Methods of Comprehensive Assessment for China’s Energy Sustainability

Zhijin Xu\textsuperscript{1,a}, Yankui Song\textsuperscript{1,b}

\textsuperscript{1}College of Management, Capital Normal University, Beijing, 100048, China
\textsuperscript{a}email:xzjccc@sina.com, \textsuperscript{b}email:sylviasong@163.com

Abstract. In order to assess the sustainable development of China’s energy objectively and accurately, we need to establish a reasonable indicator system for energy sustainability and make a targeted comprehensive assessment with the scientific methods. This paper constructs a comprehensive indicator system for energy sustainability from five aspects of economy, society, environment, energy resources and energy technology based on the theory of sustainable development and the theory of symbiosis. On this basis, it establishes and discusses the assessment models and the general assessment methods for energy sustainability with the help of fuzzy mathematics. It is of some reference for promoting the sustainable development of China’s energy, economy and society.

1. Introduction

It is of great significance to assess the sustainable development of energy objectively, scientifically and rationally for realizing the sustainable development of China’s economy and society. Since the 1990s, the assessment for China’s energy sustainability has been widely concerned by scholars and many meaningful research findings have been made. From the perspective of assessment methods, these findings are mainly involved in constructing targeted indicator systems, analyzing and calculating each indicator, and then carrying out the overall assessment of indicator system\textsuperscript{[1]}. However, there are some problems in these methods. Especially, some calculation methods are not reasonable when indicators are uneasy to be quantified and weighted synthetically. Those indicators cannot be well analyzed and calculated frequently. Obviously, unreasonable calculation methods seriously affect the final overall assessment results.

This paper constructs a relatively simple and comprehensive assessment indicator system for energy sustainability composed of 26 indicators from five aspects of economy, society, environment, energy resources and energy technology based on the theory of sustainable development and the theory of symbiosis\textsuperscript{[2]}. It establishes a set of comprehensive assessment models for energy sustainability with the help of fuzzy mathematics. On this basis, it further discusses the general methods of comprehensive assessment for energy sustainability. It is of some reference for promoting the sustainable development of China’s energy, economy and society.

2. Comprehensive assessment indicator system for energy sustainability

Sustainable development is a concept of symbiotic development. According to the theory of sustainable development and the theory of symbiosis, we think that energy sustainability refers to the energy can effectively support the sustainable development in all fields of economy, society, resources, technology and environment, meanwhile ensure the efficient operation of energy exploitation, processing, transmission, consumption, recycling and utilization and then realize its own sustainable
development[3]. Thus, we can regard energy sustainability as a symbiotic and complex system of “economy-society-environment-energy resources-energy technology”.

Based on the theoretical understanding, this paper divides energy sustainability system into five subsystems of economic sustainability, social sustainability, environmental sustainability, energy resource sustainability and energy technology sustainability. There is an interactive relationship among them, that is, if they coordinate with each other, the energy will be in a sustainable state of development; otherwise, the energy in an unsustainable state. Therefore, the assessment for energy sustainability needs to start from the sustainability of the five subsystems, follows certain basic principles, and constructs a comprehensive assessment indicator system scientifically and rationally.

2.1. Principles of constructing indicator system
The following are the basic principles of constructing a comprehensive assessment indicator system for energy sustainability in China.

2.1.1. The principle of scientificity. The assessment indicator system for energy sustainability should be objective and scientific. We should ensure indicator data are authority, accuracy and objectivity on the basis of actual statistical data and avoid subjective assumptions and randomness, so as to reflect the characteristics and effects of energy sustainability system objectively and truly.

2.1.2. The principle of systematicness. Energy sustainability system is composed of the sustainability of many subsystems such as economy, society, environment, energy resources and energy technology. Factors impacting energy sustainability are diverse and relatively independent. Therefore, the indicator system should reflect the sustainability characteristics of each subsystem in the system and the degree of system sustainability comprehensively.

2.1.3. The principle of dynamicity. The sustainable development of energy is a continuous dynamic process. The dynamic characteristics should be taken into account in the construct of indicator system, reflecting the present situation and future trends of the energy sustainability system.

2.1.4. The principle of goal. This principle emphasizes the goal requirements of assessing energy sustainability. Purposeful and targeted selection of different assessment indicators can highlight the fundamental requirements of energy sustainability.

2.1.5. The principle of feasibility. We should ensure that each indicator has a clear meaning and is relatively independent. At the same time we should also take into account the operability of the indicator data collection and indicators should be very operable and convenient to calculate.

2.1.6. The principle of the combination between qualitative and quantitative. The qualitative is to analyze the “quality” characteristics of things and the quantitative is to describe the “quantity” characteristics of things through mathematics method. The combination between qualitative and quantitative can better reflect the essence of assessment indicators for energy sustainability and especially deal with those uneasy to be quantified.

In a word, only by following the above basic principles, can we construct a set of scientific and reasonable comprehensive assessment indicator systems for China’s energy sustainability.

