CHEMICAL ENGINEERING TRANSACTIONS
VOL. 51, 2016

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Tichun Wang, Hongyang Zhang, Lei Tian

**ISBN** 978-88-95608-43-3; **ISSN** 2283-9216
DOI: 10.3303/CET1651136

# Research on the Ecological Evaluation of the Competitiveness of Based on Set Pair Analysis - A Case Study

Nan Xiao

Business School,Hohai University,Nanjing,China
57081@qq.com

Based on the systematic analysis of relevant researches in China and beyond, this paper built the system of Jiangsu province ecological competitiveness evaluation indices. The set pair and entropy methods were adopted to comprehensively analyze the ecological competitiveness of all regions in Jiangsu, leading to the following findings. Firstly, different regions in Jiangsu province differ greatly in the evaluation results of such subsystems as economic growth, social harmony, ecological health and environmental friendliness. Secondly, despite the relatively high level of overall ecological competitiveness, significant differences still exist among regions, with the northern region ranking first, the central ranking second and the southern ranking third. Specifically, Xuzhou has the highest ecological competitiveness and Suzhou's the lowest. Thirdly, such great differences are attributable to the pressure of their distinct natural resources, development paths and industrial structures on the ecological environment to different degrees.

## 1. Introduction

Currently, facing constraints of resources and the environment, people have gradually realized that the traditional economic development model of high consumption and heavy pollution can no longer be applied to the present and future development. With emerging significance of ecological environment, people tend to reach a consensus that ecology equals competitiveness. Nowadays, all countries and regions are trying to improve their ecological competitiveness to gain consistent impetus and lead the regional development as the active role in regional competition.

At present, few researches have been done on the ecological competitiveness both at home and abroad. Outside China, ecological competitiveness has not been proposed as a definition and lacks specialized systematic researches. However, foreign researches on the environment, resources and sustainable development all contain the concept of ecological competitiveness, providing reference for the ecological competitiveness evaluation (Caldmel, 1984; Dobso, 1990; Umberto, 2001). In China, comprehensive researches on ecological competitiveness start from the end of last century (Umberto, 2001). Generally speaking, domestic researches focus on empirical analysis to present a comprehensive evaluation on the ecological environment quality of the studied area and propose corresponding suggestions and solutions; methods related are mainly energy synthesis(Zhang, et al., 2008), fuzzy comprehensive evaluation method(Liang, et al., 2001), principal component analysis(He and Li, 2001), intuition fuzzy comprehensive evaluation method and strategic environmental assessment method (SEA) (Chen et al., 2014). Despite a large number of empirical researches, they are not systematic and cannot form a complete evaluation system. Also, they tend to the same by nature, so these researches are of limited significance for reference. In this sense, this paper established a targeted evaluation system based on analysis of current researches and social and economic development, environment and resources of Jiangsu province, for the quantitative evaluation on ecological competitiveness of all regions in Jiangsu. The status quo could thus be obtained to provide scientific theoretical guidance for relevant governments to formulate targeted strategies for improvement of the ecological competitiveness of all regions in Jiangsu.

Please cite this article as: Xiao N, 2016, Research on the ecological evaluation of the competitiveness of based on set pair analysis—a case study, Chemical Engineering Transactions, 51, 811-816 DOI:10.3303/CET1651136

## 2. Overview of Jiangsu Province

Jiangsu province, ranging from 116°18′to 121°57′east longitude and 30°45′to 35°20′north latitude, is located at the center of the eastern coastal regions in China and at the downstream of Yangtze River. With a total area of 102,600m$^2$, 1.1% of China's total, Jiangsu province has 13 cities with districts or can be divided into such three areas as North Jiangsu, Central Jiangsu and South Jiangsu. From 1978 to 2013, the annual growth rate of Jiangsu's GDP was 12.4%, higher than China's average growth rate. However, with such huge economic achievements, Jiangsu province faces alarming ecological problems. Resources and the environment are and will still be serious constraints of its sustainable development in the near future.

