STUDY ON GOVERNMENT SUBSIDY IN A TWO-LEVEL SUPPLY CHAIN OF DIRECT-FIRED BIOMASS POWER GENERATION BASED ON CONTRACT COORDINATION

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ABSTRACT. Biomass power generation is helpful to build a clean, low-carbon, and green energy system, but the shortage of raw materials supply severely restricts the development of the biomass power generation industry in China. To solve problems of supply chain disharmony and low efficiency of government subsidy caused by stochastic factors in biomass power supply chain, this paper studies the decision-making of government subsidy on biomass power generation supply chain. First, a two-level supply chain model under stochastic supply and stochastic output environment is built. The two-level supply chain consists of farmers and the biomass power plant. Second, to achieve the coordination of the two-level supply chain through the calculation of the model, it sets up the combined contract model based on surplus compensation, shortage penalty, and revenue sharing. Then, the validity of the contract is demonstrated by the data obtained from the field survey. Finally, depending on the model and contract coordination results of the supply chain, the impacts of government subsidies on two members’ decision-making are analyzed, and the changes of members’ profits and chain’s profits are discussed. Therefore, the government subsidy strategy for biomass direct-fired power generation is proposed.

1. Introduction. The economy of the world depends heavily on the consumption of energy produced from fossil fuels, and depletion in fossil fuel reserves is major threats to energy security. At the same time, the burning of fossil fuel is piling up pollutants to our environment which is eventually affecting not only human health but also our whole ecosystem. Therefore, it falls within the competence of

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every country in the world to explore renewable energy resources to alleviate the energy crisis and environmental pollution. Under the background of severe global environmental pollution and scarce resources, the development of clean energy is an essential task in promoting the construction of ecological civilization. Biofuel has been suggested as a socio-economically sustainable source of renewable energy and the fourth largest energy reserve to replace fossil fuels. Compared to coal power generation, biomass direct-fired power generation can significantly promote poverty alleviation and reduce adverse environmental impacts caused by pollution emissions.

However, the biomass power generation supply chain still faces many problems. On the one hand, due to factors such as seasonal weather and supply willingness of farmers (as defined below), the supply of raw materials is uncertain and in short. On the other hand, the construction cost of equipment is relatively high, and the current biomass energy utilization is still below the par of minimizing our dependence on fossil fuel. The efficiency of power generation equipment is low, which leads to low production efficiency, high production cost, and limited progress of the biomass power generation industry. Under the circumstance of these problems, the economic benefits of biomass power generation are not shrill. Power plants mainly rely on government subsidies to maintain operations.

Therefore, this paper studies the supply chain of biomass direct-fired power generation from the perspective of contract coordination and considers the stochastic supply and stochastic output of the supply chain. Build on the realization of supply chain coordination, this study focuses on government subsidy strategies. At present, there is little research on how to formulate the subsidy strategy of biomass power generation supply chain from the perspective of supply chain coordination, and this paper catches up with the lack of research in this field. Secondly, studying government subsidies from the perspective of supply chain contract coordination is the outstanding innovation of this paper. Finally, the research conclusion of this paper not only determines the appropriate range of government subsidies for biomass fuel supply chain but also provides a new perspective for government subsidy policy research.

The structure of the article is reproduced below. In Section 2, we review some research on biomass fuels, supply chain contract coordination, and government subsidy strategy. In Section 3, we construct a two-level supply chain model under stochastic supply and stochastic output environment and design contracts to coordinate the supply. Section 4 analyzes a numerical example in check to see the effect of the combination contract of risk-sharing contract and revenue-sharing contract on the two-level supply chain. The risk-sharing contract contains the over-production risk-sharing contract (where the biomass power plant pays a discount price for the farmers’ excess units) and the under-production risk-sharing contract (where the farmers are penalized by a penalty price for the under-delivery of units). Section 5 analyzes the government subsidy strategy for biomass direct-fired power generation. In the last, section 6 summarizes the work and highlights suggestions to promote the synergetic development of biomass direct-fired power generation.

2. Literature review.

2.1. Biomass fuels. Biomass fuel refers to the energy that is mainly produced by forestry and agricultural residues which be converted into energy in many ways. The
utilization of biomass fuels is mainly included gas fuels, liquid fuels, briquette fuels, biomass power generation, and biomass-based materials and chemicals. Biomass raw materials are abundant and agricultural and forestry production residues are the main source of biomass raw materials which are mainly used as fuel raw materials. Due to the complexity of technology and transportation difficulties in biomass energy industry, Laurén et al.[1], Salimi and Vahdani [17] have been exploring the optimal supply mode of biomass resources, especially the application of crop straw.

