

Quantitative assessment of eco-environmental stress of Anhui Province (China) using the eco-environmental stress index

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Abstract. The eco-environmental stress index (ESI) is used to quantitatively assess the stress caused by economic development to the environment. This study analyzed environmental and economic data for the period 2000-2014 in the Anhui Province (China) and quantified eco-environmental stress in every city of the Province for the year 2014 to provide the springboard for sustainable development strategies in the area. The results show increasing eco-environmental stress in the Anhui Province, driven by significant increase in the annual resource and energy consumption. The highest eco-environmental stress during 2014 was observed in the Hefei City, followed by Ma'anshan and Huainan. While the Hefei and Ma'anshan cities had the highest consumption of energy and resources, the environmental pollution index was relatively small, in contrast to the city of Huainan. Minimum stress was observed in the Huangshan City. This study highlights the necessity for green strategies in the Anhui Province to reduce eco-environmental stress and ensure a sustainable future for the Province and its citizens.

1. Introduction

Ecological environment is the basic of living and development for human society. As the rapid development of economy and society, the activities of human beings have a negative impact on ecological environment, such as environmental pollution, Destruction of the ecosystem. Scientifically perceiving and relieving eco-environmental stress from the activities of human beings, and realizing the sustainable development of economy, society and ecological environment have been a focus and difficult question. They have already aroused the domestic and foreign scholar's attention.

The early studies focusing on the relationship between environmental quality deterioration and economic development is the environmental Kuznets curve (EKC) hypothesis, which was theorized by Kuznets in 1955[1]. After that, numerous studies were carried out based on the cases study from the relationship between the pollution emissions or CO₂ emissions and economic development [2-4]. Up to now, EKC is still used to study the relationship [5].

Energy analysis, which was Odom's method of emery accounting [6], can bridge the gap between socio-economic development and protection of the environment that sustains the development [7].



Brown et al. [8] adopted the emery-based indices and ratios to assess the sustainability of economy and technology. Su et al. [9] adopted the emery and set pair analysis to assess the ecosystem health of typical cities in China. Sun et al. [10] assessed the sustainable development of eco-economic system in Liaoning Province based on emery analysis.

Another method employed to assess the sustainable development is the theory of ecological footprint. Ecological footprint was developed by William and Wackernagel [11-12]. In view of its characteristic, many recent studies have used EF as an indicator of environmental impact [13-15]. The ecological footprint of consumption (EFC) represents a comprehensive indicator of anthropogenic pressure on the environment [16]. Wackernagel et al. [17] presented two different conventional coefficients for calculating Ecological Footprints in time series, and applies them to Austria, the Philippines, and South Korea for the time period from 1961 to 1999. Uddin et al. [18] employed the statistical method to study the effects of real income, financial development and trade openness on the ecological footprint of consumption using a panel data.

Some other methods which were used to explore the environment and economic development (or sustainability development) were included as follows: Li et al. [19] analyzed development of urban ecological economy in the Yangtze basin based on the model of data envelopment analysis (DEA). Wu et al. [20] analyzed the coordination of regional economic growth and environmental conservation in China. Xiao et al. [21] analyzed input-output state for ecological- economic system of Chongqing city based on the ascendancy theory. Nguyen et al. [22] used GIS technology to zone the eco-environmental vulnerability region for environmental management and protection. Based on systematic dynamics, Cu et al. [23] studied and simulated the “industry-economy-resources” system for the eco-industrial clusters of Poyang Lake. Chu et al. [24] put forward ecological tension index (ETI), ecological occupancy index (EOI) and ecological economic coordination index (EECI) to evaluate ecological security of the Beijing-Tianjin-Hubei region between 1995 and 2010.

