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# Regional differentiation of rural household biogas development and related driving factors in China

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ABSTRACT

Lack of clean energy supply remains a challenge in China, particularly in rural areas with large population. Biogas production from anaerobic digestion of biomass is an efficient technology for energy strategy in China. This paper reviews the importance of household biogas in China and discusses the regional differentiation of rural household biogas (RHB), and related driving factors. Gray correlation analysis showed that regional differentiation of RHB exhibited the highest correlation degree with temperature (0.889), followed by raw materials, rural population, and levels of income and education. According to the total biogas production in China, the development regions of RHB was separated into Region 1, Region 2 and Region 3. The highest development level of RHB was found in Region 2 with a total biogas production of $1.2 \times 10^{10}$ $m^3$, accounting for 77.6% of the total TBP of China in 2012. Moreover, the RHB development levels in Region 1 and Region 3 were $1.84 \times 10^9$ and $1.69 \times 10^9$ $m^3$, respectively. Basing on the results of regional differentiation of RHB and characteristic of the primary influence factors in different regions, this study proposes that RHB development must be further promoted by combining actual situation of different regions to avoid blind development.



**Contents**



*Abbreviations:* AD, Anaerobic digestion; GCA, Gray correlation analysis; LPB, Livestock and poultry breeding; LPM, Livestock and poultry manure; MAT, Monthly average temperature; PDC, Pollutants and discharging coefficient; RPR, Residue to Product Ratio; RHB, Rural household biogas; SSB, State Statistical Bureau; TBP, Total biogas production

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## 1. Introduction

### 1.1. Significance of household biogas in rural China

China is agriculture-oriented populous country, with rural population of 63.2 million, accounting for 46.8% of total national population in 2012 [1]. Historically, rural areas, including county town, used firewood and coals for lighting, heating, and cooking for a long period of time. In recent decades, most rural areas use straw, grass, or cattle manure as alternatives because of the scarcity of forest resources and coal reserve [2,3]. Traditional energy consumption is the primary cause of indoor air pollution and contributes to global warming [4–6]. Thus, energy problem in rural areas is related to security of energy and environment in China [7]. In this regard, alternative energy sources, particularly biomass, must be identified to mitigate the pressure of limited resources and ensure domestic energy security [8].

Rural household biogas (RHB) has been drawn increased attention as one of the most prominent bioenergy technology for biomass utilization worldwide [4–6]. The most important economic and environmental benefit of RHB is production of biogas, a renewable green energy for heating, cooking and lighting [9-12]. This technology also generates solid and liquid by-products, which can be used as fertilizer for soil amendment [13,14]. Obviously, the benefits of biogas on economy, society and environment link to agricultural [15]. Therefore, biogas utilization is a promising strategy for reducing fossil energy consumption and greenhouse gas emission in rural China [16].

Over 40 million household scale reactors and 30,000 large-scale digesters were built in China in 2010 [11]. The total biogas production (TBP) of all provinces reached $1.58 \times 10^{10}$ $m^3$ in 2012, which can save $1.12 \times 10^{10}$ t of coal equivalent [17,18]. RHB is important for rural development in China because it functions as the connection chain among livestock breeding, agricultural production, and energy supply [19].

### 1.2. Household biogas development in China

Currently, biogas in China is mainly produced from medium and large-scale biogas projects (MLBPs) and household biogas digesters (HBDs) [20]. MLBPs concentrate large amounts of manure and municipal and industrial organic waste, whereas HBDs are more appropriate for recycling agriculture waste in rural China [11]. Commonly, RHB is the main product by animal feces and crop straw. The maximum size of a single-digester is generally 20 $m^3$ [19].

As a novel and renewable energy source, RHB technology plays an important role in promoting new rural construction and improving the environment and quality of life in rural areas [20–22]. This technology encourages farmers to collect locally available raw materials to ferment, which reduces their cost of living. Biogas slurry and residues can return to the field and improve the fertility of soil. Government subsidies for building biogas digesters relief the farmers' burden and promote RHB development [23].

