Evaluation Model of Energy-economy-environment (3E) System Coordinating Degree: Empirical Analysis on China Regionally

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Abstract. With the development of the third industrial revolution, energy and environment have more and more influence on economy. So academics designed system called 3E to describe the relation of energy, economy and environment. The coordinating degree is an important conception for 3E system. This paper designs a model to evaluate the coordinating degree of 3E system. Based on the evaluation model, we make an empirical analysis on coordinating degree of 8 provinces and come to conclusions about regional characteristics of 3E system in China.

1. Introduction

3E system consists of energy, economy and environment. Economic development demands for amounts of energy. However, excessive energy consumption puts a burden to the environment. At the same time, environment could affect on the economy. In a word, the three subsystems interact with each other. And their coordinating degree plays an important role in the sustainable development for a nation.

Nowadays, China has entered the economic transition period. Economic development cannot depend on the energy completely and environmental-friendly society becomes the new orientation. Therefore, it is vital to balance the energy, economy and environment for China.

3E system was originally proposed by International Energy Agency (IEA) and they designed MARAKL (the Market Allocation of Technologies Model). David Hawdon adopted Input-Output Model to analyse the relation of environment, energy and economy. Chinese academics have also proposed some views on evaluating the coordinating degree of 3E system. Zhao Fang evaluated the coordinating degree in China from 2000 to 2007 by membership function. Zhu Dayun set up Logarithmic regression model for China energy demand and environmental influence. They make a great contribution to the field.

However, most of researches just consider two subsystems. To evaluate the coordinating degree of 3E system comprehensively, this paper assesses the subsystems firstly and then considers their coordinating degree, which refers the comparison of three evaluation models made by Chen Liming. After that, this paper evaluates the coordinating degrees of several typical conventional energy areas in China and concludes regional characteristics of 3E system.
2. Evaluation Model Design

2.1. Subsystem Evaluation

2.1.1. Indicators Selection. Based on the former researches and Chinese actuality, this paper selects 9 indicators to evaluate the subsystems, as shown in the Table 1. The indicators can be divided two parts: one has positive impact on the subsystem (marked with “+”), and the other has negative impact on the subsystem (marked with “-”).

| Indicator                     | Explanation                                      |
|-------------------------------|--------------------------------------------------|
| Economy                       |                                                  |
| Per-ca pita GDP (+)           | It reflects economic development.                |
| GDP growth rate (+)           | It reflects economic prospect.                   |
| Environment                   |                                                  |
| Surface water quality index (-)| It reflects water environment.                   |
| Air quality index (-)         | It reflects atmospheric environment.             |
| Per-ca pita green space area (+)| It reflects human settlement.                 |
| Energy                        |                                                  |
| Raw coal production (+)       | It reflects energy scale.                        |
| Raw coal consumption (+)      | It reflects energy scale.                        |
| Input-output ratio (-)        | It reflects energy efficacy.                     |
| Rate of power generation by new energy (+)| It reflects new energy utilization. |

2.1.2. Weight Determination. This paper adopts the Analytic Hierarchy Process (AHP) to determine the weights according to the experts’ evaluation in the method of 1-9 scale. The expert-group includes ten professors who specialize in energy, environment or economy. Synthesizing the evaluation of these experts, this paper sets the judgment matrices shown as follows.

- Economy Judgment Matrix:

\[
W_1 = \begin{bmatrix}
1 & \frac{1}{1.2} \\
1.2 & 1
\end{bmatrix}
\]

- Environment Judgment Matrix:

\[
W_2 = \begin{bmatrix}
1 & 1 & 1.5 \\
1 & 1 & 1.5 \\
1.5 & 1 & 1
\end{bmatrix}
\]

- Energy Judgment Matrix:

\[
W_3 = \begin{bmatrix}
1 & \frac{1}{2} & \frac{1}{2} \\
1 & \frac{1}{2} & \frac{1}{2} \\
2 & 2 & 1 & 3 \\
2 & 2 & \frac{1}{2} & 1
\end{bmatrix}
\]

The three matrices pass consistency test so we can obtain combined weight vector:

- \( W_1 = [0.45 \ 0.55]^T \)
- \( W_2 = [0.375 \ 0.375 \ 0.25]^T \)
- \( W_3 = [0.162 \ 0.162 \ 0.423 \ 0.253]^T \)

