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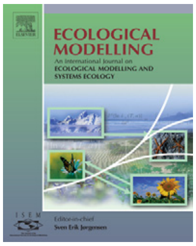

Exergetic assessment for ecological economic system: Chinese agriculture

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ABSTRACT

Based on the thermodynamic concept of exergy as a unified measure for environmental resources and economic products, a framework for systems assessment is presented for ecological economies. With a typical systems diagram devised for a general ecological economy with four arm fluxes for free local natural resources, purchased economic investment, environmental impact and economic yield, system indices of the renewability index, exergy yield ratio, exergy investment ratio, environmental resource to yield ratio, system transformity and environmental stress index are defined for a congregated systems ecological assessment with essential implications to sustainability. As a detailed case study to the Chinese agriculture from 1980 to 2000 with cropping, forestry, stockbreeding and fishery sectors, extensive exergy account and systems assessment are carried out with emphasis on annual and structural variations against social political transitions. For the overall agriculture as a congregated ecological stage, the value of the system transformity is found around 10, the typical value for the general ecological hierarchy as well devised by Odum associated with Lindeman's Tenth Law.

1. Introduction

As an indicator of the distance from thermodynamic equilibrium, exergy provides a unified measure of various forms of materials and energy carriers, and thus qualified as a basic medium used in the bookkeeping to qualify ecological networks of exchange. Due to the scarcity of the cosmic exergy as the fundamental natural resource for the ecosystem of the earth, an exergetic ecology based on the second law of thermodynamics has gained momentum to emerge in the field of systems ecology, as development of and to replace the solar energy-based energetic ecology (Jørgensen and Mejer, 1981; Schneider and Kay, 1994a,b; Jørgensen et al., 1995, 2000; Ulanowicz and Abarca-Arenas, 1997; Valero, 1998; Fath et al., 2001, 2004; Jørgensen and Fath, 2004; Szargut, 2004; Chen, 2005, 2006; Ulanowicz et al., 2006; Jørgensen, 2006).

Instead of solar energy as usually supposed, the cosmic exergy due to the thermal difference between the solar radiation and the CBM (cosmic background microwave) field has been shown to be the driving force of the earth system, and the scarcity of cosmic exergy availability as the fundamental natural resource for the ecosphere and the human society has been revealed by a systematic study on the global consumption of the cosmic exergy in the earth and a balance of the exergy consumption with respect to main terrestrial processes (Chen, 2005). Anthropogenic utilization of terrestrial exergy defined with reference to the terrestrial environment characteristic of the crust, ocean and atmosphere (Szargut et al.,

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1988), derived from the cosmic exergy according to the mechanism of multiplication for the case of thermal radiation (Chen, 2005), is therefore the basic physical cause of the global ecological crisis. The systems account of the exergy utilization in the environment and human interacted ecological economy would present a basic vision of a basic stage of the universal exergy hierarchy, on a scale just next to the global, terrestrial and national or regional scales, and the basic systems structure in terms of exergy thus revealed may serve as the basis for the ecological diagnosis of the economy. To optimize the exergy utilization as anthropogenic ecological impact in fundamental biophysical terms is essential for the sustainability associated with an ecological economy.

Exergy account for natural resources has been carried out in various forms (Rosen and Dincer, 1997, 2001, 2003; Dincer, 2002a,b; Dincer and Rosen, 2005, 2007; Erek and Dincer, 2008). The application of the exergy method for a society was initially presented merely for flows of energy carriers for energy use (Reistad, 1975; Rosen and Dincer, 1997; Ayres et al., 2003). Society exergy account for the use and conversion of natural resources including both energy carriers and materials was introduced by Wall (1977) and carried out for many countries (e.g., Wall, 1990; Rosen, 1992; Schaeffer and Wirtshafter, 1992; Wall et al., 1994; Ertesvåg and Mielnik, 2000; Chen and Chen, 2006a,b; Chen et al., 2006a,b; Chen and Chen, 2007a,b,c,d,e,f). A systems account for societal exergy utilization has been developed towards an exergetic ecology for society, or in another term, exergy-based social ecology (Ertesvåg, 2005; Chen and Qi, 2007).