Large-scale production of RHB began in 1950s in China. The development of RHB was stable until the 1980s and declined thereafter because of backward technology. The annual average growth rate of household biogas was 4.6% from 1983 to 2000 and the amount of RHB reached 8.48 million by the end of 2000 [11,24]. In 2003, the state promulgated the "Measures for the administration of rural biogas construction bond project (Trial)," which allowed the government to use national debt to subsidize rural biogas projects and promote household biogas construction in rural China [25]. Moreover, "renewable energy and long-term development plan" was promulgated in 2007 to focus on the development and utilization of biogas energy from biomass. According to Rural Energy Yearbook from 2001 to 2009, the total investments for biogas construction reached 19.61 billion Chinese Yuan; of which, 79.7% was allotted for rural household projects [1]. To improve the biogas service system, the government began to invest on biogas service network in 2007. The investment reached 700 million Chinese Yuan in 2009 [26]. The annual average growth rate of RHB reached 17.1% from 2009 to 2010 and its ratio to the total rural energy increased from 0.4% in 2000 to 1.9% in 2009. More than 40 million HBDs were built in rural areas in 2010 [18,26], and the national household biogas production reached $1.58 \times 10^{10}$ $m^3$ in 2012 [1].

### 1.3. Background

Biogas production and utilization require low capital investment and operating costs to improve environment quality and supply sustainable energy in rural areas [16]. Generally, the digester has a standard size of 6 $m^3$, 8 $m^3$ or 10 $m^3$ and a simple structure. Rural HBDs are categorized into four basic types: hydraulic pressure, floating cover, semi plastic and tank, which can adapt to different climate conditions and raw materials. Concrete, steel and wood are recently used in digester construction, furthermore, fiber glass monomer digesters are being developed and commercialized [27]. In addition, basic RHB patterns changed from "three-in-one" to "five-in-one" in China; such patterns (Fig. 1) include "solar greenhouse planting-biogas digester-breeding-processing-daily living" [28]. The wastes of planting are used to feed livestock and poultry, and with dung are used as raw material to produce biogas to provide energy for daily living; biogas slurry and residues are used as fodder and green fertilizers for breeding and planting by processing, which can provide meat and vegetables for household. This model is named to "Five-in-one" in many literatures [29–35]. Although these ecological models play a significant role in development of ecological agriculture, blindly promoting RHB development in every province is irrational because regional RHB differentiation is unbalanced and restricted by many factors.

Cioabla et al. and Li suggested that agro-climatic conditions, such as temperature, restrict the RHB development [14,36]. Yang et al. indicated that regional differences in the distribution of straw resources in China significantly influence RHB development [37]. Fan et al. reported that and biogas promotion is negatively correlation with the level of economic development, income, education [38]. Feng et al. emphasized that policy support is the key initial impetus for RHB development [25], whereas Sun et al. suggested that the influence of the current subsidy policy on RHB use is negligible [23]. Sidh and Basu showed that the foresightedness of women influenced the promotion of RHB [39]. In addition, rural commodity energy price and household consumption concept have a significant impact on RHB [40]. However, researchers have rarely investigated the regional differentiation of RHB. In the present study, the RHB potentials of 31 provinces (or municipalities) in 2012 were estimated. Moreover, the regional differentiation regularity of RHB and the influencing factors were analyzed by gray correlation analysis (GCA), SPSS19.0 and ArcGIS.

The purposes of this paper is to summarize the importance of RHB and discuss the correlation degree between influence factors and the regional differentiation of RHB, determine the primary influencing factors and analyzed its characteristic in different regions. Basing on the results, this study proposes that the RHB development must be combine actual situation of different regions to avoid blind development in further. It also provides a basis for rational planning for household biogas. In this paper, we attempt to answer the following:

What are the regularities of RHB distribution in China?

Which influencing factors are the dominant factors that could cause the regional differentiation of RHB?