The Dynamic Analysis of Agro-ecological Economic System on the Basis of Emergy: A Case Study of Wu'an City in Hebei Province

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Abstract Using the method of emergy analysis, we analyze the input and output of agro-ecological economic system, and select five indicators (net emergy yield ratio, emergy investment ratio, environmental loading ratio, emergy sustainability index, and dominance of emergy yield system) for assessment. The results show that the emergy input-output in Wu'an City is in general on the rise; the emergy investment ratio rises constantly, but the net emergy yield ratio decreases, and the comparative advantage in the prices of agricultural products is gradually lost. At the same time, with increase in the non-renewable industrial support emergy, the environmental pressures are also mounting. In the future agricultural development, it is necessary to pay more attention to the coordination between agricultural development and ecological environment, achieving sustainable development of agriculture.

Key words Agro-ecological economic system, Sustainable development, Wu'an City

Emergy analysis was developed by the famous American ecologist Odum in the 1980s[1]. Emergy is the available energy (exergy) of one kind that is used up in transformations directly and indirectly to make a product or service. Emergy accounts for, and in effect, measures quality differences between forms of energy. Emergy is an expression of all the energy used in the work processes that generate a product or service in units of one type of energy. The unit of emergy is the emjoule, a unit referring to the available energy of one kind consumed in transformations. Emergy accounts for different forms of energy and resources (*e. g.* sunlight, water, fossil fuels, minerals, *etc.*). Each form is generated by transformation processes in nature and each has different ability to support work in natural and human dominated systems. Emergy analysis achieves the organic unity of ecological and economic analysis of system, which is of great significance to scientific evaluation and rational use of natural resources, formulation of economic development policy, and implementation of sustainable development strategy[2].

In the mining cities, there are some universal ecological environment problems, such as soil erosion, environmental pollution, and loss of soil fertility, causing a huge impact on agro-ecological system[3]. Meanwhile, the existence of the workers and farmers' comparative advantage, also limits the development of agro-ecological economic system. The emergy analysis of agro-ecological economic system in mining cities can provide a scientific basis for optimizing the emergy input-output structure of agro-ecological system, rationally developing agricultural environment resources, and achieving sustainable development of agriculture.

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1 Data source and research method

1.1 Overview of the study area Wu'an City, located in the northwestern Taihang Mountain of Handan City in Hebei Province, is the central zone of Shanxi, Hebei, Shandong and Henan. The average temperature for many years is 11.0 – 13.5 ℃; the city's average frost-free period is 196 d; the average annual precipitation is about 560 mm. In 2008, the gross regional product in Wu'an City achieved 39.6 billion yuan; the proportion of three industries was 2.6: 68.2: 29.2, and the value-added of the primary industry was 1.01 billion yuan.

1.2 Data source Agricultural natural economic data comes mainly from *Wu'an Socio-economic Statistics* and *New Wu'an Comprehensive Resource Zoning* provided by Wu'an Bureau of Statistics. The specific energy conversion coefficient[4-5] and the emergy conversion rate[1, 6] are based on previous research results[7].

1.3 Research method According to the operating characteristics of agro-ecological economic system, we establish the emergy structure of agro-ecological economic system in Wu'an City. The emergy flow structure can be divided into the following aspects: (1) Renewable environmental emergy (R), including solar energy, wind energy, rain energy, and earth's rotation energy; (2) Non-renewable environmental emergy (N), including the topsoil emergy; (3) Non-renewable industrial emergy (F), including chemical fertilizer, pesticide, agricultural plastic film, diesel oil, machinery power, and agricultural electricity consumption; (4) Renewable organic emergy (R_1), including the input emergy of agricultural practitioners, organic fertilizer, seed and feed; (5) The output emergy, including crop farming (Y_1), animal husbandry (Y_2), forestry (Y_3), and fisheries (Y_4). In accordance with this structure, we calculate the emergy input and output in Wu'an City, and evaluate the emergy indicators.

2 Results and analysis

According to existing data, we refer to the relevant energy conver-

sion coefficient and emergy conversion rate, to get the emergy structure of ecological and economic system in Wu'an City (Table 1). We select the following 5 indicators for structure and system analysis: net emergy yield ratio, emergy investment ratio, environmental loading ratio, emergy sustainability index, dominance of system production.

