Study on urban ecological sustainability based on emergy theory-taking Zhenjiang city as an example

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Abstract. With the rapid development of the economy, the deterioration of the ecological environment problem has followed and the city's ecological assessment has become increasingly important. This article uses a quantitative ecological analysis method-emergy method to assess the ecological status of the city. The research object is Zhenjiang City. Through the calculation of a series of ecological sustainability parameters about Zhenjiang City, the city's ecological system is quantitatively evaluated. The results show that: 1. there is little change in renewable resources from 2012 to 2016 and a rapid increase according to the value of non-renewable resources; 2. the environmental load rate (ELR) has rapidly increased and the urban ecological sustainability has not improved; 3. Through Zhenjiang's GDP and GDP per capita grew rapidly from 2012 to 2016, it did not achieve satisfied results about industrial restructuring. In summary, the development in recent years has not achieved the expected effect and sustainable ecological development of Yangzhou City. The research significance of this article can provide a reference for the Zhenjiang municipal government to formulate better policies. Secondly, it has positive significance for the formulation of other urban policies.

1. Introduction
Along with the rapid development of China's economy, the city has experienced an explosive growth mode. The excessive use of non-renewable resources (such as petroleum and coal resources) for the city, not only cause a shortage of energy in China, but also generate numerous urban problems, even national pollution problems.
In the face of increasingly severe urban environmental issues, domestic and foreign experts have focused on the study of urban ecological sustainability, ensuring that people enjoy the economic development results while enjoying the city's good ecological environment.
This paper selects Zhenjiang City as the research object in the Yangtze River Delta region. The reasons for the selection of target city include: based on the economic sector of Jiangsu Province in terms of economic scale, Zhenjiang city is a typical medium level city.
Zhenjiang City has set a strategy for sustainable development, but there is still a tendency that sacrifices the ecological environment to develop the economy.
For this reason, the municipal government has to make specific policy adjustments to ensure that the proportion of agriculture remains unchanged, while minimizing industrial the proportion and enhancing the proportion the service industry.
The paper selects the emergy method to make the ecological assessment of Zhenjiang City. The emergy method is a world-recognized ecological assessment method [1-7], which can quantitatively
evaluate the ecological changes of cities and provide verification basis for the implementation of government departments' policies.

2. Emergy Method and System Diagram

2.1. Emergy method introduction
The emergy is a typical "embodied energy". With the sun as the initial energy source, each object has a corresponding energy value and the unit is solar joules (sej). The emergy method originally came from the ecological field. It was a new ecological assessment method established by H.T.Odum of American ecologist in the 1980s and 1990s. It is widely used in agriculture, urban, industrial and ecological fields [8]. After 30 years of development, a complete theory has been formed and it has become a reliable ecological assessment method.

Professors of the University of Pennsylvania have integrated the emergy assessment methods into the urban field, providing a new way to explore green assessments. At present, the emergy research is developing rapidly in the urban field, involving diversification of research objects, refinement of method indicators, and localization of unit emergy value.

The basic steps of emergy analysis include basic data acquisition and data collection; emergy system diagram; emergy analysis table; emergy comprehensive index calculation; system development comprehensive evaluation and strategy analysis.

The basic calculation formula is as follows:
Solar emergy (sej) = energy (J) × unit emergy value (sej / J);
Solar emergy (sej) = substance (g) × unit emergy value (sej / g);
Solar emergy (sej) = substance ($) × unit emergy value (sej / $);

2.2. Zhenjiang city ecosystem map

The precondition for the evaluation of the emergy assessment is to establish the evaluation boundary conditions. Figure 1 is a schematic diagram of the emergy evaluated boundary of Zhenjiang City in China.

The left side of Figure 1 shows the types of renewable energy, including: the sun, rain, wind and geothermal energy, which are the basic natural energy sources of the city. The upper column is a non-renewable source, including: water, fuel, energy, products and services. At the right is the output, including currency, people, and market. In addition to these three items, there is also the flow of recycling system. All basic natural and industrial types of Zhenjiang city model are inside the boundary.

