Research on Environmental Innovation Effect Based on Low Carbon Evaluation System①*

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Abstract From the view of environment innovation, this article firstly sets up an evaluation indicator system of low-carbon economy for environment innovation, and based on dissipation theory,the paper introduces gray relational entropy(GRM) as the analysis methods. Secondly the paper makes an empirical research on the environmental innovation effect of low-carbon economy by taking Liaoning Province as an example, in the analysis process the raw data cited according to the five low carbon indicators. Finally the paper draws a scientific and precise entropy change series of low carbon system with the gray relational entropy model, and as to Liaoning Province the results means that environmental innovation effect of low carbon system in Liaoning Province is in a disorderly and inefficient situation.
Key words Environmental innovation; Low-carbon economy; Gray relational entropy

1 Introduction

Since the 21st century, there are numerous global problems and challenges such as climate change, strategic resource constraints and financial crisis frequently so on, which need a transformation from the traditional development pattern focusing on economic growth to the low carbon development pattern. As an effective carrier of sustainable development environmental ethics the low-carbon economy is the efficient approach to establish a saving society.

Nowadays the low carbon effect draws Wide attention from the international community. Friedl (2003) considers that the relationship between CO_2 emissions and economy growth of Austria during the 1960- 1999 was "N" type rather than the inverted "u"shape. Treffers (2005) discusses the possibility of reduction of GHG emissions of German by 80% due to 2050based on 1990 and think it is possible to realize the strong economy growth and the reduced GHG emissions at the same time. Awase (2006) proposes that the emissions change is decomposed into three factors: carbon intensity, energy efficiency and economic activities and plans to reduce CO_2 emissions by 60~80%[1]. Climate Group (2008) introduces the concept of low carbon economy in the published report"Surplus: the growth of low-carbon economy", and manifests that low-carbon economy has a higher return on investment.

At present, China has established "low-carbon economy" as the important development direction of future "12th Five-Year" strategic planning. While more and more scholars transfer research focus to this innovative economy growth mode. Zhuang Guiyang (2005) thinks that the substance of low carbon is the problem of energy efficiency and clean energy structure, core of which is energy technology innovation and system innovation. Jin Yueqin (2007) analyzes the constraints that China faces in the transition to low carbon economy, and proposes a "win-win" economy transition strategy of "development and low carbon" [2]. Fu Yun (2008) considers that low-carbon economy is a kind of green economic development model, and it is based on low power consumption, low pollution, low emissions and high performance, high efficiency, high efficiency (3 lows and 3 highs) which takes carbon neutrality as the development methods of green economic development model[3].

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From the view point of sustainable development following the article makes a systematical and deep research on the environmental innovation effect of low-carbon economy.

2 Evaluation Mechanism of Low Carbon System

2.1 Determination of evaluating indicators

According to the real and objective analysis based on comprehensive data, this article takes the relevant data of "China Sustainable Development Strategy Report" (2009 and 2010) and "China Statistical Yearbook" (2009) as the main source of information. And in order to achieve the integrated and continual sample space, the article selects 5 low carbon evaluation indicators from 45 sustainable development indicators according to the above first report. The name and implication of the low carbon evaluation indicators are shown as the Table 1.

Table 1 Evaluation Indicators of Low Carbon System on Environmental Innovation Effect

	Name of Low carbon Evaluation Indicator	Implication of the Low Carbon Evaluation Indicator
1	Economic Intensive Index	● Water Consumption / per million output value ● Energy Consumption / per million output value ● Waste-water Emissions / per million output value ● Waste-air Emissions / per million output value ● Solid-waste Emissions / per million output value
2	Emissions Intensity Index	● Waste-air Emissions level ● Waste-water Emissions Level ● Waste Emissions Level
3	Air Pollution Index	● SO_2 Emissions Level ● Dust Emissions Level
4	Water Pollution Index	● Point Source Pollution ● Area Source Pollution
5	Environmental Governance Index	● GDP Proportion of Investment in Pollution Government ● Industrial Waste-water Discharge Standard ● Industrial Boiler Dust Discharge Standard ● Industrial Waste Comprehensive Utilization Rate ● Urban Living Garbage Disposal Rate ● Industrial Water Recycling Rate ● GDP Proportion of Industrial Value in Environmental Protection

