Emergy Analysis of the Construction Industry System in Xining

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Abstract: The rapid development of the construction industry since the 21st century has intensified the contradiction between the use of environmental resources and economic development, and sustainable development is facing severe challenges. In order to coordinate the development of the construction industry's resource consumption and the eco-economic system, this article uses the emergy analysis method and combines the original data of the construction industry in Xining City from 2011 to 2017 to build a comprehensive analysis of the construction industry system in Xining by constructing an emergy index system. The results show that Xining's construction industry is more and more dependent on various external energy inputs, and the proportion of local environmental resources it is relying on is getting smaller and smaller, indicating that Xining's construction industry is more open to the outside world and the more economic development and the quality of life of the people Come the better.

1. Introduction

The large consumption of energy and resources in the construction of new buildings has led to a sharp reduction in human resources. Among them, the energy consumption of buildings accounts for 27% of the total energy consumption in the country [1]. The construction industry has adopted extensive production methods for a long time, which has produced various ecological and environmental problems: environmental damage, excessive consumption of resources, pollution and ecological damage are very serious, which has affected human health and sustainable development of the regional economy.

At present, there are many evaluation methods for resource consumption and environmental impact. For example, Azari use life cycle assessment methods to carry out energy and environmental life cycles on several types of envelope structure programs that change some of the main components of building envelope Compare assessments to verify the life-cycle energy and environmental performance of building envelopes [2]. Teng Used the ecological footprint method to evaluate the efficiency of the ecological footprint of a building project's resource consumption throughout its life cycle [3]. Acquaye A Used stochastic techniques and physical and chemical energy to estimate the distribution of energy and emissions contained in buildings [4]. The main reason for using the emergy analysis method in this paper is that this method overcomes the problem that the energy of different energy masses cannot be compared in the traditional analysis method, and effectively solves the comparative analysis of energy from the same category to different categories.

Emergy analysis theory and method was established by the famous American ecologist H.T.Odum in the 1980s. It is a method for measuring and analyzing the energy flow and currency flow in a regional ecological economic system through the emergy conversion rate into a unified unit [5]. At present, domestic and foreign scholars have done a lot of valuable research based on the theory of
emergy analysis. The main areas involved are agricultural ecosystems, land resource ecosystems, water resources ecosystems, and environmental resource evaluations [6]-[9]. The research in the field of construction industry mainly includes: Yuan and other researches on the application of emergy analysis on construction waste recycling programs [10]. Li applied emergy analysis to study the ecological efficiency evaluation method of building manufacturing [11]. It is not difficult to find that the research in the field of construction based on emergy analysis is obviously inadequate compared with other fields based on comprehensive research at home and abroad. This is not only a pity for the use and management of resources in the construction industry, but also a loss for better exploration and development of emergy theory.

This paper applies the emergy analysis method to study the construction industry system of Xining, and analysis the development status and characteristics of the construction industry in Xining through the calculation of corresponding emergy indicators.

2. Methods of emergy analysis

Emergy is a new metric created by the famous American ecologist H.T.Odum as an assessment of ecological products and services and a common analysis of ecological and economic systems. He defined emergy as: the amount of another basic energy contained in a substance or energy [12]. Since the fundamental energy source for all matter and energy on the planet is the sun, solar energy joules (sej) are used as the basic unit of emergy analysis to measure all resources, energy and other intangible products on the planet Contained energy. To convert all kinds of resources with different dimensions into solar energy values, the solar energy value conversion rate must be used.

Through inductive calculation of various types of emergy data within the boundary of the system under study, corresponding emergy indicators can be obtained. These indicators can quantitatively analyze the relationship between the natural environment and the economy, so as to truly reflect the structure and function of the system. Therefore, these indicators also have important reference functions for social and economic development.

This article mainly analyzes the operation status and self-development ability of the construction industry system and the driving force for human economic and social development in the system. Therefore, based on the three natural-social-economic systems, the emergy indicator system of the construction industry system is mainly composed of: emergy investment rate, emergy self-sufficiency rate (belonging to natural systems); per capita energy usage, emergy density (belonging to society System); emergy currency ratio, industrial auxiliary contribution rate (belonging to the economic system). The calculation method of the above-mentioned emergy index is shown in Table 1.

| Emergy index                      | Calculation expression             |
|-----------------------------------|-----------------------------------|
| Emergy investment rate            | (EmI+EmN)/EmR                     |
| Emergy self-sufficiency rate      | (EmR+EmN)/EmU                     |
| Per capita energy use             | EmU/P                             |
| Emergy density                    | EmU/(Land area)                   |
| Emergy currency ratio             | EmU/(GNP)                         |
| Industrial auxiliary contribution rate | Industrial auxiliary energy /EmI   |

Note: EmR-local renewable resource emergy; EmN-non-renewable resource emergy; EmI-input energy value; EmU-total energy value; P-population engaged in construction; GNP-total national product value.