## 3. Establishment of the Evaluation Indices System and Research Methods

### 3.1 Establishment of the evaluation indices system

This paper, considering ecological competitiveness concerns economy, society, ecology and environment, through qualitative and quantitative analysis, frequency statistics and reference of relevant researches, established the ecological competitiveness evaluation indices system for Jiangsu province from four perspectives of economic development, social harmony, ecological health and environment friendliness. Meanwhile, the application layer structure was decomposed to layer and structure the indices system for clear indices and clear relations among them. Details can be seen in Table 1.

*Table 1: Establishment of Jiangsu province ecological competitiveness evaluation indices system and its weight*

| Target layer | System layer | Weight | Index layer | Unit | Weight |
|---|---|---|---|---|---|
| Ecological competitiveness evaluation | Economic growth | 0.091 | Per capita GDP | yuan/person | 0.282 |
| | | | Industrial value added | million hundred yuan | 0.245 |
| | | | Output growth rate of the tertiary industry | % | 0.294 |
| | | | Per capita grain output | kg/person | 0.179 |
| | Social harmony | 0.216 | Population growth rate | ‰ | 0.257 |
| | | | Urbanization rate | % | 0.167 |
| | | | Urban registered unemployment rate at the end of the year | % | 0.088 |
| | | | Per capita disposable income of urban residents | yuan/person | 0.190 |
| | | | Engel coefficient of rural households | % | 0.130 |
| | | | Per capita daily domestic water consumption | ton/person | 0.167 |
| | Ecological health | 0.629 | Population density per square kilometer | person/km2 | 0.100 |
| | | | Per capita water resource amount | m3/person | 0.080 |
| | | | Forest coverage rate | % | 0.336 |
| | | | Green area of cities | hectare | 0.109 |
| | | | Green coverage ratio built in cities | % | 0.068 |
| | | | Per capita forest area | mu/person | 0.308 |
| | Environmental friendly | 0.063 | Waste water emission amount | 10,000 ton | 0.192 |
| | | | Comprehensive use ratio of industrial solid wastes | % | 0.105 |
| | | | Waste water emission amount per 10,000 yuan GDP | ton/10,000 yuan | 0.112 |
| | | | Ammonia and nitrogen emission amount per 10,000 yuan GDP | kg/10,000 yuan | 0.123 |
| | | | SO2 emission amount per 10,000 yuan GDP | kg/10,000 yuan | 0.118 |
| | | | Elastic coefficient of energy consumption | % | 0.109 |
| | | | Proportion of investment in approved environmental protection projects in GDP | % | 0.241 |

### 3.2 Research methods

#### 3.2.1 Set pair analysis evaluation method

Based on current researches (Su and Zhang, 2010), the set pair method was modified to establish the set pair analysis static evaluation model for the objective evaluation on the ecological competitiveness of Jiangsu province.

1. Building the evaluation matrix

Assume that n objects to be evaluated constitute the set E= {$e_1$, $e_2$, … , $e_n$} and $e_n$ is the nth. Every object to be evaluated has *m* evaluation indices F= {$f_1$, $f_2$, … , $f_m$}, and $f_m$ refers to the mth index. The value of the evaluation index is recorded as $d_{ij}$ (i=1, 2,…, n; j=1,2,…,m). Then in line with set pair analysis method, a multi-target evaluation matrix Q is got:

$$Q=\begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{m1} & d_{m2} & \dots & d_{mn} \end{bmatrix} \tag{1}$$

Based on the matrix Q, the evaluation indices are compared and chosen to decide the optimal evaluation set U=[$d_{u1}$, $d_{u2}$, …, $d_{un}$]$^T$ made up of optimal evaluation indices in all evaluation plans. In a similar way, the worst evaluation set is obtained as V= [$d_{v1}$, $d_{v2}$, …, $d_{vn}$]$^T$. $d_{uj}$ is the evaluation index value ranking $c_{pk}$ in the optimal evaluation set U=[$d_{u1}$, $d_{u2}$, …, $d_{un}$]$^T$, which is the optimal one during [$v_p$, $u_p$] in the matrix Q, while $d_{vj}$ is the evaluation index value ranking $c_{pk}$ in the worst evaluation set V= [$d_{v1}$, $d_{v2}$, …, $d_{vn}$]$^T$, which is the worst one during [$v_p$, $u_p$] in the matrix Q.

