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## Article

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## Research paper

# Economic analysis of marsh gas development in countryside of China: A case study of Gongcheng County in Guangxi Province<sup>☆</sup>

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## ABSTRACT

Marsh gas is an important type of renewable energies and plays important role to solve the energy issue in remote countryside. This article captures the development of marsh gas in Gongcheng County of China with game theory model. Firstly, the development history of marsh gas in Gongcheng County is introduced. Secondly, the economic effects of all subsidy strategy are discussed. Subsidy to family marsh gas popularizes the marsh gas. Thirdly, whether to subsidize firms depends on transportation costs. Therefore, for the disperse residents, subsidy to family marsh gas seems more rational than that to firms. For concentrated residents, the conclusions are contrary.

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## 1. Introduction

Gongcheng Yao Nationality Autonomous County (Gongcheng County in brief) lies in the northeastern part in Guangxi Province of southern China, which includes 0.282 Million population and covers 2419 square kilometers.<sup>1</sup> As a peaceful and beautiful town in Southern China, Gongcheng County is currently covered by forests about 80.93%. The usage of energy of Gongcheng County is focused because the energy in countryside plays determinative roles in the development of these regions.

From 2010, Chinese government invested 5.2 Billion RMB (¥) (about 7.7376 Billion US dollar(\$)) to develop marsh gas in countryside and, more and more marsh gas tanks are built (Yang et al.,

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<sup>1</sup> <http://www.gx.xinhuanet.com/dtzx/guilin/gongcheng/>.

2012). Gongcheng County also launched marsh gas tank subsidy for family in 2011. This subsidy almost covers all fixed costs to build a marsh gas tank. For large marsh gas tank, the subsidy covers about 50% of its construction costs. Till the end of 2014, about 68,700 marsh gas tanks were built in Gongcheng County and more than 89.6% residents in countryside used marsh gas. In some regions of Gongcheng County, all residents employ marsh gas. For example, In Huangling Village of Gongcheng County (Huang Guang-lin always lives a peaceful and healthful life in this village), all residents share marsh gas and Huanglin Village is called the “First Village of marsh gas in China” because the ratio of residents to use marsh gas is the highest in China (Fig. 2). Moreover, Huangling Village in Gongcheng County initially established the marsh gas tank in Gongcheng County in 1975.

From 2015, Gongcheng County proposed a new model to develop marsh gas. A type of marsh gas “agent pattern” was proposed in 2015. In this pattern, firms receive governmental subsidy to build large marsh gas tanks and sell marsh gas to residents nearby. In general, because of the population and transportation costs, these firms are small to support marsh gas to no more than 20 families.

In summary, the development of marsh gas in Gongcheng County includes three stages: Before 1975, no marsh gas tank exists. From 1975 to 2014, more and more marsh gas tanks were built for families. From 2015, marsh gas firms appear and subject to governmental subsidy.

## 2. Literature review

Moreover, energy in countryside of developing countries always attracts attentions of both local residents and academic experts in energy security (Cao and Bluth, 2013), countryside development (He et al., 2016; Arriaga et al., 2016), economic development in remote countryside (Bai et al., 2016; Chen et al., 2019), and others (Chen and Nie, 2016; Nie and Yang, 2016b; Chen et al., 2017a,b; Nie et al., 2017).

Because of high expenditures and infrastructure to transport, it is very difficult to obtain the suitable energy in the remote countryside of China (Zhang et al., 2009), especially in norther China (Yang et al., 2018; Nie and Wang, 2019) and mountain areas (Chen et al., 2018). Before 1970s, like other rural areas in southern China, residents of Gongcheng County heavily depended on wood and the forests were destroyed seriously. According to the data of this region, compared with 1960, the reserves of wood in Gongcheng County in 1979 sharply reduced 44.6%. The drastic change of wood reserves is attached importance by both regional government and residents. Government tried to find outlets to solve this big problem in Gongcheng County to maintain ecological balance.