The diagram establishes the boundary conditions for the system assessment and provides a guarantee for the sustainability assessment of the city [9].
2.3. Emergy sustainability assessment indicator

There are 10 energy assessment indicators, as shown in Table 1. The value of Geobiosphere Emergy Baseline (GEB) is 12E+24 sej/year that comes from research by other scholars [10].

| Table 1. Emergy assessment indicators. |
| index | meaning | unit       |
|-------|---------|------------|
| R     | Renewable Energy | Sej       |
| N     | Non-renewable energy | Sej   |
| Y     | Total energy | Sej       |
| F     | Input and output emergy | Sej   |
| Ep    | Per capita emergy | Sej/person |
| Em    | Emergy value | Sej/money  |
| Ec    | Emergy density | Sej/m2    |
| ELR   | Energy load ratio: (N + F)/R | ~ |
| EYR   | Emergy yield ratio: Y/F | ~ |
| ESI   | Emergy sustainability indicator: EYR/ELR | ~ |

3. Results and Discussion

3.1. Emergy assessment of urban ecology

Table 2 shows the statistical data of the main energy and products of Zhenjiang City and the unit emergy value of various energy types. It can be divided into three categories: renewable data, non-renewable resources and others. The specific contents are shown in Table 2.

| Table 2. The energy calculation of main energy and products in Zhenjiang City |
|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| Type                        | unit                        | 2012                        | 2013                        | 2014                        | 2015                        | 2016                        |
|                            |                             | J                           | J                           | J                           | J                           | J                           |
| Renewable                   |                             |                             |                             |                             |                             |                             |
| Sun radiation               | J                           | 4.15E+23                    | 4.57E+23                    | 4.24E+23                    | 4.88E+23                    | 4.03E+23                    | 1.00E+04sej/J               |
| Wind energy                 | J                           | 7.88E+15                    | 7.67E+15                    | 7.56E+15                    | 7.29E+15                    | 7.65E+15                    | 1.50E+03sej/J               |
| Rain energy                 | J                           | 6.36E+15                    | 6.55E+15                    | 6.33E+15                    | 6.84E+15                    | 6.48E+15                    | 1.80E+04sej/J               |
| Tidal energy                | J                           | 3.27E+15                    | 3.02E+15                    | 3.51E+15                    | 3.16E+15                    | 3.56E+15                    | 1.00E+04sej/J               |
| Coal                        | J                           | 8.84E+08                    | 5.49E+09                    | 7.52E+09                    | 9.49E+09                    | 2.04E+10                    | 1.00E+04sej/J               |
| Oil                         | J                           | 1.71E+19                    | 3.64E+13                    | 6.46E+13                    | 8.68E+13                    | 2.86E+14                    | 6.60E+04sej/J               |
| Electricity                 | J                           | 2.46E+17                    | 6.58E+17                    | 8.48E+17                    | 1.02E+18                    | 1.47E+18                    | 1.88E+08sej/J               |
| Cement                      | kg                          | 5.41E+09                    | 6.17E+09                    | 7.56E+09                    | 8.92E+09                    | 1.59E+10                    | 2.59E+12sej/kg              |
| Steel                       | kg                          | 1.64E+09                    | 1.75E+09                    | 2.68E+09                    | 3.35E+09                    | 3.73E+09                    | 6.97E+12sej/kg              |
| Plastic                     | kg                          | 1.14E+08                    | 1.23E+08                    | 1.46E+08                    | 1.59E+08                    | 1.81E+08                    | 5.76E+12sej/kg              |
| Paper                       | Kg                          | 8.69E+07                    | 2.71E+08                    | 4.98E+08                    | 7.23E+08                    | 2.57E+08                    | 2.38E+12sej/kg              |
| Food                        | Kg                          | 8.54E+08                    | 8.32E+09                    | 8.79E+09                    | 9.26E+09                    | 1.19E+10                    | 8.30E+04sej/kg              |
| Aquatic products            | Kg                          | 2.98E+07                    | 3.69E+07                    | 5.56E+07                    | 7.69E+07                    | 9.85E+07                    | 2.00E+06sej/kg              |
| Others                      |                             |                             |                             |                             |                             |                             |                             |
| Input money                 | $                           | 5.34E+11                    | 6.94E+11                    | 9.83E+11                    | 1.91E+12                    | 2.15E+12                    | 8.67E+12sej/$               |
| Output money                | $                           | 5.23E+11                    | 7.41E+11                    | 9.79E+11                    | 2.91E+12                    | 4.43E+12                    | 1.45E+12sej/$               |
| Waste water                 | Kg                          | 1.64E+10                    | 4.55E+10                    | 7.64E+10                    | 9.22E+10                    | 1.66E+11                    | 8.60E+05sej/kg              |
| Waste                       | Kg                          | 8.69E+07                    | 2.54E+08                    | 4.05E+08                    | 6.92E+08                    | 7.89E+08                    | 1.80E+06sej/kg              |
Based on the data of Table 2, through the basic calculated formula of emergy, the evaluation indicators of Table 3 are obtained, and the sustainability evaluation of Zhenjiang City's ecological development can be carried out through 10 emergy assessment indicators, so as to provide a strategic support of urban development.