Table 1 Emergy input-output and emergy indicator evaluation in Wu'an City

Item	Expression	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Input of renewable resources//1E+20sej	R	0.95	1.44	1.12	1.13	1.49	1.29	1.44	1.19	1.24	1.17
Input of nonrenewable resources//1E+20sej	N	0.08	0.02	0.01	0.02	0.01	0.00	0.21	0.29	0.28	0.36
Industrial auxiliary input//1E+20sej	F	2.92	4.51	3.22	3.26	4.89	5.94	6.94	3.67	7.00	5.14
Input of organic energy //1E+20sej	R_1	1.59	1.61	2.16	1.89	2.35	2.58	2.76	2.78	2.89	2.58
Total energy input//1E+20sej	$T=R+N+F+R_1$	5.55	7.58	6.51	6.30	8.74	9.81	11.35	7.94	11.41	9.25
Total energy output// 1E+20sej	$Y=Y_1+Y_2+Y_3+Y_4$	17.65	17.71	28.06	20.54	27.30	28.24	29.67	29.76	30.67	27.93
Input of renewable emergy//1E+20sej	$R+R_1$	2.55	3.06	3.28	3.02	3.84	3.87	4.20	3.97	4.13	3.74
Input of nonrenewable emergy//1E+20sej	N+F	3.00	4.52	3.23	3.29	4.90	5.94	7.15	3.96	7.28	5.51
Net emergy yield ratio	$NEYR=Y/(F+R_1)$	3.91	2.89	5.22	3.99	3.77	3.32	3.06	4.61	3.10	3.62
Emergy investment ratio	$EIR=(F+R_1)/(R+N)$	4.35	4.20	4.73	4.47	4.85	6.57	5.87	4.35	6.53	5.04
Environmental loading ratio	$ELR(N+F+R_1)$	4.81	4.25	4.80	4.57	4.87	6.59	6.89	5.67	8.23	6.93
Emergy sustainability index	ESI=NEYR/ELR	0.81	0.68	1.09	0.87	0.77	0.50	0.44	0.81	0.38	0.52
Dominance of system production	$SPA=\sum_{i=1}^{4}(Y_i/Y)^2$	0.61	0.64	0.48	0.67	0.56	0.66	0.70	0.71	0.73	0.66

2.1 Emergy input-output analysis

2.1.1 Renewable emergy input analysis. With the continuous improvement in attention to agriculture and development of agriculture, the total renewable resource emergy input to agriculture in Wu'an City is continuously rising, from 2.55E+20sej in 1999 to 3.74E+20sej in 2008, but due to incessant increase in the industrial assistant energy input, the share of renewable emergy input in total emergy input declines constantly, from 45.93% to 40.47%, indicating that the role of renewable emergy input in material circulation and self-sustaining of agro-ecological system is gradually abated. The emergy input of renewable environmental resources mainly includes solar energy, rainwater chemical energy, the earth's cycle energy, rainwater potential energy and wind energy. Since there is coupling relationship in precipitation, solar energy and earth cycle, in order to avoid double counting, we only take the maximum value, and through analysis, the renewable environmental resources input in Wu'an City is the value of rainwater chemical energy.

Therefore, precipitation plays a decisive role in agricultural development of Wu'an City. But in history, Wu'an City was often hit by drought 9 years out of 10. For a long time, water resource is an important factor constraining agricultural development. In 2002, the per capita water resource in Wu'an City was 268 , one fifth of the national average. According to the survey data, the dry land accounts for 73.21% of cultivated land in the entire city, and the irrigated land accounts for only 26.79%. The development of animal husbandry is in part dependent on pool and water cellar. Therefore, in view of the importance of water resource to agriculture in Wu'an City, Wu'an City should strengthen the construction of irrigation and water conservancy facilities, actively promote advanced water-saving irrigation techniques, and strengthen the comprehensive governance of small watershed, to reduce the impact of water resource on agriculture to the extreme, and ensure the stability in farmers' income.

