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A design of straw acquisition mode for China's straw power plant based on supply chain coordination

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ABSTRACT

China's straw power industry has developed rapidly in recent years. However, SPPs (straw power plants) were always under financial deficit, which mainly arose from high operating costs and undersupply of feedstock. In order to break through feedstock dilemma, we apply game theory to model China's straw supply chain and design an applicable straw acquisition mode for China's SPPs by coordination. It is found that a SPP's payoff varies under different straw acquisition modes. The more straws a SPP acquires directly from farmers, the higher profit it achieves. In a coordinating way, a Mixed Acquisition Mode is designed, which can be conducted in practice and ensure SPP's straw supply with lower cost. The model has been applied to the case of Rudong SPP in China, which shows that the Mixed Acquisition Mode designed in this paper can help the SPP run in a better condition.

1. Introduction

With depleting fossil fuel reserve and deteriorating environment, countries all around the world are trying to enhance the utilization of renewable energy, in order to have a sustainable future [1]. As a sort of renewable energy, bioenergy has been explored greatly since 1970s, and is now the fourth largest energy, following coal, oil, and natural gas [2]. Presently, the most common utilizing way of bioenergy is power generation through combustion of lignocellulosic biomass such as forestry biomass and agricultural residues [3]. Such technology is relatively mature and has been widely spread in the United States and Europe [4].

Chinese government has also realized the importance of exploiting and utilizing renewable energy, and issued the Renewable Energy Act in 2005, which was put into effect on January 1st, 2006 [5]. Since then, a series of policies have been released for supporting the development of renewable energy generation, including straw power [6]. As a result, the number of SPPs[1] in China increased dramatically in the last decade [7]. However, almost 70% of those running SPPs were under financial deficit in 2012 [8], although straw-electricity was all purchased by SGCC[2] with fixed price 1.5 times to conventional electricity [9]. The key reasons for loss were claimed as high feedstock cost accounting over 55% of SPP's total cost [10], and straw supply shortage leading to SPP's low capacity utilization rate, which was about 60% [11]. Actually, China is a large agricultural country, with more than 700 million tons of straws produced annually [12]. The high cost and deficiency of feedstock for China's SPPs are not because of resource shortage, but lack of supply chain management and coordination [13]. Chinese government has already recognized this fact, and proposed to study and find an applicable straw acquisition mode, ensuring the feedstock supply for SPPs [14,15].

Different from America and European countries, China implements the household-responsibility system in agriculture. The straw holders are thousands of small farmers, with small farming area and scattered distribution [16]. After harvesting, straws are left in field separately, as shown in Fig. 1. To become feedstock at plant, straws in field are collected and stored at collection spot first, and then conveyed to the nearest collection centre or SPP by small vehicles; straws in collection centre are processed and transported to SPP by trucks. The whole procedure takes a great deal of manpower, so straw broker appears as a new occupation which is concomitant with straw power industry. The brokers buy straws

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[1] SPP: Straw Power Plant.

[2] SGCC: State Grid Corporation of China.

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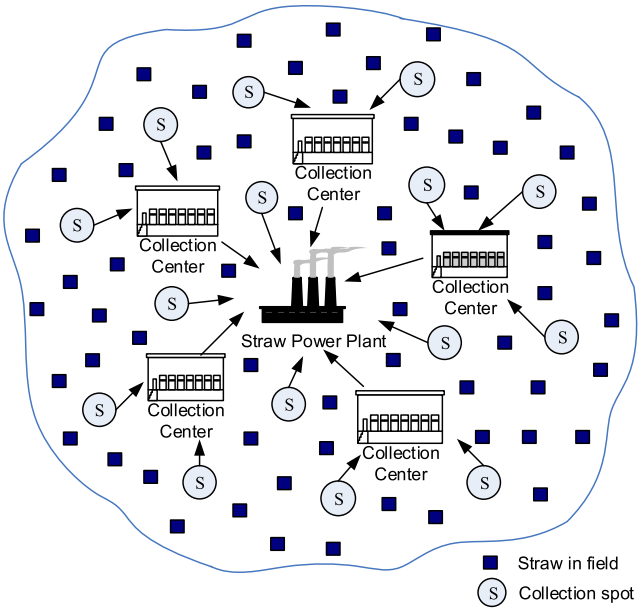

Fig. 1. Flows of straws from field to SPP.

from farmers, take charge of all the intermediate activities, and sell them to SPP with higher price to earn the price spread [17].

