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An assessment of the availability of household biogas resources in rural China

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Abstract
Three resources, climate, biomass and social economic, all of which are essential to the production of household biogas in rural China, are evaluated for six areas whose boundaries are based on the average ground temperature at a depth of 1.6 m. This paper brings forward the index system for evaluating the household biogas resource potential, calculates the weighing of each index with Analytic Hierarchy Process (AHP) method. The evaluation results indicate that Area IV has the optimum region to develop household biogas in rural China; both Areas III and V are suitable; Area I is less-than-suitable; both Areas II and VI are unsuitable. A key recommendation is that investment patterns be modeled on the local availability of these resources.

Keywords: Household biogas, China, Resources, Evaluation.

1. Introduction

Biogas is a mixture of CO_2 and the inflammable gas CH_4, which is produced through the biodegradation of organic materials under anaerobic conditions. Biogas producing materials (substrates) range from animal manures 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 m3 in 1996 to 4.61 trillion m3 in 2003. These amounts were equivalent to 1.3 million and 3.3 million tons of standard coal. By 2003, annual average biogas output had reached 400 m3 per household and biogas consumption had risen from 0.33% to 0.72% of total rural energy consumption [3]. The 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 plans to increase the total number of biogas plants to 50 million by 2010. This will require an average 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, that fermentation be fully achieved, and that both the use and management capability of the biogas users be enhanced [5]. With these factors in mind, the potential capacity for biogas production in rural China was here evaluated.

2. Methods

2.1 Calculation of evaluation index weight

We calculated the weighing of each index with Analytic Hierarchy Process (AHP) method. AHP arrays the factors into several levels in decreasing order in terms of their subordinate relationship, establishes the relationship of the factors of different levels, compares the importance of the factors at the same level and then decides the order (see [7,8] for details).

2.2 Evaluation formula

The formula used to make the actual value of the indices dimensionless:

$$di = x_i / x_{max} \tag{1}$$

(di represents the evaluation value of the index, xi represents the actual value, and xmax represents the maximum value)

Evaluation formula:

$$T = \sum_{i=1}^{7} W_i di \tag{2}$$

(T represents the evaluation result value, di represents the evaluation value of index, Wi represents the index weight)

2.3 Data

Official statistical data was used for this study.

3. Results and analysis

3.1 Climatic resources

3.1.1 Ground temperature

In rural China, the majority of biogas plants are constructed underground at a depth of 2 m. The most influential factor affecting both the quantity and duration of biogas production is ground temperature. The temperature in a 2 m deep biogas plant is approximately the same as the average ground temperature at a depth of 1.6 m [6]. The fermentation temperature of household biogas generally ranges between 8°C and 25°C. The minimum temperature for biogas production is 10°C, and biogas production is rapid when temperatures are above 20ºC [9].

The distribution of the average ground temperature at a depth of 1.6 m is shown in Table 1 [6]. Six areas are defined based on the average ground temperature at a depth of 1.6 m (Fig. 1).

Table 1 shows that optimum temperature conditions are available in Area IV, where the biogas digester can produce biogas throughout the year, and time available for the digester to produce biogas efficiently and rapidly is 8 months. Suitable temperature conditions are available in Areas III and V, where the biogas digester can also produce biogas all year, but the time available for the digester to produce biogas efficiently and effectively are 5 and 4 months, respectively. In Area I, the average ground temperature at 1.6 m depth is above 10°C for 9 months of the year, and equal to or above 20°C for 3 months. In Areas II and VI, the time available for biogas production is short. At no time is the average ground temperature at the depth of 1.6 m above 20°C. Thus, the biogas is produced slowly and inefficiently in Areas II and VI..