By comparing the evaluation index value $w_p$ and the corresponding index value $d_{uj}$ in the optimal set U= [$d_{u1}$, $d_{u2}$, …, $d_{un}$]$^T$, the similar degree matrix A of objects and the set [U,V] without weights can be got:

$$A=\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} \tag{2}$$

By comparing the evaluation index value $w_p$ and the corresponding index value $d_{vj}$ in the worst set V= [$d_{v1}$, $d_{v2}$, …, $d_{vn}$]$^T$, the opposite degree matrix A of objects and the set [U,V] without weights can be got:

$$B=\begin{bmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \dots & \dots & \dots & \dots \\ b_{m1} & b_{m2} & \dots & b_{mn} \end{bmatrix} \tag{3}$$

In the matrix A and B,$a_{pk}=u_pv_p/d_{pk}(u_p+v_p)$,$c_{pk}=d_{pk}/(u_p+v_p)$, with $b_{ij}$ as the similar degree and the opposite degree of the object evaluated $f_m$ and the set [U,V].

If $d_{ij}$ imposes positive influence on the evaluation result,

$$\begin{cases} a_{ij}=\dfrac{d_{ij}}{d_{uj}+d_{vj}} \\ b_{ij}=\dfrac{d_{uj}d_{vj}}{d_{ij}(d_{uj}+d_{vj})} \end{cases} \tag{4}$$

If $d_{ij}$ imposes negative influence on the evaluation result,

$$\begin{cases} a_{ij} = \dfrac{d_{uj} d_{vj}}{d_{ij}(d_{uj} + d_{vj})} \\ b_{ij} = \dfrac{d_{ij}}{d_{uj} + d_{vj}} \end{cases} \tag{5}$$

2. Building the evaluation model

Combined weights of all evaluation indices W= ($w_1$, $w_2$, … ,$w_m$) and the similar degree matrix A, the weighted similar degree matrix $A_w$ of the objects and the set [U,V] can be obtained as follows:

$$A_w = W \times A = (w_1 \quad w_2 \ \dots \ w_m) \times \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} \end{bmatrix} = (a_1, a_2, \dots, a_n) \tag{6}$$

Similarly, the weighted opposite degree matrix $B_w$ of the objects and the set [U,V] can be obtained as follows:

$$B_w = W \times B = (w_1 \quad w_2 \ \dots \ w_m) \times \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \dots & \dots & \dots & \dots \\ b_{m1} & b_{m2} & \dots & b_{mn} \end{bmatrix} = (b_1, b_2, \dots, b_n) \tag{7}$$

$a_j$ in the formula (6) is the similar degree of the j th object and the set [U,V] and $b_j$ in the formula (7) the opposite degree of the j th object and the set [U,V].

3. Calculating the relative closeness degree

The relative closeness degree $r_j$ of the jth object and the optimal evaluation set U=[$d_{u1}$, $d_{u2}$, …, $d_{un}$]$^T$ is calculated as:

$$r_j = \frac{a_j}{a_j + b_j} \tag{8}$$

Then the relative closeness degree matrix R of the objects evaluated can be got:

$$R = (r_1, r_2, \dots, r_m) \tag{9}$$

$r_j$ refers to the closeness degree of the object evaluated and the optimal evaluation set U=[$d_{u1}$, $d_{u2}$, …, $d_{un}$]$^T$, which means the bigger $r_j$ is, the closer the object is to the optimal plan. In this way, the plan ranks higher among all plans evaluated.