Farmers, brokers, and SPPs are playing different but essential roles in China's straw power feedstock supply chain. Standing in disparate interest group, they are affected by different factors and make decisions in different way. Over the centuries, Chinese farmers have been using straws for fire, animal feeding, and fertilizing. Their intensions for selling straws are not strong. Especially in some developed regions, farmers are not willing to sell straws if the price is lower than their expectation [18]. Brokers are motivated by interests and conform to the rational hypothesis of economic person. They would like to make any efforts for gaining more, even including offering malicious high straw price to SPP and adulterating to increase straws' weight [19]. SPP is the core enterprise and terminal point of the chain. Its decisions affect all the supply chain members, and the straw acquisition mode which it takes decides the structure of the chain.

The straw acquisition modes taken by China's SPPs can be sorted as three main categories: Self Acquisition Mode, Broker Acquisition Mode, and Mixed Acquisition Mode (Fig. 2). In Self Acquisition Mode, a SPP acquires straws directly from farmers and accomplishes straw collection, storage, processing, and transportation by its own. Taking such mode, the SPP has to invest on logistics system, hire lots of employees for straw acquisition, and get enough straw acquiring channels. Only SPPs with small installed capacity less than 2 MW can afford it. For most China's SPPs right now, with installed capacity about or more than 25 MW, Self Acquisition Mode is virtually impossible to achieve as it takes too much. In Broker Acquisition Mode, a SPP acquires straws through brokers only, which means that the SPP doesn't take part in the intermediate activities, but get straws at plant and pay by weight and quality. It is true that taking such mode can make up SPP's deficiency in manpower and capital. But it also leads to SPP's high feedstock cost as brokers make exploitation of profits in the supply chain. Currently, most China's SPPs are taking this mode, and that's one reason why they keep losing. In Mixed Acquisition Mode, a SPP acquires straws both from farmers and brokers, and handles the part of straws which come from farmers. It was reported that Kaidi Electric Power Corporation has turned losses into gains by transiting Broker Acquisition Mode to Mixed Acquisition Mode [20,21].

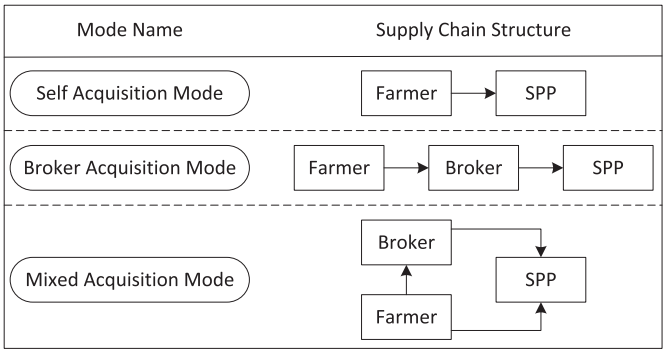

Fig. 2. Supply chain structures of different straw acquisition modes.

But it still needs to be proved whether Mixed Acquisition Mode can work well and what's the appropriate ratio of straws should be acquired from farmers directly. Thus China's SPPs are facing challenges on how to design an effective straw acquisition mode, and how to coordinate the straw supply chain members.

Up till now, there have been many studies on biomass/straw supply chain issues [22]. However, only a few of them focused on supply chain coordination, or constructed game analysis among biomass/straw supply chain members. Researches involving straw acquisition mode for China's SPPs are even fewer. Zhang et al. investigated the operating mode and existing problems for China's straw storage and transportation system [23]. Ding et al. made field surveys on straw collecting, processing, storing, and transporting problems in Huanghuaihai region, and gave qualitative analysis of two different straw acquisition modes [24]. Nasiri and Zaccour first applied game theory to bio-electricity supply chain analysis in 2009, and proposed a sequential game among farmer, electricity generator, and electric utility, which was abstracting from Canadian actualities [25]. Sun et al. established a game among one biomass supplier and two competing buyers with Chinese background [26,27]. In Sun's another work [28], the game was further discussed with a price alliance consists of the single biomass supplier and one buyer.

Inspired by revenue-sharing contracts used in traditional supply chain with “manufacturer-retailer-consumer” structure [29,30], as well as the sequential game idea of Nasiri and Zaccour [25], this paper aims to build a game model applicable to China's straw supply chain, and tries to design a straw acquisition mode for China's SPPs through coordination. Hence, we will structure a “Farmer-Broker-SPP” supply chain with Chinese background, and apply the sequential game and coordinating concepts to design straw acquisition mode.

The remaining contents are organized as follows. Section 2 proposes a game model among China's straw supply chain members including Farmer, Broker, and SPP, and designs a Mixed Acquisition Mode for China's SPPs by coordinating SPP and Broker. In Section 3, the model is applied to the case of Rudong SPP in China, and results are obtained and discussed. Finally in Section 4, conclusions are given.

2. Methodology

2.1. Game model

2.1.1. Assumptions

Three players in the game model are defined as follows: Farmer represents the straw owner, it decides the quantity of straw for sale; Broker stands for the entirety of all those individuals or organizations who act between farmers and SPPs, it offers services to