| Index | 2012      | 2013      | 2014      | 2015      | 2016      | Unit |
|-------|-----------|-----------|-----------|-----------|-----------|------|
| R     | 1.77E+25  | 1.63E+25  | 1.73E+25  | 1.57E+25  | 1.69E+25  | sej  |
| N     | 1.19E+26  | 1.42E+26  | 1.76E+26  | 2.13E+26  | 2.76E+26  | sej  |
| Y     | 1.33E+26  | 1.61E+26  | 1.89E+26  | 2.23E+26  | 2.77E+26  | sej  |
| F     | 1.43E+25  | 1.69E+25  | 1.84E+25  | 2.06E+25  | 2.46E+25  | sej  |
| Ep    | 1.08E+19  | 2.09E+19  | 4.64E+19  | 7.35E+19  | 8.45E+19  | sej/person |
| Em    | 1.53E+14  | 2.01E+14  | 4.36E+14  | 6.49E+14  | 7.29E+14  | sej/capita |
| Ec    | 1.59E+16  | 3.57E+16  | 4.06E+16  | 5.22E+16  | 7.21E+16  | sej/m² |
| ELR   | 7.9       | 10.4      | 10.9      | 19.1      | 16.5      | none |
| EYR   | 0.93      | 0.95      | 1.02      | 1.13      | 1.63      | none |
| ESI   | 0.12      | 0.08      | 0.09      | 0.06      | 0.09      | none |

As the basis of the emergy calculation, the basic data needs to be sorted and calculated in advance, including: renewable resource R, non-renewable resource N, total emergy quality Y, and input and output emergy value F. The specific values are shown in Table 3. The basic data of figure 2 shows the trend in Zhenjiang from 2012 to 2016. It can be seen from Figure 2 that the renewable resources have not changed much, which is caused by the limitation of natural conditions; the amount of non-renewable resources increases with time, indicating that the city is developing rapidly and urban energy and materials are increasing rapidly. With the growth of non-renewable resources, the total emergy also increased greatly. The import and export situation showed an increasing trend from 2012 to 2016, but the change was not obvious.
Figure 3 shows the mean emergy for the five years from 2012 to 16 years, including the per capita emergy, the emergy money value and emergy density. The three data are all increasing from 2012 to 2016. As been shown in Figure 3, the change of emergy density is the largest. This is that because the area of Zhenjiang city is fixed and the increase in emergy money value is directly corresponded to the emergy density. For per capita emergy and emergy money value, although the population is growing and GDP is increasing, the rate of emergy increment grows more, causing the same rapid growth in the emergy money value and per capita energy.

As the final indicators of the emergy evaluation, the emergy load ratio, the emergy yield ratio and the ecological sustainability indicator constitute the basic elements of the emergy method assessment. Figure 4 shows the ecological sustainability indicators of Zhenjiang City from 2012 to 2016. The most obvious market value load is increasing. The most obvious is the emergy load increment. It is the maximum value of 19.1 in 2015 and slightly decreased in 2016 and the emergy yield ratio also shows an increasing trend, but the change is not obvious. The indicators of the ecological sustainability are very low in figure 4. The indicators in Table 3 are 0.12, 0.08, 0.09, 0.06 and 0.09, respectively. The phenomenon indicates that ecological strategy of Zhenjiang city needs to be adjusted in order to improve ecological sustainability.

3.2 Urban analysis based on Gross Domestic Product (GDP)

The emergy evaluation has a direct relationship with the industrial result of the city. The proportion of the industrial structure will affect the evaluated result using the emergy method. Therefore, this paper uses the GDP proportion analysis in different industries to verify the analysis results of the above emergy assessment.

Table 4 shows the GDP from 2012 to 2016, including the GDP share and GDP per capita of the three industries. The specific values are shown in the detailed statistics in Table 4.
The total GDP of Zhenjiang City shows an increasing trend and the added value is obvious. The change illustrates that the non-renewable energy in Zhenjiang City increases rapidly in figure 5, which is consistent with the trend of emergy in figure 2.

Among the three major industries, the proportion of the primary industry (agriculture) has not changed much. This is caused by several reasons, including the hardware conditions of the city and the correct guidance of the government. The second industry (industry) also shows an increased trend. However, the increased trend is smaller than that of the tertiary industry (service). This is a clear result of the government's industrial adjustment. The result is consistent with the analysis of the results in figure 3.

