Evaluation of Regional Energy Structure to Low Carbon Based on Optimal Evaluation Method

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Abstract
To study regional energy structure to low carbon, a selecting model for the optimal evaluation method is built, according to the generalized distance minimum principle. Based on the model, the rough set theory is taken to be more suitable than the entropy for one given regional energy structure to low carbon in 2001-2012. Evaluation results show that the given regional energy structure to low carbon is mainly reflected comprehensively by SO_2 emissions, carbon productivity, energy intensity, proportion of renewable energy consumption and GDP growth rate, etc. Additionally, a environmental thought "treatment after pollution", as well as an imbalance between energy planning and economic development results in the given regional energy structure to low carbon has fluctuated greatly in recent years. Therefore, the given regional energy structure adjustment to low carbon should make the socioeconomic benefits as priority, the energy planning benefits as means, and pay attention to environmental benefits, so as to transform the economic development in a fashion from a "fast and good development" to a "good and fast development".
Key words: REGIONAL, ENERGY STRUCTURE ADJUSTMENT TO LOW CARBON, EVALUATION, THE OPTIMAL EVALUATION METHOD

1. Introduction

China’s economic development has continuously shown extensive features, casting strong reliance on energy consumption. Since 2000 the average annual growth rate of energy consumption has increased to around 7.34%, in 2013 reached 3750million tce. However, the energy consumption structure in China is extremely unreasonable. Coal consumption accounted for more than 70% of the total consumption with a long-term stability, which results in the contribution rate of energy consumption to economic growth is declining, and carbon emissions caused by energy consumption are rising rapidly. The unreasonable energy structure inhibits development of low-carbon economy in China. Therefore, optimizing the energy structure bears great potential to achieve the goal of low-carbon economy in China.

About energy structure optimization, Song Jiashu [1], Toshihiko Nakata [2], Li Jia and Zhang Baosheng [3], through analysis on the effect of energy structure change on economic growth, industrial structure, import and export trade, environment, etc, argued that the energy structure optimization should consider restriction of macroeconomic system. As the practice of low-carbon economy mode, S. Jebaraj and S. Iniyan [4], Lin Boqiang, Yao Xin, et al. [5], Wang Di, Nie Rui, et al [6] based on a comprehensive consideration of the restriction conditions such as energy conservation and emissions reduction, constructed an energy structure optimization model by using a goal programming method, and designed optimization project of energy structure. The studies on the existing problems and how to adjust the energy structure has obtained a universal understanding, but related studies on evaluation of the energy structure to low-carbon are few, and largely limited to impact of energy structure optimizing cost to macroeconomic factors from perspective of the qualitative research. There were a small amount of quantitative evaluation research on level of energy structure to low-carbon, including Wang Xian, Gu Lixia, et al. [7], Li Hong, Dong Liang, et al [8], using the analytic hierarchy process (AHP) conducted a comprehensive evaluation of different renewable energy development from four aspects of economy, technology, resource and environment and ranked them according to prioritization. Lin Boqiang, Yao Xin, et al [5] evaluated impact of increasing energy costs caused by energy structure optimizing on macroeconomic through a construction of CGE model. Wang Feng, Feng Genfu [9] used co-integration techniques and Markov chain model to evaluate the potential contribution of the energy structure optimization under different scenarios to carbon intensity.

Through accurate evaluation of the energy structure, it is useful to find out specific manifestation of unreasonable energy structure, so as to put forward targeted countermeasures. Therefore, with the deepening research on energy structure, the quantitative measure of evaluation of energy structure to low-carbon is bound to become one of the hot spots. In practice, commonly used evaluation methods mainly include principal component analysis, AHP, entropy method, maximum deviation method, rough set theory, etc., with each method having its advantages and disadvantages. So precondition of research is to choose one optimal evaluation method which will be both suitable for specific areas and objects. Therefore, this paper has great significance to evaluate energy structure to low-carbon in Hebei Province through constructing optimal evaluation selecting model to choose the optimal evaluation method.

2. Construction of optimal evaluation selecting model and evaluating index system of energy structure to low carbon

2.1. Construction of optimal evaluation selecting model

2.1.1. Standardization of index

Set X_{ij} as the standardized value of the j_{th} index of the i_{th} evaluating object, x_{ij} as the actual observed value of the j_{th} index of the i_{th} evaluating object, I as the number of evaluating objects; $\min_{1\leq i\leq I} x_{ij} = m_j$ stands for that in a number of I evaluating objects, the minimal observed value of the j_{th} index is m_j; similarly, $\max_{1\leq i\leq I} x_{ij} = M_j$ stands for that in a number of I evaluating objects, the maximal observed value of the j_{th} index is M_j.