As a human controlled or at least human interfered ecosystem dependent on environmental resources with production or service goals, an ecological economy is a socio-economic-ecological entity bounded with various dimensions. The diversity of attributes of an ecological economy necessitates systems ecological analysis based on exergy as a unified measure of natural resource, economic investment, environmental impact and industrial product (Wall, 1977; Ayres et al., 1996; Sciubba, 2001; Rosen, 2001; Szargut, 2004; Chen, 2006; Chen and Ji, 2007; Chen et al., 2006a,b; Jiang et al., 2007).

Agriculture is a typical ecological economy, dependent on the support from environmental resources in terms of natural resources such as sunlight, wind, water and soil, and of environmental impact due to pollutant emissions, and from the economy with investment of fertilizer, pesticide, fuel, electricity, human labor and service, with economic yield as outcome from sectors such as cropping, forest, stockbreeding and fishery. As a mainstream field for energetic ecology, agriculture has been extensively assessed in terms of material and energy fluxes in general and emergy (embodied solar energy) in particular (e.g., Odum, 1996; Ulgiati and Brown, 1999; Chen et al., 2006a,b; Jiang et al., 2007). With the emergence of exergetic ecology, it is time to fully integrate natural resources, environmental impact, economic investment and economic yield in the agriculture.

In the present study, a general framework for exergetic analysis of an ecological economy is proposed and illustrated with a detailed case study for the Chinese agriculture 1980–2000. An exergy systems diagram is presented with arms of economic investment, free natural resource input, environmental impact and economic yield, and a variety of system indicators are illustrated with essential implications to sustainability. Detailed structure of the input/output and system indicators is examined in a historical perspective for the Chinese agriculture.

2. Methodology

For an ecological economy with combined action of environmental resources and anthropogenic interference, such as agriculture, a typical systems diagram can be shown in Fig. 1. The input fluxes from free local resources (I_{res}), categorized into free renewable (FR) and nonrenewable (FN) resources, are combined in the pathway towards the left of the main box of the system; the purchased input (I_{econ}) involving renewable (PR) and nonrenewable (PN) investments is combined in the pathway from the top; the yield (Y) as economic outflow is represented by the pathway from the right; the environmental impact (EI) is from the bottom, corresponding to a virtual environmental input (I_{env}) equal in magnitude to the environmental impact as the cost of the environment supporting the system, illustrated as a dotted line with arrow towards the bottom. Then due to additivity of exergy, the environmental resource input is the sum of the environmental input and the resource input, i.e., $I_{er} = I_{env} + I_{res} = EI + FR + FN$, and the total ecological input (I_{ecol}) is the sum of the environmental, resource and economic input, i.e., $I_{ecol} = I_{env} + I_{res} + I_{econ} = EI + FR + FN + PR + PN$.

To illustrate different aspects of sustainability, we may define several indices, with reference to those in embodied energy and embodied exergy analyses (Odum, 1996; Brown and Ulgiati, 1997; Chen, 2006), as follows:

(1) Renewability index $RI = (FR + PR)/(FN + PN)$
This is the ratio of renewable resources (free and purchased) to nonrenewable resources (free and purchased). In the long run, only economic patterns with higher renewability index are sustainable.

(2) Exergy yield ratio $EYR = Y/(PF + PN)$
As yield divided by economic investment, this ratio indicates the efficacy of the system to make use of economic investment.

(3) Exergy investment ratio $EIR = (PR + PN)/(FR + FN)$
As the ratio of economic investment to free natural resource input, this index measures the loading of economic investment on the local natural resource associated with economic development. The less the ratio, the more the local free resource cost associated with the economic investment. A system with lower ratio tends to compete and prosper as an ecological economy; the higher the ratio, the higher the economic development level of a system. If the ratio value for a concrete sector is higher than the average of corresponding large-scale economy, the investment intensity is considered too high.

(4) Environmental resource to yield ratio $ERYR = (EI + FR + FN)/Y$
As the ratio of the environmental resource input to the yield, this index indicates the intensity of the environmental resource contribution to a production system. The system with higher ratio depends more on environmental resource.