

# APPLICABILITY OF EMERGY ANALYSIS METHOD TO INDICATORS FOR SUSTAINABLE DEVELOPMENT BY COMPARISON WITH EXERGY, LCA AND ECOLOGICAL FOOTPRINT METHODS

Juan LIU<sup>1</sup>, Toru MATSUMOTO<sup>2</sup> and Yonghai XUE<sup>3</sup>

<sup>1</sup>PhD Candidate, Faculty of Environmental Engineering, the University of Kitakyushu  
(1-1, Hibikino, Wakamatsu-ku, Kitakyushu, 808-0135, Japan)  
E-mail: d7650201@hibikino.ne.jp

<sup>2</sup> Professor, Faculty of Environmental Engineering, the University of Kitakyushu  
(1-1, Hibikino, Wakamatsu-ku, Kitakyushu, 808-0135, Japan)  
E-mail: matsumoto-t@env.kitakyu-u.ac.jp

<sup>3</sup> Research Fellow, Faculty of Environmental Engineering, the University of Kitakyushu  
(1-1, Hibikino, Wakamatsu-ku, Kitakyushu, 808-0135, Japan)  
E-mail: y-xue@env.kitakyu-u.ac.jp

Emergy, developed by Howard Thomas Odum, is a quantitative method for evaluating systems, both ecological system and society system. This paper introduces the concept and development of Emergy analysis method, and makes a comparison between this method and other system analysis methods, such as Exergy, LCA and ecological footprint. The comparison analyzes principles of these methods and summarizes the advantage and disadvantage of each method on system evaluation. Through comparison, the applicability of the indicators for sustainable development from Emergy analysis method is also analyzed.

**Key Words :** *comparison, Emergy, Exergy, LCA, ecological footprint*

## 1. INTRODUCTION

Before the prosperity of the concept of Sustainable Development, people were generally used to evaluating the social system which they are living in with economic methods, such as the Cost Benefit Analysis. Through evaluating with these economic methods, people search for the development role of social economy. It endowed people with ability on forecast of economic developing trend in a certain period of future.

In 1980, the term "Sustainability" was first introduced in the book "The World Conservation Strategy". From that time, people began to rejudge the social system they live in, rejudge the economic development mode, and rejudge the development trend of the society. Also from that time, researchers

began continuous attempt on the field of how to quantitatively evaluate the sustainability. In this process, some ecological system assessment methods have been induced and developed. People were able to integrately evaluate their system not only on economic visual angle but also on social and environmental visual angle. Representative methods for these ecological methods are Ecological Footprint, Life Cycle Assessment (LCA), Exergy and Emergy Analysis Method. Every method has their fanatics and they always want to persuade the others that their method is the best one on system assessment.

This paper makes simple introduction and comparison on these four methods, attempts to find the core characteristic of them and analyzes their advantage and disadvantage on assessment of system

sustainability.

## 2. COMPARISON

### (1) Ecological Footprint (EF)

The ecological footprint method was introduced by Rees (Rees, 1992) and elaborated by Wackernagel and Rees (Wackernagel and Rees, 1996).

*Ecological footprint analysis is an accounting tool that enable us to estimate the resource consumption and waste assimilation requirements of a defined human population or economy in terms of a corresponding productive land area.* (Wackernagel and Rees, 1996) Complete ecological footprint analysis would include both the direct land requirements and indirect effects of all forms of material and energy consumption. It allows a cumulative approach to impact analysis. Ecological footprint method calculates the land-use implications of consumption-related resource flows and waste sinks required to support a system or a population, that is translating consumption into land areas, and simply, consumption is separated into five major categories: food, housing, transportation, consumer goods and services. Basically, comparison and analysis on systems could base on the calculation result of Ecological Deficit.

### (2) Life Cycle Assessment (LCA)

Life cycle assessment, also known as cradle-to-grave analysis, is developed based on environmental burden evaluation of returnable bottle and can which was conducted by Midwest Research Institute (now Franklin Institute) and commissioned by Coca-cola.