The standardization formula for positive indicator [10]:

$$X_{ij} = \frac{x_{ij} - m_j}{M_j - m_j} \tag{1}$$

(2) The standardization formula for negative indicator [10]:

$$X_{ij} = \frac{M_j - x_{ij}}{M_j - m_j} \tag{2}$$

According to the above standardization formula, the standardized value $X_{ij} \in [0, 1]$.

2.1.2. Model construction based on the generalized distance minimum principle

$G_1, G_2, G_3, \cdots, G_K$ are K kinds of evaluating methods suitable for one evaluating question. Making generalized distance between the weighted score of each appraisal object and the ideal point reach the minimum is the basis of choosing the optimal evaluation method, and then based on this to construct the selecting model of optimal evaluation method [11].

$$\begin{cases} \min D = \min \sum_{i=1}^{I} D_i = \left| \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \theta_k w_{kj} \left(1 - X_{ij}\right) \right| \\ \sum_{k=1}^{K} \theta_k = 1, \theta_k \geq 0 \end{cases}$$

(3)

There into D stands for the generalized distance between the weighted score of I evaluating objects and the ideal point, θ_k for the combination weight coefficient of the k_{th} evaluation method, w_{kj} for the weight of j_{th} index calculated by the k_{th} evaluation method.

According to model (3),

$$\sum_{i=1}^{I} D_i = \sum_{k=1}^{K} D_k \tag{4}$$

namely,

$$\sum_{i=1}^{I} \sum_{j=1}^{J} w_{kj} \left(1 - X_{ij}\right) = I - \sum_{i=1}^{I} \sum_{j=1}^{J} w_{kj} X_{ij}, \quad k = 1 \cdots K \tag{5}$$

Then, model (3) can be changed into

$$\begin{cases} \min D = \left|\sum_{k=1}^{K} \theta_k \cdot (I - \sum_{i=1}^{I} \sum_{j=1}^{J} w_{kj} X_{ij})\right| \\ \sum_{k=1}^{K} \theta_k = 1, \theta_k \geq 0 \end{cases} \quad (6)$$

since $0 \leq w_{kj} \leq 1$, $0 \leq X_{ij} \leq 1$, then $I - \sum_{i=1}^{I} \sum_{j=1}^{J} w_{kj} X_{ij} \geq 0$, model (6) can be simplified as

$$\begin{cases} \min D = \sum_{k=1}^{K} \theta_k \cdot (I - \sum_{i=1}^{I} \sum_{j=1}^{J} w_{kj} X_{ij}) \\ \sum_{k=1}^{K} \theta_k = 1, \theta_k \geq 0 \end{cases} \quad (7)$$

Assuming that the p_{th} kind of evaluation method makes the shortest distance between the evaluating object and the ideal point, namely, $\min(I - \sum_{i=1}^{I} \sum_{j=1}^{J} w_{kj} X_{ij}) = I - \sum_{i=1}^{I} \sum_{j=1}^{J} w_{pj} X_{ij}$, then the solution of model (7) is

$$\begin{cases} \theta_p = 1 \\ \theta_k = 0, (k = 1,2,3, \cdots K, k \neq p) \end{cases} \quad (8)$$

So on each index, evaluating method G_p is better than the others, which makes G_p the optimal one.

2.1.3. Selecting of evaluation methods

In previous studies, according to the degree of objectivity the widely used evaluation methods can be divided into subjective evaluation methods (such as analytic hierarchy process (AHP), Delphi method, etc.) and objective evaluation methods (such as principal component analysis, rough set theory, entropy value method, etc.), each evaluation methods with advantages and disadvantages. The subjective evaluation method is not restricted by statistics but easily influenced by subjective factors. Objective evaluation method can be exempt from personal experience and influence of subjective consciousness, therefore is more objectivity but also more rigid, lack of flexibility. Purpose of establishing an selecting model of optimal evaluation method is to reduce the influence of the personal subjective to a great extent, so as to make ensure the reliability and accuracy of evaluation results. Based on this purpose, this paper adopts rough set theory and entropy value method which are widely used and relatively systematic in objective method in order, to conduct an empirical research on regional energy structure to low-carbon evaluation.

