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Renewability assessment of a production system: Based on embodied energy as emergy

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ABSTRACT

Based on a comprehensive review of previous renewability assessment studies, the present work contributes a framework to assess the renewability of a production system based on the systems ecological concept of embodied energy as emergy (embodied solar energy). An input–output analysis based transformity database is adopted to concretely trace the renewable and nonrenewable resources embodied in the supply chain for all product materials. A renewability index as the percentage of total renewable resources over the total resources used for the production process is devised to assess the renewability of a production system. The renewability assessment of a typical wastewater treatment system in Beijing is performed as a case study to illustrate the framework in context of water–energy nexus. The renewability index of the case system is evaluated around 13%, and fossil energy is revealed as a key source for total resources use. The presented framework is shown to have broad application prospects and can be very useful in sustainability studies.

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1. Introduction

1.1. A review of renewability assessment studies

Renewability has been a key topic in context of sustainable development. As renewable resources are usually related to those continually replenishing energy sources such as the solar energy, wind power, and biofuel, the renewability assessment of renewable energy systems have been intensively carried out [1–10]. Almost all these studies were based on embodied energy analysis: the historical energy use of a renewable energy system has been traced and accounted by net energy analysis or thermodynamic methods, such as emergy analysis and exergy analysis, and the renewability has been assessed by either the input/output ratio of a specific renewable energy source (energy return on investment), or the proportion of renewable energy use to total energy use (renewability index).

The net energy analysis was originally proposed to assess the energy exploitation efficiency of a conventional energy supply system in face of the worldwide energy crisis in 1970s [11]. The main indicators of net energy analysis are NE (net energy) and EROI (energy return on investment), which are denoted as the energy gained and the ratio of the energy extracted or delivered to the energy consumed directly and indirectly in its supply chain, respectively [12,13]. To assess the renewability (non-renewability indeed) of renewable energy with reference to the EROI, Chen et al. developed an indicator of NEIED (nonrenewable energy investment in energy delivered). It was defined as the ratio of nonrenewable energy used directly and indirectly through the production process to the net delivered energy of the concerned renewable energy system [9,10].

The net energy analysis is regarded as a decent way to reveal the efficiency of an energy system, but its application in renewability assessment has its limitation. In early studies dealing with conventional energy system, it only concerned the fossil energy. The subsequent renewability assessment studies made some progresses by additionally concerning the specific renewable energy source the system obtained. However, many other kinds of resources have been ignored and even the specific renewable energy source was not completely traced as its historic consumption embodied in the production of the material inputs of the system was not reflected. For example, in the estimation of nonrenewable energy cost of a 1.5 MW solar power tower plant in China [10], for the solar power as the delivered energy only the fossil energy cost of the material inputs has been accounted, with the previous solar energy cost for the geophysical formation of the fossil fuel not mentioned.

On a broader scale the resources as essential and fundamental material base to sustain the human society can also refer to some other categories of resources besides the aforementioned common energy sources. For example, water and soil. Regarding this, a lot of existing renewability assessment studies have applied the method of thermodynamic analysis to trace and measure the historical energy use, i.e., embodied energy of a production system. As solar energy is conventionally believed to be the primary driving force of the ecosphere, solar emergy analysis (often referred to as emergy analysis) was then proposed by famous systems ecologist H.T. Odum to evaluate the solar energy previously required to be used up directly and indirectly to make the product or service [14,15]. By generally translating each environmental and economic input, including energy, materials, labor and currency, into solar energy equivalents by way of a conversion factor (transformity), this approach is able to illustrate the total previous resources use of each product. It therefore has been widely utilized to account the resources uses of a production system.

A set of indicators have been contributed by emergy analysis to illustrate the efficacy, sustainability, environment cost and benefit as well as the interaction between nature and human society of the production systems, among which the Renewable Index (RI) is devised to reveal the proportion of total renewable resources [16–18]. The similar indicator has also been applied in a lot of exergy-based studies to carry out renewability assessment [1,2,6,8]. However, most of these studies defined only the environmental renewable resources as renewable resources and missed the renewable resources consumption triggered by the economic products inputs.

Some scholars realized this problem and developed some improved indicators to include the renewable resources embedded in social products into the renewability assessment [5,16]. However, they only subjectively picked off limited renewable items from purchased inputs. For example, the substrate and vegetation were categorized as renewable resources in [16] while the other purchased inputs were regarded as nonrenewable resources. Actually, apart from a few essentially natural resources, each material, especial social product or service has consumed both renewable and nonrenewable resources through its supply chain, which cannot simply be classified as total renewable or nonrenewable source. The failure in completely tracing and clearly distinguishing between renewable and nonrenewable resources would hinder us from achieving a sustainability assessment. In order to assess the overall renewability of a production system, the renewable and nonrenewable resources use as well as their components of each social product input should be identified and concerned.

Therefore this work aims at providing a framework to assess the renewability of a production system. The renewable and nonrenewable resources accompanied with all the inputs, especially with the economic product inputs, of the concerned system will be traced and accounted by the integration of concrete emergy analysis and powerful input–output analysis. On one hand, the framework would clarify the misunderstandings in previous renewability assessment studies by identifying both renewable and nonrenewable resources components of each input, and the related renewability assessment results would become more accurate. On the other hand, an improved indicator for renewability assessment is devised as the ratio of renewable resources use to total resources use, which is regarded as having broad application prospects and can be applied to any production system. By doing so, the connotation of renewability would be extended, and the enriched and enlarged results of renewability assessment could be very useful in sustainability studies.