The research of Cambero and Sowlati[15] found that the increasing utility of agricultural and forestry biomass raw materials can support the reduction of anthropogenic carbon emission to the environment and help forest-dependent communities achieve energy independence while generating jobs. Based on the current market environment and government policies, Xie[20] thought that the biomass fuel supply chain is forming gradually. Lim and Lam[13] use life cycle analysis methods to analyse biomass fuels. However, there are few studies on the analysis of biomass fuels from the perspective of contract coordination.

2.2. Supply chain contract coordination. In a supply chain, members tend to make business decisions to maximize their profits, which will lead to an imbalance between the supply and purchasing side, and the loss of profit of the whole supply chain. This phenomenon is called double marginalization effect proposed by Spengler[18]. Pastermack[16] proposed the concept of a supply chain contract in order to solve the double marginalization effect and improve the overall profit of the supply chain. Common supply chain contracts include wholesale price contracts, subsidy contracts, revenue-sharing contracts, gain/loss contracts, risk-sharing contracts, shortage penalty contracts, and quantity discount contracts. At this stage, scholars’ research on supply chain coordination focuses on the characteristics of the supply chain and the design of supply chain contracts.

The environment faced by supply chain members is often uncertain. The information between members of the supply chain cannot be fully shared, so it is difficult for supply chain members to make optimal decisions, which increases the difficulty of supply chain coordination. At present, many works of literature show that there are mainly three situations of random supply, output, and demand in the supply chain. In fact, under the influence of the environment and technology, most industries have the characteristics of both uncertain demand and random output[24][10]. For example, Influenza vaccine supply chains are subject to yield and demand uncertainty, which leads to the mismatch between supply and demand[14]. For a specific supply chain environment, Hu and Feng[9], Ye et al.[26], Zhao and Zhu [25] and so many scholars establish corresponding stochastic supply, output, and demand models.

By the research of Gérard[2], it turns out that only wholesale price contracts cannot achieve supply chain coordination. In view of the present situation of both the supplier and the manufacturer face random yield in production, a composite contract having two components—a contingent buyback with target sales rebate and penalty, and a revenue-sharing contract is proposed to achieve supply chain coordination and allows arbitrary allocation of total channel profit among all the chain members[6]. Yan et al.[21] constructed a supply chain contract coordination model under an innovative cost-sharing option contract considering supply interruption and retailer’s loss avoidance behavior. Supply chain members need to avoid certain risks when faced with random supply, random output and stochastic demand according to results of Giri et al[5], and Heydari et al[8]. It is found that the
joint contract of revenue sharing-green manufacturing cost-sharing can reduce the risk of supply chain default under a random demand environment according to the results of Li and Wei[12]. As can be seen from studies of Ghadge et al.[4], Yang and Chen[22],Yang et al.[23] for supply chain contract coordination in the face of a random environment, risk-sharing contracts and revenue-sharing contracts are more suitable.

2.3. **Government subsidy strategy.** In order to cope with the fossil fuel crisis and optimize the energy structure, government departments have provided various policies and economic support, such as government subsidies, tax incentives for biomass products, which help to accelerate the industrialization of biomass energy and promote green development.

Research by Hafezalkotob[7] shows that in recent years, many socially responsible governments have adopted economic incentives and deterrence measures to manage the environmental impact of enterprises. The study specifically analyses the impact of government tariffs on the optimal strategies of supply chain members. Wang et al. [19] considered the relationship between the operation effect of supply chain enterprises and government carbon emission policies. Government subsidy policy also has a certain impact on the pricing of supply chain members. Fan and Dong[3] put forward four kinds of government subsidy strategies, and analyzed the impact of different percent of enterprises and consumers with low-carbon strategy and low-carbon consumption. Chen et al.[11] find that when the target collection level set by the government is high, subsidies can coordinate the government and the manufacturer; however, when the governments target is too low, the governments subsidies cannot coordinate the government and the manufacturer.

According to the literature above, scholars have done enough research on supply chain contract coordination. However, for biomass direct-fired power supply chain with complex supply and demand environment, there is no research on establishing stochastic model and conducting contract coordination analysis. In addition, there are few studies on subsidy strategies, so this study is of great significance from the theoretical point of view of supply chain coordination model and the practical point of view of biomass power generation.