Knowledge reduction of Rough Set Theory [12, 13]

The Rough set theory was put forward by a Polish mathematician Z. Pawlak in 1982, a mathematical tool of processing the fuzzy and uncertain knowledge. Its core concept is on the premise of maintaining the classification ability, to delete unimportant and irrelevant knowledge by knowledge reduction.

Definition1: set U set is not empty, R is an equivalence relation on U, then U/R stands for all the equivalence class of R, $K = (U, \boldsymbol{R})$ for knowledge base, thereinto, $\boldsymbol{R}$ is the set of equivalence relation on U, U called theory domain.

Definition2: if $\boldsymbol{P} \subseteq \boldsymbol{R}$, and $\boldsymbol{P} \neq \emptyset$, then $\cap P$ (the intersection of all the equivalence relation in p) is also an equivalence relation, called the indistinguishable relationship on p, denoted by $ind(\boldsymbol{P})$.

Definition3: set $\boldsymbol{R}$ is gens of equivalence relation, $R \in \boldsymbol{R}$, if $ind(\boldsymbol{R}) = U/ind(\boldsymbol{R} - \{R\})$, then R is unnecessary in $\boldsymbol{R}$; Otherwise R is necessary in $\boldsymbol{R}$. If every $R \in \boldsymbol{R}$ is necessary in $\boldsymbol{R}$, then $\boldsymbol{R}$ is independent; Otherwise dependent.

Definition4: set $\boldsymbol{Q} \subseteq \boldsymbol{P}$, if $\boldsymbol{Q}$ is independent, and $ind(\boldsymbol{P}) = ind(\boldsymbol{Q})$, then $\boldsymbol{Q}$ is a reduction of $\boldsymbol{P}$, denoted by $red(\boldsymbol{P})$.

Definition5: set P and Q are the equivalence relation in U, $Pos_P(Q)$ means that Q is the positive domain of P, referring to the collection that can be accurately classified into the equivalence class of Q according to the classifying information U/R.

Definition6: set $S = (U, \boldsymbol{R}, V, f)$ as a knowledge representation system, $P, Q \subseteq \boldsymbol{R}$, then the importance of attribute R is as follows:

$$\mu_R = \frac{\left||Pos_P(Q)| - |Pos_{P-|R|}(Q)|\right|}{|U|} \quad (9)$$

According to the concept of attribute importance of rough set theory, evaluate the importance of each index μ, for those $\mu > 0$ conduct the "normalization" processing, and then get the indices weights w_j^R :

$$w_j^R = \mu_j / \sum_{j=1}^{J} \mu_j \quad (10)$$

Steps of weights determination by entropy [14]

"Normalization" processing of different objects in the same index value:

$$s_{ij} = \frac{X_{ij}}{\sum_{i=1}^{I} X_{ij}}, j = 1 \cdots J \quad (11)$$

Thereinto, X_{ij} is the original value of the j_{th} index of the i_{th} evaluating object, s_{ij} is the corresponding normalized value.

entropy calculation

$$e_j = -\sum_{i=1}^{I} s_{ij} \ln(s_{ij}) / \ln I \quad (12)$$

There into, e_j is the entropy of the j_{th} index, I is the number of evaluating objects.

entropy determination

$$w_j^E = \frac{1 - e_j}{\sum_{j=1}^{J}(1 - e_j)} \quad (13)$$

There into, w_j^E for the weights of the j_{th} index determined by entropy, J is the number of index.

2.2. The construction of evaluating index system of regional energy structure to low carbon

Low-carbon, narrow understanding of it is improvement of carbon production capacity, namely the reduction of carbon emissions per unit by GDP. The general concept refers to sustainable economic development mode characterized by low energy consumption, low pollution and low emissions [15, 16]. Energy structure adjustment to low carbon refers to that under the realization of social economic development goals, by formulating scientific and reasonable energy planning, adjust the energy structure, and improve energy efficiency, so as to reduce pollution and emissions. Based on the connotation of energy structure adjustment to low carbon, the related research results at domestic and abroad [17, 18] as well as "The 12th Five-Year Plan for Energy Conservation and Emissions Reduction ", this paper constructs three criteria, including socioeconomic benefits, energy planning benefits and environment benefits under principles of comprehensive, scientific, and index availability. The evaluating index system of energy structure to low-carbon, which includes 11 specific indices is shown in Table1. Among them, the socioeconomic benefits include the following four indices: GDP growth rate, total volume of import and export, industrial structure, and carbon productivity. Energy planning benefits includes four indices: energy intensity, total energy consumption, proportion of coal consumption, and proportion of renewable energy consumption. Environmental benefits include carbon dioxide (CO_2) emissions, chemical oxygen demand (COD) emissions, and sulfur dioxide (SO_2) emissions. Detailed description of every index is shown in Table 1.

