Sustainability accounting of a household biogas project based on emergy

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HIGHLIGHTS

• An emergy-based sustainability accounting framework is established.
• A set of sustainability accounting statements and indicators are constructed.
• Environmental support is incorporated into the accounting framework.

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ABSTRACT

Biogas has been earmarked as an efficient way to promote economic development and mitigate environmental emissions, and it requires a better accounting framework to evaluate its performance. In this study, we aim to develop an emergy-based accounting framework to assess and report the sustainability performance of biogas projects. First, the existing financial accounting and environmental accounting methodologies are combined to measure and report the economic events and environmental characteristics of a biogas project. Then, using the new metric of Emdollar value, the cost and revenue flows within the system boundary are unified and quantified by multiplying specific emergy transformity to reflect their embodiment and hierarchical characteristics. An integrated accounting framework covering economic aspects (economic profitability, economic efficiency, operation risk), environmental aspects (environmental resource utilization, load, emissions) and environmental-economic composited characteristics (emissions reduction efficiency, Emdollar intensity of emission reduction, emission intensity of profit) is set up accordingly. Results show that the biogas project has a positive net present value of $1.64E+04 Emdollars. The total cost can be returned after 5 years. The renewability ratio, environmental load ratio (ELR), and composite sustainability indicator (CSI) reflecting environmental load are 9%, 10.1, and 0.76, respectively. The proposed sustainability accounting framework may unveil the real environmental support and assess the ecological economic performance of a biogas project.

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1. Introduction

Biogas is an environmentally advantageous energy source generated from anaerobic digestion of waste materials through treating various organic wastes, such as industrial waste, sewage sludge and animal manure as well as agricultural residues. It has been widely used in the development of the energy supply mix and eco-agriculture in rural areas [1–4].

Biogas has been used for 100 years in China [5,6]. In the 1880s, the first attempt at biogas fermentation was undertaken in Guangdong. In 1920, rectangular hydraulic digesters were invented in Taiwan [7]. So far, household biogas digester and medium and large-scale biogas plants have been developed as two primary sources of biogas production in China; the former is suitable for undeveloped areas where the residents live far from each other, whereas the latter is suitable for developed regions where people live close together [8]. Fig. 1 shows the development of household biogas and medium and large-scale biogas plants in China from 2000 to 2014. The rapid development of household biogas projects is closely tied to the availability of enriched fermentation materials and the strong support of laws and government funds. There are a large number of fermentation materials in China, such as crop straw, forest residue, livestock and poultry manure and various organic wastes and wastewaters of industries [8,9]. According to the plan for livestock industry development, the amount of livestock and poultry manure will reach 4 billion tons in 2020 [10]. In terms of current crop production, nearly 681 million tons of agricultural residues are produced annually in China, of which 546 million tons can be gained for fermentation [11].
Moreover, the Chinese government has tilted the policy toward household biogas projects by providing financial loans for their construction and issuing a series of laws and policies, such as “Rural Household Biogas State Debt Project”, “Renewable Energy Law” and “Medium and Long-Term Development Plan for Renewable Energy in China” [11]. For example, with the strong incentive of financial support and policy promotion, household biogas projects such as the “Three-in-One”, “Four-in-One” and “Five-in-One” modes have been developing at accelerating speed [12–15].

Regarding the large-scale promotion of biogas projects, economic feasibility analysis is essential to evaluate potential financial costs and revenues in advance. There are many studies on the financial accounting of biogas projects [16–26]. Pipatmanomai [18] assessed the financial performance of electricity generation from biogas in small pig farms of Thailand prior to biogas utilization, with a range of scenarios of subsidy on digester construction and fixed electricity price being considered to investigate the effects on payback period and evaluate the operation risk in various situations. Gwavuya [19] conducted financial accounting on a household biogas project in Ethiopia, showing that positive net present values were obtained when residents collected energy sources by themselves. Walekhuwa [25] used cost–benefit analysis to account for the economic viability of three biogas plants in Uganda, indicating that the plants were economically viable with positive net present values of 4500 USD, 7000 USD and 9500 USD. Mudasser [26] used “Model for Electric Renewables” to investigate the sustainable performance and influence of selected energy policy schemes on wind-biogas hybrid energy production in Canada and improve their economic profitability. However, the environmental contributions to the biogas project are often ignored in favor of common issues like monetary dependence, capital orientation and business focus [27,28]. Moreover, monetary value as the core of traditional financial accounting may allow deviation, which may not reflect the actual value of items or reveal the essence and principles of nature because of its anthropogenic manipulation [29–31]. To identify the trade-off between economic revenue and environmental cost, it is necessary to establish an integrated accounting framework covering both economic and environmental characteristics for biogas projects.

Sustainability accounting, referred to as “accounting for sustainability”, is an updated form of traditional financial accounting with consideration of both economic and environmental issues at multiple levels, accounting and reporting the comprehensive performance of entities from two dimensions of time and space [32], through which specific activities and corresponding effects on cost and revenue flows can be reflected to identify key factors for improving the economic profitability and environmental sustainability. It has been widely used in environmental engineering, especially at macro levels [33,34]. However, the studies at micro level are still quite few [33,35,36], and most focus on economic profitability and operation risk without consideration of biophysical foundation.

Energy, first introduced by Odum in the biophysical context, is defined as the total amount of available energy of one type that is required to form a product or service both in direct and indirect ways [37–40]. It differs little from the general concept of “energy” except that it represents the total historical energy embodied in any substance. With its consideration of economic activities for further processing such as resource extraction, manufacturing, delivery and natural properties donated from the supporting ecosystems and the biosphere as a whole, energy represents a shift from the anthropocentric environmental management paradigm to an ecocentric paradigm, which tallies with the intrinsic characteristic of sustainable development [41–44]. Thus, energy could be used as the proper metric for sustainability accounting to seek the balance between the socioeconomic and natural environments of biogas projects and fit projects into the multidimensional hierarchy of the universe [44].

In this paper, we aim to establish the sustainability accounting framework based on emergy to capture both economic and biosphere characteristics of a typical household biogas project. Based on the new metric of Emdollar value, the embodiment and hierarchical characteristics of cost and revenue flows could be reflected. Moreover, the financial situation, environmental issues as well as sustainability of biogas project can be evaluated based on different sustainability accounting statements and series of indicators, through which the potential pathways for the sustainable development of biogas projects could be identified. The remainder of this paper is organized as follows. Section 2 describes the study site and the biogas project operating mechanism, emergy analysis, sustainability accounting framework and data sources. According to the sustainability accounting framework, costs and revenues are recognized and measured using emergy metrics, and sustainable reporting statements are also prepared in Section 3. Section 4
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