Life cycle assessment quantifies and evaluates the environmental impacts of a product from the acquisition of raw materials, through manufacture and use, to final disposal. Life cycle assessment can also provide a framework for the analysis of environmental impacts from process, activity or system such as transport, or waste management.

The procedures of life cycle assessment are part of the ISO 14000 environmental management standards.

### (3) Exergy

Exergy is formally defined as the useful work performed by a system. The term was coined by Zoran Rant in 1956, but the concept was developed by J. Willard Gibbs in 1873.

In thermodynamics, the Exergy of a system is the maximum work possible during a process that brings

the system into equilibrium with a heat reservoir. When the surroundings are the reservoir, Exergy is the potential of a system to cause a change as it achieves equilibrium with its environment. Exergy is then the energy that is available to be used. After the system and surroundings reach equilibrium, the Exergy is zero.

Exergy analysis is performed in the field of industrial ecology to use energy more efficiently. The great advantage of Exergy calculations over energy calculations is that Exergy calculation pinpoints exactly where the real losses in processes appear, which is very useful in order to make the necessary changes in the process to improve its sustainability by reducing the Exergy consumption.

### (4) Emergy Analysis Method (EMA)

Emergy, developed by Howard Thomas Odum in 1996, is a universal measure of real wealth of the work of nature and society made on a common basis. It is a quantitative method for evaluating systems, both ecological system and society system. It is based on the use of energy as a common denominator so that flows and storages of different types can be expressed and compared in the same units.

Emergy, specifically Solar Emergy, is the available solar energy used up directly and indirectly to make a service or product. (H. T. Odum, 1996) Emergy analysis considers all systems to be networks of energy flow and determines the Emergy value of the streams and systems involved.

Table 1 shows the common information and comments of these 4 methods.

## 3. ANALYSIS

### (1) Similarity

Basically, the concept and original intention of these 4 methods are nearly the same. They attempt to account all the direct and indirect consumption or input of a system, aggregation of the factors relating environmental support and impact including energy, material, emission and etc., and assess the system as comprehensive as possible. The ecological footprint calculates all the consumption of a system or a population, life cycle assessment accounts all the environmental impact of a product during its whole life, Exergy accounts all the energy consumption in a process, and Emergy analysis method records all the material and energy flow input and output the system.

The methodologies of these 4 methods are all unification of the material and energy flow relating

Table 1 Comparison between EF, LCA, Exergy and EMA.

Items	EF	LCA	Exergy	EMA
Originated from	1992	1969	1956	1996
Originated by	Ecologist	Economist	Engineering scientist	Systems ecologist
Original purpose	Cumulative impact analysis	Comprehensive environmental impact assessment	How to use energy in a more economic and efficient way	Sustainable development level
Main object	System or population	Product or process	Process	System
Analysis scope	Boundary of system	Life cycle of product or process	Boundary of process	Boundary of system
Academic basis	Land support population to produce all their food and absorb all their waste	Environmental impact of a product should including all the impact through its whole life	Second law of thermodynamics	All energy and material on earth are originated from solar energy
Keywords	Yield factor, equivalence factor, ecological deficit	Emission factor, $LCOC_2$	Thermodynamic potentials	Transformity
Merit	Simple and could be easily understood	Easily accepted concept	Precise calculation and universally accepted	Extended research boundary to cumulative of energy and material
Criticism	<ul style="list-style-type: none"> <li>●Single indicator resulting in weak on analysis</li> <li>●Aggregated calculation on consumption</li> </ul>	<ul style="list-style-type: none"> <li>●Uncertainties on the methodology</li> <li>●Regard all processes as linear</li> </ul>	<ul style="list-style-type: none"> <li>●Analysis just on thermodynamic aspect, don't take the ecological and social factors into account</li> </ul>	<ul style="list-style-type: none"> <li>●Complicated methodology and abundance calculation</li> </ul>

to the system under analysis into identical unit, which makes it possible to compare among systems and makes the analysis more visual.