3. **The model of two-stage supply chain.**

3.1. **Problem description and parameters setting.** Members of the supply chain include farmers and the biomass power plant. We regard farmers and foresters within a radius of 50 kilometers of a biomass power plant as a whole, which is known as farmers. As the supplier, farmers supply raw materials directly to the biomass power plant. The biomass power plant uses biomass fuels to generate electricity and transmit it to the power grid. In this two-level supply chain, on the one hand, affected by season, weather, and other factors, there is uncertainty in the raw material supply of the supplier. In addition, the biomass power plant requires the quality of raw materials, so the actual supply is random. On the other hand, the output of biomass power plants is uncertain due to factors such as the efficiency of power generation equipment and the impurity content of raw materials. That is, the output of a biomass power plant with the input of 1 kg of raw materials is random. Firstly, the decision variables in this model are set as follows:

- $x$: Planned supply level of raw materials of farmers and foresters;
- $q$: Planned input quantity of raw materials of biomass power plant.
Secondly, the basic parameters of the model are set as follows:
\( c_A \) Marginal supply cost of farmers and foresters;
\( c_p \) Marginal transportation cost of raw materials;
\( c_B \) Marginal generation cost of the biomass power plant;
\( p_A \) The price of raw materials per unit of farmers and foresters;
\( p_B \) Subsidies-free electricity feed-in tariff for biomass power generation;
\( p_m \) Marginal cost of raw material acquisition per unit in spot market;
\( r_A \) Subsidies to farmers and foresters for the supply by the government;
\( r_B \) Subsidies to the biomass power plant for power generation by the government;
\( D \) Maximum power generation;
\( \theta \) Random supply factors of raw materials;
\( \beta \) The conversion rate of raw materials of the biomass power plant;
\( \pi_i \) The profit of each supply member.

Finally, the basic assumptions in the two-level supply chain are as follows:
- The supply of raw materials is random, the planned supply level of raw materials is \( x \), the actual supply is \( \theta x \). \( \theta \) is a random variable on the interval \([a, b]\) whose mean value is \( \mu_1 \). The density function is \( f(\theta) \) and the distribution function is \( F(\theta) \);
- The efficiency of the power generation is random. The conversion rate of raw materials to electricity is \( \beta \). The random conversion rate \( \beta \in [c, d] \), whose mean value is \( \mu_2 \), and the density function and distribution function are \( h(\beta), H(\beta) \), respectively;
- Because of the diverse use of biomass raw materials, the supply of raw materials of farmers and foresters is different from the order quantity of the biomass power plant. In order to ensure the adequate supply of power generation materials, the biomass power plant needs to purchase materials from other sources to make up for the shortage. The marginal cost of raw materials acquisition in spot market is \( p_m \);
- The model assumes that the government provides subsidies to farmers and foresters and biomass power plant.

3.2. Two-stage supply chain of centralized decision-making. In the centralized decision-making supply chain, the profit of the whole supply chain is determined by government subsidies, power generation income, raw material cost from the spot market, raw material supply cost, transportation cost, and power generation cost. The total profit of the supply chain is as follows:

\[
\pi_C = r_A \min(\theta x, q) + (p_B + r_B) \min(\beta q, D) - p_m \max[q - \theta x, 0]^+ - c_p \min(\theta x, q) - c_A x - c_B q
\]  

(1)

The expected profit of the whole supply chain under centralized decision-making is:

\[
E(\pi_C) = (r_A + p_m - c_p) \left[ \int_a^b \theta x f(\theta) d\theta + \int_{\frac{c}{2}}^b q f(\theta) d\theta \right] + \\
(p_B + r_B) \left[ \int_c^{\frac{d}{2}} \beta q h(\beta) d\beta + \int_{\frac{d}{2}}^d D h(\beta) d\beta \right] - c_A x - (c_B + p_m) q
\]  

(2)

Theorem 3.1. The expected profit of supply chain under centralized decision-making \( E(\pi_C) \) is a concave function of planned supply level \( x \) and order quantity \( q \), and there is an optimal combination of \( (x^*_C, q^*_C) \) to maximize the expected profit of supply chain.
Proof. Firstly, the first-order partial derivative of \( E(\pi_c) \) to x can be obtained:

\[
\frac{\partial E(\pi_c)}{\partial x} = (r_A + p_m - c_p) \int_\theta^2 \theta f(\theta)d\theta - c_A \tag{3}
\]

