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Resource availability for household biogas production in rural China

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ABSTRACT

The objective of this study was to assess biogas production capacity in different regions of China based on climate conditions and substrate availability. The results of our analysis indicated large differences in below-ground temperature and solar energy resources among different regions of China. According to data collected in 2006, slightly more than 1200 million tons of crop residue and manure could be used as substrates for biogas production. We suggest that household biogas technology must be developed according to local conditions.

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1. Introduction

Biogas consists of about 2/3 methane (CH_4), 1/3 carbon dioxide (CO_2), a little hydrogen sulfide (H_2S) and a little hydrogen (H_2), which is produced through the biodegradation of organic materials under anaerobic conditions. Biogas producing materials (substrates) range from animal manure to household, agricultural and industrial wastes [1]. The construction of biogas digesters in rural areas is a key program for the development of renewable energy sources in China [2]. Household biogas construction has developed rapidly in China's rural areas since the 1990s. For example, there were 4.9 million rural households using biogas in 1996. By 2003, the number had increased to 12.3 million households, an annual increase of 14.1%. Annual biogas output increased from 1.59 trillion m^3 in 1996 to 4.61 trillion m^3 in 2003. These amounts were equivalent to 3.8×10^7 J and 9.7×10^7 J. By 2003, annual average biogas output had reached 400 m^3 per household and biogas consumption had risen from 0.33% to 0.72% of total rural energy consumption [3]. This increase in biogas production has not only helped to meet energy demands but also contributed to environmental and economic development in rural areas. In line with its goal of sustainable environmental development, the Chinese government had planned to increase the total number of biogas plants to 50 million by 2010. This required an average

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Table 1
Average ground temperatures at a depth of 1.6 m in different areas of China [6].

Region	Months $>10\ ^{\circ}C$	Months $>20\ ^{\circ}C$	Areas
I	12	7–12	Taiwan; Fujian; Guangdong; Southern Guangxi; lower reaches of the Yuanjiang River and Xishuanbanna in Yunnan Province; Northern Fujian; Guangdong and Guangxi; Jiangxi; Southern Hunan; Guizhou; some areas in Southern Yunnan Province
II	12	4–6	Zhejiang; Anhui; Hubei; Jiangsu; Northern Jiangxi and Hubei; Southern Henan Province; some areas in southern Shaanxi Province; East central Sichuan Province; some regions in Yunnan and Guizhou Province
III	7–12	1–3	Tianjin; Beijing; Hebei; most of Shandong; North central Henan; South central Shaanxi; some areas in southern Shanxi Province; Tarim basin Xinjiang
IV	6	0	South central Liaoning; Northern Hebei; South central Shanxi; North central Shaanxi; most of Ningxia; Eastern Gansu; Eastern area of the Gansu Corridor and Yunan

increase of 6 million new biogas plants per year [4]. To successfully develop household biogas production, it is crucial that the temperature regime be suitable and that fermentation be fully achieved [5]. With both of these factors in mind, the potential capacity for biogas production in rural China is evaluated here.

2. Analysis of household biogas resources

The factors that influence the development of household biogas in rural China include (1) climate resources (i.e. the average ground temperature at a depth of 1.6 m, solar energy resources) and (2) biomass resources (i.e. crop residue and manure resources). Climate resources are the main factor for evaluating the fermentation temperature of biogas production. Biomass quantity is the factor which determines whether there is adequate raw material for biogas fermentation.

2.1. Climate resources

2.1.1. Ground temperature

In rural China, most biogas plants are built underground at a depth of about 2 m. Ground temperature is the most important factor affecting the amount and rate of biogas production. The temperature in a 2 m deep biogas plant is appoximately the same as the average ground temperature at a depth of 1.6 m [6]. Generally, the temperature is between 8 °C and 25 °C. The minimum temperature for biogas production is 10 °C; however, biogas production is most rapid when temperatures are above 20 °C [7].

Average ground temperatures at a depth of 1.6 m are shown for different regions of China in Table 1 [6]. The data indicate that ground temperatures are most suitable in regions I and II. In these regions, digesters can produce biogas year round. Biogas production is especially rapid and efficient during the 4–12 months when the ground temperature is above 20 °C. In region III, biogas production is possible for more than half the year; however efficient and rapid biogas production is limited to a timespan of 1–3 months. Cool ground temperatures in region IV severely limit biogas production. Ground temperatures at the depth of 1.6 m are $>10\ ^{\circ}C$ for only 6 months each year. Furthermore, ground temperatures never exceed 20 °C. Therefore, it is inappropriate to develop biogas in region IV.

2.1.2. Solar energy resources

In China, solar-heated livestock buildings or greenhouses are often used in combination with biogas digesters. The solar heat increases the temperature within the digester. Therefore, it is important to consider solar radiation and total sunshine hours for each region [8]. Solar radiation is the total frequency spectrum of electromagnetic radiation produced by the sun.

The distribution of China's solar energy resources is shown in Table 2. Solar radiation is abundant in regions I and II. In these areas, annual total solar radiation is $>5400\ MJ\ m^{-2}\ yr^{-1}$ and the annual number of sunshine hours is 2800–3300 h. In region III, annual total solar radiation ranges from 4200 to 5400 $MJ\ m^{-2}\ yr^{-1}$ and the annual number of sunshine hours ranges from 2200 to 3000 h. In region IV, the annual total solar radiation is below 4200 $MJ\ m^{-2}\ yr^{-1}$ and the annual number sunshine hours ranges from 1400 to 2200 h, making these areas poor in solar energy.

2.2. Biomass resources

This analysis contains the estimation of biomass quantities potentially available in two categories: crop residue and manure resources.

2.2.1. Agricultural residues

Crop residue amounts depend on the output of farm crops. After harvest, a portion of the crop residue can be collected for biogas production. Rice, wheat, corn, beans, potatoes, cotton and oil-seed crops are the main crops in China. Analysis in this paper is limited to rice straw, wheat straw, corn cobs, corn stalks, soybean stalks, sweet potato stalks, cotton stalks, and oil-seed crop stalks. Crop residue amounts were estimated from crop yield and residue factors (the residue factor is sometimes referred to as shoot to grain ratio) [10].

Yields for the major crops in China in 2006 are shown in Table 3.

Data in Table 4 indicate that a total of 725.09 million tons of crop residue was produced during 2006. Corn residue accounted for 40% of the total crop residue (Tables 3 and 4). Areas with the largest amount of corn residue were the North China Plain (Hebei Province and the Inner Mongolia Autonomous Region), northeastern China (Lioning, Jilin, and Heilongjiang Provinces), eastern China (parts of Shandong Province), and south central China (parts of Henan Province). The second largest amount of crop residue was rice straw, which accounted for 25% of the total crop residue produced in China during 2006. Areas with large amounts of rice straw included south central China (Hunan, Hubei, Guangdong and Guangxi Provinces), eastern China (Jiangsu, Jiangxi, Zhejiang and Anhui Provinces) and southwest China (Sichuan). Wheat residue accounted for 14% of the total crop residue. Areas with large amounts of wheat straw included eastern China (Shandong, Jiangsu and Anhui Provinces), south central China (Henan Province) and northern China (Hebei Province). Oil seed crops accounted for 8% of total crop residue production while tubers accounted for 7%, beans accounted for 4%, and cotton accounted for 3%.

2.2.2. Manure resources

Animal manure is an important input in biogas production. Most animal manure in China comes from (1) swine, (2) cattle and buffaloes, and (3) sheep and goats. Potential manure amounts