Emergy Analysis of Agro-ecosystem in Poyang Lake Area

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Abstract By using emergy analysis theory and methods, we conduct quantitative analysis on the input and output of emergy, and sustainable development of agro-ecological system in Poyang Lake Area. The results show that compared with the national average, the environmental loading ratio is relatively low in this area; the net emergy yield rate is high; the sustainable development ability is strong. Finally according to the results of emergy analysis, corresponding countermeasures are put forward as follows: develop agriculture based on the existing rich natural resources; increase technological inputs; develop circular agriculture; promote sustainable agricultural development.

Key words Emergy analysis, Agro-ecological system, Poyang Lake Area, Sustainable development index, China

In the late 1980s, the famous American ecologist H. T. Odum initiated emergy analysis method on the basis of emergy analysis[1]. Taking solar emergy as standard, the emergy analysis is to convert emergy with different types and quality into the emergy with unified standard through conversion rate of solar emergy, so as to appraise the a variety of incomparable materials and emergy, which overcomes the shortcomings of traditional evaluation methods. Since the inception of this theory, it has been widely applied to various types of ecological economic systems, such as agriculture, industry, industrial park, and urban complexes, in conjunction with analysis on different development modes. It has conducted improvement and perfection on the research methods. Zhang Yun *etc.* introduce emergy analysis method into iron and steel industrial system, and conduct sustainability assessment on iron and steel industrial park[2]; Zhou Ping analyses the changes of emergy index of ecological economic system of agriculture before and after the policy implementation of returning farmland to forest in loess hilly region[3]; Yan Maochao[4], Li Haitao[5], Sui Chunhua[6] and other scholars have used emergy analysis method one after another to research the status of sustainable development of ecological economic system in Tibet, Jiangxi, and Guangzhou.

This paper aims to use emergy analysis method to conduct quantitative analysis and assessment on agro-ecosystem in Poyang Lake Area. Through conducting quantitative analysis on the overall emergy of natural environment, and the artificial support emergy input and yield in Poyang Lake Area, we are to assess the emergy basis of environmental resources, emergy input, and the level of productivity, in order to provide scientific basis for the rational development of agricultural environment resources and realization of sustainable development of agriculture.

1 Data source and research method

1.1 Overview of the study area On December 12, 2009, the State Council officially approved *Poyang Lake Ecological Economic Zone Planning*, which marks that building Poyang Lake Ecological Economic Zone is elevated to national strategy. Poyang Lake is an important flood storage lake of Yangtze River and world famous wetland. The ecological economic zone, taking Poyang Lake as a core, includes Nanchang City, Jingdezhen City, and Yingtan City, and Jiujiang, Xinyu, Fuzhou, Yichun, Shangrao, Ji'an and other counties (cities, districts), a total of 38 counties (cities, districts), with land area of 51 200 square kilometers. In 2009, it realized regional GDP of 403.1 billion yuan, wherein the primary industry accounted for 17%, and at the end of that year, the total population is 20.066 million. In Poyang Lake Area, the agricultural resources are rich and the agricultural population is so large, so it is always an important production base of commodity grain, cotton, oil, pig and aquatic products in Jiangxi and China, with good prospects for the development of ecological agriculture. Vigorously developing agricultural ecological economy in Poyang Lake Area is of great practical significance and long-term strategic significance to promoting the building of Poyang Lake ecological economic zone.

1.2 Data source The raw data for this study is mainly from *Statistical Yearbook of Jiangxi Province* in 2010, statistical yearbooks of cities in Jiangxi Province in 2010, *Poyang Lake Ecological Economic Zone Planning*, and statistical information network in all regions. In order to facilitate data acquisition, based on statistical caliber, the paper integrates the study area into four prefecture-level cities, namely Nanchang City, Jiujiang City, Jingdezhen City, and Yingtan City, and 10 counties (cit-

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ies, districts), namely Zhangshu City, Fengcheng City, Gao'an City, Yushui District, Xin' gan County, Linchuan District, Dongxiang County, Poyang County, Yugan County, and Wannian County. As for the emergy conversion of agricultural products, it is mainly based on *Agricultural Technology Economic Manual* (*Revised Edition*)[7] and *Agricultural Ecology*[8]. The solar emergy conversion rate and calculation formula are primarily based on *Eco-economic System Emergy Analysis*[9] and related references[9-12]. Several data are extrapolated, slightly affecting the final results.

