Construction and Case Study of Rural Environmental Value-added Evaluation System Based on Emergy Theory

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Abstract. In order to solve the problem that the current rural environment value-added benefits are difficult to estimate, based on the emergy theory, this paper built a rural environmental value-added evaluation system with resources, development, space and environmental protection as the main elements, including 18 sub-indicators. This study also quantitatively evaluated the value-added situation of ecological environment in Queshan Village, Shanxi Province, from 2010 to 2015, and put forward development strategies. It is found that from 2010 to 2015, the resource factor decreased from 0.02 to 0.00, the development factor decreased from 0.16 to 0.06, the space factor increased by 0.19 from 0.07, the environmental protection factor decreased from 0.21 to 0.05, and the composite index decreased from 0.61 to 0.31. The results show that the ecological environment of Queshan Village was negative in the evaluation period, and the development showed an imbalance law and an unsustainable development trend. This method constructs a quantitative analysis system for rural environmental value-added evaluation, and has certain theoretical and practical value in rural planning guidance and evaluation.

1. Introduction

While seeking social development, the construction of ecological civilization cannot be ignored. How to use and maintain the ecological environment while promoting the production and living process, and accelerate capital appreciation, is the key proposition to revitalize the countryside. As a kind of environmental value-added technology, rural planning aims to realize the comprehensive appreciation of the rural environment through rural planning and construction. However, the existing rural environmental value-added research is often qualitative analysis, and its quantitative research has always been the focus and difficulty. The emergy theory is a common method based on natural value, which converts various ecological flows and economic flows in the system into energy values, and makes a unified evaluation of natural environment production and human economic activities, and quantitatively analysis the system structure, function and ecological economic benefits[1]. Emergy theory has been widely used in different spatial scales and different types of ecosystem research. The research objects cover natural ecosystem[2], urban composite system[3], environmental management engineering[4], industrial system[5], construction industry[6], agricultural system[7] and other types of ecosystems. However, the application of emergy theory in rural environmental value-added assessment is less studied.

Based on the emergy theory, this paper established a rural environmental value-added evaluation system. Based on this evaluation method, this paper selected the data of Queshan Village in Shanxi Province of China from 2010 to 2015, and quantitatively analyzed the structural characteristics and value-added effects of the social-economic-natural complex environment. This quantitative research and exploration will provide new methods and ideas for rural planning and environmental value-added evaluation.
2. Materials and methods

2.1. Study area and data sources

Queshan Village is located in the east of central Shanxi Province. It is one of the important crossing sections in the less developed regions of China's central and western regions and the developed areas of the Bohai Rim Economic Belt. The village is a temperate continental monsoon climate with four distinct seasons. The annual average rainfall is 498.4mm. Queshan Village is located in hilly and mountainous areas with many slopes, thin soil layers and poor water storage performance. The village is rich in mineral resources, mainly including coal (anthracite), pyrite, bauxite and other mineral deposits. Coal mining has a long history but has now completely stopped. The government introduced a brick factory through investment promotion to provide greater employment for the villagers.

The original data in the text mainly are derived from the Queshan Village Chronicle, the Pingding County Statistical Yearbook (2010-2017) and National Weather Service data. The volume of imports and exports involved is derived using relevant data. Partially missing data is complemented by smooth interpolation. The emergy conversion rate and emergy value conversion standards mainly refer to odmu[8] and Lan Shengfang[9].

2.2. Emergy Approach

Based on the contents of the Strategic Planning for Rural Revitalization (2018-2022) which is issued by the Central Committee of the Communist Party of China and the State Council, and referred to the research results of Lu Miao[10], Wang Ran[11], Lan Shengfang[9] and the emergy theory, this paper constructed the rural environmental value-added evaluation system (Table 1). The resources factor layer and the development factor layer reflect the value-added potential of the rural environment from the perspective of resources and economy. The space factor layer reflects the ability of the rural ecosystem to meet human needs. And the environmental protection factor layer is the basic condition for environmental value-added evaluation.

Table 1. Queshan village environmental value-added evaluation system index table.

| Target layer | Factor layer | Indicator layer | Expression | unit | Significance |
|--------------|--------------|-----------------|------------|------|--------------|
| Rural Environmental Value-added Evaluation System Based on Emergy Theory | resources | Energy self-sufficiency rate | R+N/U | - | System self-sufficiency |
| | renewable resource | R/U | - | Resource utilization structure and renewable energy potential |
| | energy ratio | | | | |
| | Purchase | I/U | - | Dependence on external resources |
| | emergy ratio | | | | |
| | Input energy | I/ (R+N) | - | System internal industry competitiveness |
| | and self-energy ratio | | | | |
| | Energy currency ratio | U/GDP | Sej/$ | The energy per unit of money |
| | Emery exchange rate | I/O | - | Import and export exchange relationship |
| | Electric energy ratio | El/U | - | Industrial development level |
| | Net energy output rate | U/I | - | Economic input efficiency and development drivers |
| | space | Per capita energy | U/P | Sej/inh. | The level of per capita living standard |
| | | Emergy density | U/Area | Sej/m² | Emergency Intensity Degree |
Population carrying capacity \( \frac{(R+I)}{(U/P)} \) inh. Current environment can accommodate population

