Emergy Ternary Evaluation of Industrial Agglomeration Area

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Abstract. The development status, ecological efficiency and sustainability of two industrial agglomeration systems with different economic and environmental foundations in Liaoning Province were analyzed by using emergy phase diagram analysis method. The results show that the phase diagram analysis method is more systematic and comprehensive in analyzing the development process, current situation and possible future development direction of the system. The emergy phase diagram provides an effective research tool for the emergy analysis method.

1. Introduction

Emergy theory is a new scientific concept and measurement standard founded by Odum, a famous American ecologist, in the 1970s. There are many kinds of inputs in a system, so there are various forms and units. This requires that all inputs (material, energy, even information, labor, etc.) be transformed into a unified form of measurement for processing. Emergy theory has been gradually improved, and has developed into a complete theoretical system for ecosystem sustainability analysis and evaluation indicators.

Through emergy analysis, different kinds, grades and incomparable energy in ecosystem or eco-economic system can be transformed into the same standard emergy to measure and analyze, and its role and status in the system can be evaluated. Comprehensive analysis of various ecological flows (energy logistics, currency flow, population flow and information flow) in the system, a series of energy indices are obtained, and quantitative analysis of the structural and functional characteristics of the system and ecological and economic benefits is made. The main indicators of emergy investment ratio (EIR), emergy yield ratio (EYR), environmental load ratio (ELR), and sustainable development index (ESI) [1] are the main indicators of emergy investment ratio (EIR), emergy yield ratio (EYR), environmental load ratio (ELR), and so on. The meanings and expressions of the indicators are shown in the table below.
Table 1. Indicator of emergy analysis.

| Indicator                           | Formula                                                                 | Meaning                                                                                     |
|-------------------------------------|-------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|
| Emergy investment ratio (EIR)       | Input emergy F/renewable resource emergy R                              | Indicators to measure the load of environmental and resource conditions on economic activities. |
| Emergy yield ratio (EYR)            | (Outsourcing Emergy F+Non-renewable Emergy N)/Renewable Emergy R        | System Outsourcing Emergy plus Non-renewable Emergy and Ratio of Renewable Emergy            |
| Environmental loading ratio (ELR)   | Outsourcing Emergy F/(Non-renewable Emergy N+Renewable Emergy R)        | Ratio of the input energy (input energy) of the external feedback to the energy of the system itself |
| Emergy sustainability index (ESI)   | EYR/ELR                                                                 | Evaluate the sustainability of eco-economic system.                                         |

Li W. [2] elaborated that there is a great correlation between emergy ratio and various indicators, and a single indicator cannot fully and intuitively describe the development status and trends of different systems. Giannetti and Almedia [3, 4] put forward a method to analyze the emergy index by referring to the expression of ternary diagrams through in-depth study of the relationship between the emergy inputs of the system. Ternary diagrams are widely used in the field of physical research, especially in the fields of metal and material science, geology and physical chemistry. Three-ternary diagrams refer to the composition of a whole consisting of three parts. Generally, the sum of the three Parts' percentages is regarded as one or 100. Two of the three variables are independent of each other, and the different proportion of each component corresponds to the different states and properties of the object studied.

2. Case of Study

This section will use emergy ternary diagram to compare and analyze Shenyang Economic and Technological Development Zone and Dalian High-tech Industrial Park, a national comprehensive ecological industrial demonstration zone located in Liaoning Province. Shenyang Economic and Technological Development Zone was founded in June 1988 and is located in the southwest of Shenyang, the mother city. It covers an area of 32.1m² in 2008. Industry distribution mainly concentrates on equipment manufacturing industry, automobile parts and power industry, pharmaceutical and chemical industry, food and beverage and packaging industry, textile and garment dyeing and finishing industry. The data source of this study is related to "Shenyang Statistical Yearbook (2006-2009)" and "Tiexi Statistical Yearbook (2006-2009)", and the first-hand data are obtained by combining on-site interviews with questionnaires for important enterprises.

The Qixianling Industrialization Base of Dalian Economic and Technological Development Zone was founded in 1988. It belongs to Dalian High-tech Industrial Park and covers an area of 5.68km². At present, Qixianling Industrial Base is an industrial agglomeration with software information, biopharmaceuticals and mechanical processing as the main body [5]. The emergy evaluation data of Qixianling Industrialization Base of Dalian High-tech Industrial Park are shown in the table below. The data in Table 2 are the emergy index of Qixianling Base in Shenyang Economic and Technological Development Zone (Shenyang Development Zone) and Dalian High-tech Industrial Park (Dalian Industrial Park).
Table 2. Indices of emergy analysis of the two industrial agglomeration zones.

| Emergy indicator         | Shenyang Development Zone | Dalian Industrial Park |
|--------------------------|---------------------------|------------------------|
|                         | 2005          | 2006          | 2007          | 2008          | 2003          | 2004          | 2005          | 2006          |
| Emergy flow (1.00E+19Sej) |               |               |               |               |               |               |               |               |
| Renewable Resource Emergy (R) | 93.54   | 98.65     | 100.94    | 106.38     | 168           | 216           | 290           | 362           |
| Non-renewable resource emergy (N) | 227.68  | 325.98   | 475.32    | 574.51     | 8.39          | 9.73          | 11.5          | 13.4          |
| Input Emergy (F)          | 14.93        | 18.58     | 23.73     | 29.06      | 10.7          | 16.7          | 23.8          | 29.9          |
| Emergy evaluation indicators |            |            |            |            |               |               |               |               |
| EYR                      | 5.35         | 6.16      | 6.67      | 8.01       | 5.98          | 5.10          | 5.21          |               |
| EIR                      | 0.19         | 0.23      | 0.29      | 0.32       | 7.82          | 7.18          | 7.22          | 7.36          |
| ELR                      | 2.74         | 3.94      | 5.80      | 7.01       | 19.10         | 21.26         | 24.27         | 25.94         |
| ESI                      | 1.95         | 1.56      | 1.15      | 1.14       | 0.311         | 0.281         | 0.210         | 0.201         |