Table 1. The evaluating index system of regional energy structure to low-carbon

Primary index	Secondary index	The third level index		
Name	Name	Name (Unit)	Statement of calculation	Direction
level of energy consumption structure to low-carbon (A)	socioeconomic benefits (B_1)	GDP growth rate(%)(B_{11})	Data source: Statistical Yearbook of China over the years	(+)
		total volume of import and export (10^8 dollar)(B_{12})	according to the domestic destination and supply Data source: Statistical Yearbook of China	(+)
		industrial structure(%) (B_{13})	the tertiary industry output value /GDP	(+)
		carbon productivity (10^4 yuan /ton carbon)(B_{14})	GDP/ CO_2 emission	(+)
	Energy planning benefits (B_2)	energy intensity (tce/10^4 yuan)(B_{21})	energy consumption per unit GDP （energy consumption/GDP）	(-)
		total energy consumption (10^4 tce) (B_{22})	Data source: Statistical Yearbook of China	(-)
		proportion of coal consumption(%)(B_{23})	Data source: Statistical Yearbook of China	(-)
		proportion of renewable energy consumption (%)(B_{24})	Data source: Statistical Yearbook of China	(+)
	Environment benefits (B_3)	CO_2 emission (10^4 ton carbon)(B_{31})	$\sum i$ kinds of energy consumption×coefficient of carbon emissions	(-)
		chemical oxygen demand emissions (10^4 ton)(B_{32})	Data source: Statistical Yearbook of China	(-)
		SO_2 emission (10^4 ton)(B_{33})	Data source: Statistical Yearbook of China	(-)

Note: (+) for positive index, (-) for negative index

3. Empirical analysis

3.1.Data selecting and processing

Based on the principle of scientificity and data availability, this paper selects a total of 12 years from 2001 to 2012 as the research object to evaluate the energy structure to low-carbon in Hebei Province. The raw data of every year are shown in Table 2.

Table 2. The raw data of the evaluating index of energy structure to low-carbon from year 2001-2012 in Hebei Province

Year	B_{11}	B_{12}	B_{13}	B_{14}	B_{21}	B_{22}	B_{23}	B_{24}	B_{31}	B_{32}	B_{33}
2001	9.37	58.16	34.0	0.621	2.32	12114.29	91.84	0.04	8879	65.2	128.9
2002	9.09	68.29	34.6	0.614	2.34	13404.53	91.12	0.03	9809	64.0	127.9
2003	15.00	96.86	33.5	0.616	2.39	15297.89	92.78	0.07	11234	63.6	142.2
2004	22.49	152.80	31.5	0.668	2.40	17347.79	91.14	0.10	12687	65.8	142.8
2005	18.10	193.28	33.3	0.689	2.42	19835.99	91.82	0.12	14531	66.1	149.6
2006	14.54	234.77	33.8	0.719	2.35	21794.09	91.59	0.10	15958	68.8	154.5
2007	18.66	344.72	34.0	0.787	2.25	23585.13	92.36	0.09	17300	66.7	149.2
2008	17.67	508.85	33.2	0.898	2.11	24321.87	92.31	0.08	17831	60.5	134.5
2009	7.64	402.67	35.2	0.925	2.00	25418.79	92.51	0.07	18636	57.0	125.3
2010	18.33	620.52	34.9	1.021	1.93	27531.11	90.45	0.74	19974	54.6	123.4
2011	20.21	841.50	34.6	1.151	1.86	29498.29	89.61	1.08	21297	138.9	141.2
2012	8.40	822.89	35.3	1.225	1.14	30250.21	88.80	1.56	21699	134.9	134.1

Note: see Table 1 for all the index name and unit the letter and value respectively stand for

The specific connotation of the indicators and calculation show that, the GDP growth rate, the total import and export, industrial structure, carbon productivity, the proportion of renewable energy consumption are positive indices, so accordingly they are standardized processed by the positive index standardization formula (1); And the energy intensity, the total energy consumption, proportion of coal consumption, CO_2 emissions, chemical oxygen demand (cod) emissions, and SO_2 emissions are negative indices, so accordingly they are standardized processed by negative index standardization formula (2). The standardized values of all these indices are shown in Table 3.