Per capita fuel energy Fuel/P Sej/inh. Dependence on petrochemical energy

Per capita power energy EI/P Sej/inh. Dependence on electricity

Waste and renewable energy ratio W/R - The Pressure of Waste on Natural Environment

Waste generation rate \( \frac{W}{U} \) - Utilization Value of Waste

Environmental load rate \( \frac{(U-R)}{R} \) - Affordability of the natural environment

Sustainable indicator NEYR/EL R - System sustainability

Population affordability R/(U/P) inh. Population affordability of the natural environment

In the table, R refers to the renewable resource emergy, N refers to the non-renewable resource emergy, U refers to the total emergy, I refers to the input emergy, O refers to the output emergy, GDP refers to the gross domestic product, EL refers to the electric emergy, Fuel refers to the fuel emergy, P refers to the population, Area refers to the village area, W refers to the waste emergy, NEYR refers to the net emergy output rate, ELR refers to the environmental load rate.

2.3. Weight determination method of each indicator

In the evaluation process, the entropy method is used to determine the weight of the evaluation index, which has a certain objective basis[12].

3. Results and analysis

The basic data of Queshan Village is convert into solar energy value, and the index values are obtained (Table 2) according to the calculation method of energy value evaluation index (Table 1). Then the entropy method is used to determine the weight of the evaluation index and the scores are calculated for each index. The results are shown in Table 3.

| Table 2. Queshan Village Environmental Value-added Index Data Table (2010-2015). |
|-----------------|-----------------|----------------|----------------|----------------|----------------|----------------|
|                | 2010            | 2011            | 2012            | 2013            | 2014            | 2015            |
| Energy self-sufficiency rate | 8.32E-02        | 7.68E-02        | 4.86E-02        | 5.08E-02        | 3.89E-02        | 3.25E-02        |
| renewable resource emergy ratio | 7.24E-02        | 6.79E-02        | 4.19E-02        | 4.47E-02        | 3.36E-02        | 2.77E-02        |
| Purchased energy ratio | 9.17E-01        | 9.23E-01        | 9.51E-01        | 9.49E-01        | 9.61E-01        | 9.68E-01        |
| Per capita energy | 1.94E+16        | 2.14E+16        | 2.64E+16        | 2.65E+16        | 2.87E+16        | 3.19E+16        |
| Energy density | 1.34E+13        | 1.62E+13        | 2.17E+13        | 2.37E+13        | 2.69E+13        | 3.07E+13        |
| Population carrying capacity | 4.36E+02        | 4.79E+02        | 5.21E+02        | 5.70E+02        | 5.97E+02        | 6.12E+02        |
| Per capita fuel emergy | 4.67E+15        | 4.27E+15        | 3.23E+15        | 2.99E+15        | 2.88E+15        | 2.82E+15        |
| Per capita power emergy | 1.57E+14        | 3.56E+14        | 3.29E+14        | 3.02E+14        | 2.88E+14        | 2.81E+14        |
| Input energy and self-emergy ratio | 1.10E+01        | 1.20E+01        | 1.96E+01        | 1.87E+01        | 2.47E+01        | 2.98E+01        |
| Emergy currency ratio | 2.31E+12        | 2.34E+12        | 2.93E+12        | 2.92E+12        | 3.29E+12        | 3.62E+12        |
| Emergy exchange rate | 2.56E+00        | 2.60E+00        | 3.36E+00        | 3.35E+00        | 3.81E+00        | 4.23E+00        |
| Electric emergy ratio | 8.07E-03        | 1.66E-02        | 1.24E-02        | 1.14E-02        | 1.00E-02        | 8.81E-03        |
| Net emergy output rate | 1.09E+00        | 1.08E+00        | 1.05E+00        | 1.05E+00        | 1.04E+00        | 1.03E+00        |
| Waste and renewable emergy ratio | 5.34E-01        | 5.16E-01        | 6.78E-01        | 6.33E-01        | 7.78E-01        | 8.48E-01        |
One of the factors that needed improvement in Queshan Village was the spa development factor. The environmental value-added index of Queshan Village increased from 2010 to 2011 and decreased after 2011 (except for a small fluctuation in 2013). The 2015 composite index was 0.31, which was about half of the 2010 composite index of 0.61. The overall environment of Queshan Village was poor and showed a negative growth trend. This was mainly due to the obvious decline of resources, development and environmental protection (decreased by 0.02, 0.10, 0.16 respectively) in the system during the evaluation period. Although the capacity to meet human needs reflected by space factor had increased (increased by 0.12), it still could not compensate for the overall downward trend. In 2011, the comprehensive environmental index was 0.11 higher than that in 2010. According to the data, it was found that after the first old village relocation and transformation in 2010, collective heating and gas supply were realized, and the efficiency of some energy sources was improved. In 2013, the comprehensive index was temporarily improved by the construction of "beautiful countryside" in the villages. Although the relocation of village and the implementation of policies could temporarily improve the environmental index of the Village, the overall trend was still declining due to the lack of sustainability.