1.3 Methods and basic steps of emergy analysis

1.3.1 Collect data. We collect a variety of information and data related to the research objective, sort them out, and input all into computer for storage and processing.

1.3.2 Draw emergy system figure. We determine the boundary of the research system, main emergy sources in system, and adopt the emergy sign and ecosystem schema method proposed by Odum, to draw system emergy schema (Fig. 1).

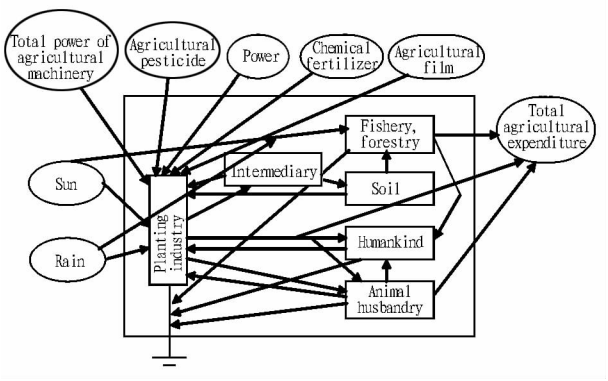

Fig. 1 The emergy system of agro-ecosystem in Poyang Lake Area in 2009

1.3.3 Draw up emergy analysis table. Based on emergy input and yield data of Poyang Lake agricultural ecological economic system, in accordance with the emergy conversion coefficient and the relevant rules, we convert the various types of raw data into emergy J and amount of substance g. Then the data is multiplied by the corresponding solar emergy conversion rate, to get the solar emergy (sej), finally forming Poyang Lake Area agro-ecosystem emergy input and yield table in 2009.

1.3.4 Establish emergy evaluation index system. According to emergy analysis table and emergy system figure, we further establish and calculate out a series of emergy indices that can reflect ecology, environment, sustainable development, economic efficiency and so on, in order to assess the contribution of the natural resources environment to the economic system and the forcing of economy on natural environment.

2 Results and analysis

2.1 Analysis on emergy input-output structure of agro-ecosystem in Poyang Lake Area

2.1.1 Analysis on emergy input of agro-ecosystem in Poyang Lake Area. Table 1 shows that in 2009, the total emergy input in this region was 1.93E+22sej, wherein renewable environmental resources, non-renewable environmental resources, industrial support emergy, and renewable organic emergy, account for 41.7%, 3.3%, 49.3%, and 8.5% respectively. The proportion of natural environment emergy is much greater than China's average proportion of 1.6%[9], indicating that the environmental resources in this region is rich, with abundant rain, suitable for agricultural development. Industrial support emergy input (9.51E+21sej) is 6 times the renewable organic emergy input (1.65E+21sej), indicating that the agricultural development mode that this region is mainly dependent on natural conditions and organic emergy has changed, and at present, the agricultural input in this region is mainly from non-renewable industrial support emergy. However, excessive input of industrial support emergy and overuse of chemical fertilizers and pesticide not only cause a waste of resources and increase agricultural production costs, but also occasion serious ecological consequences. Renewable organic emergy accounts for 8.5% of total emergy input. The greater the share of system input into renewable support emergy, the stronger the ability of sustainable development in system. As for the use of biological re-

Table 1 Emergy input of agro-ecosystem in Poyang Lake Area (2009)

Item	Original data J(g)	Solar emergy conversion rate sej/J(g)	Solar emergy sej
Renewable environment resources (*R*)			8.05E+21
Solar emergy	1.80E+20	1	1.80E+20
Rain potential emergy	1.08E+16	1.00E+4	1.08E+20
Rain chemical emergy	8.70E+16	1.80E+4	1.56E+21
Wind emergy	5.00E+17	1.50E+3	7.50E+20
Cycling emergy of earth	1.60E+17	3.40E+4	5.45E+21
Non-renewable environment resources (*N*)			6.39E+19
Net loss of mantle soil	8.63E+14	7.40E+4	6.39E+19
Industrial auxiliary emergy (*F*)			9.51E+21
Chemical fertilizer	6.55E+11	4.62E+9	3.02E+21
Pesticide	5.10E+10	1.62E+9	8.27E+19
Total power of agricultural machinery	5.70E+13	7.50E+7	4.28E+21
Agricultural power consumption	1.06E+16	2.00E+5	2.12E+21
Agricultural film (*T*)	1.42E+10	3.80E+8	5.38E+18
Renewable organic emergy			1.65E+21
Agricultural labour forces	1.01E+15	3.80E+5	3.83E+20
Seeds	1.05E+14	6.60E+6	6.93E+20
Organic fertilizer	2.12E+14	2.70E+6	5.72E+20
Total input emergy ($U=R+N+F+T$)			1.93E+22

sources, improving use efficiency of organic emergy is an important means to prevent ecological degradation and reduce environmental pollution. In addition, through referring to most of literatures, we find that the use of organic fertilizer and other organic resources is little, so it is negligible in this study, not affecting the final result.