Figure 6 shows the trend of per capita GDP, which the increased trend is obvious. It demonstrates that non-renewable of Zhenjiang City resources are invested heavily, driving the rapid growth of substances and the economy, which is consistent with the trend of per capita emergy in Figure 3.

3.3. Sensitivity analysis
As a vital aspect of emergy method, sensitivity analysis should be used to assess the uncertainty, in order to determine the biggest influencing factors. Non-renewable sources are the most energy consumption for the city and the results of sensitivity have been shown in Figure 7, Figure 8, Figure 9, Figure 10, Figure 11.
Based on emergy method, urban ecological analysis of this paper includes 9 non-renewable sources, involved with coal, oil, electricity, cement, steel, plastic, paper, food and aquatic products. In 2012, the main power is oil for Zhen Jiang city and the fact can be found in Figure 7. Others have very low emergy.

In addition to 2012 year, the electricity is the largest source of emergy and the results can be seen in Figure 8, Figure 9, Figure 10 and Figure 11. Electricity is the main impact factor of sensitivity analysis of non-renewable for Zhen Jiang city. In order to keep the accuracy of emergy analysis, electricity data should be collected carefully and analyse seriously.

**4. Conclusion**
Through the ecological sustainability analysis and the analysis of GDP verification of Zhenjiang City from 2012 to 2016, some results can be got, as following:
1. From 2012 to 2016, there had been little change in renewable resources and non-renewable resources and import and export emergy grow rapidly.
2. With the development of Zhenjiang City, the environmental load ratio (ELR) increased rapidly and the urban ecological sustainability did not been improved.

3. From 2012 to 2016, Zhenjiang's GDP and per capita GDP increased rapidly, but the industrial structure adjustment target did not obtain satisfactory results.

In short, the development from 2012 to 2016 did not reach the expected effect and ecological sustainable development in Zhenjiang City.

The research significance of this paper can provide reference for Zhenjiang Municipal Government to formulate better policies. Secondly, it has positive significance for other urban policy formulation.

Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this article.

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6. Reference

[1] Ling Shao, G.Q.Chen. Renewability assessment of a production system: Based on embodied energy as emergy. Renewable and Sustainable Energy Reviews, 57(2016)380-392.

[2] Yi-Bo Zhao, etc. An emergy-GIS method of selecting areas for sponge-like urban Reconstruction. Journal of Hydrology 564 (2018) 640 - 650.

[3] S. Mellino, M. Ripa, A. Zucaro, S. Ulgiati, An emergy–GIS approach to the evaluation of renewable resource flows: a case study of Campania Region, Italy, Ecol. Model. 271 (2014) 103-112.

[4] Jiang, Y., Zevenbergen, C., Ma, Y., 2018. Urban pluvial flooding and stormwater management: a contemporary review of China's challenges and “sponge cities” strategy. Environ. Sci. Policy 80, 132–143.

[5] Chang Liu, etc. Comparative Analysis for the Urban Metabolic Differences of Two Types of Cities in the Resource-Dependent Region Based on Emergy Theory. Sustainability 2016, 8, 635.

[6] Junying Zhang, etc. Quantifying the emergy flow of an urban complex and the ecological services of a satellite town: a case study of Zengcheng, China. Journal of Cleaner Production 163 (2017) S267-S276.

[7] Kampeng Lei, Lu Liu, Dan Hu, Inchio Lou, 2016. Mass, energy, and emergy analysis of the metabolism of Macao. Journal of Cleaner Production, 114 (2016) 160-170.

[8] Odum. H. T. Environmental Accounting, 1996. Emergy and Environmental Decision Making [M] NewYork: John Wiley, 1996. 32—34.

[9] Brown, M.T., and Ulgiati, S., “Energy quality, emergy, and transformity: H.T.Odum’s contributions to quantifying and understanding systems,” Ecological Modelling, 178(1), 2004; pp. 201-213.

[10] Brown, M.T., Campbell, D.E., De Vilbiss, C., Ulgiati, S., 2016. The geobiosphere emergy baseline: a synthesis. Ecol. Modell. 339, 92-95.

[11] http://tjj.zhenjiang.gov.cn/

[12] Brown, M.T., Herendeen, R.A., 1996. Embodied energy analysis and emergy synthesis: a comparative view. Ecol. Econ. 19, 219-235.

[13] Brown, M.T., Ulgiati, S., 1997. Emergy-based indices and ratios to evaluate sustainability: monitoring economies and technology toward environmentally sound innovation. Ecol. Eng. 9, 51-69.