The second partial derivative of \( E(\pi_c) \) to x is

\[
\frac{\partial^2 E(\pi_c)}{\partial x^2} = - (r_A + p_m - c_p) \frac{q^2}{2\pi f \left( \frac{q}{2} \right)};
\]

The mixed partial derivatives of \( E(\pi_c) \) to x and q is

\[
\frac{\partial^2 E(\pi_c)}{\partial x \partial q} = (r_A + p_m - c_p) \frac{q}{2\pi f \left( \frac{q}{2} \right)}
\]

The first-order partial derivative of \( E(\pi_c) \) to q can be obtained:

\[
\frac{\partial E(\pi_c)}{\partial q} = (p_B + r_B) \int_\beta^\frac{q}{h} \beta h(\beta)d\beta - (r_A + p_m - c_p) \int_\theta^\frac{q}{h} f(\theta)d\theta + (r_A - c_p - c_B) \tag{4}
\]

The second partial derivative of \( E(\pi_c) \) to q is

\[
\frac{\partial^2 E(\pi_c)}{\partial q^2} = - (p_B + r_B) \frac{D^2}{q^2} h \left( \frac{q}{h} \right).
\]

The Heisser Matrix is set to be H, and

\[
|H| = \frac{\partial^2 E(\pi_c)}{\partial x^2} \ast \frac{\partial^2 E(\pi_c)}{\partial q^2} - \left[ \frac{\partial^2 E(\pi_c)}{\partial x \partial q} \right]^2 = (r_A + p_m - c_p)(p_B + r_B) \frac{D^2}{q^2} > 0.
\]

The Heisser Matrix is negative definite. Therefore, the expected profit of supply chain \( E(\pi_c) \) is a concave function of x and q. When \( (x_c^*, q_c^*) \) simultaneously satisfies the formula (5) and formula (6), the expected profit of supply chain can reach the maximum value.

\[
(r_A + p_m - c_p) \int_\theta^\frac{q}{h} \theta f(\theta)d\theta - c_A = 0 \tag{5}
\]

\[
(p_B + r_B) \int_\beta^\frac{q}{h} \beta h(\beta)d\beta - (r_A + p_m - c_p) \int_\theta^\frac{q}{h} f(\theta)d\theta + (r_A - c_p - c_B) = 0 \tag{6}
\]

Different from the supply chain under centralized decision-making, farmers and the biomass power plant in the decentralized decision-making supply chain take maximizing their profits as their decision-making objectives. The optimal order quantity of the biomass power plant under decentralized decision-making is not equal to that under centralized decision-making. Therefore, the total profit of the supply chain cannot reach the maximum, it is necessary to design contracts to achieve supply chain coordination.

3.3. Contracts coordination of the supply chain. According to the stochastic characteristics of supply and output of the supply chain, both farmers and the biomass power plant are faced with the risk of difference between supply and order quantity. Therefore, contract design can be carried out from the perspective of risk aversion and risk sharing. In addition, the problem of raw materials shortage needs to be solved. Based on these, the study designs a surplus compensation contract with shortage penalty contract, which gives a subsidy of r yuan per unit for the actual supply of raw materials that exceeds the order quantity, and charges b yuan per unit for the actual supply of raw materials that is less than the order quantity. At the same time, in order to promote a more reasonable distribution of supply chain profits and help farmers and foresters to increase their income and get rid of poverty, a revenue-sharing contract is designed. The revenue-sharing coefficient is λ.
3.3.1. Farmers and foresters. After the introduction of contracts, farmers and foresters’ profit is as follows:

$$\pi_A' = (r_A + p_A) \min(\theta x, q) - c_A x$$

$$- b[q - \min(\theta x, q)]^+ + r[\theta x - \min(\theta x, q)]^+ + \lambda (p_B + r_B) \min(\beta q, D)$$

(7)

And the expected profit of farmers is:

$$E(\pi_A)' = (r_A + p_A + b - r) \left[ \int_a^{\frac{\pi}{2}} \theta x f(\theta) d\theta + \int_{\frac{\pi}{2}}^b q f(\theta) d\theta \right] -$$

$$c_A x - b q + r \mu_1 x + \lambda (p_B + r_B) \left[ \int_c^{\frac{\pi}{2}} \beta q h(\beta) d\beta + \int_{\frac{\pi}{2}}^d D h(\beta) d\beta \right]$$

(8)

**Theorem 3.2.** The expected profit of farmers $E(\pi_A)'$ is a concave function of $x$, and there is an optimal decision variable $x_A^*$ to maximize the expected profit.