2.1.2 Analysis on emergy output of agro-ecosystem in Poyang Lake Area. Table 2 shows that the total emergy yield of Poyang Lake Area agro-ecosystem in 2009 was 6.87E +22sej, mainly including farming yield, animal husbandry yield and forestry yield, which accounts for 21.1%, 66.7 % and 12.2 % in total yield respectively. In farming yield emergy, the grain crops account for 69.7%, cash crops account for only 30.7%, which is not conducive to increasing farmers' income and improving their living standards. The total emergy yield of animal husbandry makes the greatest contribution to total agricultural emergy yield, so we should promote the industrialization development of animal husbandry, improve the level of scale, standardization and healthy breeding, in order to make animal husbandry achieve great breakthrough on the quantity and quality. The emergy yield of fisheries is least, only accounting for 1/10 000. Poyang Lake should make full use of high-quality local water resources to develop fisheries, especially the breeding of famous high-quality fishes.

2.2 Analysis on emergy index of agro-ecosystem in Poyang Lake Area

2.2.1 Analysis of level of agricultural foundation of agro-ecosystem in Poyang Lake Area.

2.2.1.1 The ratio of environmental emergy, the ratio of industrial support emergy and the ratio of organic support emergy. Environment emergy ratio, namely the contribution rate of emergy, is the ratio of natural environmental resources and total emergy input, reflecting the self-sufficiency rate of emergy in one region. Table 3 shows that environment emergy ratio in Poyang Lake Area agro-ecosystem is 44%, higher than the national average of 13%[9], indicating that the degree of self-sufficiency of emergy in this system is high, and environmental resources make great contribution to agricultural development. The ratio of industrial support emergy is 0.49, lower than the national average of 0.62[9], on the one hand, indicating that Poyang Lake Economic Zone needs to increase economic input to agriculture and develop agriculture, and on the other hand, indicating that the agriculture in Poyang Lake Economic Zone still has large space for development.

Table 2 Analysis on emergy output of agro-ecosystem in Poyang Lake Area (2009)

Item	Original data J(g)	Solar emergy conversion rate sej/J(g)	Solar emergy sej
Total of planting			1.45E +22
Rice	1.22E +17	8.3E +4	1.01E +22
Wheat	4.01E +14	6.8E +4	2.73E +19
Minor cereals	6.64E +10	2.7E +4	1.79E +15
Beans	1.48E +11	8.3E +4	1.23E +16
Potato	7.62E +10	8.3E +4	6.32E +18
Cotton	1.97E +15	8.6E +5	1.69E +21
Oil	1.63E +16	8.6E +4	1.40E +21
Fruit	1.54E +15	5.3E +4	8.16E +20
Sugar	2.57E +15	8.5E +4	2.19E +20
Tea	1.55E +14	2.0E +5	3.10E +19
Total of animal husbandry			4.58E +22
Honey	5.64E +13	2.0E +6	1.13E +20
Cocoon	7.60E +13	1.2E +6	9.11E +19
Meat	1.86E +16	2.0E +6	3.72E +22
Milk	1.82E +15	1.7E +6	3.09E +21
Egg	2.63E +15	2.0E +6	5.26E +21
Total of fishery			7.68E +17
Aquatic products	3.84E +11	2.0E +6	7.68E +17
Total of forestry			8.37E +21
Forest product	1.01E +9	8.3E +12	8.37E +21
Total output emergy (Y)			6.87E +22

Table 3 Emergy analysis index system of agro-ecosystem in Poyang Lake Area (2009)

