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城市可持续发展能力的能值评价新指标

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摘要:能值理论、方法克服了传统能量与经济分析方法的诸多缺憾,为城市可持续发展的研究提供了全新的视角。但作为一种新兴的理论,其评价指标,尤其是针对城市可持续发展能力的综合评价指标尚不完善。从生态经济效益及环境影响的全面表达角度,剖析了国际现行可持续发展能值指标(ESI)的不足之处,并在此基础上拓展构建了新的可持续发展能值指标(EISD)。以珠江三角洲中山市 1996～2000 年的发展动态为例进行了案例研究。结果表明,新拓展的可持续发展能值指标,在系统效益评价中考虑了系统能值产出的实际经济效果,在环境影响评价中同时考虑了系统的消耗影响和排放影响,可以更全面明晰的评价城市系统的可持续发展能力、状态及其成因,为系统的优化指明方向。

关键词:指标;能值;城市可持续发展;中山市

A new emergy index for urban sustainable development

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Abstract: The evaluation of the sustainable development ability of urban ecological economic systems quantitatively has been more and more highlighted, following the non-invertible urbanization trend of the world. New methods are needed to solving the interface problem between nature and economic society. Founded by H. T. Odum, emergy synthesis has been seemed as a bridge between natural and economic system. Broken through the "energy quality wall" of traditional energy theory, emergy theory realized the unified assessment of energies with different quality and type and moved the energy analysis into a new phase. But the emergy indices system for this evaluation is still young and need to be improved. The establishment of Emergy Sustainable index (*ESI*) and its quantification partly covered the gap of emergy index for sustainable development and promoted the study of sustainable development. However, the sub-index which it used to express the sustainable benefit is not always beneficial and helpful to our sustainable development, limited by our current knowledge and technology. Simultaneously, the sub-index which it used to express the environmental impact can only reflect the consumption structure of resource, leaving the environmental impact of expelled pollutant be neglected. This paper is a study on emergy indices for

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the evaluation of urban's sustainable development ability. Based on the deficiency analysis of *ESI* and the concept of sustainable development, a new Emergy Index for Sustainable Development (*EISD*) is deduced.

Employing *EISD*, a case study is conducted to evaluate the development of Zhongshan city Pearl Delta, during 1996 to 2000. The result is that the *EISD* of Zhongshan had appreciably declined from 0.1573 in 1996 to 0.1510 in 1998, and quickly improved from 0.1510 in 1998 to 0.1785 in 2000. The consume structure of Zhongshan city was less and less depended on nonrenewable resource come from local natural or purchasing, with its Environmental Loading Ratio (*ELR*) decreased from 5.2761 in 1996 to 3.6769 in 2000. On the contrary, the Emergy Waste Ratio (*EWR*) increased from 0.1384 in 1996 to 0.1779 in 2000. Finally, the whole environmental impact decreased from 5.4145 in 1996 to 3.8548 in 2000. The decreasing of Emergy Yield Ratio (*EYR*) of Zhongshan city shows that Zhongshan city is more and more depended on the purchased input, and the percent of renewable resource in purchased input had increased during 1997 to 2000. The Emergy Exchange Ratio (*EER*) of Zhongshan city had decreased from 1997 to 2000, partly because of its product construction and the influence of economic decline of the whole world. Zhongshan city should pay more attention to improve its production efficiency and decrease its waste ratio. More ecology principles should by applied into the development of urban system, with the accelerated urbanization of our country. The case study shows that *EISD* can assessment the sustainable development ability more roundly, with the consideration of environmental impact and social-economic effect simultaneously. The *EISD* can be used in both transverse comparison study of different systems which have the same output and fore-and-aft optimizing accounting of a current or burgeoning system. The *EISD* still has some weakness, such as the neglect of social benefits etc., need to be promoted by further analysis and practice.