2.2. Constituents of the comprehensive assessment indicator system
According to the theory of sustainable development and the theory of symbiosis, we follow the above principles of constructing assessment indicator system and initially construct a comprehensive assessment indicator system composed of 26 indicators for China’s energy sustainability (see Table 1) through extensive domestic and foreign literature research and expert consultation, especially with reference to the report “Energy Indicators for Sustainable Development: Guidelines and
Methodologies” published by the International Atomic Energy Agency[4-7]. This assessment indicator system can better describe the status and level of energy sustainability in China. Due to space limitation, there is no further explanation for the specific connotation of indicators in the above assessment indicator system.

**Table 1. Comprehensive assessment indicator system for energy sustainability**

| Object(E) | Factor layer(Ei) | Indicator layer(eij) |
|-----------|------------------|----------------------|
| Economic sustainability (E1) | GDP (e11) | Proportion of the third industry (e12) |
| | Energy consumption elasticity coefficient (e13) | Energy investment boom exponential (e14) |
| | Energy price exponential (e15) | |
| Social sustainability (E2) | Unemployment rate (e21) | Engel coefficient (e22) |
| | Education investment accounts for fixed investment ratio (e23) | Construction of energy security guarantee system (e24) |
| | Regional equity exponential (e25) | Intergenerational equity exponential (e26) |
| Environmental sustainability (E3) | Environmental investment account for proportion of GDP (e31) | Standard rate of industrial wastewater discharge (e32) |
| | Standard rate of industrial smoke and dust emission (e33) | Standard rate of industrial solid waste (e34) |
| | Low carbon policy implementation exponential (e35) | |
| Energy resource sustainability (E4) | Per capita raw coal production (e41) | Per capita crude oil production (e42) |
| | Per capita natural gas production (e43) | Per capita electrical output (e44) |
| | Energy consumption per unit of GDP (e45) | |
| Energy technology sustainability (E5) | Technical level of energy exploitation (e51) | Technology efficiency of energy processing and conversion (e52) |
| | Efficiency of energy transmission and distribution (e53) | Technical level of energy recycling and utilization (e54) |
| | Development exponential of energy security technology (e55) | |

3. Models of comprehensive assessment for energy sustainability

In order to assess energy sustainability reasonably, the assessment method must be selected scientifically on the basis of the determination of constituents and assessment indicator system. In all kinds of assessment methods, we think that it is more appropriate to assess energy sustainability with the selection of Fuzzy Comprehensive Assessment (FCA)[8] since the assessment for energy sustainability is essentially a multi-factor, multi-layer, fuzzy and comprehensive assessment problem.

According to FCA, we can construct the following fuzzy comprehensive assessment models for energy sustainability, including a initial model and an expanded multi-layer model.

3.1. Initial model

Let the factor set E={ei}=(e1, e2, ..., em), ei as the indicators considered; the comment set D={dj}=(d1, d2, ..., dn), and dj is the grades of comment, j=1,2,...,n; the fuzzy set Q={qi}=(q1, q2, ..., qm) is called the weight distribution of factor E, qi (0≤qi≤1) the weights of indicator ei considered; the single factor assessment matrix P=(pij) is called the transformation matrix, pij (0≤pij≤1) when Q and P are known, we conduct a comprehensive assessment by the application of fuzzy matrix compound operation (min) and (max) and get the initial model of fuzzy comprehensive assessment.
\[ Z = QoP = (z_1, z_2, \ldots, z_n) \]  

### 3.2. Multi-layer model

The above initial model can be extended into a multilevel fuzzy comprehensive assessment model by stratified division of factor sets. The extended method is to apply the initial model to multi-layer factors and assessment results of each layer are the input of the upper layer of assessment, which lasts until to the top.

When the factor set \( E \) is made division \( p \), we can extend the model of comprehensive assessment in the upper layer \( E \) or \( E/p \) and then obtain the result of fuzzy comprehensive assessment.

\[ Z_e = QoP = \{Q_1oP_1, Q_2oP_2, \ldots, Q_moP_m\}^T = (z_{c1}, z_{c2}, \ldots, z_{cm}) \]  

In the same way, more layer models of comprehensive assessment can be obtained if \( E \) is made division \( p \) step by step, which is no longer described here.

### 4. Methods of comprehensive assessment for energy sustainability

The general methods of comprehensive assessment for energy sustainability by FCA are to determine the factors (or indicators) set and the comment set of assessment objects first. Then the weights of each factor (or indicator) and their membership degrees are obtained respectively, and the fuzzy assessment matrix is obtained from the membership degrees. Finally, the comprehensive assessment results of energy sustainability are obtained by using the above assessment models and making fuzzy compound operation step by step with the assessment matrixes and the weights of the factors (or indicators). Due to the limit of length, this paper does not enumerate examples to further illustrate the effective methods of comprehensive assessment for energy sustainability.