Table 3. The standardized value of all these indices

Year	B_{11}	B_{12}	B_{13}	B_{14}	B_{21}	B_{22}	B_{23}	B_{24}	B_{31}	B_{32}	B_{33}
2001	0.276094	0.540541	0.003724	0.160714	1.000000	0.019048	0.580442	1.000000	1.000000	0.809068	0.719293
2002	0.116498	0.675676	0.013035	0.178571	0.949811	0.009524	0.296530	0.670079	0.976250	0.874315	0.823151
2003	0.097643	0.837838	0.000000	0.142857	0.879316	0.000000	0.523659	0.578498	0.957149	0.888551	0.855305
2004	0.495623	0.540541	0.003724	0.053571	0.775869	0.038095	0.000000	0.540403	0.912219	0.893208	0.395048
2005	1.000000	0.000000	0.100559	0.035714	0.663868	0.066667	0.517350	0.072509	0.824172	0.867103	0.376206
2006	0.704377	0.486486	0.139665	0.000000	0.527920	0.085714	0.302839	0.142538	0.752551	0.863996	0.157556
2007	0.464646	0.621622	0.195531	0.125000	0.420935	0.066667	0.375394	0.000000	0.592749	0.831790	0.000000
2008	0.742088	0.675676	0.322160	0.303571	0.323078	0.057143	0.132492	0.166986	0.432947	0.856104	0.168875
2009	0.675421	0.459459	0.528864	0.553571	0.282825	0.047619	0.148265	0.225037	0.588575	0.930315	0.642765
2010	0.000000	1.000000	0.579143	0.750000	0.222892	0.038095	0.085174	0.497840	0.392205	0.971485	0.938907

2011	0.719865	0.918919	0.757914	0.875000	0.107481	0.676190	0.735016	0.395385	0.309846	1.000000	1.000000
2012	0.846465	0.837838	1.000000	1.000000	0.000000	1.000000	1.000000	0.290501	0.000000	0.000000	0.427331

Note: see Table 1 for the indices the letters stand for

3.2. Determination of index weight and selecting of optimal evaluating method

3.2.1. Determination of index weight based on Rough Set Theory

A discretization process is conducted on the processed data with k-means clustering analysis (class number set to 3) by SPSS16.0 statistical software. The result sees Table4.

The reduction process and results of the energy structure to low-carbon index in Hebei Province according to the theory of rough set knowledge reduction are shown in Table 5. According to the definition3, because of $U/ind(\mathbf{R}) = U/ind(\mathbf{R} - \{\cap B_{12}\})$, the presence of B_{12} is unnecessary, so B_{12} should be deleted and the remaining 10 indices are retained. Therefore, in the energy structure to low-carbon in Hebei Province, the socioeconomic benefit is mainly comprehensively reflected by three indices, including the GDP growth rate, industrial structure and carbon productivity; the energy planning is benefitted by four indices, including the total energy consumption, energy intensity, proportion of coal consumption, and the proportion of renewable energy consumption; the environmental benefit is mainly by three indexes, including carbon indices emissions, chemical oxygen demand (COD) emissions, sulfur dioxide emissions.

Table 4. Data after discretization

Year	B_{11}	B_{12}	B_{13}	B_{14}	B_{21}	B_{22}	B_{23}	B_{24}	B_{31}	B_{32}	B_{33}
2001	2	2	3	2	1	3	2	1	1	2	3
2002	3	2	3	2	1	3	2	2	1	2	3
2003	3	3	3	1	1	3	2	2	1	2	3
2004	2	2	3	1	2	3	3	2	2	2	2
2005	1	1	3	1	2	3	2	3	2	2	2
2006	2	2	3	1	2	3	2	3	2	2	1
2007	2	2	2	1	2	3	2	3	2	2	1
2008	2	2	2	2	3	3	3	3	3	2	1
2009	2	2	2	2	3	3	2	3	3	3	2
2010	3	3	2	3	3	3	3	2	3	3	3
2011	2	3	1	3	3	1	1	2	3	3	3
2012	1	3	1	3	3	2	1	2	3	1	2

Note: For the letters standing for see Table 1.