3. Data source

This article takes Xining as the research area and Xining's construction industry as the research object. The basic data mainly comes from statistical yearbook data. Among them, we mainly consulted the Qinghai Statistical Yearbook, the China Construction Industry Statistical Yearbook, and the Xining
Statistical Yearbook from 2011 to 2017. The construction industry is mainly divided into renewable environmental resources, non-renewable environmental resources, non-renewable industrial auxiliary energy, renewable organic energy, among which renewable environmental resources include renewable natural environmental resources such as solar energy, rainwater potential energy, and rainwater chemical energy. The non-renewable environmental resources are mainly some non-renewable natural environmental resources of petroleum and electricity. The non-renewable industrial auxiliary energy mainly includes the purchase of emergy for construction machinery and equipment, steel, wood, glass, cement, aluminum, etc. Renewable organic energy is primarily human labor. The raw data of Xining's construction industry from 2011 to 2017 are shown in Table 2.

According to the data in Table 2 and the solar value conversion rate and emergy theory of H.T. Odum and so on, the substances and energy of each category in the system are converted into solar energy values with a unified emergy unit. The energy value calculated is shown in Table 3. In the end, 2011-2017 Xining construction industry emergy index system is shown in Table 4.

### Table 2. Statistics of raw Data of Xining Construction Industry System from 2011 to 2017

| Project                        | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  | 2017  |
|-------------------------------|-------|-------|-------|-------|-------|-------|-------|
| Annual rainfall (mm)          | 390.4 | 446.1 | 413.6 | 447.7 | 306.2 | 444.1 | 464   |
| Annual sunshine (hours)       | 2547  | 2655.2| 2660.6| 2373.3| 2590.1| 2690.4| 2555.9|
| Petroleum (10,000 tons)       | 1.83  | 2.12  | 1.89  | 2.39  | 2.51  | 3.71  | 4.55  |
| Electricity (billion kWh)     | 4.24  | 4.89  | 4.66  | 5.87  | 3.92  | 4.48  | 3.74  |
| Total power of mechanical equipment (kw) | 933032 | 996928 | 644607 | 1272320 | 976800 | 1105272 | 1120684 |
| Steel (ton)                   | 576225| 761755| 647808.5| 865971.6| 541590.8| 787216.7| 887248.9|
| Timber (cubic meters)         | 192678.4| 148000.6| 152338.9| 224252.5| 210600| 192781.1| 191904.8|
| Cement (tons)                 | 2592316| 2656535| 2366750| 3170140| 2153159| 2983841| 3384461|
| Glass (weight box)            | 168885.2| 109786.3| 109509.6| 204789.5| 173945| 121969.7| 406204.9|
| Aluminum (ton)                | 24237.15| 44541.2| 56068.75| 67207.6| 132015| 73161| 70673.42|
| Number of employees in the construction industry (10,000 people) | 8.92  | 11.84 | 10.69 | 11.2  | 11    | 14.62 | 11.14 |
| Total output value of construction industry (100 million yuan) | 320.1 | 326.31| 414.6| 434.16| 410.69| 411.38| 408.17|
### Table 3. Emergy Statistics of Xining Construction Industry System from 2011 to 2017 (Sej)