**Proof.** Firstly, the first-order partial derivative of $E(\pi_A)'$ to $x$ can be obtained:

$$\frac{\partial E(\pi_A)'}{\partial x} = (r_A + p_A + b - r) \int_a^{\frac{\pi}{2}} \theta x f(\theta) d\theta - c_A + r \mu.$$  

The second partial derivative of $E(\pi_A)'$ to $x$ is

$$\frac{\partial^2 E(\pi_A)'}{\partial x^2} = -(r_A + p_A + b - r) \frac{\pi^2}{4} f \left( \frac{\pi}{2} \right) < 0.$$  

Therefore, after the introduction of contracts, the expected profit of farmers and foresters $E(\pi_A)'$ is a concave function of planned supply level $x$. When $x_A^*$ satisfies the formula (9), $E(\pi_A)'$ can reach the maximum value. $x_A^*$ is the optimal planned supply.

$$(r_A + p_A + b - r) \int_a^{\frac{\pi}{2}} \theta x f(\theta) d\theta - c_A + r \mu = 0$$

(9)

3.3.2. Biomass power plant. After the introduction of contracts, the power plant’s profit is as follows:

$$\pi_B' = (1 - \lambda) (p_B + r_B) \min(\beta q, D) + b[q - \min(\theta x, q)]^+ - r[\theta x - \min(\theta x, q)]^+$$

$$- p_m \max[q - \theta x, 0]^+ - (c_p + p_A) \min(\theta x, q) - c_B q$$

(10)

And the expected profit of the power plant is:

$$E(\pi_B)' = (1 - \lambda) (p_B + r_B) \left[ \int_c^{\frac{\pi}{2}} \beta q h(\beta) d\beta + \int_{\frac{\pi}{2}}^d D h(\beta) d\beta \right] - (c_B + p_m - b) q$$

$$- r \mu_1 x - (c_p + p_A - p_m + b - r) \left[ \int_a^{\frac{\pi}{2}} \theta x f(\theta) d\theta + \int_{\frac{\pi}{2}}^b q f(\theta) d\theta \right]$$

(11)

**Theorem 3.3.** The expected profit of the power plant $E(\pi_B)'$ is a concave function of $q$, and there is an optimal decision variable $q_B^*$ to maximize the expected profit.

**Proof.** The second partial derivative of $E(\pi_B)'$ to $q$ is

$$\frac{\partial^2 E(\pi_B)'}{\partial q^2} = -(1 - \lambda) (p_B + r_B) \frac{\pi^2}{4} f \left( \frac{\pi}{2} \right) + \frac{1}{2} f \left( \frac{\pi}{2} \right) (c_p + p_A - p_m + b - r) < 0.$$  

Therefore, the expected profit of the power plant $E(\pi_B)'$ is a concave function of
the order quantity $q$. When $q^*_d$ satisfies the formula (12), $E(\pi_B)'$ can reach the maximum value. $q^*_d$ is the optimal order quantity of the biomass power plant.

\[(1-\lambda) (p_B+r_B) \int_c^{D} \beta h(\beta) d\beta - (c_p+p_A-p_m+b-r) \int_{q^*_d}^{b} f(\theta) d\theta - (c_B+p_m-b) = 0 \tag{12}\]

When the supply chain is coordinated, the optimal decision variables of supply chain members under decentralized decision-making are the same as those under centralized decision-making. Therefore, contract parameters should be set in accordance with formula (13) to achieve the coordination of the supply chain.

\[
\begin{align*}
  \tau &= \frac{c_A c_B + c_A p_A + c_A p_m - r_A \mu_1}{c_A + c_B \mu_1 + c_p \mu_1 - r_A \mu_1} \\
  b &= \frac{(c_B + p_m)(c_A - p_A \mu_1 - r_A \mu_1)}{c_A + c_B \mu_1 + c_p \mu_1 - r_A \mu_1} \\
  \lambda &= \frac{c_A + c_B \mu_1 + c_p \mu_1 - r_A \mu_1}{c_A + c_B \mu_1 + c_p \mu_1 - r_A \mu_1} \\
\end{align*}
\tag{13}\]