Key words: index; emergy; urban sustainable development; Zhongshan city

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Urbanization has become the non-invertible development trend of the world. Consequently, How to realize the sustainable development of city has been more and more highlighted. A central point and advancing problem of this challenge is how to evaluate the sustainable development ability of those ecological-economic systems quantitatively. Researchers have been trying to solve this problem in different ways[1~3], but most of them staying in the separate accounting levels. They are not able to consider both the system's environmental impact and the social-economic effect at the same time.

With the unified unit, emergy theory can bridge the natural system and social-economic system[4], and can evaluate the sustainable development ability of ecological-economic system thoroughly. Ecologists and economical ecologists have applied the theory all over the world[5~12], and the trend is continuous. The putting forward of *ESI*[7] filled up the vacancy of emergy index for sustainable development and promoted the study of sustainable development. Environmental impact includes not only resource cost but also polluting impact, but both of current emergy analysis and *ESI* have neglected the polluting impact assessment. To fill up the shortage of polluting impact assessment in emergy analysis method and to optimize the emergy indices for sustainable development, the new index for sustainable development (*EISD*) is put forward. Based on *EISD*, a case study of the development of Zhongshan city in 1996 to 2000 is followed.

1 Emergy Sustainable Index (*ESI*)

Based on energy ecology, system ecology, ecological engineering and economical ecology, Emergy analysis theory was founded by H. T. Odum in the end of 80's 20th century[13]. With the unified unit, emergy, emergy theory broke through the "energy quality wall" of traditional energy theory, realized the unified assessment of energies with different quality and type. Emergy theory has moved the energy analysis into a new phase, and enriched the evaluation methods of sustainable development. But for a long time, it has been lacking a multiple emergy index to evaluate the system's sustainable development ability roundly in emergy indices system until Brown and Ulgiati established one in 1997. The new index was named as EMERGY sustainable index (*ESI*), and defined as Emergy Yield Ratio (*EYR*)/Environment Lording Ratio (*ELR*). *EYR* is the ratio of the total emergy output to the purchased emergy input. *ELR* is the ratio of nonrenewable resource emergy input to the renewable resource emergy input. Through a case study, they quantified the *ESI* as: When $ESI > 10$, it means environmental overloading; When $10 > ESI > 1$, it means developing economies; When $ESI < 1$, it means developed economies. The putting forward of *ESI* is a great advancement of emergy evaluation for sustainable development, but it still cannot fill the need of sustainable development evaluation. There are two points that have been neglected by them.

1.1 Not all the high *EYR* is beneficial and helpful to our sustainable development

Although all the output of a system is valuable from ecological point of view, our current knowledge and technology are limited to make full use of them. So not all the outputs of a system are economic to our ecological- economic system and have plus benefit. Some of them are even harmful and have negative benefit, such as castoff and pollution etc.. At the same time, in the exchange of target system with other systems, the ratio of emergy paid back to emergy sold out (*EER*) is influenced by market, culture and ethics etc., and is dependent on the time and location too. Therefore, even the same *EYR* can have different effects on the system's sustainable development[14,15].

1.2 Enviornmental Load Ratio cannot express the environment impacts of target system from multiple sites

System's environmental pressure not only expressed as the consumption structure of resource but also expressed as the environmental impact of expelled pollutant. Defined by H. T. Odum, *ELR* is the quotient of nonrenewable resource input and renewable resource input, which can only reflect one sides of the above environmental impact, and neglect the other side.

2 New emergy indices for sustainable development (*EISD*)

Hold in 1992, the world convention for sustainable development defined Sustainable development as the development both accommodating modern need and not harming our offspring's ability to accommodate their need, and achieving the society's economic growth, structure perfection and the natural resource's sustainability, optimum natural environment at the same time, namely harmonious development of the economy, society, resource and environment. This definition has two connotations: Firstly, the social-economic must be developed quickly. Secondly, the natural environment must be sustainable. The social-economic development requires the system's emergy output to be high benefit for us. Simply speaking, the $EYR \times EER$ must be high. The natural environment's sustainability requires the Environmental Impact Ratio (*EIR*) to be low. The environment is both a source and a sink. It is a source of resources for economic processes and a sink for by-products and wastes from these same processes[16]. So *EIR* should include the environment impact from not only resources consuming but also the waste or by-products emission.