Table 1. Distribution of average ground temperature at 1.6 m depth in China [6]

Regions	Months ≥ 10°C	Months ≥ 15°C	Months ≥ 20°C	Months ≥ 25°C
I	9	6	3	0
II	4	1	0	0
III	12	8	4	0
IV	12	10	8	4
V	12	9	5	0
VI	7	3	0	0

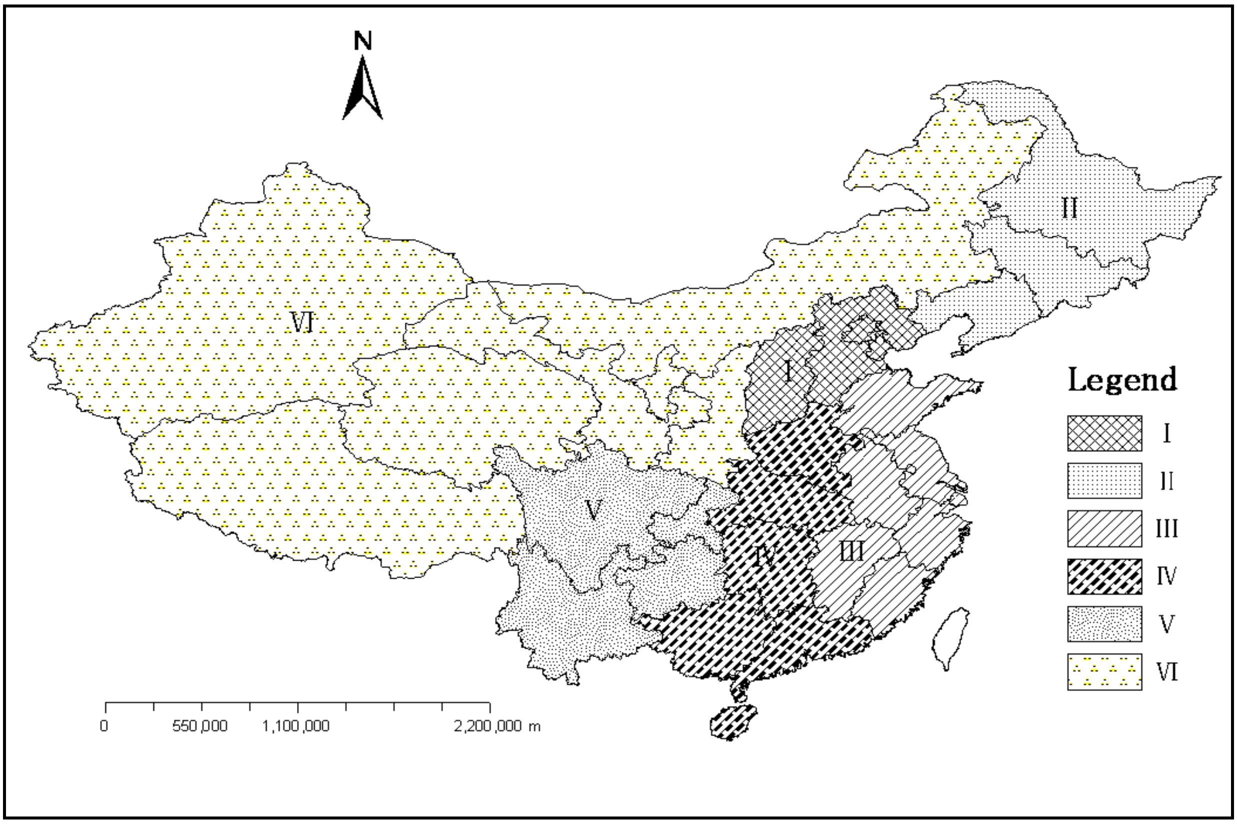

Figure 1. Six areas in China

3.1.2 Solar energy resources

Chinese biogas experts combine solar-powered barns, greenhouses, and biogas fermentation to passively increase the temperature of the biogas digester, thus the geographic distribution of solar resources, including the solar radiation energy and the sunshine duration, needs to be considered [10]. Table 2 presents the distribution of solar energy in China [11]. Area VI is the most abundant in solar energy. In this area, the annual total solar radiation is above 5,750 MJ (m-2. a-1) and the annual sunshine hours range from 2,400-3,300 h. In Areas I and II, the annual total solar radiation ranges from 5,000-5,750 MJ (m-2. a-1) and the annual sunshine hours range from 2,000-2,400 hours per year. In Areas III and IV, the annual solar radiation ranges from 4,200-5,000 MJ (m-2.a-1) and the annual sunshine hours range from 1,300 to 2,000 h; in Area V, the annual solar radiation ranges from 3,350-4,200 MJ (m-2.a-1) and the annual sunshine hours range from 1,000- 1,300 h, making these areas poor in solar energy.

