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A game theory analysis of China's agri-biomass-based power generation supply chain: A co-opetition strategy

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Abstract

The purpose of this paper is to propose a co-opetition agri-biomass feedstock supply strategy for China's biomass-based power plants that the broker method and the villagers' committee method co-exist. We use game theory and Monte Carlo simulation to study its efficiency, compared with that of the competition and cooperation strategies that there exists only the broker method or villagers' method. Results show that the co-opetition strategy supplies sufficient agri-biomass for a plant's one year's operation, while the other two strategies could not. And the strategy brings highest profits for the plant and the entire agri-biomass supply chain, followed by the cooperation and the competition strategies. The sensitivity analysis is conducted with the recommendation proposed.

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Keywords: co-opetition; feedstock supply; biomass-based power generation; game theory; Monte Carlo simulation

1. Introduction

China, as a major agricultural producer, has the potential to produce a large amount of crop residues [1]. The theoretical annual production of China's agri-biomass resources is about 870 million tons (440 million tons of coal equivalent), and about 400 million tons (200 million tons of coal equivalent) are available as energy sources [2], including corn stover, rice and wheat straw, etc. With the comprehensive utilization of these crop residues, biomass-based power generation, if implemented with appropriate technologies, could provide clean electricity, mitigate green-house gas emission, and increase farmers' income.

China has proposed a series of policies and goals to stimulate the growth of biomass power industry. The total installed biomass power capacity has increased from about 1400 MW in 2006 to 9477.10 MW in 2014. However, due to the shortage of feedstock, the real generated electricity in 2014 was 41.65 billion

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kWh with the average capacity factor of biomass generating units was about 50% [2]. Because farmers are scattered across the country, it is highly difficult to collect crop residues in China. Therefore, developing efficient agri-biomass feedstock supply chain is an important issue.

The purpose of this paper is to propose a co-opetition strategy of agri-biomass feedstock supply for China's biomass-based power plants. In this strategy, the broker (as resellers) method and the villagers' committee (the official organization in China's rural areas) method co-exist. The latter method introduces the villagers' committee, which has great influence on farmers' behaviors, into the supply chain to cooperate with farmers for collecting agri-biomass and delivering them to the plant, and to improve infrastructure and provide public welfares with the revenue.

Methodologically, game theory is used to study the efficiency of the co-opetition strategy, compared with the competition and cooperation strategies that there exists only the broker method or villagers' method. Numbers of studies focused on modeling and analyzing the biomass feedstock supply system with the approach of game theory [3-6], which made good examples of using game-theoretical modeling in biomass supply systems. Moreover, Monte Carlo method is applied to numerically simulate the game equilibrium, which is a powerful approach with the considerations of parameters' uncertainty and variability.

2. Game-theoretical modeling and analysis

2.1. Competition

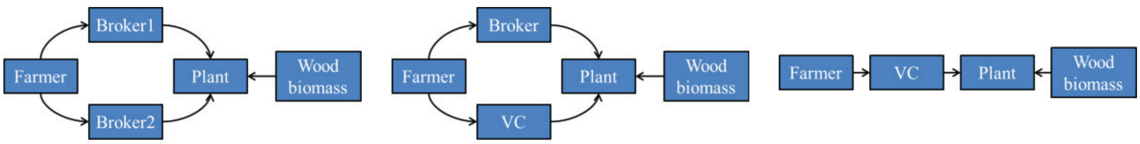
With this strategy, only the broker method exists, where equilibrium is reached with the competition among farmers, brokers and the plant, as well as forest biomass suppliers (Fig. 1). Farmers are assumed as a single game player, Player f, whose payoff function is Eq. (1), with the two brokers' payoff as Eq. (2).

$$\pi_f(a) = aq_a \tag{1}$$

where, a denotes the unit profit of the farmer; q_a, the total agri-biomass quantity purchased by brokers, subject to $q_a = q_1 + q_2$.

$$\pi_i(q_i) = (p_2 - p_1 - c_t d)q_i,\ i = 1,2 \tag{2}$$

where, q_i denotes the agri-biomass quantity purchased by Broker i; p_2, the plant's agri-biomass procurement price; p_1, the brokers' agri-biomass procurement price, subject to $p_1 = a + b\sqrt{q_1 + q_2}$; c_t, the unit transportation cost; d, the transportation distance; b, the agri-biomass collection cost coefficient, subject to $b = 2\sqrt{2}c_t / 3\sqrt{\pi y_r}$; y_r, the unit yield of crop residues.



(a) (b) (c)

Fig. 1. Supply chain architectures with the strategies of (a) Competition, (b) Co-opetition and (c) Cooperation

This is a sequential game, where the farmer moves first to decide the unite profit, and the broker decide the purchased agri-biomass quantity. The equilibrium is calculated with backward induction as Eq. (3).

$$a^{\mathbf{E}} = \frac{p_2 - c_t d}{3},\quad q_1^{\mathbf{E}} = q_2^{\mathbf{E}} = \frac{32(p_2 - c_t d)^2}{225b^2} \tag{3}$$

where the superscript $\mathbf{E}$ denotes equilibrium value of the corresponding variable.