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Life-cycle energy production and emissions mitigation by comprehensive biogas–digestate utilization

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ABSTRACT

In the context of global energy shortages and climate change, developing biogas plants with links to agricultural system has become an important strategy for cleaner rural energy and renewable agriculture. In this study, a life-cycle energy and environmental assessment was performed for a biogas–digestate utilization system in China. The results suggest that biogas utilization (heating, illumination, and fuel) and comprehensive digestate reuse are of equal importance in the total energy production of the system, and they also play an important role in systemic greenhouse gas mitigation. Improvement can be achieved in both energy production and emissions mitigation when the ratio of the current three biogas utilization pathways is adjusted. Regarding digestate reuse, a tradeoff between energy and environmental performance can be obtained by focusing on the substitution for top-dressing, base fertilizers, and the application to seed soaking.

1. Introduction

Anaerobic digestion and biogas production are promising ways to achieve energy and environmental benefits at both the local and global level (Börjesson and Berglund, 2006, 2007). Biogas plants can provide an alternative energy source for rural households and mitigate environmental emissions from agricultural activities (Chen and Chen, 2012; Prochnow et al., 2009). Biogas is different from traditional forms of rural energy in two main ways: first, it replaces fossil fuels with clean methane, which reduces not only the release of greenhouse gases, but also other detrimental emissions; second, the multiple utilization of digestates (i.e., substitution for such materials as fertilizers, pesticides, and feed additives) facilitates more efficient use of organic waste or plant nutrients in daily agricultural practice (Collet et al., 2011; Rehl and Müller, 2011). Such procedures are of particular importance in coping with the increasing pressure of problems related to global energy scarcity and climate change.

To date, biogas projects have been implemented in many rural areas around the world, particularly in China, whose household biogas system has become a key program in the country's renewable-energy construction efforts (Liu et al., 2008b). Household biogas construction and energy production have undergone a boost in rural China during the last three decades. As of 2009, about 35 million anaerobic digesters were put into use in China, which produced 2.73×10^{10} MJ of energy (Chen et al., 2010).

Following years of practice, various comprehensive biogas-utilization modes have been established in different parts of the country, commonly linking biogas production with the agricultural industry (Chen et al., 2010; Wei et al., 2009). Among these modes, the so-called Six in One biogas system (SIOBS; the system comprises six components—pig breeding, anaerobic digester, cropping, fruit cultivation, vegetable growing, and agricultural processing) has recently become a widespread means of biogas–digestate utilization in South China thanks to its efficient, economical use of fermentation by-products. The technical overview of a typical SIOBS is provided in Fig. 1. The core of SIOBS is an 8-m^3 fermenting reactor, surrounded by a set of supporting devices for raw-material treatment, methane utilization, and digestate recycling. The SIOBS has significant advantages over conventional agricultural practices and waste-handling procedures: it provides clean, cheap methane fuel for heating, illumination, or machinery; via the fermentation of household and agricultural waste, it is also effective in processing both liquid and solid digestates into substitutes for such materials as base fertilizer, top-dressings, and feed additives, which would otherwise demand high-emission chemicals.

Life-cycle assessment (LCA) enables the evaluation of energy and environmental performance of a product or system at all stages. A handful of studies have evaluated household and industrial biogas projects in terms of their environmental benefits. The focus of these evaluations has included methane production from different types of feedstock (e.g., Al-Masri, 2001; El-Mashad and

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