Table 2. Distribution of solar energy in China [11]

Regions	Annual sunshine hours	Annual total solar radiation MJ (m-2.a-1)
I	2,200-2,400	5,350-5,750
II	2,000-2,200	5,000-5,350
III	1,400-2,000	4,200-5,000
IV	1,300-1,800	4,200-5,000
V	1,000-1,300	3,350-4,200
VI	2,400-3,300	≥5,750

3.2 Biomass resources

The quantity of potentially available biomass derives from two sources: manure resources and agricultural residues. Agricultural residues have a higher C:N ratio, whereas pre-silage and fermentation of manures are necessary to regulate the C:N ratio to obtain a higher gas yield. Usually, the weight of agricultural residues is required to be below ⅓ of the raw materials for biogas generation [12], so, manures are the main resource for biogas fermentation.

3.2.1 Manure resources

Most animal manures in China are from pigs, cattle and buffalos, sheep and goats. The potential quantity of manures is estimated using the number of animals and the annual dry excrement production of one animal [13]. Manure resources in China in 2006 are included in Table 4 [14]. Data in Table 4 indicates that Area VI is the most abundant in manure resources, with the per capita dry excrement at 9.3 thousand ton. In Area III, the per capita dry excrement is 3.2 thousand ton, making this area poor in manure resources.

Table 3. Annual dry excrement production per animal (Unit: ton/head) [13]

Livestock	Cattle/Buffalo	Pig	Sheep/Goat
Annual dry excrement production of one animal (ton/ head)	1.1	0.22	0.18

Table 4. Manure resources in China in 2006

Regions	Cattle and Buffalo (106 head) [14]	Pig (106 head) [14]	Sheep and Goats (106 head) [14]	Amount of dry excrement (106 ton)	Per capita dry excrement (104 ton/capita)
I	11.24	101.99	37.43	41.53	0.49
II	15.13	87.92	22.65	40.06	0.70
III	16.99	268.91	53.75	87.52	0.32
IV	36.76	395.07	57.16	137.64	0.48
V	29.09	260.48	33.40	95.32	0.59
VI	30.24	60.55	164.57	76.21	0.93
Total	139.45	1174.92	368.96	478.28	3.51

3.2.2 Agricultural residues

The quantity of agricultural residues depends on the output of farm crops. After harvest, a portion of the agricultural residue can be collected for biogas production. Rice, wheat, corn, cotton, beans, potatoes and oil-bearing crops currently dominate croplands, therefore, in this paper agricultural residues are limited to rice straw, wheat straw, corn cobs, corn stalk, cotton stalk, bean straw, potato stalks and the stalks of oil-bearing crops. The quantity of agricultural residues is estimated using the output of crops and their residue factors [15]. Agricultural residues in rural China in 2006 are included in Table 6 [14]. Area II is the most abundant in agricultural residues, with the per capita agricultural residue at 22.3 thousand ton. In Area V, the per capita agricultural residue is 5.4 thousand ton, making this area poor in agricultural residues.

Table 5. Crop residue factor [16]

Crop	Rice	Wheat	Corn	Cotton	Potatoes	Beans	Oil-bearing crop
Residue factor	1	1	2	3	1	1.5	2