#### 4.1. Establish the comprehensive assessment indicator system and get an assessment factor set \( E \)

On the basis of the comprehensive assessment indicator system for energy sustainability, the assessment factor set \( E = \{E_i\} \) \((i=1,2,\ldots,m)\) can be established. According to Table 1, \( m=5, E=\{E_1, E_2, E_3, E_4, E_5\}=\{\text{economic sustainability}, \text{social sustainability}, \text{environmental sustainability}, \text{energy resource sustainability}, \text{energy technology sustainability}\}\).

#### 4.2. Determine the grades and criteria of assessment and get a comment set \( D \)

When the division of assessment grades and the meaning of assessment criteria are determined, the comment set \( D = \{d_j\} \) \((j=1,2,\ldots,n)\) is also determined accordingly. In this paper, \( n=5, D=(d_1, d_2, d_3, d_4, d_5)=(\text{highest, higher, normal, lower, lowest})\).

#### 4.3. Obtain the weights \( Q \) of assessment factors and indicators

For each factor and indicator, we generally use the AHP method\[9\] proposed by Professor Saaty to obtain respectively their weight \( Q=(Q_1, Q_2, \ldots, Q_m) \) and \( Q_i=(q_{i1}, q_{i2}, \ldots, q_{in}) \).

#### 4.4. Obtain the single factor fuzzy assessment matrix \( P_i \)

Through determining the membership degree \( p_{ij,k} \) of each indicator \( e_{ij} \) belonging to grades \( d_j \) respectively in factor \( E_i \), we can obtain a single factor fuzzy assessment matrix \( P_i \) of each \( E_i \):

\[ P_i = \{p_{ij,k}\} = \begin{bmatrix} p_{11,1} & p_{11,2} & p_{11,3} & p_{11,4} & p_{11,5} \\ p_{12,1} & p_{12,2} & p_{12,3} & p_{12,4} & p_{12,5} \\ p_{13,1} & p_{13,2} & p_{13,3} & p_{13,4} & p_{13,5} \\ p_{14,1} & p_{14,2} & p_{14,3} & p_{14,4} & p_{14,5} \\ p_{15,1} & p_{15,2} & p_{15,3} & p_{15,4} & p_{15,5} \end{bmatrix} \quad (i=1,2,\ldots,m, \ j=1,2,\ldots,n, \ k=1,2,\ldots,s), \text{obviously, } \sum_k p_{ij,k} = 1. \]

Two basic methods to obtain \( p_{ij,k} \) are Experience Table Method and Peer Review Statistics\[10\].

#### 4.5. Obtain single factor fuzzy assessment value \( Z_i \) and fuzzy comprehensive assessment value \( Z \)

We make fuzzy compound operation step by step with assessment models and then obtain single factor fuzzy assessment value \( Z_i \) and fuzzy comprehensive assessment value \( Z \) of the upper layer.
The single factor fuzzy assessment value is $Z_i=q_i \circ P_i$ ($i=1,2,\cdots,m$). In this paper, $m=5$, $Z_i=q_i \circ P_i=(z_{1i}, z_{2i}, z_{3i}, z_{4i}, z_{5i})$. We can also obtain the single factor fuzzy assessment value $Z_2, Z_3, Z_4$ and $Z_5$ of other 4 factors $E_2, E_3, E_4$ and $E_5$ respectively with the same method.

On this basis, we can further obtain the upper layer value $Z$ of fuzzy comprehensive assessment for energy sustainability.

$$Z = Q \circ P = \{Q_i\} \circ \{Z_i\} = (z_1, z_2, \cdots, z_m)$$

In this paper, $m=5$, $Z = Q \circ P = [q_1, q_2, q_3, q_4, q_5] \circ [Z_1, Z_2, Z_3, Z_4, Z_5] = (z_1, z_2, z_3, z_4, z_5)$.

If needed, we can obtain more upper layer values of fuzzy comprehensive assessment for energy sustainability step by step with the same method.

4.6. **Determine the final result of fuzzy comprehensive assessment for energy sustainability**

Finally, on the basis of “Cannikin Law”[11] and obtaining the fuzzy comprehensive assessment value $Z=\{z_i\}$ for energy sustainability, we take the minimum $z_{\text{min}}$ of each subsystem sustainability $z_i$ as the final result of fuzzy comprehensive assessment for energy sustainability.

In a word, it is reasonable and feasible to select FCA as a scientific method for comprehensive assessment of energy sustainability which can more accurately reflect and measure the status and level of energy sustainable development in China.

5. **Conclusions**

It is very necessary to assess China’s energy sustainability scientifically and reasonably for the guarantee and promotion of sustainable development in economy, society, environment and energy itself. The above models and methods of comprehensive assessment for energy sustainability are very suitable and show their advantages especially to assess those indicators uneasy to be quantified. Of course, any assessment model and method has its own limitations because of the extreme complexity of energy development in China. We must combine it with specific situations in practice and use it as reasonably as possible. In short, it will be a dynamic process and a long-term arduous task to explore and perfect constantly the comprehensive assessment indicator systems and the more scientific and reasonable assessment methods for China’s energy sustainability.

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