| Projects                             | 2011     | 2012     | 2013     | 2014     | 2015     | 2016     | 2017     |
|--------------------------------------|----------|----------|----------|----------|----------|----------|----------|
| Solar energy                         | 3.91E+16 | 3.37E+16 | 4.03E+16 | 4.19E+16 | 2.70E+16 | 3.09E+16 | 3.15E+16 |
| Rainwater chemical energy            | 1.48E+17 | 1.40E+17 | 1.54E+17 | 1.95E+17 | 7.89E+16 | 1.25E+17 | 1.41E+17 |
| Rain potential energy               | 3.69E+17 | 3.48E+17 | 3.85E+17 | 4.87E+17 | 1.96E+17 | 3.13E+17 | 3.52E+17 |
| Total                               | 5.56E+17 | 5.22E+17 | 5.81E+17 | 7.24E+17 | 3.02E+17 | 4.70E+17 | 5.25E+17 |
| oil                                 | 4.13E+22 | 4.78E+22 | 4.26E+22 | 5.39E+22 | 5.66E+22 | 8.37E+22 | 1.02E+23 |
| Electric power                       | 2.44E+20 | 2.81E+20 | 2.68E+20 | 3.38E+20 | 2.25E+20 | 2.58E+20 | 2.15E+20 |
| Total                               | 4.15E+22 | 4.81E+22 | 4.29E+22 | 5.42E+22 | 3.02E+22 | 4.70E+22 | 5.25E+22 |
| Total power of mechanical equipment  | 3.01E+23 | 3.22E+23 | 2.08E+23 | 4.11E+23 | 3.15E+23 | 3.57E+23 | 3.62E+23 |
| Steel                               | 8.06E+20 | 1.06E+21 | 9.06E+20 | 1.21E+21 | 7.58E+20 | 1.10E+21 | 1.24E+21 |
| Wood                                | 7.09E+19 | 5.44E+19 | 5.60E+19 | 8.25E+19 | 7.75E+19 | 7.09E+19 | 7.06E+19 |
| Glass                               | 7.09E+18 | 4.61E+18 | 4.60E+18 | 8.60E+18 | 7.30E+18 | 5.12E+18 | 1.70E+19 |
| Cement                              | 8.55E+22 | 8.76E+22 | 7.81E+22 | 1.04E+23 | 7.10E+22 | 9.84E+22 | 1.11E+23 |
| Aluminum                            | 3.87E+20 | 7.12E+20 | 8.97E+20 | 1.07E+21 | 2.11E+21 | 1.17E+21 | 1.13E+21 |
| Total                               | 3.88E+23 | 4.11E+23 | 2.88E+23 | 5.18E+23 | 3.89E+23 | 4.58E+23 | 4.76E+23 |
| Construction labor force             | 6.80E+19 | 9.03E+19 | 8.15E+19 | 8.54E+19 | 8.39E+19 | 1.11E+20 | 8.49E+19 |
| Total                               | 6.80E+19 | 9.03E+19 | 8.15E+19 | 8.54E+19 | 8.39E+19 | 1.11E+20 | 8.49E+19 |

### Table 4. Emergy Index System of Xining Construction Industry from 2011 to 2017

| Emergy index                                      | 2011     | 2012     | 2013     | 2014     | 2015     | 2016     | 2017     |
|---------------------------------------------------|----------|----------|----------|----------|----------|----------|----------|
| Emergy investment rate                            | 10.35    | 9.55     | 7.71     | 10.54    | 7.85     | 6.45     | 5.63     |
| Emergy self-sufficiency rate                       | 0.09     | 0.10     | 0.12     | 0.09     | 0.12     | 0.15     | 0.17     |
| Per capita energy use ($10^{18}$ Sej/person)       | 4.82     | 3.89     | 3.10     | 5.11     | 4.06     | 3.71     | 5.20     |
| Emergy density ($10^{13}$ Sej/m²)                 | 5.62     | 6.01     | 4.33     | 7.49     | 5.84     | 7.09     | 7.58     |
| Emergy currency ratio ($10^{18}$ Sej/$)            | 1.34     | 1.41     | 0.80     | 1.32     | 1.09     | 1.32     | 1.42     |
| Industrial auxiliary contribution rate             | 0.90     | 0.89     | 0.87     | 0.90     | 0.87     | 0.84     | 0.82     |

### 4. Results and discussion

Analyze each indicator in the emergy system of the construction industry system in Xining according to Table 4, and analyze the development status of the construction industry system in Xining according to the changes of each indicator.

#### 4.1 Emergy investment rate

The emergy investment rate is the ratio of the feedback emergy from the economy in the system to the natural environment emergy input to the system, and is an indicator of the degree of economic development and environmental load. The larger emergy investment rate indicates that the system has a better economic development and a higher degree of opening up. From 2011 to 2017, the emergy investment rate of the construction industry system in Xining City showed a downward trend. In 2014, the reason for the rise was that the investment in real estate development in Xining City increased in this year, and the investment in construction materials increased sharply. Increase. In general, the
resources of Xining's construction industry are more dependent on external energy input, and the system is highly open to the outside world.