Type of index	Name of index	Expression	Value
The level of agricultural foundation	The ratio of environmental emergy	$(R+N)/U$	0.44
	The ratio of industrial support emergy	F/U	0.49
	The ratio of organic support emergy	T/U	0.08
	Environment loading rate *ELR*	$(N+F)/(R+T)$	1.103
The level of agricultural economic development	Emergy input rate	$(F+T)/(R+N)$	0.67
	Net emergy yield rate *EYR*	$Y/(F+T)$	5.081
	Use amount of emergy per capita//sej/person	U/Population	5.43E +15
	The industrial support emergy per capita//sej/people	F/Population	2.68E +15
The level of sustainable development	Agricultural production dominance index C	$\sum(Y_i/Y)^2$	0.5
	Sustainable development emergy index	EYR/ELR	4.6

2.2.1.2 Environment loading rate. Environmental loading rate is the ratio of non-renewable resources input emergy in system and renewable input emergy, reflecting the loading pressure of renewable resources under the current economic conditions, and the pressure of agricultural production on the natural environment. The environmental loading rate of Poyang Lake Area agro-ecosystem is 1.103, lower than the national average of 2.8[9], indicating that the agricultural environmental resources in this region have potential for further development and utilization, and can further increase the emergy input, and improve productivity.

2.2.2 Analysis of level of economic development of agro-ecosystem in Poyang Lake Area.

2.2.2.1 Emergy input rate. Emergy input rate refers to the ratio of human economic system input emergy and the natural environment free input emergy. The former refers to goods, services, fuel, *etc.*, which are required to be paid for, called as "purchase emergy"; the latter includes land, solar emergy, wind emergy, and other free emergy in the nature.

The emergy input rate of Poyang Lake Area agro-ecosystem is 0.67, far below 4.88 of Huang – Huai – Hai areas[12] and

14.03 of Japan[9], indicating that the purchase emergy input of unit free environmental resource in this region is low, and the use of free environmental resources cannot reach the best efficiency. We should increase input to agriculture, especially technology and organic emergy inputs, to maintain sustainable development.

2.2.2.2 Net emergy yield rate. The net emergy yield rate is the ratio of system yield emergy and input (economic feedback) emergy. The feedback emergy is from human society and economy, including fuel and a variety of means of production as well as human labour services. *EYR* is the indicator of measuring the contribution of system yield to economy, which can effectively measure the system production efficiency. If the net emergy yield rate is higher, it indicates that the system input of certain economic emergy can get more emergy of products, that is, the higher the production efficiency of system, the more competitive the economic activities.

The net emergy yield rate of Poyang Lake Area agro-ecosystem is 5.081, which is at high level, in comparison with the average net agricultural emergy yield rate of 0.27 in China[9], indicating that the the holistic function of Poyang Lake ecological economic system of agriculture is good, the operating efficiency is high, the return rate of emergy is high, and the products have strong market competitiveness.

2.2.2.3 Use amount of emergy per capita and the industrial support emergy per capita. The utilization amount of emergy per capita can be used for measuring the farmers' living standards and farmers' life quality; industrial support emergy per capita can be used to measure the level of mechanization of agriculture and popularization rate of farmers' electrical appliances, objectively reflecting the living standards of farmers.

The utilization amount of emergy per capita and industrial support emergy per capita in Poyang Lake Area agro-ecosystem is 5.43E+15, 2.68 E+15sej respectively, lower than the national average, indicating that there are many problems existing in rural economic development, the life quality of farmers is low and the infrastructure building in rural areas needs to be improved.

2.2.3 Analysis of level of sustainable development of agro-ecosystem in Poyang Lake Area.

2.2.3.1 Agricultural production dominance index. Dominance index reflects the equalization degree of all production units in overall structure. If this index is high, it indicates that in agro-ecosystem, one or several industries are dominant; on the contrary, it shows that the system structure tends to be more balanced and reasonable. The dominance index of agricultural development in the region is 0.5, relatively low, indicating that all industries in the agricultural system in the region are relatively balanced. But there are still problems along with balance, for example, the leading industries and characteristic industries are not prominent, so we should pay attention to industry restructuring.

2.2.3.2 Sustainable development index of agriculture. Sustainable agricultural development index is the ratio of net emergy yield ratio and environmental loading rate. If the net emergy yield rate in system in one region is high, while the environmental loading rate is relatively low, then it is sustainable, and vice versa. According to the research of Odum and the like, if the sustainable development index is greater than 10, it indicates that the use of resources is not enough, and the regional economy is not developed; if the sustainable development index is in in between 1 –10, it indicates that this economic system has vitality and development potential; if the sustainable development index is smaller than 1, it indicates that the environmental loading rate is relatively high, and it is consumer-oriented economic system[13].

