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Optimization of harmonious development on regional energy-economy-atmospheric environment system*

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Abstract——The energy, industrial economy and atmospheric environment were taken into account as a whole complex system in this study. Based on the application of grey system theory and the analysis of development coefficients about major parameters of the system, the method of grey development decision was approached, and a new concept-integrated development coefficient was put forward. Furthermore, the reasonable ranking of development decision within eight industrial sectors (building materials, coking, food and drink, chemical engineering, paper making, machinery and electrical appliance, textile, mining) has been concluded from the viewpoint of economic growth, energy saving and ambient air quality protection.

Keywords: economy; atmospheric environment; grey development decision.

1 Introduction

Besides natural dust-raising, the energy consumption structure of taking coal as a primary energy is an important factor which results into the degradation of ambient air quality over northern China. In accordance with the national standard of annual average concentration, the exceeding rate of TSP currently almost goes up to 100% over northern cities of China. Investigation indicates that concerning the fine particulate with diameter less than 2.5 μm, the ratio of the portion which originates from anthropogenic emission to the portion from natural dust-raising is extremely different from the ratio of that in total suspended particulate. The former ratio is 15:1 while the latter is 1:1. In a whole year round, the organic carbon and elemental carbon is always the major composition in fine aerosol particulates (Chen, 1994). Even for the particles with diameter of 2.5—1.5 μm, the fly ash from coal burning takes up 82.8% in winter over Taiyuan City(Han, 1988). Of which, the fine dust may be transported over a long range by upper wind in general weather condition, and has an impact on the downwind area where may be far from the source.

Since the energy policy of considering coal as main fuel will still be carried out for

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another several decades, in order to ensure sustainable development, a study on harmonious development of energy-economy-atmospheric environment system has obviously significance (Ning, 1994). Shanxi Province is " the kingdom of coal", and the industrial base of energy and chemical engineering of coal in China. In addition, Jiexiu City is well-known throughout the nation in its coking by indigenous method. The serious pollution due to coal burning over there has greatly degraded the ambient air quality in the local and downwind region. Therefore, the case study at Jiexiu City is of typical importance, and the method can be applied and disseminated in other polluted cities.

Taking the complex system of regional energy—industrial economy—atmospheric environment as a study object, utilizing the characteristics of grey system theory which is good at dealing with uncertain data, is able to make full use of known information to find the regular pattern of a system, and is strong in solving the problems of incomplete information system, the method of grey development decision (Deng, 1990) is applied in discussion of a harmonious development problem from the view point of industrial structure adjustment. This method can be used for quantitatively examining the dynamic development characteristics between energy and economy in each industrial sector and ambient air quality, so as to strictly control those enterprises that they are in high energy consumption, low economic benefit and heavy pollution, while devote major efforts to develop those enterprises that they are in high quality, high benefit, and resource saving.

2 Method of grey development decision

2.1 Construction of index setup

Three types of indexes (economy index, energy index, atmospheric environmental index) are included in the set up(Table 1). In the study process, the indexes sometimes

Table 1 Index setup of energy, industrial economy and atmospheric environment system

Index setup	Economy index	Total output value of industry	
	Atmospheric environmental index	Remedial and planning index	. Cleaning rate of air pollutants . Abatement rate of smoke . Elimination rate of SO_2 . Standardized rate of waste gases emission
		Pollutant discharge index	. Emission volume of waste gases per 10 thousand Yuan output value . Emission volume of smoke dust per 10 thousand Yuan output value . Emission volume of SO_2 per 10 thousand Yuan output value . Emission volume of other air pollutants per 10 thousand Yuan output value
	Energy index	. Energy consumption per 10 thousand Yuan industrial output value	

should be decided which to choose in terms of different research purposes or levels of energy utilization, economy development and environmental protection requirement, especially in the following situations: (1) insufficient statistical data; (2) when a serious environmental issues need to taken into account, the other secondary environmental problem can be tentatively forgotten.