The above researches displayed the complex relationship of the economic, social development and ecological environment. And they achieved some valuable achievements. But then, the comprehensive evaluation index system is widely used in various evaluation practices. To assess quantitatively the regional economic development status, Cu et al. [25] put forward eco-environmental stress index (ESI) to estimate the trends of ecological environment, which was of great importance for evaluating the efficiency of development. Song et al. [26] employed the model to analyze the trend in stress of economic development to eco-environment in Jilin province for the period 2000-2010 and characterize the eco-environment stress in every city in Jilin province for 2010. Due to the difference of the patterns of industrial structure in the different study areas [26], the original model showed the single and uncertainty for the construction of index system and the methods determining the weight. Therefore, in order to provide a better understanding of environmental pressure, this paper made some improvements: added some indicators to the index system, and used entropy method to decide the weights of indicators.

Along with its promoting of urbanization and economic activity, the ecological environment of Anhui province was suffered with the pollution. Since 2004, the ecological province strategy began to come into effect in Anhui. In the practice of circular economy and construction of ecological province, ecological environment protection works had been done, but then there were still some eco-environment problems: the pollution emissions from energy consumption and industry production, soil degradation and so on [27]. So, it is very valuable to assess the eco-environmental stress index to the economic and social development. Resource, energy consumption index and environmental pollution index were employed to construct the index system of assessment.

2. Materials and Methods

2.1. Study area

Anhui province is located in the east of China and belongs to the Middle East Economic Zone in China. It is located in the middle and lower reaches of the Yangtze River and the Hua River. It stretches 450 kilometers from east to west and 570 kilometers from north to south. It has a land area of 139,400 km²,

accounting for 1.45% of the total land area of China. Anhui is located in the transitional area between temperate zone and subtropical zone, so the climate is warm and moist, and the four seasons are distinct. North of the Hua River is located in sub-humid warm temperate monsoon climate zone and south of the Hua River is located in subtropical humid monsoon climate zone. Anhui is composed by the mountains, hills and plains, and each class accounts for one-third of proportion.

Anhui is the major base of agricultural products, energy, raw materials and manufacturing industries in China. It plays an important role in many industries, such as car, machinery and so forth. As far as energy is concerned, there are 11.31 billion tons of coal reserves in Anhui [28]. In 2014, the three industrial structure was 11.5:53.7:34.8. The proportion of industrial added value to GDP was 46%.

2.2. The principles of constructing the index system

The evaluation indicators of eco-environmental stress varied widely [29-31], so the paper chose the indicators according to the following general principles:

(1) Quantification: taking the quantitative data as a priority when choosing indicators, the value was expressed by the standardized value.

(2) Independence: the indicators were chosen by its independence and representativeness, the connotation of those indicators should avoid the overlapping.

(3) Scientificity: the chosen indicators should confirm to the current situation and trends of ecological environment of study area and be according with the reality.

Detailed index system was seen in table 1. The data sources of the paper were mainly from the statistical yearbooks of Anhui province (2001~2015) [32].

Table 1. Indicators and weights for assessing the stress trend of economic development to eco-environment in Anhui province during 2000-2014.

Sub-index			indicators			
Code	Meaning	Weight	Code	Meaning	Unit	Weight
RECI	Resource and energy consumption index	0.5	REC1	Total energy consumption(coal)	104t	0.402
			REC2	Energy consumption by industries (coal)	104t	0.266
			REC3	Total water consumption	104m3	0.0624
			REC4	farmland area	107m2	0.0006
			REC5	urban construction land area	106m2	0.269
EPI	Environmental pollution index	0.5	EPI1	Usage of fertilizer in agriculture	105t	0.011
			EPI2	Discharge of industrial waste gas	109m3	0.562
			EPI3	Discharge of industrial dust	104t	0.083
			EPI4	Discharge of industrial SO2	104t	0.023
			EPI5	Discharge of industrial wastewater	104t	0.004
			EPI6	Mass of industrial solid wastes produced	104t	0.317

2.3. Calculation principle of eco-environmental stress index (ESI)

2.3.1 Eco-environmental stress index. Eco-environmental stress index, proposed by Cu et al. (2014), was designed in a scale of 0 to 100 and divided into five parts: 0 to 20, 20 to 40, 40 to 60, 60 to 80, 80 to 100, and meant the stress of very low, low, medium, high and very high, respectively. The index was calculated from two sub-index, RECI (Resource-Energy Consumption Index) and EPI (Environmental Pollution Index).