To protect environment and to reduce the costs incurred by energy (Zhao and Wan, 2014; Ou and Hong, 2014), governments and some local peasants tried to find alternative energy outlets (renewable energies) with various policies, including biomass fuel policy (Wang et al., 2015), direct subsidy (Nie and Yang, 2016a), portfolio standard policy (Sun and Nie, 2015), feed-in-tariff (Alizamir et al., 2016) and other market mechanism (Yang et al., 2016; Wang and Nie, 2018; Nie et al., 2019). Some policies focus on the technology to complete carbon transition (Dumas et al., 2016), green building (Khalid et al., 2016; Yang and Nie, 2016), tax (Chen et al., 2017a,b) and others (Polishuk et al., 2016). In general, it is necessary for a large amount of finance to develop renewable energy (Wang et al., 2016; Li et al., 2015), such as insurance (Nie et al., 2018) and others (Yang et al., 2019a,b). After many times to attempt, people found marsh gas as an easy way to solve energy shortage. Moreover, marsh gas, as a type of bioenergy and renewable energy, can efficiently guarantee the energy security (Cao and Bluth, 2013). Mr. Huang Guang-lin initially tried to establish a marsh gas tank in 1975 by himself, which sets up an example for the marsh gas utility in Gongcheng County. After several times of failures, Huang succeeded to obtain marsh gas in 1975. The first marsh gas tank is still in good operation (Fig. 1). Huang then helped many residents in his town to build marsh gas tanks and is called “the father of marsh gas in Gongcheng County” (Jin et al., 2013). Till the end of 1982, followed Huang Guang-lin’s helps, 42 marsh gas tanks in Huanglin Village and 129 tanks in their town were built to share marsh gas (Jin et al., 2013).

Because of the special effects of marsh gas in Gongcheng County, some researchers focus on this region and investigated the ecological system of this region. Dai et al. (2015) reviewed the ecological effects of Gongcheng marsh gas. Yang and Chen (2014) recently evaluated the energy of the marsh gas of Gongcheng County.

Marsh gas helps to solve the energy problem to a great degree (Verlinden et al., 2015). To utilize marsh gas, a marsh gas tank is necessary. The costs to employ marsh gas include the construction costs incurred by a marsh gas tank (fixed costs) and the maintenance costs (variable costs).

Although marsh gas can efficiently utilize in countryside in China, in the existed literature about countryside energy in China, marsh gas is neglected. Especially, there lacks theoretical support for marsh gas development for remote countryside. It is important to develop policies to support marsh gas in countryside to solve energy issue. This article aims to analyze the marsh gas policy of countryside in China.



Fig. 1. The first marsh gas tank built in 1975.



Fig. 2. First Village of marsh gas in China.



This article captures the essence of the policy to develop marsh gas in countryside. According to the reality of Gongcheng County, the subsidies both to families and to firms are discussed, respectively. The subsidy to family will popularize the marsh gas is argued. Moreover, whether to subsidize to firms depends on the situation in detail. Under the disperse residents, Subsidy to family marsh gas seems more rational than subsidy to firms.

The contributions of this article are in two aspects. On one hand, the stimulating effects of governmental subsidy on the marsh gas development in theory. Considering the resident situation, the optimal subsidy pattern is given. These conclusions support theory for marsh gas development.

On the other hand, this article captures the situation in Gongcheng County and explains the development evolution of marsh gas. This article presents the further decisions for remote countryside in China and other development countries. In developing countries, residents of countryside are very poor and the energy heavily depends on natural resource, in which destroy the natural environment. This article supports a suitable outlet for the energy in developing countries.

The existed work identifies effects of policy and cares little about the affecting mechanism of policy on the development of marsh gas. This article hopes to capture this topic. The rest of this paper is organized as follows: The model is presented in Section 2. The model is analyzed in Section 3. In the analysis, the development of marsh gas in Gongcheng County is discussed and the rationality of the subsidy is remarked. Moreover, the subsidy both to families and to firms is investigated. Conclusions are remarked in the final section.

The nomenclature of this article is listed as follows

- $W$ : the reserves of woods in this region
- $\omega_0$ : The lowest demand of woods for a family
- $c(W)$ : costs to obtain a unit wood
- $c_f > 0$ : the costs of construction marsh gas tank for a family
- $c_v > 0$ : other maintenance costs for a family gas tank
- $p$ : the price of marsh gas
- $c_{f,f} > 0$ : the construction costs of a marsh gas tank for firms
- $p > c_{v,f} > 0$ : other marginal maintenance costs for firms
- ¥: RMB
- \$: US dollar
- J: Joule (Energy input SI unit).

### 3. Economic model

Here the economic model or game theory model is established to discuss the governmental subsidy to develop marsh gas in Gongcheng County. Assume that the reserves of woods in this region to be  $W$ . The lowest demand of woods for a family is  $\omega_0$ . The costs to obtain a unit wood are assumed to be  $c(W)$ , where  $\frac{dc(W)}{dW} < 0$  or the larger reserves imply the lower costs to achieve a unit wood. Therefore, the costs to obtain  $\omega_0$  woods are

$$\bar{c}(\omega_0, W) = c(W)\omega_0. \quad (1)$$

Denote the utility with  $\omega_0$  woods to be  $u_0 > 0$ .

To simplify the model, two types of marsh tanks are considered: One is to meet the demand of a family (about 6 square meters) and the other is to satisfy the demand of local markets (about 100 square meters).