2.2 Establishing of the Evaluation Model

(1) Normalization of indicator data: Here, m evaluation dictators are selected which aim to n evaluation targets, then the original data matrix is noted as X, and the dictator data group of ideal evaluation targets is Y :

$$X=\left(x_{ij}\right)_{n*m}=\left(x_{i1},x_{i2},\ldots,x_{im}\right)\quad\left(i=1,2,\ldots,n;j=1,2,\ldots,m\right)$$

$$Y=\left(y_{ij}\right)_{n*m}=\left(y_{i1},y_{i2},\ldots,y_{im}\right)\quad\left(i=1,2,\ldots,n;j=1,2,\ldots,m\right)$$

Since evaluation dictators are different in property and magnitude each other, the normalization of indicator data is necessary to evaluate the statistics confusion, just shown as follows:

$$x_{ij}^{*}=x_{ij}\Big/\frac{1}{n}\sum_{i=1}^{n}x_{ij}\quad\left(i=1,2,\ldots,n;j=1,2,\ldots,m\right)$$
$$y_{ij}^{*}=y_{ij}\Big/\frac{1}{n}\sum_{i=1}^{n}y_{ij}\quad\left(i=1,2,\ldots,n;j=1,2,\ldots,m\right)\qquad(1)$$

(2) Estimation of relation entropy: According to the gray relational analysis (GRA), the relation coefficient that the evaluation object expressed as i corresponding to the j indicator is shown as ξ_{ij}. Then there is:

$$\xi_{ij} = \frac{\Delta(\min) + \rho\Delta(\max)}{\left|x_{ij}^* - y_{ij}^*\right| + \rho\Delta(\max)} \quad (i = 1,2,\ldots,n; j = 1,2,\ldots,m) \tag{2}$$

In the formula (2), $\Delta(\min) = \min\left\{\left|x_{ij}^* - y_{ij}^*\right|\right\}$, $\Delta(\max) = \max\left\{\left|x_{ij}^* - y_{ij}^*\right|\right\}$, and $\rho(0 < \rho < 1)$ is the resolution ratio, here the paper checks the value 0.5.[4][5]

According to the concept of gray relational entropy and relational coefficient distribution map, the gray rational entropy can be expressed as:

$$S_i = -\sum_{j=1}^{m} P_{ij} \ln\left(P_{ij}\right)\Delta S \tag{3}$$

In the formula (3), $P_{ij} = \xi_{ij} \Big/ \sum_{i=1}^{n} \xi_{ij} \quad (i = 1,2,\ldots,n; j = 1,2,\ldots,m)$, which is regarded as gray relational coefficient density. [6]With the smaller gray relational entropy is that the better the structural stability becomes and the more favorably the system develops and evolves.

3 Empirical Studies

3.1 Data sources and variable processing

Firstly, according to the specific sustainable development indicator data cited form "China Sustainable Development Strategy Report" (2009 and 2010) and "China Statistical Yearbook" (2009) this article selects the low carbon index data of Liaoning Province in past years (from 2002 to 2007). On the above basis the paper indexes processing on the environmental innovation effect of low-carbon economy of Liaoning Province. The detailed is shown as Table 2.

Table 2 Environmental Innovation Effect of Low Carbon Economy of Liaoning Province in 2002-2007

Year	Item	Economic Intensive Index	Emissions Intensity Index	Air Pollution Index	Water Pollution Index	Environmental Governance Index
2002	Liaoning Province	107.0	94.9	96.8	97.2	103.5
	Optimum value	120.0	89.2	92.3	93.5	109.1
2003	Liaoning Province	108.1	94.5	96.6	98.0	106.7
	Optimum value	121.8	89.4	91.7	94.1	109.4
2004	Liaoning Province	109.1	94.1	96.7	99.5	104.8
	Optimum value	123.6	89.1	91.6	93.1	107.9
2005	Liaoning Province	109.2	92.2	94.3	96.9	107.2
	Optimum value	125.3	89.2	91.2	92.8	110.8
2006	Liaoning Province	110.0	91.3	94.6	96.1	107.4
	Optimum value	127.2	89.1	91.5	92.5	110.0
2007	Liaoning Province	111.6	91.3	94.4	95.7	107.0
	Optimum value	129.5	89.0	92.2	91.9	109.9

Secondly, the above original data need to be in dimensionless processing, which may take the environmental innovation effect of low-carbon economy of Liaoning Province in 2002 year as an example.