Table 6. Agricultural residues in rural China in 2006

Regions	Rice [14] (10^6 ton)	Wheat [14] (10^6 ton)	Corn [14] (10^6 ton)	Cotton [14] (10^6 ton)	Beans [14] (10^6 ton)	Tubers [14] (10^6 ton)	Oil-bearing crop [14] (10^6 ton)	Agricultural residue 10^6 ton	Per capita agricultural residue (10^4 ton/capita)
I	0.67	14.84	20.77	0.86	0.99	1.77	1.73	66.32	0.78
II	21.26	1.025	43.46	0.01	8.38	1.69	1.59	126.68	2.23
III	62.79	37.14	23.06	1.93	3.88	6.53	9.96	184.11	0.67
IV	66.83	30.83	20.57	1.53	2.66	7.99	10.60	176.55	0.62
V	28.16	6.99	15.08	0.02	2.40	10.79	3.86	87.49	0.54
VI	2.88	13.64	22.54	2.41	2.74	5.28	2.85	83.92	1.03
Total	182.59	104.47	145.48	6.76	21.05	34.05	30.59	725.07	

3.3 Social economic resources

3.3.1 Farmers' annual mean income

The initial investment cost influences the decision of a family to adopt biogas technology to meet its domestic fuel requirements [1]. The average cost for constructing a 6.0 ~ 12 m3 family-sized biogas digester is 1,000 ~ 2,000 Yuan in rural China [17]. Therefore biogas plants can be acquired only by relatively rich farmers. Farmers' annual mean income in China in 2006 is shown in Table 7 [18].

Table 7. Farmers' annual mean income in China in 2006 [18] (Unit:Yuan)

Regions	I	II	III	IV	V	VI
Farmers' annual mean income	4825	3392	4905	3213	2382	2320

3.3.2 Educational levels

A close relationship exists between the development of household biogas and the educational level of farmers . Skills are needed for farmers for repair and maintenance of biogas plants. Inadequate skills from farmers have resulted in poor construction and ineffective performance of some biogas plants [19]. The educational level of rural labors in China in 2006 is shown in Table 8 [18]. The data shows that rural labors in Area I have a relatively higher level in education, with 81.47% receiving middle school and higher education. In contrast, in Area VI, where many minority peoples live, a lower quality of education

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predominates. Rural labors who have received middle school and higher education only account for 39.66%.

Table 8. The educational level of rural labourers in China in 2006 [18]

Regions	Illiterate %	Primary %	Middle school or higher %
I	2.21	16.35	81.47
II	2.36	26.73	70.91
III	6.52	25.21	68.28
IV	4.77	24.84	70.40
V	10.43	37.53	53.54
VI	24.22	35.82	39.66

3.4 Evaluating

The index system for evaluating household biogas resource potential is shown in Fig.2., with climatic factors (C1), biomass factors (C2) and social economic factors (C3) as the system layer; number of months that average ground temperature at 1.6 m below ground is above 10°C (D1), number of months that average ground temperature of 1.6 m is above 20°C (D2), annual sunshine hours (D3), per capita dry excrement (D4), per capita agricultural residue (D5), farmers' annual mean income (D6) and the educational level of rural labors (D7) as the index layer.

Climatic factors are the main factors in evaluating the potential for biogas production; supply of biomass addresses whether there is sufficient raw materials for biogas fermentation; farmers' annual mean income decides whether the construction cost of a biogas digester is affordable for local farmers; and the educational level of rural labors concerns an individual's ability to manage a biogas digester.