The system's *EER* is all the emergy contained in the money which is got from the material or abstract trade with the emergy traded out. Different with *ELR*, which is the ratio of nonrenewable resource emergy input to the renewable resource emergy input, *EIR* is the sum of *ELR* and Emergy Waste Impact

(*EWI*). *EWI* is named as the ratio of waste emergy output to the renewable resource emergy input. So, *EIR* extend the *ELR* to include the waste and pollution impact at the same time. It can express the environmental impact of the urban system roundly. The reason why we don't use Emergy Waste Ratio is that we need to give the environmental impact of waste emission and resource consuming the same weight.

From the above concepts we know that there is no correlation among these three emergy indices. So, we can combine them to get a multiple indices for sustainable development which can take into consideration the system's social economic benefits and the natural environmental impact at the same time. Considering that the social economic benefit is directly proportional to urban system's sustainable development and the *EIR* is inversely proportional to the system's sustainable development, we put the $EYR \times EER$ as the numerator, and put the *EIR* as the denominator, to construct a new emergy index named Emergy Index for Sustainable Development (*EISD*). *EISD* is directly proportional to the system's sustainable development ability. It can be expressed as:

$$EISD = \frac{EYR \times EER}{EIR} = \frac{EYR \times EER}{ELR + EWI}$$

The higher the *EISD* is, the higher the social economic benefit per unit environmental impact we can get, the more comparable in sustainable development the urban system is.

Associated with the *ETR* (emergy transformation ratio), *EER* and *EIR*, *EISD* can be used in the following two aspects:

(1) Used in transverse comparison study of different systems which have the same output. The higher the *EISD* is, the more comparable the system is, in the longtime scale of sustainable development.

(2) Used in fore-and-aft optimizing accounting of a current or burgeoning system. Based on the original system, the system's *EYR* and *EER* can be improved, and its dependence on nonrenewable resource and environmental impact can be minimized, through the continuous introduction of new technical innovations. Finally, the benefit per unit environmental loading ratio can be improved and the system's optimization can be achieved.

3 Case studies: the evaluation of Zhongshan city, Pearl Delta

With the improving urbanization of the whole world and the consequently serious pollution problem, urban ecology study has become one of the main direction of ecology study. As an developing country, China must be serious to choose its owe way to realize urbanization and sustainable development at the same time. We choose Zhongshan city, Pear Delta here, as a case to study the change of its sustainable development ability from 1996 to 2000.

From the input and output data mention in Table 1, we can get the consequent emergy indices of Zhongshan city ecosystem from 1996 to 2000(Table 2). From Tab. 2 we can see that, as a whole, the sustainable development ability of Zhongshan city ecosystem had appreciably declined during 1996 to 1998 with its *EISD* decreased from 0.1573 to 0.1510, and quickly improved during 1998 to 2000 with its *EISD* increased from 0.1510 to 0.1785. We can analysis this trends from the following three sides. First, the consume structure of Zhongshan city was less and less depended on nonrenewable resource come from local natural or purchasing, with its *ELR* decreased from 5.2761 in 1996 to 3.6769 in 2000. On the contrary, the *EWI* increased from 0.1384 in 1996 to 0.1779 in 2000. Finally, the whole environmental impact decreased from 5.4145 in 1996 to 3.8548 in 2000. Second, the decreasing of *EYR* of Zhongshan city shows that Zhongshan city is more and more depended on the purchased input, and the percent of renewable resource in purchased input had increased during 1997 to 2000. Third, The *EER* of Zhongshan city had decreased from 1997 to 2000, partly because of its product construction and the influence of economic decline of the whole world. Zhongshan city should pay more attention to adjust its product construction to improve its production efficiency and decrease its waste ratio, so that it can get rational economic reward from the market, and showing its accomplishment in environment protection and development completely.