Table 5. Index reduction process and result of rough set knowledge reduction

index	(U, R)	$\cap P$	$U/ind(R\text{-}\{R\})$
Socioeco-nomic benefits	U={1,2,3,4,5,6,7,8,9,10,11,12} $R=\{\cap B_{11}, \cap B_{12}, \cap B_{13}, \cap B_{14}\}$	$\cap B_{11}$={{1,4,6,7,8,9,11},{2,3,10},{5,12}}	{{1,2},{3},{4,6},{5},{7},{8,9},{10},{11,12}}
		$\cap B_{12}$={{1,2,4,6,7,8,9},{3,10,11,12},{5}}	{{1},{2},{3},{4,6},{5},{7},{8,9},{10},{11},{12}}
		$\cap B_{13}$={{1,2,3,4,5,6},{7,8,9,10},{11,12}}	{{1},{2},{3},{4,6,7},{5},{8,9},{10},{11},{12}}
		$\cap B_{14}$={{1,2,8,9},{3,4,5,6,7},{10,11,12}}	{{1,4,6},{2},{3},{5},{7,8,9},{10},{11},{12}}
		$U/ind(R)$={{1},{2},{3},{4,6},{5},{7},{8,9},{10},{11},{12}}	
Energy planning benefits	U={1,2,3,4,5,6,7,8,9,10,11,12} $R=\{\cap B_{21}, \cap B_{22}, \cap B_{23}, \cap B_{24}\}$	$\cap B_{21}$={{1,2,3},{4,5,6,7},{8,9,10,11,12}}	{{1},{2,3},{4,10},{5,6,7,9},{8},{11},{12}}
		$\cap B_{22}$={{1,2,3,4,5,6,7,8,9,10},{11},{12}}	{{1},{2,3},{4},{5,6,7},{8},{9},{10},{11,12}}
		$\cap B_{23}$={{1,2,3,5,6,7,9},{4,8,10	{{1},{2,3},{4},{5,6,7},{8,9},{10},

		},{11,12}}	{11},{12}}
		$\cap B_{24}$={{1},{2,3,4,10,11,12},{5,6,7,8,9}}	{{1,2,3},{4},{5,6,7},{8,10},{9},{11},{12}}
		$U/ind(R)$={{1},{2,3},{4},{5,6,7},{8},{9},{10},{11},{12}}	
Environm-ental benefits	U={1,2,3,4,5,6,7,8,9,10,11,12} R={$\cap B_{31}$, $\cap B_{32}$, $\cap B_{33}$, $\cap B_{34}$}	$\cap B_{31}$={{1,2,3},{4,5,6,7},{8,9,10,11,12}}	{{1,2,3},{4,5},{6,7,8},{9},{10,11},{12}}
		$\cap B_{32}$={{1,2,3,4,5,6,7,8},{9,10,11},{12}}	{{1,2,3},{4,5},{6,7},{8},{9,12},{10,11}}
		$\cap B_{33}$={{1,2,3,10,11},{4,5,9,12},{6,7,8}}	{{1,2,3},{4,5,6,7},{8},{9,10,11},{12}}
		$U/ind(R)$={{1,2,3},{4,5},{6,7},{8},{9},{10,11},{12}}	

Note: the bold part stands for $U/\mathrm{ind}(\mathbf{R}) = \mathrm{U}/\mathrm{ind}(\mathbf{R} - \{\mathrm{R}\})$, according to knowledge reduction theory, they are reduction indices.

According to the definition4 and definition5 of rough set knowledge reduction theory, $ind(\boldsymbol{P}) = ind(\boldsymbol{Q}) = ind(\boldsymbol{R})$, then based on definition6 and formula(9) and (10), the importance and weights of single layer of the secondary index of energy structure to low-carbon evaluation in Hebei Province can be obtained, and the importance and weight of the primary index can be calculated. At last, the comprehensive weights of every secondary index can be obtained and is shown in Table 6.

Table 6. The weights of rough set theory and entropy theory of Hebei's energy structure to low carbon index

Primary index	importance	weight	Secondary index	Weight of rough set theory			entropy
				importance	single layer	comprehensi-ve weight	
B_1	61/156	0.3245	B_{11} (+)	4/12	0.3077	0.0999	0.0642
			B_{12} (+)	_	_	_	0.0319
			B_{13} (+)	3/12	0.2308	0.0749	0.1616
			B_{14} (+)	6/12	0.4615	0.1498	0.1267
B_2	69/180	0.3182	B_{21} (-)	6/12	0.4000	0.1273	0.0647
			B_{22} (-)	2/12	0.1333	0.0424	0.2745
			B_{23} (-)	2/12	0.1333	0.0424	0.0763
			B_{24} (+)	5/12	0.3334	0.1061	0.0773
B_3	62/144	0.3573	B_{31} (-)	3/12	0.2500	0.0893	0.0402
			B_{32} (-)	2/12	0.1667	0.0595	0.0239
			B_{33} (-)	7/12	0.5833	0.2084	0.0587