4.2 Emergy self-sufficiency rate
The emergy self-sufficiency rate is the ratio of the emergy input of the local resources of the system to the emergy input from the outside, and can describe the opening of the system and the degree of economic development. From 2011 to 2017, although the emergy self-sufficiency rate of the construction industry system in Xining City has been increasing year by year, its ratio is low, which indicates that Xining City has a low degree of dependence on local resources, and local resources cannot fully utilize its utilization value, resulting in the regional economy is underdeveloped and the level of economic development is low. Therefore, we should make full use of local resources and purchase appropriate emergy from outside for economic development.

4.3 Per capita energy use
The per capita emergy usage index comprehensively reflects the people's living standards and the degree of economic development. In general, the higher the per capita energy use, the more energy each person enjoys in the system and the better the quality of life. The per capita energy use of the construction industry's eco-economic system in Xining City fluctuated greatly between 2010 and 2017, of which the lowest reached $3.1 \times 10^{18} \text{sej} / \text{person}$ in 2013. This is because there were many demolished buildings and new buildings in this year, so the per capita energy usage is lower than in other years. Since Xining is an underdeveloped region, the reason for the low per capita energy use has a lot to do with the underdeveloped economy.

4.4 Emergy density
Emergy density can be used to objectively reflect the level of economic development of a system. If the economy is more developed, the economic activities will be more frequent, the emergy usage will be larger, the emergy exchange volume will be larger, and the emergy usage intensity will definitely be higher. The energy density of the construction industry's eco-economic system in Xining City is not very stable, and it declined significantly between 2013 and 2015, indicating that the system's energy exchange with the outside world was small during this period. In general, Xining's construction industry is in a good stage of economic growth and development.

4.5 Emergy currency ratio
The emergy currency ratio represents the amount of emergy produced per unit of economic activity, so it represents the degree of economic development and the level of economic development. From 2011 to 2013, the emergy currency ratio of the ecological and economic system of the construction industry in Xining City decreased from year to year, indicating that the construction industry's dependence on natural resources became less during this period. The upward trend after 2013 indicates that construction activities are frequent and the consumption of natural resources is increasing.

4.6 Industrial auxiliary contribution rate
The contribution rate of industrial auxiliary energy of the construction industry's ecological and economic system in Xining City is generally on the decline. It increased slightly in 2014 because the investment in real estate development in Xining City increased in this year, and the construction materials introduced from the outside increased sharply. Comparing this year's emergy self-sufficiency rate to the lowest value in the system, it shows that the system is more dependent on the input of external resources. Although the industrial auxiliary contribution rate is gradually decreasing, it is still at a high level, which is also in line with the actual situation of Xining City. The construction industry still relies more on external energy input, and the requirements for natural environment resources are not so high.
5. Conclusion
Based on emergy analysis related theories, this paper analyzes the ecological and economic system of the construction industry in Xining. The relevant raw data of Xining's construction industry from 2011 to 2017 were obtained through review and arrangement. These data were calculated and analyzed to obtain the corresponding emergy index values and analyze them. Summarize some characteristics of Xining's construction industry:

(1) The first is the input structure, of which the non-renewable industrial auxiliary energy accounts for the vast majority of the total emergy input, and the second is the non-renewable environmental resources, renewable energy, and the smallest proportion of renewable environmental resources. The total energy input of the construction industry in Xining increased year by year from 2011 to 2017, and the industrial auxiliary energy remained basically stable. Looking at output, Xining's total construction output value increased from 32.01 billion yuan in 2011 to 40.817 billion yuan in 2017, an increase of nearly 1.3 times.

(2) The annual increase in emergy investment rate and the decrease in self-sufficiency rate embody a problem: Xining's construction industry is increasingly relying on various external emergy inputs, and the proportion of local environmental resources it is relying on is increasing. The smaller it is, the higher the degree of opening up of Xining's construction industry and the better and better economic development;

(3) The contribution rate of industrial auxiliary energy is always at a high value, which indicates that the construction industry in Xining City has an increasing demand for external energy value and has a relatively small degree of development of its own resources. The per capita emergy usage and emergy density both fluctuated slightly from 2011 to 2017, but generally showed an upward trend, reflecting the improvement of the living standards of the people in Xining City, and the economic development of the construction industry in Xining City is on the rise status.

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