Table 1　The input and output of Zhongshan city ecosystem from 1996 to 2000 ($\times 10^{22}$sej·a^{-1})

Item	1996	1997	1998	1999	2000
Renewable local resources emergy input[a] (R)	0.0261	0.0258	0.0252	0.0252	0.0252
Renewable purchased resources emergy input[b] ($R1$)	0.2723	0.2510	0.3120	0.4460	0.5600
Nonrenewable purchased resources emergy input[c] (F)	1.5744	1.5927	1.7921	2.0282	2.1528
Emergy yiel[d] (Y)	1.8728	1.8697	2.1294	2.4997	2.7383
Waste emergy output[d] (W)	0.2592	0.2557	0.2543	0.3572	0.4871
GEP (10^9 \$·a^{-1})	2.3160	2.6650	3.0080	3.2930	3.7780
The Emergy/\$ of China (10^{12}sej·\$$^{-1}$)	6.7905	6.1872	5.7371	5.4828	4.9409

a　R = maxim of solar radiation emergy, wind emergy, rain chemical emergy, rain potential emergy and earth cycle emergy = rain chemical emergy = area × rainfall × rain density × Gibbs number × ETR (Odum, 1996)
= (____ m^2)(1.6916m·a^{-1})(1000kg·m^{-3})(4.94×10^3J·kg^{-1})(1.54×10^4sej·J^{-1})

b　$R1 = \sum_{i=1}^{n} R1i = \sum_{i=1}^{n}$(renewable purchased inputi × $ETRi$)

c　$F = \sum_{i=1}^{n} Fi = \sum_{i=1}^{n}$(nonrenewable purchased inputi × $ETRi$)

d　$W = \sum_{i=1}^{n}$ Liquid Waste$_i$ × 5J·g^{-1} × 8.60E5sej·J^{-1} + $\sum_{i=1}^{n}$Solid Waste$_i$ × 4.22E3J·g^{-1} × 1.8E6sej·J^{-1}

Table 2　The emergy indices of Zhongshan city ecosystem from 1996 to 2000

Item	1996	1997	1998	1999	2000
Emergy yield ratio ($EYR = Y/(R1+F)$)	1.0129	1.0130	1.0114	1.0097	1.0088
Environmental Loading Ratio ($ELR = (N+F)/(R+R1)$)	5.3153	5.7938	5.3352	4.3162	3.6869
Emergy Waste Ratio ($EWI = W/(R+R1)$)	0.8751	0.9302	0.7571	0.7602	0.8342
Environmental Impact ratio ($EIR = ELR + EWI$))	6.1904	6.7239	6.0923	5.0764	4.5212
Emergy exchange ratio ($EER = GEP/(Y/emergy/\$)$)	0.8398	0.8819	0.8104	0.7223	0.6817
Emergy indices for sustainable development ($EISD$)	0.1374	0.1329	0.1345	0.1437	0.1521
EMERGY sustainable indices ($ESI = EYR/ELR$)	0.1906	0.1748	0.1896	0.2339	0.2736

4　Conclusion

Pay attention to show the social-economic benefit under unit environment impact, *EISD* can show the sustainable development ability of the system under study more roundly, with the considering of social-economic benefit and environment impact at the same time. The analysis of *EISD* and its three sub-indices can supply more reference for the policy maker to realize sustainable development. *EISD* is more sensitive in the assessment of the system's sustainable development ability and in the discovery of the system's development result.

Put the case study into consideration, the sustainable development ability of Zhongshan city had appreciably declined during 1996 to 1998, and quickly improved from 1998 to 2000, partly because of its environment protection and product construction. Zhongshan city should pay more attention to adjust its product construction to improve its production efficiency and decrease its waste ratio, so that it can get rational economic reward from the market, and showing its accomplishment in environment protection and development completely. Comparing with dike-pond agro-ecological engineering modes, which we have done in 2000, we can see that, the *EISD* of dike-pond agro-ecological engineering modes (3.0 on average) is much higher than the *EISD* of city, even comparing with the Zhongshan city which is one of the six ecological city of China. So with the accelerated urbanization of our country, we should apply more ecology principles into the development of urban systems.

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