The renewable organic emergy input in Wu'an City includes agricultural practitioners, application of seed, feed, and organic fertilizer. In the period 1999–2008, the renewable organic emergy input rose from the original 1.59E+20 sej to 2.58E+20 sej. With improvement in the non-renewable industrial assistant emergy input, the dependence of Wu'an City on the organic energy input continues to be reduced, and Wu'an's agriculture develops toward intensification and modernization.

2.1.2 Non-renewable emergy input analysis. The emergy input of non-renewable resources in Wu'an City increased from 3.00E+20 sej in 1999 to 5.51E+20sej in 2008. The emergy input of non-renewable resources is mainly from the non-renewable industrial assistant emergy input, which account for 49% to 62% of total emergy input.

On the one hand, continuous increase in the industrial assistant emergy input arises from ceaseless improvement in the level of agricultural mechanization. This plays a positive role in changing the traditional mode of agriculture, transferring the rural surplus labor, and achieving the mechanization of agriculture and industrialization development. On the other hand, continuous increase in the industrial assistant emergy input is also caused by incessant rise in the consumption of chemical fertilizer and pesticide. Rational use of chemical fertilizer and pesticide plays a positive role in promoting agricultural productivity, but irrational use will contaminate the soil and water environment, affecting the sustainable development of agriculture.

2.2 Analysis of emergy indicators

2.2.1 Net emergy yield ratio. The net emergy yield ratio is an indicator for assessing the efficiency of resource use, which reflects the system's ability to obtain the economic input emergy. If the net emergy yield ratio is high, there will be many opportunities obtained for economic development.

As is shown in Fig. 1, except 2000, the net emergy yield ratio in Wu'an City during the period 1999–2008 was always above 3.00, higher than the national average of 1.42, indicating that the agricultural products in Wu'an City have certain competitiveness of price. But from 2001, on the whole, the net emergy output in Wu'an City showed a slow downward trend, suggesting that the conversion rate of emergy input was declining and the cost of agricultural production was rising. The reason is that with constant increase in the emergy input of the agricultural economy, the marginal effect is also ceaselessly declining, and the degree of inten-

sive use of economic emergy is also declining. The price competitiveness of the agricultural products is also reduced constantly along with constant decline in the net emergy yield ratio, imposing an adverse impact on the development of agriculture.

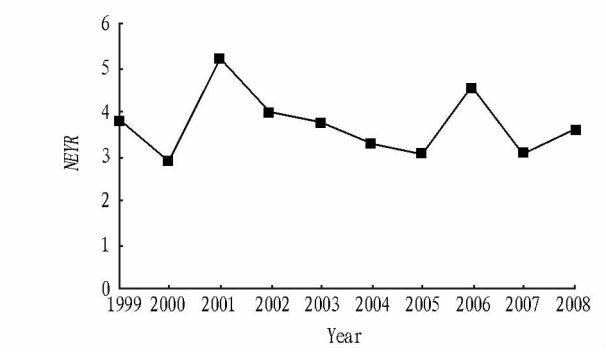

Fig. 1 Dynamic changes of net emergy yield ratio in Wu'an City during the period 1999 – 2008

2.2.2 Emergy investment ratio. The emergy investment ratio can reflect the system's dependence on system and the system's utilization of environmental resources.

Fig. 2 shows that from 1999 to 2008, the emergy investment ratio in Wu'an City was at the stage of rise, indicating that local government and people continued to increase input to agriculture and change the agricultural mode depending on the weather for survival and relying on a lot of labor input to obtain agricultural output, moving towards the modernization of agriculture. Agricultural system's dependence on natural resources is decreased, and the exploitation efficiency of natural resources is continuously improved. But in the process of rise in the emergy investment ratio, the environmental resources emergy used gratuitously in the value composition of agricultural products is also ceaselessly reduced, and the price competitiveness of agricultural products is bound to decline.