ESI was computed using formula (1):

$$ESI = RECI \times W_1 + EPI \times W_2 \quad (1)$$

RECI and EPI were computed using formula (2):

$$RECI = \sum_{i=1}^n RECI_i \times w_i ; EPI = \sum_{j=1}^m EPI_j \times w_j \quad (2)$$

Where W_1 and W_2 were the weight of $RECI$ and EPI , respectively, they were directly set to 0.5 according to their importance; $RECI_i$ and w_i were the value and weight of it indicator of $RECI$, respectively; EPI_j and w_j were the value and weight of jet indicator of EPI , respectively.

If $RECI_i$ and EPI_j were the positive index, their normalization were calculated by using formula (3) and formula (4); if $RECI_i$ and EPI_j were the negative index, formula (5) and formula (6) were used.

$$RECI_i = RECI_{ii} / \max(RECI_{ii}) \times 100, i = 1, 2, \dots, n; ii = 1, 2, \dots, n \quad (3)$$

$$EPI_j = EPI_{jj} / \max(EPI_{jj}) \times 100, j = 1, 2, \dots, m; jj = 1, 2, \dots, m \quad (4)$$

$$RECI_i = \left(1 - \frac{RECI_{ii}}{\max(RECI_{ii})}\right) \times 100, i = 1, 2, \dots, n; ii = 1, 2, \dots, n \quad (5)$$

$$EPI_j = (1 - EPI_{jj} / \max(EPI_{jj})) \times 100, j = 1, 2, \dots, m; jj = 1, 2, \dots, m \quad (6)$$

Where, $RECI_{ii}$ and EPI_{jj} were the real value from yearbooks; $\max(RECI_{ii})$ and $\max(EPI_{jj})$ were respectively the maximum of the corresponding index.

The two dimensional space, composed of $RECI$ and EPI , would be used to describe the correlation between resource-energy consumption and environmental pollution [25]. By the superposition of five states (very low, low, medium, high, very high) of $RECI$ and EPI , the two dimensional space was divided into 25 regions to classify the types of eco-environmental stress. When the ratio of $RECI$ to EPI was equal to 1, it meant the eco-environmental stress was determined by both environmental pollution and resource-energy consumption. When the ratio of $RECI$ to EPI was less than 1, it meant the eco-environmental stress was determined by environmental pollution. When the ratio of $RECI$ to EPI was more than 1, it meant the eco-environmental stress was determined by resource-energy consumption.

When $RECI$ and EPI were both very low and low, it meant the negative impact of the resource-energy consumption and pollution on ecological environment would be weak. When the two indicators were both at the medium level, it meant the consumption and pollution on ecological environment would be acceptable, but if the two indicators were both high and very high, it meant the consumption and pollution on ecological environment would be unacceptable and unsustainable, so the development mode of social economy needed to be adjusted or improved.

2.4. The determination of index weight

The common methods of determining the weights included experience method, expert consultation method, analytical hierarchy process and so forth[33]. This paper adopted the entropy weight method[34], which was an objective method to calculate weight. The entropy weight method was based on Shannon entropy theory according to their variation degrees.

Assumed that there was a data set of m years for evaluation and each year had n evaluation indicators, they formed the following decision matrix:

$$R_{ij} = \begin{bmatrix} r_{11} & r_{12} & \dots & r_{1n} \\ r_{21} & r_{22} & \dots & r_{2n} \\ \dots & \dots & \dots & \dots \\ r_{m1} & r_{m2} & \dots & r_{mn} \end{bmatrix} \quad (7)$$

Where, r_{mn} is the value of n th evaluation indicator for M Th year? Due to the difference of every indicator in dimension, magnitude and units, the paper adopted the extreme normalization method [35].

$$r'_{ij} = r_{ij} / r_j^{\max} \quad (8)$$

$$r'_{ij} = 1 - \frac{r_{ij}}{r_j^{\max}} + \left\{ 1 - \max \left[1 - \frac{r_{ij}}{r_j^{\max}} \right] \right\} \quad (9)$$

Where, $r_j^{\max}$ is the maximum value of jet indicator, r'_{ij} is the standardized value. The positive indicators were calculated by formula (8), while the reverse indicators were calculated by formula (9).