All the indexes are divided into positive index and adverse index. The positive index refers to those one that they are the greater, the better, such as economic indexes, environmental remedial and planning indexes. While the adverse index refers to those one that they are the less, the better, such as energy consumption indexes and pollutant discharge indexes.

2.2 Selection for industrial sectors

Based on the economic situation in a region, some representative industrial sectors are selected as the object of study in order to enhance the convincing level of results. Meanwhile, an enough attention should be paid to those energy oriented industries, heavy polluted industries and distinctive local feature industries.

2.3 Solution of the development coefficient

At least four year's recent datum sequence must be acquired for the calculation. Afterwards, suppose m industrial sectors will be considered as the decision objects, and there are n characteristic sequences in each sector (one primary sequence and n-1 reference sequences). Then, for the kth sector, its characteristic sequence can be expressed as follows:

Primary sequence: $x_{mk}^{(0)}=\{x_{mk}^{(0)}(1),x_{mk}^{(0)}(2),\cdots\cdots,x_{mk}^{(0)}(h)\}$,

Reference sequence: $x_{rki}^{(0)}=\{x_{rki}^{(0)}(1),x_{rki}^{(0)}(2),\cdots\cdots,x_{rki}^{(0)}(h)\}$,

where, $k=1,2,\ldots,m$; $i=1,2,\ldots,n-1$; h is the number of time sequence ($h\geqslant 4$).

Then, $GM(1,1)$ model is established for each sequence respectively:

$(\mathrm{d}x/\mathrm{d}t)+ax^{(1)}=b$.

Parameter vector $\hat{A}=\begin{bmatrix}a\\b\end{bmatrix}=[B^TB]^{-1}B^TY_n$. Where,

$$B=\begin{bmatrix}-\frac{1}{2}(x^{(1)}(2)+x^{(1)}(1)), & 1\\ \cdots\ \cdots\ \cdots\ \cdots\ \cdots\ \cdots\ \cdots & \\ -\frac{1}{2}(x^{(1)}(h)+x^{(1)}(h-1)), & 1\end{bmatrix}$$

$$Yn=[x^{(0)}(2),x^{(0)}(3),\cdots x^{(0)}(h)^T],$$

$$x^{(1)}(k)=\sum_{m=1}^{k}x^{(0)}(m),\ m=1,2,\cdots,h.$$

It follows the response solution of $GM(1,1)$:

$$\hat{x}^{(1)}(k+1)=(x^{(0)}(1)-b/a)e^{-ak}+b/a,$$

where, $-a$ is development coefficient. It shows the development situation of $\hat{x}^{(1)}$ and $x^{(0)}$. The more the $-a$ is, the potential development situation in time sequence would be. It is the quantization result of inherent development characteristics of the system factors, and $-a$

plays a decisive role in the process of system development at present and for the future.

2.4 Construction of development matrix

Considering the development coefficients of M industrial sectors as rows and the deve lopment coefficients of N characteristics sequences as files, a matrix with m rows and n files is constructed. Which is called as development matrix:

$$A_{m\times n}=\begin{bmatrix} a_{m1} & a_{r11} & a_{r12}\cdots\cdots & a_{r1(n-1)} \\ a_{m2} & a_{r21} & a_{r22}\cdots\cdots & a_{r2(n-1)} \\ \cdots & \cdots & \cdots\cdots & \cdots \\ a_{mn} & a_{rm1} & a_{rm2}\cdots\cdots & a_{rm(n-1)} \end{bmatrix}$$

In which the first file is composed of development coefficients of principal sequence and is called as principle coefficient file. The other files are called reference coefficient file.