When the family employs the marsh gas to meet the necessity of family, the utility is denoted as

$$u_{mg} = u_0 + u_1, \quad (2)$$

where  $u_0$  is above defined and  $u_1$  is other utilities from marsh gas, which includes the promotion of environment and extra earns from organic vegetable. The costs of marsh gas include

the construction costs of a marsh gas tank ( $c_f > 0$ ) and other maintenance costs ( $c_v > 0$ ). The costs with marsh gas for family are

$$\bar{c}(mg) = c_f + c_v - s. \quad (3)$$

Without loss of generality,  $c_v < \bar{c}(\omega_0, W) = c(W)\omega_0$  is assumed. In (3), the term  $s$  means the subsidy from government.

From 2015, Gongcheng County launched the new pattern of marsh gas. A firm produces marsh gas to sell the marsh gas to all families. Assume the price of marsh gas to be  $p > 0$  for each cubic meter. The costs of marsh gas include the construction costs of a marsh gas tank ( $c_{f,f} > 0$ ) and other marginal maintenance costs ( $p > c_{v,f} > 0$ ). Give the outputs  $q$ ,  $0 < q \leq q_0$ , the costs with marsh gas for firms are

$$\hat{c}(mg) = c_{f,f} + c_{v,f}q. \quad (4)$$

Given the outputs of marsh gas  $q$ , profits of firms are given as follows

$$\pi = pq - c_{f,f} + (c_{v,f} + \tau)q + s. \quad (5)$$

In (5),  $\tau$  stands for the transportation costs for a unit marsh gas. Moreover, given a constant  $0 < q_0$ , the relationship  $0 < q \leq q_0$  stands for the output capacity constraints. Assume that the number of families in Gongcheng County to be  $N$ . The financial budget of family energy satisfies the dense function  $f(\theta)$  with random variable  $\theta \in [\theta_0, \theta_1]$ , where  $0 < \theta_0 < \theta_1$ . Therefore,  $\int_{\theta_0}^{\theta_1} f(\theta)d\theta = 1$ . The corresponding distribution function is  $F(\theta) = 1 - \int_{\theta_0}^{\theta} f(\theta)d\theta$ .

In the above model, based on the reality, costs to establish a marsh gas tank and the marginal cost to produce marsh gas are two major costs. The energy price affects the development of marsh gas. These important parameters constitute the model.

The researching flowchart is listed as follows (see Fig. 3).

### 4. Model analysis

First, the situation without subsidy or  $s = 0$  is considered. Under budget constraints, family with budget  $\theta$  will choose the wood under the following condition. If the energy budget of a family satisfies  $\theta < c_f + c_v$ , this family has to use wood. Denote  $\theta_{mg} = c_f + c_v$ . Therefore, the number of families to employ marsh gas is

$$q_1 = N[1 - F(c_f + c_v)]. \quad (6)$$

According to (6), the following conclusions are achieved

**Proposition 1.** Both low incomes and high costs deter the extended development of marsh gas without subsidy.

**Remarks.** Low incomes hinder the extension of marsh gas and some poor families are not able to use the marsh gas. Furthermore, higher costs to build marsh gas, less families to employ marsh gas. Moreover, large marginal costs for wood (or low reserves of wood) stimulate the usage of marsh gas.

This result is highly consistent with the reality of Gongcheng County. Before 2010, families receive no subsidy for marsh gas. Therefore, rich residents in Gongcheng County initially built marsh gas tank and replace wood with marsh gas as energy. Therefore, in poor countryside, it is important for extension of marsh gas to improve the wealth of residents. Financial transfer is an important type of measure to promote the wealth of poor residents.

Here a special finance transfer—governmental subsidy, is addressed. Consider  $s = c_f$ . Actually, in Gongcheng County, the

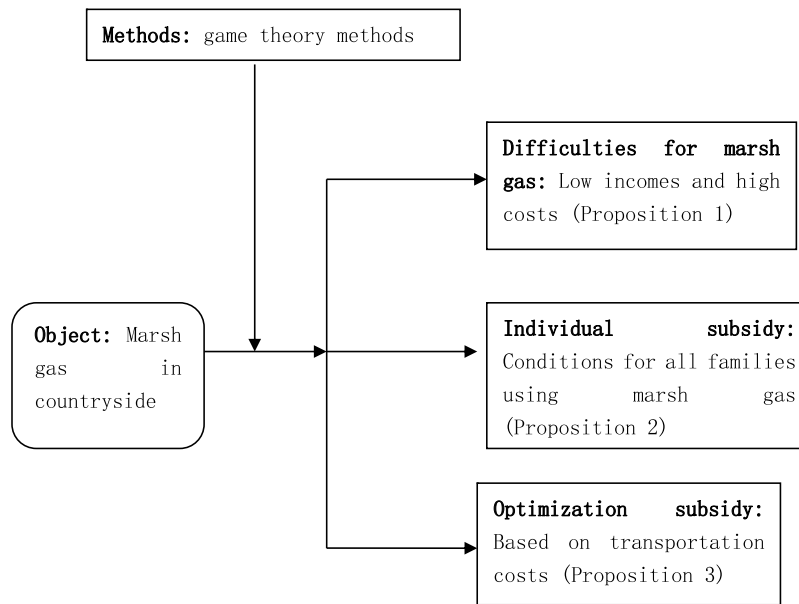


Fig. 3. Flowchart of this research.