The indicator weights are shown in the Table 2.

| Indicator                     | Weight |
|-------------------------------|--------|
| Per-ca pita GDP              | 0.45   |
| GDP growth rate              | 0.55   |
| Surface water quality index   | 0.375  |
2.1.3. Calculation. Because the criteria of each indicator are different, their data should be non-dimensionalized. We mark the dates group as \( U_i \) (i=1,2,3). In the same way, economy evaluation is marked as \( E_1 \), environment evaluation is marked as \( E_2 \), and energy evaluation is marked as \( E_3 \). And the equation is presented as:

\[
E_i = W_i \cdot U_i \quad (i = 1, 2, 3)
\]

2.2. Coordinating Degree Evaluation
This paper uses Capacitive Coupling Model for reference to evaluate the coordinating. We can get the following coordinating degree model:

\[
C = \left( \frac{E_1 \cdot E_2 \cdot E_3}{(E_1 + E_2)^2 (E_2 + E_3)^2 (E_1 + E_3)^2} \right)^{\frac{1}{3}}
\]

C presents coordinating degree of 3E system, which reflects the interaction of energy, economy and environment. The value ranges from 0 to 1. The higher the value is, the better the system coordinate. Coordination scale is shown in Table 3.

Table 3. Coordination Scale

| Scale   | Evaluation          |
|---------|---------------------|
| C→0     | Extremely uncoordinated |
| C<0.3  | Seriously uncoordinated |
| 0.3 ≤ C<0.4 | Moderately uncoordinated |
| 0.4 ≤ C<0.5 | Slightly uncoordinated |
| 0.5 ≤ C<0.6 | Marginally coordinated |
| 0.6 ≤ C<0.7 | Fairly coordinated |
| 0.7 ≤ C<0.8 | Well coordinated |
| 0.8 ≤ C<1 | Very well coordinated |
| C=1     | Excellent coordinated |

3. Empirical Analysis on Chinese Conventional Energy Province
Compared with new energy, conventional energy has negative impact on environment because of their emissions. However, conventional energy is still main energy support in China. So, if China want to achieve the goals of resource-conserving and environmentally friendly society, conventional energy provinces must promote the coordination of 3E system.

Based on the evaluation model, this paper selects 8 conventional energy provinces to evaluate: Shanxi, Shaanxi, Inner Mongolia, Xinjiang, Guizhou, Anhui, Shandong, Heilongjiang. These provinces have great of conventional energy and reflect Chinese 3E systems regionally. Shanxi, Shaanxi, Inner Mongolia reflect North China; Xinjiang reflects Northwest China; Guizhou reflects Southwest China; Anhui and Shandong reflect East China; Heilongjiang reflects Northeast China. The data from *China Energy Statistics Yearbook 2017* and *2017 Bulletin of the China Environmental*
In order to be convenient for computation, we make these data non-dimensionalized. The non-dimension method presents:

\[ u_+ = \frac{x - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}}, u_+ \in \left[0,1\right] \]  

(3)

\[ u_- = 1 - \frac{x - x_{\text{min}}}{x_{\text{max}} - x_{\text{min}}}, u_- \in \left[0,1\right] \]  

(4)

\( x \) represents the initial data. \( u_+ \) represents the non-dimensionalized data of positive indicators and \( u_- \) represents the non-dimensionalized data of negative indicators.

The non-dimensionalized value of indicators is shown in Table 4 and the coordinating degree evaluation of Chinese conventional provinces in 2017 is shown in Table 5.