The proportion values p_{ij} were calculated by formula (10):

$$p_{ij} = r'_{ij} / \sum_{i=1}^m r'_{ij} \quad (10)$$

The entropy value of j indicator (e_j) was calculated by formula (11):

$$e_j = \frac{- \sum_{i=1}^m p_{ij} \times \ln(p_{ij})}{\ln(m)} \quad (11)$$

The entropy weight of j indicator (w_j) was calculated by formula (12):

$$w_j = (1 - e_j) / \sum_{j=1}^n (1 - e_j) \quad (12)$$

3. Results and discussion

3.1. Time characteristics analysis of ecological environment stress in Anhui province

According to the indicator system (table 1) and the related data from the statistical yearbooks of Anhui province, the paper calculated the weight of every indicator for the period 2000-2014 and analyzed the time trends of eco-environmental stress of Anhui province for the fifteen years. The change trend of eco-environmental stress of Anhui province for the period 2000-2014 was showed in figure 1, and the relationship chart of resource-energy consumption and environmental pollution is presented in figure 2.

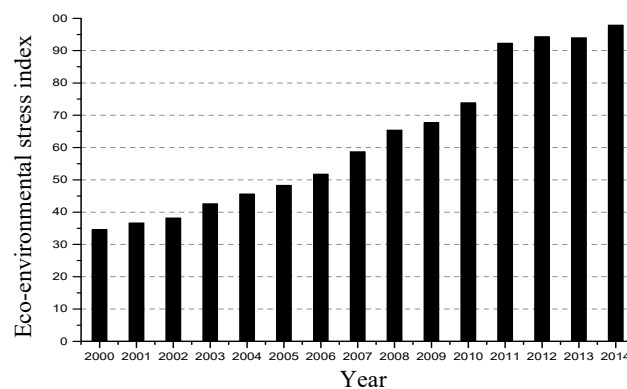


Figure 1. Variation trends of eco-environmental stress index in Anhui province during 2000-2014

The figure 1 showed that the stress of economy development to ecological environment in Anhui province had significantly upward trend on the whole. Furthermore, there are also several different variation characteristics: during 2000-2002, the stress increased relatively slow, the value of eco-environmental stress was relatively small; during 2003-2010, the increasing trend of stress was accelerating and the stress was at the medium level; during 2011-2014, the stress maintained at a very high level and kept ascending trend.

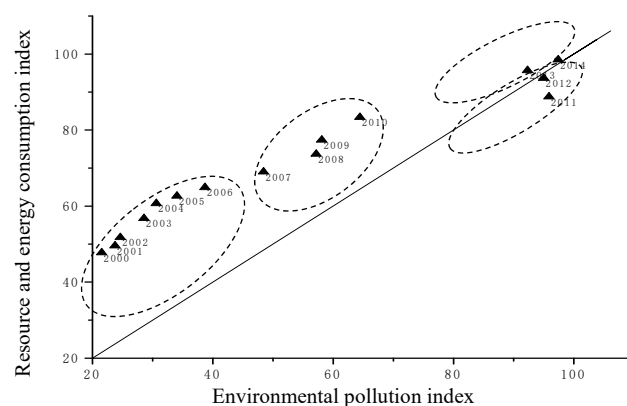


Figure 2. Interrelationship between RECI and EPI in Anhui province during 2000-2014

The figure 2 showed that the inter-relationships and variation trend of the two sub-indexes (RECI and EPI) of eco-environmental stress of Anhui province. The relationship and trend can be concluded as follows:

(1) During 2001-2006, the data points were all above the diagonal line, the values of RECI were between 47 and 65, and the values of EPI were between 21 and 40. That meant the resource and energy consumption was relatively large and the environmental pollution was relatively small. The RECI are higher than the EPI. The ESI was at the medium level with its value between 34 and 55.

