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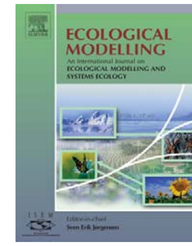

Ecological footprint accounting based on emergy—A case study of the Chinese society

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ABSTRACT

The resource consumption of the Chinese society from 1981 to 2001 is investigated using ecological footprint (EF) and emergetic ecological footprint (EEF). The latter is a newly development modification of ecological footprint based on ecological thermodynamics. Individual sectors in society are described in detail corresponding to the EF and EEF components based on different views of ecological production. The EF and EEF intensities are also presented to depict the resource consumption level corresponding to unit economic output. Finally, EEF is suggested to serve as a modified indicator of EF to illustrate the resource, environment, and population activity, and thereby reflecting the ecological overshoot of the general ecological system.

1. Introduction

Natural capital accounts focused on biophysical limits are increasingly prominent. Meanwhile, there is a felt need for the scarce productive land to support complex social–economic–ecological systems. This paper intends to present a case study of ecological footprint for the “emerging economy" of China, a country with one-fifth of the world’s population, and at present the second largest economic and energy consumption. Currently, resources, such as fossil fuels, agricultural products and forest products, have been squeezed along with the constantly increasing GDP. It is necessary to make an overall analysis of the society from the biophysical perspective.

1.1. *Chinese society from 1981 to 2001*

Chinese population increased steadily during 1981–2001 (Fig. 1). Announced in 1979, the one-child family policy was enforced as the basic principle of China in order to control population growth. Nevertheless, the one-child policy is a difficult target to achieve, with the population increasing steadily from 1.01×10^9 in 1981 to 1.28×10^9 in 2001.

The large increasing population in China leads to a low per capita availability of essential natural resources. Also, the energy efficiency of China is relative low compared with other countries. Economic development always has priority over sustainable economic-environment development. This has resulted in an overloaded and depleted resource base in China.

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As shown in Figs. 2 and 3 the rapid development of GDP or GDP per capita, which has been considered as the hallmark of the Chinese economy, experiences three major periods. During the first period (from 1981 to 1986), industrialization and reform of agriculture contributed most to the GDP growth. The rapidly growing industries and services drove the GDP during the second period (from 1987 to 1991). During the last period (from 1992 to 2001), GDP increased linearly at the average growth rate of 10%. Since the early 1990s, the Chinese economy has achieved a soft-landing after the central government took measures to adjust the economic polices and restrain over-expanded infrastructures (Teather and Yee, 1999).

In addition, there is growing concerns regarding agricultural production in China. Soil and water loss is one of the most serious problems agriculture confronts, for large amount of nutrients in nearly 5 billions tonnes of eroded soil are carried each year to the sea from the local areas, weakening the foundation of the agriculture. Lastly, different provinces and counties are often directed by the government to promote special crop production according to the local cropping conditions and economic status thus regional inequalities in grain production.

1.2. *Ecological footprint*

Vitousek et al. (1986) attempted to determine the human economy's draw on terrestrial net primary productivity and estimate the magnitude of human appropriation of the products of photosynthesis, which can be regarded as a conceptual predecessor of the EF which assesses the relationship between humans and resources (Wackernagel and Monfreda, 2004). Wackernagel and Rees (1996, 1997) proposed the ecological footprint (EF hereafter) as an indicator of the carrying capacity of regions, nations and the globe, and sometimes extended it as an indicator of sustainability. EF is defined as the aggregate area of land and water in various ecological categories that is claimed by participants in that economy to produce all the resources they consume, and to absorb all their wastes they generate on a continuous basis, using prevailing technology , and later, modified to measure the biocapacity a population, organization, or process requires to produce its resources and absorb its waste using prevailing technology (Wackernagel and Monfreda, 2004).

There are some potential improvements in the current EF method. First, as van den Bergh and Verbruggen (1999) pointed out, the physical consumption-land conversion factors function as implicit weights in the conversion as well as the aggregation, which impede the application of EF as an objective indicator in ecological evaluation without any arbitrary components. Second, an ecological evaluation indicator should reflect both the quantity and quality of the resource, not just a hypothetical land area derived from the quantity of biomass produced from different types of bioproductive areas, wherein the resource quality is the intrinsic value of the ecological products and the core of sustainable or unsustainable development mode of the ecological system, e.g., land system. Third, to avoid the debate on the land required to absorb carbon (Ayres, 2000), an alternative method should be presented to determine the ecological footprint caused by energy, especially fossil fuels. Although the energy produced from nuclear and renewable resources, such as wind power, water power, photovoltaic, tide power, etc. are roughly investigated by Wackernagel (2004), the related estimation is based on some local case studies, which is still uncertain for other regions or nations. Lastly, as Wackernagel and Monfreda (2004) indicated, embodied energy should be considered, especially the free energy source dominated by the energy embodied in most renewable resources infrastructure.

In view of the time and space scales, depending on the researcher's objectives and knowledge, the sense of the EF can be interpreted in different ways. With the fundamental time scale of the ecospherical evolution and space scale of the global earth, the EF serves as an indicator of sustainability , for each global hectare is formed and sustained by the others. Meanwhile, on smaller time and space scales, e.g., national or regional, EF can be regarded as an indicator of ecological competitive power, for the limited commodities appropriated by humans and the "actual land area" humans demand are out of consideration for the anthropogenic, temporary and local economic views, not the earth-centered ecocentrism (Chen, 2005, 2006). As Wackernagel et al. (2004a) indicated, the EF can be measured by either consumption or production. Associated with the EF based on consumption, the concept "ecological deficit" is proposed, whereas the concept "ecological overshoot" is presented based on production. Considering a country with much less net import compared to the domestic production, which can be termed as "production-based" country, the concept "ecological overshoot" is more appropriate to reflect the ecological resource depletion of the country. Meanwhile, regarding a country with much more net import compared to the domestic production, which is termed as "service-based" country, the concept "ecological deficit" describes the seized resources of the country from the "global ecological hectare share", which should be understood as ecological competitive power.

1.3. *Emergy*

Defined as the availability of energy (exergy) of one kind that is used-up in transformations directly or indirectly to make a product or service with the unit emjoule (Odum, 1983, 1988, 1994, 1996), emergy reflects the "energy memory" of the work previously done to make a product or service. Thus, emergy represents a donor value different from the general use value of certain good or service (Brown and Ulgiati, 1997, 2004a,b; Sciubba and Ulgiati, 2005). Accounting the donated exergy in the development of the system embedded in the surrounding environment, emergy measures how much resources are obtained from the context of environment on which the system relies.

With a kind of path-dependent integration, emergy and transformity calculations are determined by the process generating the product or service. Natural selection and evolution patterns are therefore implicated in the concept, for the path is presumed along with a generative trial and error process based on the maximum power-output principle stem from Darwin's theory of natural selection and Lotka's hypothesis of natura selection as an energy-maximum process (Odum and Pinkerton, 1955; Sciubba and Ulgiati, 2005). Therefore, emergy method as a kind of energy equivalent assessment performs