4.3 In multi-layer comprehensive evaluation, every layer uses the evaluation result of the next layer till that of the highest layer. Finally, based on all this, the comprehensive evaluation can be made.

### 3.2.2 Methods of weighting evaluation indices

The entropy evaluation method is to assess the practical value in line with the information loaded by the Evaluation index to ensure the credibility of the evaluation result. Thus, this paper used entropy method to evaluate index weighting.

### 3.3 Data source

Data in this paper mainly comes from Jiangsu Statistical Yearbook 2014, Jiangsu Environmental Condition Bulletin 2013 and Jiangsu Environmental Condition Annual Report 2013.

## 4. Evaluation Result and Analysis

After calculating the weights of evaluation indices via the entropy method, the set pair analysis method based on initial data is used to get the evaluation results of such subsystems as economic growth, social harmony, ecological health and environmental friendliness in the system layer of the 2013 Jiangsu ecological competitiveness evaluation indices system. More information can be seen in Table 2.

*Table 2: Subsystems evaluation results of the ecological competitiveness of all regions in Jiangsu*

| Area | Economic growth | Social harmony | Ecological health | Environmental friendliness |
|---|---|---|---|---|
| Nanjing | 0.5937 | 0.5144 | 0.5508 | 0.3935 |
| Wuxi | 0.5098 | 0.5030 | 0.4155 | 0.5679 |
| Xuzhou | 0.5469 | 0.3654 | 0.6501 | 0.3586 |
| Changzhou | 0.5541 | 0.5066 | 0.4493 | 0.5689 |
| Suzhou | 0.6051 | 0.5438 | 0.2889 | 0.5192 |
| Nantong | 0.5932 | 0.6454 | 0.4430 | 0.5006 |
| Lianyungang | 0.4075 | 0.3142 | 0.6456 | 0.4673 |
| Huaian | 0.4795 | 0.3325 | 0.6253 | 0.4446 |
| Yancheng | 0.5652 | 0.4548 | 0.5674 | 0.4120 |
| Yangzhou | 0.5254 | 0.5059 | 0.5073 | 0.5309 |
| Zhenjiang | 0.5344 | 0.4467 | 0.5254 | 0.4463 |
| Taizhou | 0.5369 | 0.4409 | 0.4179 | 0.5368 |
| Suqian | 0.4322 | 0.2939 | 0.6097 | 0.5152 |

Table2 shows that, concerning economic growth, the southern and central parts get higher value than the northern part on the whole; concerning social harmony, the southern and central parts get better result than the northern part as a whole. Compared to the evaluation results of the above two aspects, three parts of Jiangsu province see significant changes of value in ecological health, with the northern part the highest, the southern part the lowest and the central part the middle, which means the ecological environment in the northern part is better than that in the southern and central parts. And in terms of environmental friendliness, the values of the southern, central and northern parts decrease progressively.

Based on the evaluation results of the four subsystems of three parts in Jiangsu province, the set pair analysis method is adopted again to get the composite value of the ecological competitiveness evaluation indices of Jiangsu province, with details in Figure 1.