(2) During 2007-2010, the data points were all above the diagonal line, the values of RECI were between 69 and 85, and the values of EPI were between 48 and 65. That meant the increasing trend was accelerating during the period, RECI and EPI were both increasing. The ESI was at the level between medium and high with its value between 58 and 75, which was also increasing.

(3) During 2011-2012, the data points were all below the diagonal line, the values of RECI were between 88 and 94, and the values of EPI were between 94 and 96. The EPI was relatively high, which was the major indicator that impacted the ecological environment. The ESI was at the very high level with its value between 92 and 95.

(4) During 2013-2014, the data points were all above the diagonal line, the values of RECI were between 95 and 99, and the values of EPI were between 92 and 98. The RECI was relatively high, which was the major indicator that impacted the ecological environment. The ESI was at the very high level with its value between 93 and 98.

3.2. Space distributed characteristics of ecological environment stress for the cities in 2014

According to the features of cities in Anhui province, the paper used the indicator system of table 1 to assess the stress of economic development to eco-environmental for the cities of Anhui province in 2014. Suzhou, Huaibei, Bozhou, Fuyang, Bengbu, Huainan, Chuzhou, Hefei, Lu'an, Wuhu, Ma'anshan, Anqing, Chizhou, Tongling, Xuancheng and Huangshan were analyzed. Index weight, employed in 2014, was 0.154, 0.221, 0.292, 0.140, 0.193, 0.131, 0.188, 0.179, 0.114, 0.095, and 0.293. The distributed map of eco-environmental stress of the cities in Anhui province was shown in figure 3, which included the space distributed status of ESI, RECI and EPI.