Note: see Table 1 for the indices the letters stand for; the importance and weight of primary index is calculated by rough set theory; (+) for positive index, (-) for negative index

3.2.2. Determination of index weights based on entropy method

According to the steps of weights determination by entropy, put the standardized value X_{ij} into formula (11), then S_{ij} is obtained. Then put S_{ij} into formula (12), the entropy value of every index e_j is obtained, and then put e_j into (13), the corresponding w_j^E can be obtained, as shown in Table 6.

3.2.3. Selecting of optimal evaluation method and construction of evaluating model

(1) The selecting of optimal evaluation method

Set the distance between each appraisal object and the ideal point determined by the weight through rough set theory is D_R, then $D_R = I - \sum_{i=1}^{I}\sum_{j=1}^{J} w_j^R X_{ij} = 6.3013$

Set the distance between each appraisal object and the ideal point determined by the weight through the entropy theory is D_E, then $D_E = I - \sum_{i=1}^{I}\sum_{j=1}^{J} w_j^E X_{ij} = 7.6302$

It is obvious that $D_R < D_E$, namely, the weight determined by rough set theory makes the shortest distance to ideal point. Therefore, for Hebei's energy structure to low carbon in 2001-2012, rough set theory is the optimal evaluation method.

(2)Construction of evaluating model based on optimal evaluation method

Set X as the standardized numerical matrix of energy structure to low carbon index in Hebei

Province in 2001-2012, W^T as the matrix transposed weight determined by rough set theory, then the score of energy structure to low-carbon in Hebei Province in 2001-2012 is:

$$Z = W^T \times X = [Z_1, Z_2, \cdots Z_T] \quad (14)$$

There into, Z_t stands for the score of the t_{th} year in Hebei Province, $W^T = [W_1^R, W_2^R, \cdots W_J^R]$ (W_j^R stands for the weight determined by rough set theory of the j_{th} index), $X = \begin{bmatrix} X_{t1} & \cdots & X_{tJ} \\ \vdots & \vdots & \vdots \\ X_{T1} & \cdots & X_{TJ} \end{bmatrix}$ (X_{tj} is the value of the j_{th} index of the t_{th} year).

3.2.4. Evaluating analysis of energy structure to low carbon in Hebei Province based on the optimal evaluation method

According to the formula (14), the score of socioeconomic benefit, energy planning benefit, and environmental benefit as well as the total score of energy structure adjustment to low carbon in the year of 2001-2012 in Hebei Province are shown in Figure 1.