The sustainable development index of ecological economic system of agriculture in Poyang Lake Area is 4.6, in between 1 and 10, indicating that the sustainable development ability in the region is strong, with great development potential.

3 Conclusion and discussion

(1) The emergy of environmental resources of agro-ecosystem in Poyang Lake Area is high and the natural resources are rich. The agricultural development in the region should be based on local natural resources, to improve the utilization rate of solar emergy and precipitation, and exploit productivity of the land. This can reduce production costs, and the products can be sold at lower prices, with great competitiveness.

(2) The agricultural input in Poyang Lake Area is insufficient and the industrial advantages are not prominent. We should increase input of industrial support emergy, speed up the process of agricultural modernization, and promote agricultural productivity. In the mean time, we should also take into account the environmental carrying capacity in this region, avoid excessive input, especially avoid over-reliance on fossil emergy, and preclude emergy depletion, degradation of land, and agro-ecological deterioration. We should quicken the pace of adjustment of agricultural structure, enhance the combination of farming, forestry, animal husbandry, sideline production and fishery, increase technology information input, promote the quality and quantity of agricultural products with high – grade emergy, extend the planting industrial chain, increase the production of agricultural products with high added-value, and take the way of developing intensive, efficient and sustainable modern agriculture.

(3) The agricultural infrastructure in Poyang Lake Area is weak and the farmers' living standards need to be promoted. We should increase input to agricultural infrastructure, and improve irrigation, to ensure the sustainable and stable development of agriculture. We should also focus on improving the quality of the farmers, increase agricultural science and technology input, develop circular economy, raise the proportion of renewable emergy, and take the road of developing environment-friendly modern agriculture featuring ecological civilization, production development, affluent life, science and technology progress, and scientific management.

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production efficiency.

From the perspective of the *C* level, the fuzzy comprehensive weight of the " costs of violating the contract " (C_{36}) between enterprises and rural household is 0.088, which is the biggest number. It is the major factor that leads to the appearance of industrial chain risks. The low cost of violating the contract is the fundamental reasons that cause the industrial chain risks. The second major three risking factors all come from " natural risks" and they are drought(C_{23}), pest, diseases and disasters (C_{24}) and epidemic (C_{26}), the fuzzy comprehensive weight is 0.077, which is in accordance with the risking factors mainly come from natural risks level in B level . It is related to the poor geographic environment, abominable natural situation and backward infrastructure. Fire has the smallest impacts among natural risks(C_{27}), the weight of fuzzy comprehensive is 0.008 . The following one is unfair distribution of enterprises in industrial chain(C_{41}), the fuzzy comprehensive weight is 0.017.

3 Conclusions and suggestions

3.1 Conclusions

Firstly, from the perspective of the market risk, contract risk, natural risks and efficiency risks, the risking factors come from the natural risks are the highest factors. Natural risks have become the most important risks in agricultural industrial chain, which should be paid much attention to.

Secondly, low cost of violating contract is an important factor that causes the violation of contract.

Thirdly, drought, pests, diseases and epidemic are the risking factors that should be paid high attention to.

Fourthly, the risking factors come from efficiency risk, for example, the unfair distribution of profits among enterprises has little impacts on risks in industrial chain.

3.2 Suggestions In view of the problems of natural risks, the enterprises should establish the emergency response planning. The computer information should be fully made use of to establish the information handle center of risking factors. The global position supervision should be adapted to effective supervise on risking factors in various sections.

With the problems of low cost of violation, the cost of violation should be improved, the profits of violating costs should be decreased and the contract management should be intensified. The process of signing contract and performing the contract should be supervised. When the violation of contracts happens, the party who violate the contract should not only be punished, but also compensates the losses causes by his action. The cost of violating contract should be improved from the root and the profits from violating the contract should be decreased, so as to promote the stable and healthy of order agriculture[8].

Due to the distinctive features of ethnic groups in Wuling Mountain, the government should intensify the investment; perfect public equipments; vigorously support the pillar enterprises in terms of policy and finance. The government should optimize market environment, regulate market order, cultivate private cooperative organization and vigorously introduce rural households to industrial chain operation to create favorable external environment and fundamental situation for the healthy operation of industrial chain.

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