2.5 Grey development decision matrix and decision vector

Suppose grey development decision matrix $D_{m\times m}=A'_{m\times m}\cdot H^{T}_{m\times n}\cdot E_{m\times m}$. Where $E_{m\times m}$ is unit matrix; $A'_{m\times n}$ is revised development matrix ; coordinate matrix $H_{m\times n}=[\,E_c\,\vdots\,E_N\,\vdots\,E_{NV}\,]$; where E_c is sub-matrix of economy weight, E_N is sub-matrix of energy consumption weight, and E_{NV} is sub-matrix of environmental index weight. Let $S_{m\times 1}=(11\ldots\ldots 1)^T$, then $D'_{m\times 1}=D_{m\times m}\cdot S_{m\times 1}$, which is the decision vector. Each numerical value indicates the integrated benefit measurement, respectively, after the various factors about economy, energy and atmospheric environment have been taken into account, which is called as integrated development coefficient and is made a sign of $d(k)$. Integrated development coefficient $d(k)$ can be regarded as a quantitative expression of the system harmonious development.

If $d(k)\geqslant 0$, then the kth industrial sector will be in a condition of harmonious development, and the greater the $d(k)$ is, the better the harmonious degree will be. If $d(k)<0$, then the kth industrial sector basically falls into unmelodious development, and the less the $d(k)$ is, the poorer the harmonious degree will be. Therefore, the integrated development coefficient $d(k)$ can be considered as an important indicator for the readjustment of industrial structure.

3 Case study

Jiexiu City is located in the center of Shanxi Province. It is rich in coal resource. Coking coal-based chemical industry, building material industry are well-developed, which make Jiexiu City have already become one of provincial industrial bases. Coking by backward indigenous methods, however, can be found on the both sides along the main railway and road. It brings about a serious ambient air quality degradation with great waste of energy and resources. Undoubtedly, this situation has grievously disrupted the regional sustainable development over there. Consequently, readjusting the industrial structure in order to ensure a virtuous cycle in the energy-economy-atmospheric environment system has become an urgent matter.

In accordance with investigation, eight sectors are selected as study object, namely mining (k_1), food and drink (k_2), textile (k_3), paper making (k_4), coking (k_5), chemical engineering (k_6), building materials (k_7), machinery and electrical appliance (k_8). The decided positive index includes: industrial output value (principle coefficient); The adverse indexes include: energy consumption per 10 thousand Yuan industrial output value, emission volume of SO_2 per 10 thousand Yuan output value, emission volume of TSP per 10 thousand Yuan output value (adverse reference sequence). Their data obtain from 1989 to 1993 (Table 2).

On the basis of above grey development decision method, the revised development matrix A' and coordinate matrix H are respectively as follows:

$$A'=\begin{bmatrix} 0.1153 & 0.560 & 0.665 & 0.532 \\ 0.3213 & 0.015 & 0.385 & 0.631 \\ 0.1947 & -0.041 & 0.411 & 0.645 \\ 0.0601 & 0.206 & 0.189 & 0.210 \\ 0.4353 & 0.992 & 0.538 & 0.134 \\ 0.2767 & 0.369 & 0.292 & 0.289 \\ 0.2382 & 0.370 & 0.376 & 0.417 \\ 0.3315 & 0.398 & 0.483 & 0.150 \end{bmatrix} \qquad H=\begin{bmatrix} 0.220 & 0.015 & 0.005 & 0.025 \\ 0.006 & 0.133 & 0.207 & 0.189 \\ 0.210 & 0.039 & 0.044 & 0.022 \\ 0.031 & 0.196 & 0.385 & 0.124 \\ 0.297 & 0.065 & 0.038 & 0.034 \\ 0.035 & 0.258 & 0.070 & 0.137 \\ 0.015 & 0.180 & 0.222 & 0.365 \\ 0.186 & 0.075 & 0.047 & 0.104 \end{bmatrix}$$