The value of material or energy calculated by these method is "materialistic" value. As biological methods, these methods are all weak on taking economic factors into account such as willing-to-pay or human preference and most social issues influencing decision-making.

## (2) Difference

Although the concept and original intention of these methods are similar as described above, they share different algebra and concrete accounting rules. This causes the quite different in the outcomes of calculating and offers each method its own advantage on system analysis.

### a) Upstream and downstream method

S. Ulgiati separates system analysis methods into "upstream" methods and "downstream" methods. (S. Ulgiati, 2006) *The upstream methods are concerned with the inputs, and account for the depletion of environmental resources, while the downstream methods are applied to the outputs, and look at the*

*environmental consequences of the emissions.*

From this opinion, we also could consider ecological footprint method and Energy analysis method as upstream methods for their stress on material and energy input which support the system. But differently, the ecological method pays more attention on material flow so it transfer all the input into material, whereas, Energy analysis method pays more attention on energy flow and transfer all the input into energy. Life cycle assessment could be considered as downstream method because it is stress on the environmental impact from emission. Exergy method is not just a upstream method or a downstream method. It focuses on the whole process and aims to analyze the efficiency of it.

### b) Research boundary

On the first sight, the research boundary of these methods are all the boundary of the system under analysis, for example, the boundary of a country or a region, the boundary of a factory. But in fact, Energy analysis method has different time boundary with other methods for their difference on calculation. The Energy value of a certain kind of energy or material is the result calculating all the energy and

material input during the whole time for its formation, not just its exploitation or utilization. For this difference, Emergy value of energy or material is not just the material content of it but also reflect the scarcity and real environmental burden of it.

#### c) Human labor and money flow

Human labor and money flow are also important parts supporting the operation of a system, but they have not been paid enough attention and seldom the system analysis method could combine them with other factors. Emergy analysis method regards human labor and money flow to be equally with other factors from its beginning and it is also making effort on calculation of the Emergy value of information, culture and other material that conventionally thought hard to be calculated by biological methods. (H. T. Odum, 1996)

#### d) Advantage on system analysis

From the review of these method showed in Table 1, and analysis above mentioned, the emerging characteristics and key points of every method endue them respective advantage on system analysis.

Exergy is good at trace the energy depletion through the process, so it is advantage on process improving and gauge ecosystem health and stability.

Life cycle assessment account all the emissions released by all the systems involved in the life cycle of a product, and it contributes on standardization of impact assessment of a broad variety of emission. LCA could find the significant part contributing most pollution emission within the entire life of a product, consequently, it could help eco-design of product and improving environmental impact.

Ecological footprint and Emergy analysis method are all good at assessment of the sustainability of a system. Ecological footprint gives a composite view on the sustainable level of a system. And, if you want to analysis it in depth, you should turn to Emergy analysis method. At the same time, EMA gives a more accurate evaluation on sustainable level of a system for its account on the scarcity of energy and material and taking into account not only non-renewable energy but also renewable energy, which in most case reflects the environmental support on the system.

## 4. INDICATORS FOR SUSTAINABLE DEVELOPMENT FROM EMERGY ANALYSIS METHOD

As above mentioned, Emergy analysis method is a more suitable method on sustainable development method, here we introduces some conventional indicators on sustainable development from Emergy

analysis method.

Though, complicated calculation is always the object when others make criticism on Emergy, profited from this complicated calculation procedure, Emergy analysis method could design indicator more flexibly for system analysis. Traditional indicators are:

#### (1) Emergy investment ratio

Emergy investment ratio is the value of feedback energy from economic system divided by free energy input from environment. This ratio could reflect the benefit of a economic activity and also show the environmental burden from the economic activity. If the Emergy investment ratio of a system is bigger than the average ratio of this area, it announces that the economic activity in this system overloads the carrying capacity of the environmental condition in this area.

