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Progress, influence and perspectives of emergy theories in China, in support of environmentally sound economic development and equitable trade

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Abstract

Emergy Accounting and Synthesis, developed by Howard Odum in the 1980s, accounts for both the work of nature and that of humans as part of it in generating products and services. Since the 1990s, when Odum's system theories and emergy approach were introduced to China, a great attention was paid to them, since they appeared to Chinese scholars very important, comprehensive, and rich with application opportunities to China's economic development and environmental management. Until now more than 150 papers related to emergy theories were published in Chinese scientific journals, more than 20 dissertations presented in all Chinese Universities, and a large number of emergy-based papers were authored by Chinese scholars in international journals. Also, several reports dealing with emergy evaluation of different provinces of China were presented to local governments for decision-making. Emergy theories were applied to valuation of ecosystems and eco-industrial parks, as well as to studies of benefits/cost analysis and feasibility of ecological engineering. Meanwhile, a series of monographs and translated books related to emergy theories were published in China, some of which are used as text books in Chinese universities and institutes.

Compared with the great potential of emergy application, there are many new fields that should be addressed in China, including: assessing the environmental impact of processes based on matching of high-quality and low-quality resources, establishing new frameworks and systems for environmental accounting, evaluating natural capital and services and applying research results to the process of decision-making, and finally studying the patterns and the available development options of China regional eco-economic systems.

Keywords: Emergy; China; Regional eco-economic policy

1. Introduction

For over a century, theorists have sought ways of relating resource availability and constraints to the dynamics of economic–environmental systems, often using energy as a common metric. These had limited success because different kinds of available energy are not equivalent in their ability to do work (not just mechanical work is to be considered), and therefore failed in their ability to link work potential, environmental support, and wealth generated in the economy. In the last two decades a new science-based evaluation system has become available to represent both environmental values and economic values based on a common measure. Emergy (spelled with an "m"), developed by Howard Odum in the 1980s (Odum, 1988, 1996), was suggested as a measure of wealth and value based on environmental resource use. Emergy accounts for aspects that are usually not accounted for by other evaluation methods. It helps evaluating not only non-renewable resources but also the free services that a system receives from the environment (e.g., the photosynthetic

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activity driven by the solar radiation, the dilution of pollutants by the wind, the water cycling by biosphere driving forces, etc.) as well as human labor, societal services, and information. The latter are flows that carry negligible amounts of energy but are supported by a huge indirect flow of material and energy resources. Actually, the emergy approach helps understanding that a large and complex network of driving forces is necessary to support each particular economic activity in our societies. In addition, the emergy method is very helpful for the study of system on the larger scales of the biosphere, from hurricanes to global trade. The emergy method provides a powerful and comprehensive tool for better understanding of the dynamic interaction between human-dominated processes and resources and services provided for free by nature (Brown and Ulgiati, 2004).

We investigate in this paper the apparently successful introduction of the emergy synthesis approach in China. In the last decade emergy faced an increased acceptance by the Chinese scientific community, which understood the novelty and usefulness of such a holistic tool for the management of the fast economic growth of the country and the related environmental and resource use problems. For this reason, most of the first applications of the approach were applied research, aimed at solving specific local or process problems. Then, theoretical efforts were displayed in order to use the approach in a more flexible way, and meet more properly the resource management and policy demand of the Chinese society. Such an effort was mainly based on the development of differently defined performance indicators and the integration of the emergy approach with other more traditional environmental accounting systems and evaluation procedures.

We show in this paper the large variety of applications of emergy that have already been performed in China. We also describe the whole set of options available in China for further implementation of the approach towards a more balanced interplay of the environment and economic system.

2. Emergy synthesis: concepts and definitions

Energy is usually referred to as the ability to do work, based on the physical principle that work requires energy input. Energy is measured in units of heat, or molecular motion, the degree of motion resulting in expansion and quantified in degrees of temperature. Heat energy is a good measure of the ability to raise water temperature. However, it is not a good measure of more complex work processes. Processes outside of the window, defined by heat engine technology, do not use energies that lend themselves to thermodynamic heat transfers. Not all energy, matter and information flows are the same and their heat equivalent is a poor measure of their quality. Odum introduced the concept of *emergy* in the 1980s, in order to properly account for the quality of matter, energy and information flows within systems, including their degradation due to second law losses (Odum, 1988). Emergy accounts for the environmental services supporting a process, as well as for their convergence through a chain of energy and matter transformations in both space and time (Odum, 1996; Brown and Ulgiati, 2004). By definition, emergy is the amount of *available energy* (exergy) of one type (usually solar) that is directly or indirectly required to provide a given flow or storage of energy or matter. The units of solar emergy are solar emjoules (abbreviated seJ) to distinguish them from actual energy joules (abbreviated J). When the emergy required to make something is expressed as a ratio to the available energy of the product, the resulting ratio is called (solar) *transformity* and is expressed in solar emergy joules per joule of output flow (seJ/J).

The total emergy driving a process becomes a measure of the self-organization activity of the surrounding environment, which makes the process possible. Transformity is an expression of the quality of the output itself, for the higher the transformity the more emergy required to make the product flow. For example, the organic matter in forest soil represents the convergence of solar energy, rain, and winds driving the work processes of the forest over many years that has resulted in layer upon layer of detritus that ever so slowly decomposes into soil organic matter.

The emergy synthesis method is used most often as a quantitative measure of the total environmental support to the flows of energy, matter, and information involved in a system dynamics. When the focus is on human-dominated systems, emergy investigation complements and sheds light on results from other approachs such as life cycle assessment (LCA) methods, identifying patterns characterized by different demands for environmental support and different balance of renewable and non-renewable input resources. The novelty is that other thermodynamic methods do not recognize the difference in quality of the various energy sources (just think of solar radiation and gasoline: only the first source can drive photosynthesis, while only the second can fuel the internal combustion engine of a car…not all joules have the same quality), while instead emergy has a built-in quality assessment factor that takes into account the performance of energy conversion processes across their whole life cycle and hierarchical levels, thus being able to link together systems of the natural environment and human economy (Odum, 1971, 1988). Emergy aims at providing an eco-centric value assessment of ecological and industrial products and processes (Hau and Bakshi, 2004). Fundamental in emergy synthesis is the concept of maximum em-power (Odum, 1983; Maximum Em-power Principle). According to this Principle, all self-organizing systems (including human economies) tend to maximize their rate of emergy use or empower (Odum, 1988, 1996). Lotka's previous statement of the same Principle (Lotka, 1922a, b; Maximum Power Principle), although setting the stage to an energy approach to natural selection and evolution, failed to recognize the quality of flows and components at each hierarchical level of systems. In fact, maximization of energy use is not a