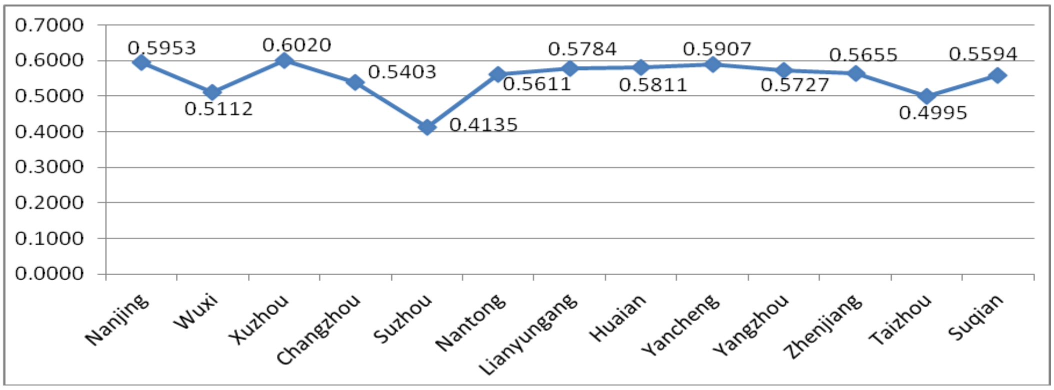


*Figure1: Comprehensive evaluation results of the ecological competitiveness evaluation of three parts in Jiangsu province*

Figure 1 demonstrates that, despite the relatively high level of overall ecological competitiveness, significant differences still exist among regions, with the northern region ranking first, the central second and the southern third. Specifically, Xuzhou ranks first with the score of 0.602, while Suzhou ranks the last with the lowest score of 0.4135. Through further researches, it can be found that the southern part with favored conditions and convenient transportation witnesses the fastest economic and social progress and relatively higher income and deeper urbanization, but the low score of ecological health of this region and the low score of environmental friendliness of cities like Nanjing and Zhenjiang lead to a lower ecological competitiveness of the southern part than the other two parts. The differences of these three parts concerning ecological competitiveness reflect the influence of economic and social development on the ecological environment.

## 5. Conclusion and Discussion

This paper, based on the establishment of the relatively comprehensive Jiangsu ecological competitiveness evaluation indices system, analyzed the ecological competitiveness of three parts in Jiangsu province in 2013, leading to the following findings:

(1) The evaluation results of three parts in Jiangsu province differ a lot concerning four subsystems as economic growth, social harmony, ecological health and environmental friendliness. Specifically, concerning economic growth, the southern and central parts get higher value than the northern part on the whole; concerning social harmony, the southern and central parts get better result than the northern part as a whole. As for ecological health, the northern part boasts better ecological environment than the southern and central parts. And in terms of environmental friendliness, the values of the southern, central and northern parts decrease progressively on the whole.

(2) Despite the relatively high level of overall ecological competitiveness, significant differences still exist among three regions of Jiangsu province, with the northern region ranking first, the central second and the southern third. Specifically, Xuzhou has the highest ecological competitiveness and Suzhou the lowest. The differences of these three parts concerning ecological competitiveness reflect the influence of economic and social development on the ecological environment.

### References

Chen W.J., Yang W.E., He Z.C., 2014,Comparing Urban Eco-competitiveness of Provincial Capitals in Midwestern China Based on Intuitionistic Fuzzy Information. China Soft Science, 5,151-163, DOI: 10.3969/j.issn.1002-9753.2014.05.015.

Caldmel L.K., 1984, Political aspects of ecologically sustainable development. Environment Conservation, 11, 299-308.

Dobso A., 1990, Green Political Thought.London: Andre Deutsch

He Y.X.., Li Jinhua., 2013, Ecological Competitiveness Estimation Based on The Strategy of Sustainable Development--A Case Study in Anhui Province. Resources and Environment in the Yangtze Basin, 4,462-467.

Liang W., Zhang H.Y., Zhu K.L., 2013, Comprehensive evaluation of urban eco-environment competitiveness based on fuzzy mathematics and gray theory. China Environmental Science, 5, 945951, DOI: 10.3969/j.issn.1000-6923.2013.05.027.

Su F., Zhang P.Y., 2010, Vulnerability Assessment of Petroleum City's Economic System Based on Set Pair Analysis: A Case Study of Daqing city. Acta Geographica Sinica, 4,454-464.

Umberto C., 2001, The Club of Rome and Sustainable Development, Futures.

Zhang L.X., Yang Z.F., Chen B., 2008, An analysis on urban ecological competition capability with biophysical accounting method. Acta Ecologica Sinica, 9, 4344-4351, DOI: 10.3321/j.issn:1000-0933.2008 .09.033.