3. Emergy Ternary Analysis

3.1. Resource Line Analysis

The resource lines of the two development zones in 2006 are shown in Figure 1. The solid line represents Shenyang Development Zone and the dotted line represents Dalian Industrial Park. From the figure, we can see that the resource allocation of the two parks is different. The resource input of Shenyang Development Zone is mainly unsustainable resources (N), while that of Dalian Industrial Park is mainly social emergy input (F). Compared with EIR, the emergy output rate of the two development zones is \( \text{EYR}_{\text{S06}} = 6.16 > \text{EYR}_{\text{D06}} = 5.21 \), \( \text{EIR}_{\text{S06}} = 0.32 < \text{EIR}_{\text{D06}} = 7.36 \). It shows that the production efficiency of Shenyang Development Zone is slightly higher than that of Dalian Industrial Park, while the natural environment of Shenyang Development Zone is far less tolerant to the economic system than that of Dalian Industrial Park. This is related to the mode of production of the system. Shenyang Development Zone is the transformation and transformation of the relatively complete industrial system established in the past. The park industry mainly consumes a large number of non-renewable resources, such as equipment manufacturing industry, automobile parts and power industry, pharmaceutical and chemical industry [6]. The use of non-renewable resources affects not only the local natural environment, but also the environment of the region where the resources are produced, so the consumption of non-renewable resources will inevitably have a greater impact on the natural environment. Comparatively, Dalian Industrial Park is an industrial cluster with software information, biopharmaceuticals and mechanical processing as its main body. Its investment is mainly technology and capital, and resource utilization has little impact on the environment. Compared with the environmental load rate of the two development zones, \( \text{ELR}_{\text{S06}} = 3.94 < \text{ELR}_{\text{D06}} = 25.49 \), and the environmental load rate of Dalian Industrial Park is more than 6 times that of Shenyang Development Zone. This shows that the pressure of Dalian Industrial Park's systematic activities on the environment is much greater than that of Shenyang Development Zone. Due to the implementation of circular economy production mode in Shenyang Development Zone, waste recycling and reuse, the final amount of waste discharged is greatly reduced. Dalian Industrial Park is dominated by high-tech industries. Although the energy value of non-renewable resources invested in Dalian Industrial Park accounts for a small proportion of the total energy value of resources invested, its final product is difficult to degrade, and the waste generated at the same time is prone to pollution, which has a greater impact on the natural environment.
3.2. Sustainable Line Analysis

From the emergy analysis ternary diagrams of the two development zones, it can be seen that Shenyang Development Zone is in an area with sustainability greater than 1. Since 2005, the park has promoted the implementation of circular economy development model, the production process of the system has created more net emergy output, emergy investment has played a greater role in the process of resource utilization, and the pressure on the local natural environment is appropriate. However, with the increase of the industrial scale of the park, the eco-industrial park, as an industrial production base transformation, has become increasingly dependent on the energy value of natural resources from outside the system, resulting in the aggravation of the local environmental load, resulting in the weakening of the sustainable development ability of the system year by year, and has become closer to the warning line of ESI=1.

The energy sustainability index of Dalian Industrial Park is less than 1, ranging from 0.20 to 0.32. The development efficiency of resources is decreasing and the pressure on local natural environment is increasing. The increase of resource recycling in Dalian Industrial Park cannot make up for the large consumption of various resources and the continuous discharge of waste. Although the added value of technological information products in high-tech industries has been increasing and the economic benefits have been significantly improved, the ability of sustainable development has been reduced. The sustainable development index of Dalian Industrial Park has not declined significantly, although its economic development has deviated from the development model of sustainable utilization of resources. However, as a high-tech industrial zone with capital and technology investment as its main part, it has a larger space to expand. Through strengthening the communication and cooperation among industries, integrating the advantages of related technologies, it can realize the resource sharing and complementary advantages among the relevant subjects, and hopefully restore the sustainable development ability of the Development Zone quickly [7].
4. Conclusion
Emergy ternary diagram analysis method can effectively evaluate the eco-economic efficiency of industrial agglomeration areas and meet the requirements of system analysis. The ternary diagram of emergy analysis directly reflects the resource allocation of the system. With the aid of emergy ternary diagram analysis tool, the relationship between emergy utilization ratio and indicators of system resources is analyzed, which can not only comprehensively evaluate the sustainability of existing industrial agglomeration system, but also predict the future development direction of the system.

The research shows that since 2005, Shenyang Development Zone has actively promoted the implementation of circular economy production mode, promoted enterprises to implement cleaner production through industrial chain integration, and paid attention to waste recycling, which to some extent alleviated the increasingly serious ecological environment problems. By contrast, Dalian Industrial Park, through adequate capital, technology and energy input, has a sound infrastructure in the industrial agglomeration area, which can effectively absorb foreign capital and talent introduction. As a result, the proportion of social and economic emergy input in Dalian Industrial Park is much higher than that in Shenyang Development Zone. However, due to the short time of its establishment, Dalian Industrial Park has not been able to achieve economies of scale, the marginal benefit of emergy input is not high, and a large amount of energy capital consumption is accompanied by a waste of resources.

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