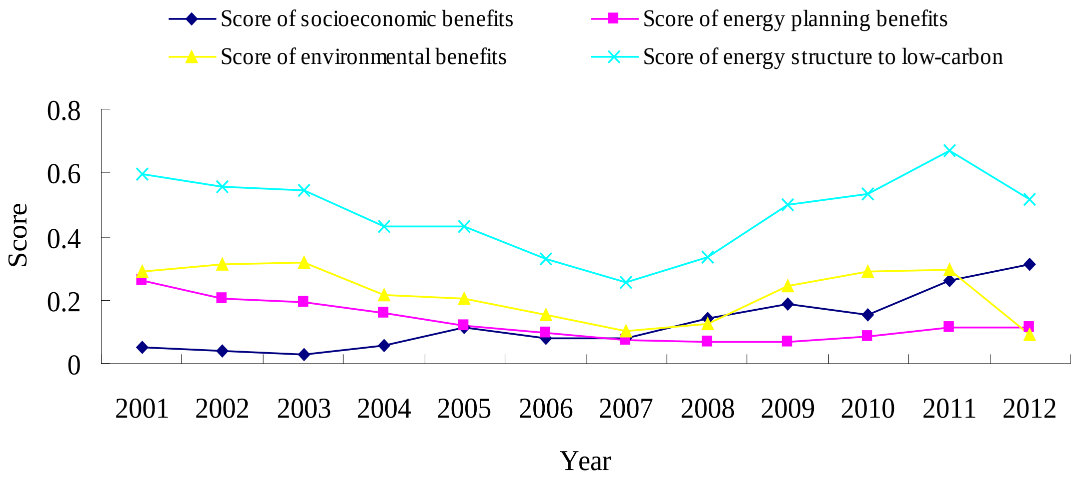

Figure 1. Evaluation result of energy structure to low carbon in Hebei Province

(1)Socioeconomic benefits analysis

As Figure 1 shows, since 2001, the socioeconomic benefits of energy structure adjustment to low carbon in Hebei have been rising year by year, except for 2005 and 2009. In 2012, it scored 0.3093. Since 2010 the growth rate has increased significantly, up to about 43%. It reflects that the energy structure adjustment to low carbon in Hebei Province in recent years has mainly focused on improving the socioeconomic benefits, and at the same time the energy structure adjustment low carbon has been obviously improved in satisfying the socioeconomic benefits. In addition, before 2007 the proportion of socioeconomic benefits scoring in the total score is relatively lower (below 25%), significantly lower than the energy planning benefit score proportion (27%) and environmental benefits (45%), which reflects that the energy structure adjustment to low carbon in Hebei Province during this period's has small contribution to the socioeconomic benefits. However, since 2007 the scoring proportion of socioeconomic benefit has improved significantly (from 30%), up to about 60.19% in 2012, suggesting that socioeconomic benefits played an important role in energy structure adjustment to low carbon in Hebei Province.

(2) Energy planning benefits analysis

Since 2001, the changing of energy planning benefits of energy structure adjustment to low carbon in Hebei Province has been at a constant speed. From 2001 to 2008 the energy planning benefits took a declining trend, with decline rate at about 17.2%. This period was right at the fast development time of social economy in Hebei, in which energy planning could not meet the need of social economy, in addition, in order to pursue high growth rate, energy planning was neglected. It was not until 2009 that energy planning benefits started to increase year over year, with rising rate at about 15.6%, which shows that the social economy in Hebei Province started on a stable and healthy path, focusing on a more harmonious development of the economy and energy.

(3)Environmental benefits analysis

The environmental benefits of energy structure adjustment in Hebei Province have gone through great fluctuation since 2001, taking an irregular stretching shape of "M", partially reflecting the environmental management in Hebei Province have been taking a principle of "treatment after pollution", a temporary solution rather than a permanent cure, which casts a great unfavorable impact on the ecological environment. In 2012 because of the surge of chemical oxygen demand (cod) emissions, increasing almost 155% over 2011, the environmental benefit fell to the lowest in nearly 12 years (0.0891), decreased by nearly 70% over 2011.

(4)Analysis on energy structure adjustment to low-carbon

Due to the large scoring proportion of environmental benefit in total score, stabled at over 40%, except in 2012, the score trend of energy structure to low carbon in Hebei Province is close to that of the environmental benefit indicating that environmental benefit has a bigger influence on the energy structure adjustment to low carbon in Hebei Province. Therefore more efforts and attention should be put on environment management. The score fluctuation of energy structure to low carbon is bigger, declining with an decline rate at about 12.71% year over year before 2007 and fell to 0.2545 in 2007. Then it rose year by year with an rising rate at about 28.35%, up to 0.6708 in 2011. But due to the sharp decline of environmental benefit in 2012, the total score dropped to 0.5139, lower than the previous year by 23.39%.

4. Conclusions

The Rough set theory and entropy value method are two evaluation methods with wide application fields. But based on the generalized distance minimum theory, rough set theory is optimal to the evaluation of energy structure to low carbon in Hebei Province in 2001-2012. According to the weights determined by rough set theory, Hebei's energy structure to low carbon is mainly reflected comprehensively by SO_2 emission, carbon productivity, energy intensity, proportion of renewable energy consumption and GDP growth rate, etc. Based on the evaluation result, due to the environmental principle "Treatment after Pollution", as well as the imbalance between the energy planning and economic development, Hebei's energy structure to low carbon fluctuated greatly in recent years. Therefore, Hebei's energy structure adjustment to low carbon should take socioeconomic benefits as the key, guaranteeing the realization of GDP growth; the energy planning benefit as means, effectively controlling energy consumption, reducing the proportion of coal consumption and raising the proportion of renewable energy consumption; additionally pay attention to environmental benefit, cutting down CO_2 and SO_2 emission; and gradually transform economic development way from the "Fast and Good Development" to the "Good and Fast development".

Acknowledgements

This work was supported by Natural Science Foundation of Hebei Province (G2015501064), Social Science Fund Project of Hebei Province (HB14YJ097) and Yanshan University Young Teachers' Independent Research Project Topic (14SKA003).

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