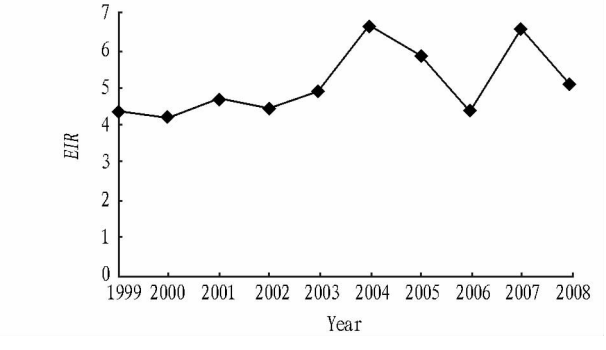

Fig. 2 Dynamic changes of net emergy investment ratio in Wu'an City during the period 1999 – 2008

2.2.3 Environmental loading ratio. Over-exploitation of local non-renewable resources is the main reason for deterioration of environmental system, and environmental loading ratio reflects the pressure of agricultural production on the natural environment.

We can see from Fig. 3 that in the period 1999 – 2008, the environmental loading ratio of agro-ecological system in Wu'an City rose in volatility, 2.80 higher than the national average. On the one hand, rise in the environmental loading ratio indicates that the technology development level of agricultural system in Wu'an City is high, which benefits from constant rise in the industrial assistant emergy input. On the other hand, rise in the environmental loading ratio indicates that in the case of poor environment, natural conditions and little rainfall, Wu'an City continues to increase the utilization rate of environmental resources, and the pressure on environmental resources is increasing.

The environmental loading ratio is a warning to the economic system. In the process of increasing the input to agriculture, we should focus on environmental protection, and achieve coordinated and balanced development of agricultural development and environmental protection.

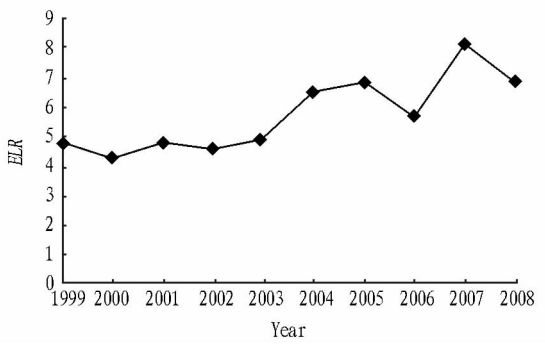

Fig. 3 Dynamic changes of environmental loading ratio in Wu'an City during the period 1999 – 2008

2.2.4 Sustainability index based on emergy analysis. According to the definition of ESI by Brow. M. T, and Ulgiati. S, $1 < Esl < 10$ shows that the system is full of vitality and development potential; $ESI > 10$ is a symbol of economic underdevelopment; when $ESI < 1$, it is the consumer-oriented economic system[8].

Fig. 4 shows that after 2001, the emergy sustainability index of agricultural system in Wu'an City was always below 1.00, in a downward trend, indicating that the agricultural system in Wu'an City is the consumer-oriented economic system; the agricultural emergy benefit is not enough, and the environment is carried heavily; the development of agricultural system is not sustainable. This shows that Wu'an City ceaselessly increases input to agriculture, and the emergy input, especially the industrial assistant emergy input is constantly increased, but it is at the expense of the environment. In Wu'an City, the natural environmental conditions are poor, and the terrain is diverse, reducing the output efficiency of agricultural machinery. Wu'an City is regarded as the mining city, and its agricultural economic system is relatively weak, therefore, in the process of continuing to strengthen the agricultural modernization, we should pay more attention to sustainability of agricultural production.

We should use intensive agricultural production to ease pressure of agriculture on the environment in Wu'an City, and continue to improve the degree of agricultural intensification, in order to promote the emergy of agricultural system and truly achieve economic and environmental sustainability.