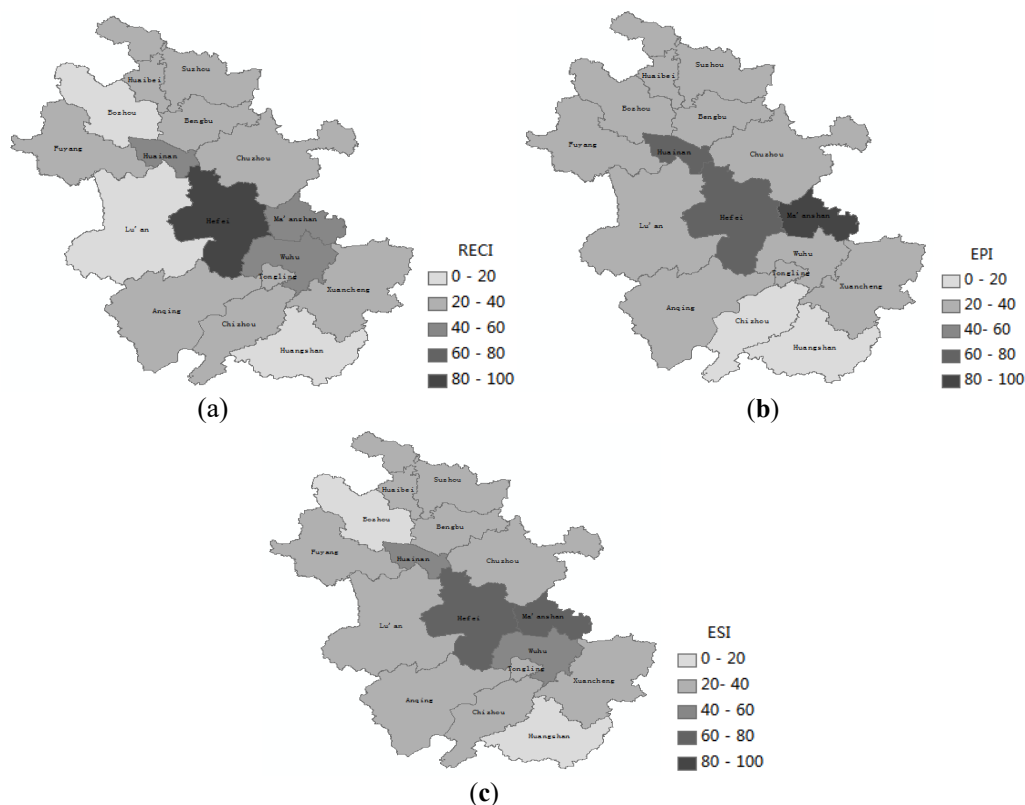


Figure 3. Distributed maps of RECI, EPI and ESI of the cities of Anhui province in 2014.(a)Distribution description of RECI in the first panel; (b) Distribution description of EPI in the second panel;(c) Distribution description of ESI in the third panel.

Figure 3(a) showed that the RECI of Hefei is highest, followed by MA 'Anshan. Figure 3(b) showed that the EPI of MA 'Anshan was the highest, followed by Hefei. Figure 3(c) showed that the ESI of Hefei was the highest with value of 72.08, which was at the high level (60-80), followed by MA 'Anshan'.

With the rapid development, Hefei had more resource and energy consumptions which led to its highest index of RECI among the cities; moreover, the environment pollution of Hefei should also get more attention. The ESI of MA 'Anshan was second with its value of 71.19, and it was also at the high level (60-80).

The highest EPI indicated that the eco-environmental stress of MA 'Anshan was significantly determined by environmental pollution. The third and fourth city in Anhui province was Huainan and Wuhu, respectively. Huainan was stressful because of its environment pollution and Wuhu was stressful because of its resource and energy consumption. By analyzing the two sub-indexes, the paper obtained the specific genesis and provided the decision support for the subsequent scientific development. The ESI of Hu Anshan and Chi Zhou were very low, which meant their ecological environment of the two cities were good.

3.3. Countermeasures

Based on the results of the above analysis, combining with the present status of ecological environment in Anhui and its major cities, the paper put forward the following development strategies:

1. Aimed at the fact that the stress of economy development to ecological environment in Anhui province has upward trend, Anhui should speed up the transformation of its economic growth pattern, optimize its industrial structure, get rid of the pattern which depended on the large resources and energy input to promote the economic development, and make a great effort to do green development and scientific development. Anhui should carry out the accounting of green GDP to provide supports for the

realizing of sustainability strategy and understand the net benefit of economic development. At the same time, Anhui should strengthen the environmental protection and pollution control, develop recycling economy, enhance the use efficiency of resource and energy, and reduce the total discharge of pollution.

2. Based on the results that the stress of Hefei, MA 'Anshan and Wuhu are the classification of resource and energy consumption, it is important to enhance the use efficiency of resource and energy, improve and optimize the energy structure, adjust and optimize the industrial structure and increase the quality and benefit of economic development.

3. Based on the results that the stress of Huainan and MA 'Anshan are the classification of environmental pollution, it is important to strengthen the environmental protection and pollution control, remedy ecological environment, do the ecological construction for the ecologically vulnerable area, transform the function of the mining industrial cities and find new development fields. And they should also reduce the total discharge of pollution and elevate the bearing capacity of ecological environment by the comprehensive control.

In addition, it is important to strengthen the new industry and transform from the middle and low end industry to middle and high end industry.

4. Conclusions

By evaluating quantitatively eco-environmental stress, the paper revealed the characteristics and status of Anhui province and its cities. The conclusions were as follows:

1). With the rapid economic growth, Anhui had the larger eco-environmental stress. Since 2011, the stress had been significantly increasing. So, it should speed up the transformation of its economic growth pattern, carry out sustainable development strategy, and strengthen the construction of ecological province.

2). From the view of the space characteristics, the ESI of Hefei, MA 'Anshan and Huainan are relatively large, while the ESI of other cities in Anhui province are relatively small.

3). The assessment method of ESI not only took ecological environmental pollution into account, but also resource and energy consumption. Compared with other methods, ESI can explicit the specific factor from economic development impacts on the eco-environmental stress, so it had advantage of strong comprehensiveness.

Acknowledgments

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