Table 2 Characteristic sequences and development coefficients of each sector

Industrial sector	Year and development coefficient (D.C.)	Primary sequence Xm_K Industrial output value 10^4 Yuan	Adverse reference sequence $Xrk1$ Energy consumption per 10 thousand Yuan output value tonne	$Xrk2$ Emission of SO_2 per 10 thousand Yuan output value tonne	$Xrk3$ Emission of TSP per thousand Yuan output value tonne
Mining	1989	13383	0.8493	0.026	0.0289
	1990	13391	0.4481	0.017	0.165
k_1	1991	12759	0.4703	0.0186	0.0169
	1992	21203	0.2237	0.0071	0.0066
	1993	17188	0.1746	0.0063	0.0076
	D.C.	0.3213	−0.560	−0.665	−0.532
Food and drink	1989	156.4	16.496	0.7918	0.227
k_2	1990	182.6	6.572	0.6133	0.215
	1991	236.7	6.337	0.3971	0.2112
	1992	401.0	6.414	0.2045	0.1112
	1993	488.5	6.141	0.2113	0.0563
	D.C.	0.3213	−0.015	−0.385	−0.631
Textile	1989	14861	1.191	0.0884	0.0638
	1990	10702	1.573	0.0570	0.0471
	1991	11450	1.304	0.0878	0.0331
k_3	1992	12173	1.075	0.0427	0.0199
	1993	16438	1.400	0.0454	0.0065
	D.C.	0.1947	0.0410	−0.411	−0.645

Table 1 (continued)

Paper making					
	1989	1512.2	15.72	0.6455	0.2161
	1990	2030	11.71	0.5015	0.0901
	1991	2035	12.77	0.5209	0.0511
k_4	1992	3547	6.84	0.2707	0.0271
	1993	2436.6	9.44	0.3940	0.0371
	D.C.	0.4353	−0.992	−0.538	−0.134
Coking	1989	9492	4.13	0.1282	0.0170
	1990	11018	3.38	0.1104	0.0085
	1991	7266	5.23	0.1791	0.0133
k_5	1992	30264	1.24	0.0353	0.0109
	1993	30953	1.13	0.039	0.0103
	D.C.	0.4353	−0.992	−0.538	−0.134
Chemical	1989	914.4	41.86	0.152	0.106
engineering	1990	1042	34.92	0.160	0.132
	1991	1319	22.74	0.116	0.090
k_6	1992	2741	12.49	0.065	0.093
	1993	2716	12.15	0.072	0.041
	D.C.	0.2767	−0.369	−0.292	−0.289
Building					
materials	1989	393.2	30	0.865	0.331
	1990	492.8	25	0.482	0.321
	1991	626.7	16	0.402	0.382
k_7	1992	1142.6	8.2	0.186	0.355
	1993	1132.8	8.8	0.227	0.109
	D.C.	0.2382	−0.370	−0.376	−0.417
Machinery					
and	1989	1820	3.97	0.190	0.058
electrical	1990	2155	3.43	0.125	0.043
appliance	1991	3105	2.37	0.072	0.040
k_8	1992	5614	1.30	0.042	0.027
	1993	6706.9	1.19	0.028	0.031
	D.C.	0.3315	−0.398	−0.483	−0.150

The final calculating result(decision vector) is:

$$D' = A'.H^T.\ E.\ S$$

$$= (0.0504\ 0.0208\ 0.0716\ 0.0410\ 0.2187\ 0.1649\ 0.3058\ 0.1298)$$

$$k_1 \quad k_2 \quad k_3 \quad k_4 \quad k_5 \quad k_6 \quad k_7 \quad k_8$$

and the figures in the vector D' are integrated development coefficients $d(k)$ of different sectors. Ranking them in order from greater to smaller, the alignment is:

$$d(k_7) > d(k_5) > d(k_2) > d(k_6) > d(k_4) > d(k_8) > d(k_3) > d(k_1).$$

In the present industrial structure of Jiexiu City, mining , coking, chemical engineering and textile play a decisive role. But the air pollution resulted from them are quite serious, which is expressed in a backward place within the $d(k)$ ranking. If these 4 sectors still develop in current scale, the atmospheric environmental deterioration will get more and more serious although temporary economic benefit may be obvious. While because building material

industry enjoys exceptional advantages in coal resource and which can use the solid waste from mining and coking as raw material, so it would reduce the secondary dust-raising pollution. It is evident that this sector has a greater potential for developing. Actually, the $d(k)$ of building materials is the greatest. Therefore, based on consolidating the dominant industries of coking and mining, more efforts should be emphatically paid to develop building materials and coking. It must have a positive effect to improve the ambient air quality in local and downwind area.

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