The environmental innovation effect entropy sequence indicator of low-carbon economy of Liaoning Province is shown as following:

$$X = \left(x_{ij}\right)_{n*m} = \left(x_{i1}, x_{i2}, \ldots, x_{im}\right) = (107.0, 94.9, 96.8, 97.2, 103.5)$$

As the reference the optimum sequence dictator is:

$$Y=\left(y_{ij}\right)_{n*m}=\left(y_{i1},y_{i2},\ldots,y_{im}\right)=(120.0,89.2,92.3,93.5,109.1)$$

According to equation (1) the above result applies dimensionless processing, and obtains the environmental innovation effect entropy sequence indicator of low-carbon economy of Liaoning Province, that is:

$$x_{ij}^{*}=x_{ij}\Big/\frac{1}{n}\sum_{i=1}^{n}x_{ij}=\ (1.070,0.950,0.969,0.973,1.036)$$

The optimum innovation effect entropy value after dimensionless process is:

$$y_{ij}^{*}=y_{ij}\Big/\frac{1}{n}\sum_{i=1}^{n}y_{ij}=\ (1.190,0.885,0.916,0.928,1.082)$$

3.2 Calculation of the value and density of gray relational coefficient

According to equation (2) the gray relational coefficient sequence is:

$$\xi_{ij}=\frac{\Delta(min)+\rho\Delta(max)}{\left|x_{ij}^{*}-y_{ij}^{*}\right|+\rho\Delta(max)}=(0.583,0.840,0.929,1,0.991)\quad 4.343$$

In which， $\Delta(\min)=\min\left\{\left|x_{ij}^{*}-y_{ij}^{*}\right|\right\}=0.045$， $\Delta(\max)=\max\left\{\left|x_{ij}^{*}-y_{ij}^{*}\right|\right\}=0.120$， $\rho=0.5$。

With the gray relational coefficient substituted into the formula $P_{ij}=\xi_{ij}\Big/\sum_{i=1}^{n}\xi_{ij}$ the gray relational coefficient density will be obtained:

$$P_i=\left(P_{i1},P_{i2},\ldots,P_{im}\right)=(0.134,0.193,0.214,0.230,0.228)$$

3.3 Calculation of gray relational entropy

With introducing the gray relational coefficient density into equation (3) we will obtain that

$$S_i=-\sum_{j=1}^{m}P_{ij}\log\left(P_{ij}\right)=-(0.134\log0.134+0.193\log0.193+0.214\log0.214+0.2301\log0.230+0.228\log0.228$$

$$=(0.117+0.138+0.143+0.147+0.146$$

$$=0.691$$

Similarly, the above process can be derived in the knowledge sharing mechanism of the other nine provinces and cities in 2009 year with gray relational entropy method, and the relevant results are shown as Table 3.

Table 3 Environmental Innovation Effect GRE of Low-carbon Economy of Liaoning Province

Results	2002	2003	2004	2005	2006	2007
$\Delta(\boldsymbol{min})$	0.045	0.021	0.027	0.016	0.002	0.002
$\Delta(\boldsymbol{max})$	0.120	0.130	0.141	0.138	0.145	0.147
GRE S	0.691	0.685	0.686	0.684	0.677	0.675
Entropy Change ΔS	—	0.006	0.005	0.007	0.014	0.016

4 Conclusions

Apparently, from Table 3 an objective rule can be found that the low carbon system of Liaoning Province will be toward a more disorderly and inefficient direction when the environmental innovation effect occurs the rapid industrial economy growth. Since 2002 Liaoning Province has employed a high-rapid industrialization economy growth strategy. The results of which is the increasingly rising entropy change (from 0.005 to 0.016), and according to the dissipation theory the bigger entropy change means the less trend. So the development trend shown by the entropy change values in the Table3 must be corrected with an environmental innovation mechanism. Overall, in the future research on the environmental problem, through the low carbon system the environmental innovation effect of a target economic zone can be analyzed by a quantitative method, which has great significance for sustainable development.

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