2.2.5 Analysis of dominance of system production. The dominance of agro-ecological system reflects the balance of the overall production units of system structure. Fig. 5 shows that in the period 1999 – 2008, the dominance of system production in Wu'an

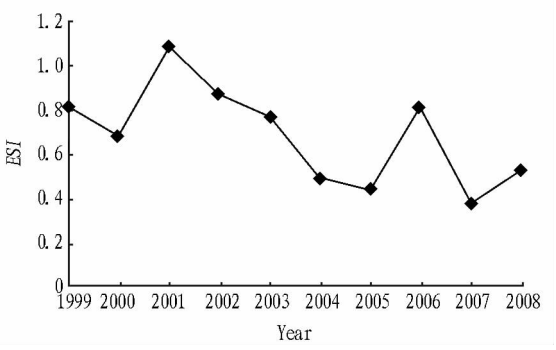

Fig. 4 Dynamic changes of sustainability index in Wu'an City during the period 1999 – 2008

City fluctuated roughly between 0.6 and 0.7, in a slow upward trend.

The development of crop farming and animal husbandry in Wu'an City is in absolute advantage, and shows an upward trend, indicating that the Wu'an production structure develops towards the uneven direction. Wu'an City is a mining city with a water shortage, so the upside potential of the development of fisheries is small.

However, the terrain is diverse in Wu'an City, so on the basis of continuing to maintain development of crop farming and animal husbandry, it is necessary to gradually strengthen the adjustment of agricultural structure; take full advantage of the existing barren hills, wasteland and other unused land; vigorously develop forestry production and develop the cultivation of sumac and other characteristic trees; improve the balanced development level of farming, forestry, husbandry and fishing; promote the diversified development of system and improve system stability; increase farmers' income.

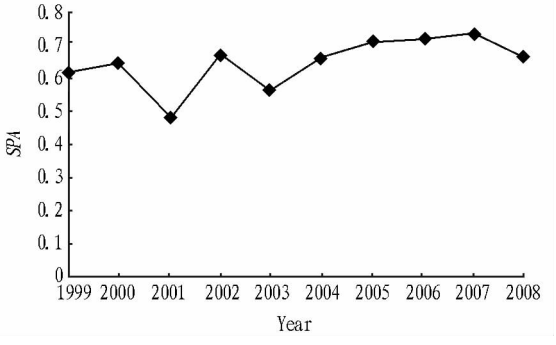

Fig. 5 Dynamic changes of dominance of system production in Wu'an City during the period 1999 – 2008

3 Conclusions and recommendations

On the basis of the basic principles and significance of emergy analysis, we derive the agricultural emergy input-output time series in Wu'an City during the period 1999 – 2008. Through a series of analyses of emergy input-output and evaluation indicators, we draw the following conclusions:

(1) Wu'an City has attached increasing importance to agricultural development and continuous advancement of scientific and technological level; the emergy input and output of agriculture in Wu'an City are in the rising trend. In the future economic development, it should continue to maintain the stability in the basis of agro-ecological economic system, and increase farmers' income.

(2) The emergy input of renewable environmental resources in Wu'an City relies mainly on the chemical energy of rainwater, but in view of the reality in Wu'an City, Wu'an is an extremely dry area, so in order to reduce the impact of the drought year on Wu'an's agriculture, achieve continuous and stable development of agricultural and rural economy, and avoid water crisis, it is necessary to rationally use water resources, save water and strive to improve the utilization rate of water resources. Non-renewable emergy input is mainly the contribution of non-renewable industrial assistant energy. In the process of increasing improvement in the industrial assistant energy and the level of agricultural science and technology, we should preclude the adverse effect arising from the excessive use of fertilizer and pesticide, pay attention to the energy ecosystem protection, strengthen the scientific application of fertilizer, vigorously promote the technique of directly or indirectly returning the wheat straw and corn stalk to farmland, and apply green manure on the basis of local circumstances, to guarantee the sustainable development of agriculture, and ceaselessly increase the emergy yield.

(3) With the development of agriculture, net emergy yield ratio in Wu'an City decreases slowly, and the emergy investment ratio climbs slowly. That is, the dependence of agricultural economic system in Wu'an City on the nature declines ceaselessly and the degree of developing land increases gradually. But in the process of increasing input to the agriculture, the agricultural costs are also increasing, and the competitiveness of prices of agricultural products is gradually abated. Therefore, it is necessary to more intensively use emergy and improve the marginal utility of emergy input, in order to constantly increase farmers' income, which is the direction of agricultural development in Wu'an City.