#### (2) Environmental load ratio

Environmental load ratio is the ratio between gross of non-renewable energy input with gross of renewable energy input. It shows the environmental support on the operation of a system.

#### (3) Emergy sustainable index (EmSI)

It is defined as the quotient between Emergy yield ratio and environmental load ratio. It means the more sustainable system is the system that could get high emergy yield with low environmental load. J.R. Sinche and etc calculate the Emergy sustainable index of several countries, as showed in Figure 1.

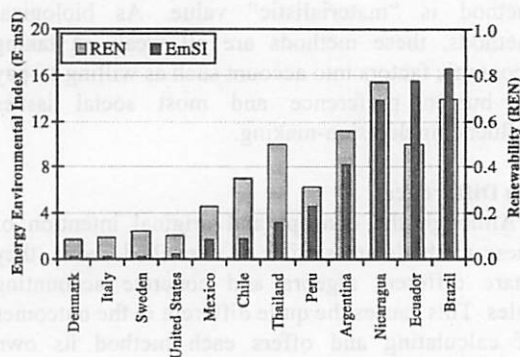


Fig.1 Renewability (REN) and Emergy sustainable index (EmSI).

\* REN is defined as the value of gross of renewable energy dividing by gross of energy used in a country.

\*Source: J.R. Sinche, et al, 2008.

## 5. CONCLUSION

### (1) Common problems of present quantitative assessment on sustainable development

The effort on evaluation of sustainable development has been continued for about thirty years, and some inspiring progresses have achieved. But there are still some insufficiency on the sustainable development assessment methods.

#### a) Quantitative assessment on ecological diversity

For its difficulty on quantification of ecological diversity, nearly all the system assessment methods are weak on taking the ecological diversity into account in their algebra and index.

#### b) Consideration of living level

Consumption on energy and material has close correlation with living level. Simple low level on energy and material consumption does not definitely mean sustainable development. The indicators for sustainable development assessment should take the living level into account.

#### c) Sustainability of nation and sustainability of the whole world

When we evaluate the sustainable development level of a nation, the influence of its development on sustainability of other nations and sustainability of the whole world should also be considered at the same time. Sustainability of a nation should not base on unsustainable development of other nations or bring negative influence on the sustainable development of the whole world.

Fortunately, some biological methods have taken notice of this problem and made effort on taking it into account. For example, in the indices of Emergy analysis method, import and export factors are

inducted to analyze the dependence and influence of a nation on other nations.

### (2) Applicability of Emergy analysis method

Compared with the other three methods introduced in this paper, Emergy analysis method is more convective on sustainable development assessment for it:

a) extend the research "time" boundary to the cumulative process of energy and material which could figure the scarcity of them and give more "real" value for them.

b) consider human labor and money flow and make effort on calculation of the Emergy value of information, culture and other material that conventionally thought hard to be calculated by biological methods.

c) take into account not only non-renewable energy but also renewable energy, which in most case reflects the environmental support on the system.

## REFERENCES

- 1) H. T. Odum: Environmental accounting: Emergy and environmental decision making, *John Wiley & Sons, Inc.*, 1996.
- 2) J.R. Siche, et al : Sustainability of nations by indices: Comparative study between environmental sustainability index, ecological footprint and the emergy performance indices, *Ecological Economics*, pp. 628-637, 2008.
- 3) Rees, W. : Ecological footprints and appropriated carrying capacity: what urban economies leaves out, *Environ. Urban.*, Vol. 4, pp. 121-130, 1992.
- 4) S. Ulgiati et al.: Overcoming the inadequacy of single-criterion approaches to Life Cycle Assessment, *Ecological Modelling*, 190, 432-442, 2006.
- 5) Wackernagel, M. and Rees, W. : Our ecological footprint, reducing human impact on the earth, *New Society Publishers, Gabriola Island, BC*, 1996.