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Constructing a network of the social-economic consumption system of China using extended exergy analysis

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ABSTRACT

The prominent conflict between consumption and environmental resources is acknowledged as a significant force in affecting the social-ecological community balance. The whole process of resource allocation, utilization, efficiency and outcome are crucial clues in uncovering the structural and functional characteristics in complex consuming systems. Herein, network relationship provides a system-oriented modeling technique for examining the structure as well as flow of materials or energy from an input–output perspective. Meanwhile, extended exergy, the only currently available thermodynamic based metric for social-economic environmental impacts associated with energy consumption, manpower and monetary operation as well as environmental emission, is an extension of the labor theory of value and a possible sustainability metric. The core purpose of this research is to construct a network of the social-economic consumption system of China using extended exergy analysis to explain the interrelationship among different sectors within a thermodynamic metric. Therefore, we firstly make a database of extended exergy accounting in the Chinese consumption system. Data are available for 2007, which can be divided into seven sectors based on the reclassification of the regularly published 42-sector Input–Output Table, namely, (1) Agriculture, (2) Extraction, (3) Conversion, (4) Industry, (5) Transportation, (6) Tertiary, and (7) Domestic sectors. Then we will construct an extended exergy network to gain insight into the thermodynamic distribution within sectoral criterion. Lastly, the network results and indicator analysis are explained for China's social metabolism maintained by a large quantity of energy, resources, and labor, as well as the environmental costs, within an exergy foundation.

Contents

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1. Introduction

Humans extensively consume ecological resources for the sake of supporting social and economic development. However, the over-exploitation and low-efficiency of energy and resource use has led the world to face shortages of the vital natural capital. In addition, the wastes generated from this social and economic production and emitted into the surrounding environments cause ecological pressure on both the regional and global systems. Therefore, it is necessary that we have adequate tools to evaluate the extent of the natural resource shortages, as well as to estimate the ecological impacts for both the scientific and broader communities.

In traditional environmental resource analysis, it is common to value the combination of socio-economic, material, and ecological influence in terms of economic currency and quantity of material flows for the understanding of government and broader communities. However, these monetary valuations lack scientific definition based on energetic or physical explanation. To identify the status, stage, and trend of ecosystem growth and development, a new method, which can value the physical quantity and quality of all socio-ecological processes, is urgently needed in the current evaluation framework.

In contrast to these monetary based approaches, some researchers, particularly those working in the field of ecological economics, have proposed methods to consider all processes and activities in terms of their energetics. In this manner, one can apply first principles such as the laws of thermodynamics, mass balance, and stoichiometry, to socio-ecological problems. Specifically, the concept of exergy, or useful work, provides a unified indicator of different forms of material and energy flows on the basis of evaluating the distance from the studied system to thermodynamic equilibrium [1,2].

Historically, the exergy analysis method was first applied in thermodynamic engineering process evaluation and thermo-chemical system analysis. It can evaluate work based on the Second Law of Thermodynamics instead of general energy flow metrics; therefore, it became a widely accepted method in thermal processing analysis [3,4]. Subsequently, exergy analysis was developed in combination with systems ecology, as a measure of ecological complexity regarding how far the observed ecosystem is from a reference environment [5] and applied to reveal the ecosystem resource availability, buffering capacity, and environmental impacts [6–8]. Therefore, exergy analysis provides a quantifiable method with physical meaning for assessing environmental and ecological degradation.

For the reason that exergy can be used as a consistent measure of material, energy, and information, Wall [1,2] creatively introduced exergy into accounting work of social resource consumption. In recent years, there has been an increasing interest in applying exergy analysis modeling techniques for energy-utilization assessments in order to attain energy saving strategies [4]. Within different national and sectoral levels, there are many established cases applying exergy evaluation: (1) For national levels, Japan [9], Sweden [2], Norway [10], America [11], Saudi Arabia [12,13], China [14], UK [15,16], Italy [17], etc. These studies have quantified the exergy embodied available energy flow structure and efficiency for natural resources to assist the country's energy policy and resource management makers. (2) In the social sectoral level, Dincer and his group have published a series of papers in transportation, industry, domestic, public and private sectors [12,13,18,19] to illustrate the efficiency and performance of an exergy analysis of available energy, to evaluate the "resource content" of social-economical input as well as environmental discharges [18,20], and to show several key perspectives of quality, energy conservation, ecological input, economy, environment and sustainable development of subsystem perspectives. Their exergy analysis research results can exhibit the potential usefulness of exergy in addressing and solving environmental problems and moving toward sustainable development, since exergy can characterize the largest amount of energy that can be extracted from material energy. Therefore, unlike energy flow which is only about the quantity, exergy is a measure of quantity and quality of the energy resources.

On the basis of cumulative research on exergy connotations and applications, it is widely acceptable that the exergy-based assessment can be correctly regarded as a physical and thermodynamical based metric in evaluating the scarcity and utility of ecological resources [20–24]. What we want to accomplish in this study is to construct an accounting diagram among social-economic sectors with a network view, to further apply exergy theory in revealing its available energy capacity and metabolic interrelationship within a sub social-economic system level. However, in view of the varied social and economic impacts from energy and resource use within the whole social system, we need a more extensive and inclusive metric to account for the intrinsic (money and primary resources) expenses and social (money and services) "payback" in different social levels. Meanwhile, for the human dominated society, systematic accounting of social exergy flux, is a comprehensive, synthetical, and unified metric for ecological and social factors, which can reveal the natural wealth in the process of socio-economic diagnoses and decision making. It does, therefore, provide biophysical-based scientists and economists a measure to minimize leading to sustainable development and social-economic-ecological harmony.

Therefore, in recent years, nonmaterial energy resource elements, labor production factors, and economic parameters have been incorporated into the horizon of exergy research. This approach is called Extended Exergy Accounting (EEA) [21]. EEA is an "embodied" measure for the total primary exergy resource equivalent consumption [22,25]. It is an extension of traditional exergy analysis by including socio-economic factors such as labor and capital costs in physical terms of the equivalent primary resource consumption. EEA had been revised and published in a series of theoretical research and applications issues [21,22,24,26]. The intrinsic measurement of extended exergy (EE) is the amount of primary exergy homogeneously expressed in Joules that being cumulatively used over the production, operation, and disposal process. EEA includes four basic parts: (1) the standard material and energy primary resource exergy (quantified by their respective cumulative exergy content), (2, 3) labor and capital (two social, economic factors), and (4) environmental remediation costs. The latter three parts represent the primary resource cost equivalent of the so-called "externalities". The advantage of EEA is that it is much easier and more meaningful to compare within one unified and rational criterion different commodities and different production processes [27]. As an extension of traditional exergy analysis, EEA is widely accepted as a comprehensive method based on the concept of a physical cost based not only on a monetary proxy, but also on the equivalent