Table 4. Values of indicator

|                     | Shanxi | Shaanxi | Inner Mongolia | Xinjiang | Guizhou | Anhui | Shandong | Heilongjiang |
|---------------------|--------|---------|----------------|----------|---------|-------|----------|--------------|
| Per-capita GDP      | 0.0745 | 0.5534  | 0.7402         | 0.2047   | 0.0000  | 0.1791| 1.0000   | 0.1359        |
| GDP growth rate     | 0.4839 | 0.6452  | 0.0000         | 0.5806   | 1.0000  | 0.7258 | 0.5484   | 0.3871        |
| Surface water       | 0.0000 | 0.2750  | 0.1631         | 1.0000   | 0.5737  | 0.3694 | 0.7780   | 0.3988        |
| quality index       | 0.6855 | 0.0000  | 0.7887         | 0.8206   | 0.9042  | 0.9312 | 0.8698   | 1.0000        |
| Air quality index   | 0.1218 | 0.0000  | 0.2423         | 0.4266   | 1.0000  | 0.2064 | 0.2793   | 0.1004        |
| Per-capita green    | 0.9807 | 0.5806  | 1.0000         | 0.1294   | 0.1393  | 0.1491 | 0.0881   | 0.0000        |
| space area          | 0.6576 | 0.1338  | 1.0000         | 0.0000   | 0.4683  | 0.2821 | 0.7500   | 0.4018        |
| Raw coal production | 0.0000 | 0.0788  | 0.5004         | 1.0000   | 0.1688  | 0.4279 | 0.6304   | 0.4006        |
| Raw coal consumption| 0.0868 | 0.1710  | 0.2913         | 0.3918   | 1.0000  | 0.0463 | 0.0000   | 0.1904        |

Table 5. Coordinating degree evaluation

| Province             | Economy | Environment | Energy | Coordinating degree | Evaluation          |
|----------------------|---------|-------------|--------|---------------------|---------------------|
| Shaanxi              | 0.6039  | 0.1031      | 0.1923 | 0.2664              | Seriously uncoordinated |
| Shanxi               | 0.2997  | 0.2875      | 0.2874 | 0.4175              | Slightly uncoordinated |
| Inner Mongolia       | 0.3331  | 0.4175      | 0.6094 | 0.4569              | Slightly uncoordinated |
| Anhui                | 0.4798  | 0.5393      | 0.2626 | 0.4977              | Marginally coordinated |
| Heilongjiang         | 0.2741  | 0.5497      | 0.2827 | 0.5160              | Marginally coordinated |
| Shandong             | 0.7516  | 0.6877      | 0.4024 | 0.5385              | Marginally coordinated |
| Xinjiang             | 0.4115  | 0.7894      | 0.5431 | 0.5785              | Marginally coordinated |
| Guizhou              | 0.5500  | 0.8042      | 0.4229 | 0.5825              | Marginally coordinated |
4. Conclusion

4.1. China is universally uncoordinated
According to Table 5, we can find that most areas in China is uncoordinated except that Guizhou is evaluated as Marginally coordinated. Therefore, it is extremely necessary to promote the coordinating degree of 3E system for China.

4.2. North China is the most uncoordinated
North China has the richest conventional energy but Table 5 shows that it is the most uncoordinated. Besides, the evaluation of energy is not outstanding. We can conclude two reasons for it.

Firstly, North China is so heavily relying on the conventional energy. Benefited from the abundant energy, conventional energy industry in North develops early and becomes the economy’s mainstays. But with the progress of economy and technology, harmful emissions and low conventional energy efficacy make it difficult to achieve sustainable development in the conventional mode. Furthermore, North China don not take charge of energy well. From Table 4, we found that it has a low input-output ratio and rate of power generation by new energy. Therefore, only reducing the dependence on conventional energy to transform economic development mode can North China get out of the trouble.

Secondly, North China is extremely lack of attention on environmental protection. From Table 5, the evaluation of environment subsystem in North China is obviously worse than other areas. These provinces sacrifice environment in order to develop economy, which must lead to the in-coordination of 3E system.

4.3. Environment should be attached importance
According to Table 5, most areas with a relatively coordinated 3E system have a good evaluation of environment, especially Guizhou. Besides, Guizhou prefer new energy rather than conventional energy, which is also good for environment. Good environment is propitious to economy. Although the per capita GDP is not as good as other regions, it gets a higher economy evaluation because of the rapid GDP growth.

4.4. Conventional energy efficacy improvement and new energy utilization are important
According to Table 4 and Table 5, the provinces with a good energy evaluation has a higher Input-output ratio and rate of power generation by new energy. The impact of energy production and consumption is not very large as expected. Besides, good utilization of energy plays a positive role in environmental protection and economic development. So it not only enhances energy subsystem, but also is beneficial to economy and environment subsystems, which promotes the coordinating degree of 3E system.

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