based on potassium resource development as the main product. The associated or

Table 36.1 The main miner of the qaidam basin

Minerals	Main ingredients	Maintain reserves (10^3 t)	Potential value (10^2 million)	Province's ratio (%)	Domestic position	Mining area number
Lithium mineral	LiCl	1388.6	3611.7	100	1	10
Sr deposits	Celestite	1589.5	79.6	100	1	3
Salt mineral	NaCl	32626.0	122349.7	100	1	24
Magnesium salt	MgCl	311866.6	9000.0	100	1	21
	$MgSO_4$	167339.7	2174.4			
Potassium salt	KCl	44299.5	2215.0	100	1	22
Mirabilite	K_2SO_4	668516.4	19246.9	100	1	9
Boron mineral	B_2O_3	1152.5	38.4	100	2	12

[a] The material comes from the tenth five-year plan of Qaidam basin mineral resources comprehensive development and utilization

symbiotic resources, like lithium, boron, magnesium, rubidium, bromine and other active ingredients do not use effectively, and most of them as the waste emissions, and formed a one-way linear process of "resources—products—waste". This unidirectional extensive irrational development, on the one hand lead to tremendous waste of the salt lake resources, and exacerbated destruction of resources; the other hand, this mode of production resulting in high production costs and affecting the economic efficiency of enterprises and the competitiveness of products in the market, and weak ability to withstand market risks (2005). Therefore, the route of development of circular economy is a priority, and effectively evaluate the circulatory levels of ability is the most important.

36.3.2 The Principle to Build Qaidam Salt Lake Recycle Economic Evaluation and Index System

The principle to build salt lake recycle economic evaluation and index system should be based on the "reducing, reusing, recycling" (3R) as the main criteria and should take into consideration the levels of corporate, regional and social at the same time. Wang and Chen (2003) proposed the five principles to build index of the salt lake resources for evaluating sustainable development: systematic principle, scientific principle, operability principle, regional principle and dynamic principle.

36.3.3 Determining the Index and Evaluation System of Qaidam Salt Lake Circular Economy

Salt lake recycle economic evaluation index system is still in the exploratory stage, and it is still not reached a uniform, accepted standard. Based on the above principles of constructing, and relying on the instructions on the "recycle economic evaluation

index system" in China and the existing statistical system of the National Bureau of Statistics proposed the output indicator of resources, the consumption indicator of resources, comprehensive utilization of resources indicator, waste disposal volume indicator. Besides, Wang and Chen (2003) based on the method of problematic focus (Yang and Hong 2001) determined index system which contains sustainable utilization of salt lake resources, the impact on the environment of exploiting and using salt lake resources, and sustainable development of the salt lake industries for themselves. Wang and Feng (2012) considered the unique characteristics of the object in the circular economy innovation evaluation, and combined with the phase characteristics of the economic and social development propose the evaluation index of the recycle economic innovation situation and effects to evaluate the capability of innovation. Then, this paper consider these evaluation index comprehensively and provide the evaluation index system with six first-grade indexes and twenty-two second-grade indexes, in the Table 36.2.

Table 36.2 The evaluation index system of the salt lake circular economy

Target layer	Criterion level layer	Index layer
The evaluation index system of the salt lake circular economy	The output indicator of resources	The main mineral resources output rate
		The energy output rate
		Water resources output rate
	The consumption indicator of resources	Water consumption per unit of GDP
		Unit GDP energy consumption
		Ten thousand production value of "three wastes" emissions
	The comprehensive utilization indicator of resources	Industrial waste gas comprehensive utilization rate
		Industrial solid waste comprehensive utilization rate
		Industrial water reuse rate
		The proportion of industrial "three wastes" comprehensive utilization output value of the production in GDP
	The waste disposal volume indicator	Waste recycling rate
		Industrial solid waste disposal quantity
		Industrial waste water emissions
		Sulfur dioxide emissions
		COD emissions
	The impact on the environment of exploiting and using salt lake resources indicator	The capability of resource consumption
		The capability of environmental bearing
		The capability of ecological system bearing
		The capability of resources environmental protection
	Recycle economic innovation situation evaluation indicator	The proportion of research funds in GDP
		The proportion of circular economy research funds in scientific and technological activities funds
		The number of patents

36.3.4 The Steps and Result Analysis for Evaluation of Qaidam Salt Lake Circular Economy

Based on the formulas of intuitionistic fuzzy sets, and then use the intuitionistic fuzzy weighted averaging (IFWA) operator to evaluate salt lake recycle economic index system. The mainly steps are as follows:

Firstly, based on the formula (36.1) to calculate the every attributive intuition fuzzy entropy, and we can get six value, that is E_{G1}, E_{G2}, E_{G3}, E_{G4}, E_{G5}, E_{G6} Secondly, based on the formula (36.2) to calculate the every attributive objective weight; Thirdly, use the formula (36.3) correct weight with the subject weights, where, the subject weights could come from experts scoring; Fourthly, use the formula (36.4) we can get the value of IFWA based on sets of programs; Finally, based on the formula (36.5) we can get the value of the S (IFWA (Y_i)) and select the maximum score value for the optimal solution.

36.4 Conclusion

With the continuous development of circular economy, the effective index system is conducive to better monitoring and evaluation for circulating levels, and realize the minimum consumption to get the maximize development benefits. This paper try to propose the evaluation index system of the salt lake circular economy, and use the intuitionistic fuzzy sets and intuitionistic fuzzy weighted averaging (IFWA) operator algorithms, and take into account the objective and subjective weights comprehensive to determining weight, then get the more accurately weight, and evaluation of the program can achieve eventually.

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