(4) The environmental loading ratio of agriculture continues to climb, and the emergy sustainability index constantly declines, which has sounded the alarm to agricultural development in Wu'an City. On the one hand, we must ensure that the economic output of the agricultural production is constantly improved, achieving the purpose of increasing yield and income for farmers, maintaining the stability of agricultural production. On the other hand, we must ensure the protection of natural resources and environment, actively improve the natural environment, and promote coordinated development of nature and economy.

(5) It is necessary to further strengthen the adjustment of agricultural structure, develop high-quality and efficient water-saving agriculture. We must adjust the quality structure of agricultural products to achieve large-scale and specialized production of agricultural products; promote the industrialized operation of animal husbandry, implement standardized production, and accelerate the conversion from the traditional animal husbandry to the modern animal husbandry, from quantity-based animal husbandry to quality-based animal husbandry; give full play to the role of forestry in ecological environment construction and the ecological and economical construction, establish developed forestry industrial system, and achieve win-win situation of the forestry economic growth and ecological protection.

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Table 3 Benefits of each crop Unit: Yuan

Crops	Wheat	Avena nuda	Flax	Rape seed	Potato	Red bean	Pea
Total mean benefit	1 104.17	1 821.06	2 059.36	2 721.88	14 924.48	5 626.43	1 194.03
Benefit per family	1 072.71	1 829.88	2 927.20	2 376.61	14 644.71	6 028.13	1 087.50

Table 4 Comparison of crops' benefit

Crops varieties	N	alpha = 0.05 subset		
		1	2	3
Wheat	22	1 072.704 5		
Pea	2	1 087.500 0		
Avena nuda	19	1 829.875 9		
Rape seed	14	2 376.607 1		
Flax	16	2 927.203 1		
Red bean	8		6 028.125 0	
Potato	17			14 644.705 9

The commercial rate of each kind of agricultural crops is shown in Table 5.

Table 5 Commercial rate of crops in Kangbao County Unit: %

Crops	Wheat	Avena nuda	Flax	Rape seed	Potato	Red bean	Pea
Commercial rate	57.64	66.38	74.20	68.08	74.80	78.16	56.82

Hence, the commercial rate of each crop is like this: red bean > potato > flax > rape seed > avena nuda > wheat > pea. Generally speaking, the commercial rate in Kangbao County is high and is highly compatible with the benefit of crops.

3 Conclusions

3.1 Significant differences of net income among crops

Growing potato can bring the highest income, with 14 645 Yuan per hectare. The area planted with potato is 4.35% of total arable land. The crop which yielded the second highest income is red bean, with 6 028 yuan per hectare. Its plantation area accounts for 2.82%.

3.2 The way to maximize benefits Local farmers have strong self-satisfaction consciousness and grow crops in an unreasonable way that the final benefit isn't maximized. Only 48% land was used to produce crops and farmers failed to plant crops with high benefits. 78.57% families grew wheat and 67.86% families grew avena nuda.

3.3 Reolucing farmers' physical input by renting agricultural machine Leasing agricultural machine reduces farmers' physical input, so this investment costs the most. Along with the development of agricultural machine lease industry, almost all works are done by machine. This investment accounts for 43.29% of total investment.

3.4 The high commercial rate of crops in Kangbao County

Modern farmers do not have to store food as their ancestors. Instead, they sell the rest of crops for money. Besides, the commercial rate of crop with large benefit is also high. For instance, the commercial rate of potato and red bean is 74.80% and 78.16% respectively. The commercial rate of crops in Kangbao County reached 68.63% in general.

4 Discussion

More than 61% families grow avena nuda and wheat, which suggested that the traditional eating habit has great influence on local farmers. Such eating habit results in significant differences in benefits of crops. 48% land is used to grow crops with low benefits and then more than half food is sold, which suggested that modern farmers would first consider their life necessities and then the commercialization of crops. With social development, the investment in agricultural machinery is increasing, accounting for 43.29%, which reduces farmers' physical input, enhances agricultural production and decreases seasonal demand of labor for in agricultural production to a certain degree. In this case, people can work in companies to increase family income.

This is only one year's data. Because of dramatic changes of market price of crops, the crop market has higher risks. The changes of crops will be further studied.

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