From the analysis of each factor index in figure 1, the resources factor in the evaluation period was reduced from 0.02 to 0.00, which indicated that there were less renewable resources in the village; and the dependence on external resources was great, and the self-sufficiency in the village was reduced. The development factor had been reduced from 0.16 to 0.06, which indicated that the overall productivity of the industrial system in Queshan Village was low, and the economic return rate of production activities was not high, resulting in weak competitiveness of its own industry. The environmental protection factor was reduced from 0.21 to 0.05, indicating that the pressure on the ecological environment of Queshan Village increased and the environmental load rate increased significantly. The space factor rose from 0.07 to 0.19, indicating that the quality of life and social welfare of the people had been increasing.

Figure 2 is a radar chart of the scores of various elemental layers in the Queshan Village environment from 2010 to 2015. The radar chart showed the relative situation of each factor layer in the Queshan Village environment in each year. And the radar chart further clarified the most needed improvement aspects of Queshan village. For example, the space factor in 2015 was the relatively best of the four factors, while the resource factor was the worst. The improvement of resources is the future development of Queshan needs to be strengthened. The area enclosed by each element in the radar chart showed a downward trend in the past six years, which meant that the comprehensive index showed a downward trend and the results were consistent with figure 1. At the same time, it could be seen intuitively that the development of various elements in Queshan Village was extremely unbalanced. In 2010, the environmental protection factor scored the highest, the space factor was the least, and it was less than one-third of the environmental protection factor. In 2015, the space factor was the highest, at 0.19, the resource factor was the least, close to 0, and the difference was obvious. It showed that the local government had put forward some measures for the construction of the village environment, which

Table 3. Results of Environmental Value-added Assessment of Queshan Village (2010-2015).

| Factor                      | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  |
|-----------------------------|-------|-------|-------|-------|-------|-------|
| Resources                   | 0.17  | 0.15  | 0.05  | 0.06  | 0.02  | 0.00  |
| Development                 | 0.16  | 0.21  | 0.13  | 0.13  | 0.09  | 0.06  |
| Space                       | 0.07  | 0.13  | 0.14  | 0.15  | 0.17  | 0.19  |
| Environmental protection    | 0.21  | 0.22  | 0.13  | 0.15  | 0.09  | 0.05  |
| Comprehensive               | 0.61  | 0.71  | 0.45  | 0.49  | 0.37  | 0.30  |
increased the space index, but ignored the comprehensive considerations of sustainable industrial development, environmental protection, and resource use structure. So, the overall environmental value-added present a negative growth state. If reforms are not implemented, green industries are not developed, and the sustainable development of Queshan Village will be in trouble.

Figure 1. Trends of the Index of Environmental Value-added Assessment of Queshan Village from 2010 to 2015

Figure 2. Radar diagram of each element of environmental Value-added assessment of Queshan Village from 2010 to 2015

4. Conclusion and suggestion
This paper established a value-added evaluation system of rural environment by using emergy theory, and took Queshan Village as an example to evaluate the value-added. The main conclusions are as follows:

(1) The rural environmental value-added evaluation system based on emergy theory provides a unified and comprehensive evaluation index for rural environmental value-added. Through quantitative research on the ecological environment, it avoids the incomparable problem of different factors in traditional methods. This method has certain theoretical and practical value in rural planning and environmental value-added evaluation.

(2) The development of the four elements of the comprehensive environment in Queshan Village was unbalanced. The space factor with the lowest score in 2010 was about one-third of the environmental factors with the highest score. In 2015, the difference between the highest scored of space factor and the lowest scored of environmental protection factor was as high as 0.19. The local government did not have a long-term systematic and comprehensive analysis of the village environment, which led to the slow and uneven development of all aspects of the village.

(3) The environmental comprehensive index of the Queshan Village during 2010 to 2015 showed a negative growth, down by 0.30. Among the four factor layers, only the value of space elements increased, increasing by 0.13, while the three factors of resources, development and environmental protection all declined to different degrees, down by 0.17, 0.10 and 0.16 respectively. Queshan Village is a resource-intensive and extensive economic development model, which is extremely disadvantageous from the perspective of sustainable development.

Queshan Village should maintain the sustainability of the composite system from the adjustment of energy structure, industrial structure and the treatment of existing waste and environmental improvement. The development of Queshan Village cannot be at the expense of the environment. In view of the above analysis results, this paper proposes the following improvement measures: (1) adjust the resource utilization structure and increase the utilization of renewable resources, (2) improve regional sustainable development industry and economic independence, and introduce industries that have less impact on the environment, such as the tertiary industry, (3) propose a reasonable planning and remediation plan to protect the fragile ecological environment in the region, (4) let more government involvement to increase its ability to attract external resources.
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