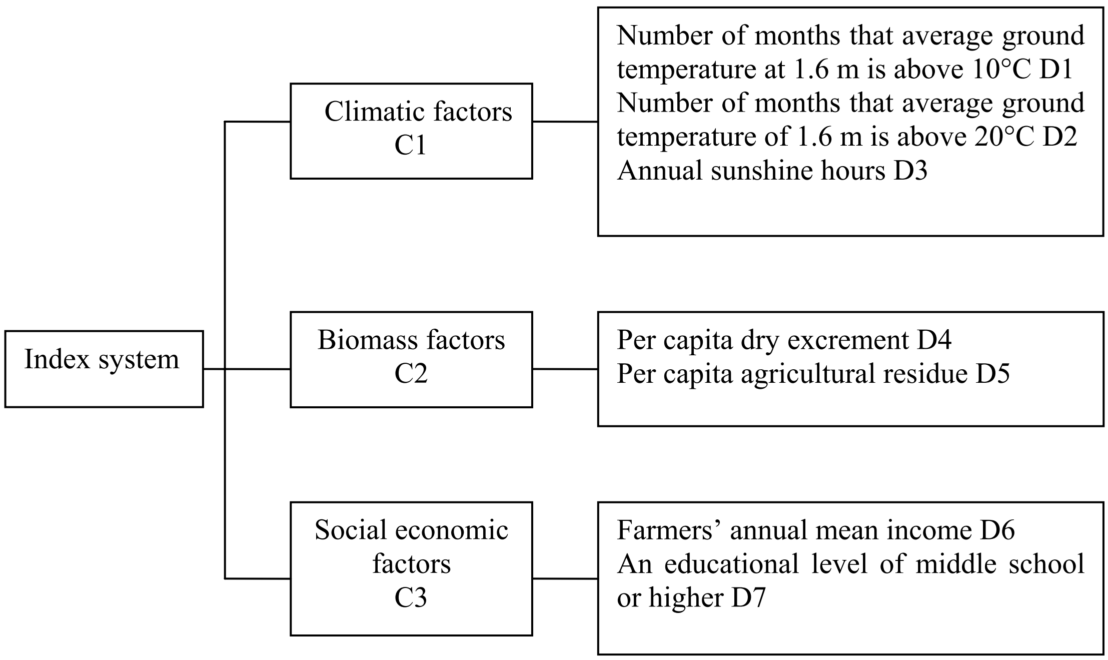

Figure 2. An index system to evaluate household biogas resource potential

The weight of the indices was calculated based on Analytic Hierarchy Process (AHP) method included in Table 9. We applied the index system, index weight and the evaluation formula proposed above to evaluate the household biogas resources of each of the six areas. The evaluation value of the indices was calculated with formula (1) and is shown in Table 10; the evaluation result value was calculated with formula (2) and is shown in Table 11. The evaluation results indicate TIV > TIII > TV> TI > TVI > TII. Area IV has the highest evaluation result value, indicating it is the optimum region to develop household biogas; Area II has the lowest evaluation result value, and hence is not suitable to develop household biogas.

Table 9. Index weight for resources of household biogas regional evaluation

The system layer		**C1**	**C2**	**C3**	**Relative weight of each index**
		0.6479	0.2229	0.1222	
index layer	D1	0.7601			0.4925
	D2	0.1307			0.0847
	D3	0.1092			0.0708
	D4		0.7500		0.1670
	D5		0.2500		0.0560
	D6			0.7500	0.0917
	D7			0.2500	0.0306

Table 10. Evaluation value of the indices

Areas	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**
I	0.75	0.38	0.95	0.52	0.35	0.98	1
II	0.33	0	0.86	0.76	1	0.69	0.87
III	1	0.5	0.72	0.34	0.3	1	0.84
IV	1	1	0.61	0.52	0.28	0.66	0.86
V	1	0.63	0.46	0.63	0.24	0.49	0.66
VI	0.58	0	1	1	0.46	0.47	0.49

Table 11. Evaluation result value

Areas	**I**	**II**	**III**	**IV**	**V**	**VI**
T	0.70	0.50	0.78	0.81	0.76	0.61

4. Conclusions and recommendations

The potential for household biogas production in rural China was regionally evaluated based on climatic, biomass and social economic resources. The evaluation results indicate that Area IV has optimum conditions for developing household biogas. Both Areas III and V have suitable conditions to develop household biogas, but less suitable than Area IV in terms of ground temperature. In Area III, raw materials required for biogas production are insufficient. Area I is less suitable than Area III in terms of ground temperature. . Areas II and VI are least suitable for developing household biogas. Farmers in Areas II and VI can combine solar greenhouses and biogas fermentation to increase the temperature of the biogas digester due to the presence of abundant solar energy in these two areas. But the construction of a solar greenhouse enlarges the capital input. Therefore, it should be considered whether its construction cost is affordable for local farmers there. Additional efforts must be made in Area VI to train farmers without much educational background to obtain skills for the use and management of biogas digesters.

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