Table 1

The ratio of forests of Gongcheng County (data collected from <http://www.gx.xinhuanet.com/dtxx/guilin/gongcheng/>).

Year	2015	2013	2011	1987
Ratio of forest	80.93%	80.72%	79.7%	47%

government subsidizes the construction material to build marsh gas tank, which is suitable to this assumption of  $s = c_f$ . Under  $s = c_f$ , the following conclusion holds

**Proposition 2.** If  $c_v < \bar{c}(\omega_0, W) = c(W)\omega_0$ , all families use marsh gas under subsidy.

**Remarks.** The governmental subsidy of the fixed costs to build marsh gas tanks efficiently stimulates all families to employ marsh gas. Our conclusion supports the governmental subsidy of Gongcheng County.

This conclusion is consistent with the reality. In Gongcheng County, government subsidy covers all fixed cost to build a marsh gas tank and a major of residents in Gongcheng County used marsh gas. In some regions of Gongcheng County, such as Huangling Village and so on, all residents benefit from governmental subsidy and utilize marsh gas. The subsidy of construction materials can avoid incomplete information. Moreover, by usage of marsh gas, the reserves of wood in Gongcheng County improved to a great degree. The ratio of forests of Gongcheng County in recent years is listed as follows (Table 1)

Here the subsidy to firms for marsh gas is considered. According to the subsidy in Gongcheng County, from 2011 to 2014, large marsh gas received subsidy equal to 50% of its construction costs. From 2015, government subsidizes all costs to build a marsh gas tank. Therefore,  $s = c_{f,f}$  under agent pattern and the price of marsh gas is also regulated by government. In this case, the following conclusion is obtained

**Proposition 3.** Under  $s = c_{f,f}$ , low transportation costs of marsh gas (small  $\tau$ ) yield the establishment of large marsh gas while high transportation costs of marsh gas (large  $\tau$ ) deters the development of “agent pattern”.

**Proof.** Conclusions are immediately achieved from (5) and the proof in detail is neglected.

**Remarks.** The above conclusions imply that it is not a good idea to set firms to supply marsh gas in remote countryside because of high transportation costs. Because of disperse residents, the transportation costs for marsh gas are very high and it is not a good choice to support firms for marsh gas. In this situation, subsidy to families seems more rational. Under the concentrated residents, the firms of marsh gas have the advantage of low marginal costs. Compared with family marsh gas, firms with marsh gas own both lower marginal cost and technology advantages. Certainly, the subsidies including innovational subsidy (Chen et al., 2015a,b), support for corporate social responsibility (Chen et al., 2016, 2015a,b), project subsidy (Nie, 2018; Yang et al., 2019a,b), are not discussed.

## 5. Concluding remarks

This article highlights the development of marsh gas in Gongcheng Yao Nationality Autonomous County. By simple economic model, the subsidies of building materials for marsh gas tanks popularize marsh gas in Gongcheng County is introduced. Moreover, whether to subsidize a firm with marsh gas depends on the situation of this project. For the concentrated residents, subsidy to firms seems more rational than that to families.

Conclusions in this article are helpful for policy-deciders to develop marsh gas in countryside. Theory to decision-maker whether to subsidize family or firms is supported. Therefore, this article helps to develop remote rural countryside. The challenges of decision-maker are to consider the differences of different families.

The advantages of this article support the theory for marsh gas in countryside. Actually, many developing countries face energy problem in remote countryside. Therefore, this article supports decision for other developing countries.

The limit of this paper is that the model cannot be identified with data of Gongcheng County. Because of the limitation of data, the total data are obtained and the relationship between subsidies with the development of marsh gas cannot be identified. Moreover, in remote countryside, different demand and costs exist

for different families. Thus, we cannot collect enough data to excavate conclusions.

Some further researching topics arise. On one hand, this article highlights the static situation about marsh gas. It is interesting to extend dynamic situation because the marsh gas tank has the long-term effects on the family. On the other hand, the distribution of residents is neglected and it is necessary for a project of large marsh gas to discuss the distribution of residents. Moreover, it is also interesting to consider other subsidies of governments.

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