4. **Numerical example.** In order to verify the effect of the combination contract of risk-sharing contract and revenue-sharing contract on the two-level supply chain, a numerical example is analyzed. The data come from the field survey of Q biomass power generation enterprises and surrounding farmers and foresters in China. In this study, the situation of power generation and raw materials supply for half a year is set as the research object. The actual quantity of raw materials supplied by farmers is affected by weather, season and other factors, and the biomass power plant has certain requirements for impurity content of raw materials, so the actual supply is random. Let the random supply factor $\theta$ be uniformly distributed in the interval $[0,1]$; The power generation efficiency of biomass power plant is random, and the conversion coefficient beta of raw material combustion into electric energy obeys uniform distribution in the interval $[800,1000]$. Let $c_A=150$, $p_A=240$, $c_p=40$, $p_m=300$, $c_B=100$, $D=160000000$, $p_e=0.393$. According to formula (5) and formula (6), the optimal planned supply of farmers under centralized decision-making is 144216 tons, and the optimal order quantity of the biomass power plant is 154913 tons. The profit of the whole supply chain is -10324060 yuan. The profit of the farmers is -4421692, and the profit of the power plant is -5902358. Under decentralized decision-making, optimal planned supply of farmers is 139691 tons, the optimal order quantity of the biomass power plant is 156179 tons and the profit of the supply chain is -10369748. It can be found that the planned supply of farmers under decentralized decision-making is less than that under centralized decision-making. Contracts are now introduced. According to formula (13), $\tau=259$, $b=55$ and $\lambda=13.6\%$. After introducing the contract, the optimal planned supply of farmers is 144216 tons, and the optimal order quantity of the biomass power plant is 154913 tons. The results reached the level of centralized decision-making, and the supply chain is coordinated. The total profit of supply chain is shown in Figure 1. The expected profit of supply chain under centralized decision-making $E(\pi_c)$ is a concave function of $x$ and $q$. The expected profit function of farmers and the power plant under decentralized decision-making is shown in Figure 2. The expected profit of farmers under decentralized decision-making $E(\pi_A)'$ is a concave function of $x$. The expected profit of the power plant under decentralized decision-making $E(\pi_B)'$ is a concave function of $q$. 


5. **Analysis of government subsidy strategy.** The development of the biomass power generation industry is of great strategic significance. However, in order to boost the biomass power generation industry, many factors such as the willingness of farmers, the high cost of raw materials collection, transportation, and power generation equipment are the major issues that need to be solved. Therefore, the state has issued a series of policy subsidies to promote the development of the biomass power generation industry, such as electricity price subsidies, transportation preferences, etc. Due to the limited government budget, the impact of government subsidies on biomass direct-fired power supply chain and how to allocate the subsidies of biomass raw materials suppliers, and the subsidies of electricity prices on the Internet are of great research value. This section will analyze the government subsidy strategy in the secondary supply chain of biomass direct-fired power generation. Combined with the existing problems of biomass direct-fired power generation subsidy in China summarized by field research, this section will put forward the reference suggestions of government subsidy strategy. According to the results of the previous section,
when the government subsidies to farmers and biomass power plant are both zero, the expected profit of farmers is -1407826 RMB yuan, and the expected profit of the biomass power plant is -8916234 RMB yuan. Each member is in a loss state. In the long run, farmers will not choose to continue supplying raw materials, and the biomass power plant cannot realize the sustainable operation. The government is supposed to set up subsidies to promote the development of biomass power generation industry. The electricity generated by burning a ton of raw materials obeys uniform distribution in the region [800,1000]. The study assumes that government subsidies for a ton of biomass power generation materials go to biomass power plants and farmers, respectively. When the subsidies for a ton of raw materials is fixed at 350 RMB yuan, the supply chain corresponding to different subsidy combinations of farmers and biomass power plant is shown in Table 1.

Table 1. Situation under different subsidy distribution policies when total subsidy value=350

| r_A | r_B | r  | b  | λ    | x    | q    |
|-----|-----|----|----|------|------|------|
| 0   | 7/18| 259| 55 | 13.64%| 161135| 173087|
| 10  | 17/45| 265| 47 | 11.63%| 164141| 173020|
| 20  | 11/30| 271| 38 | 9.52% | 167091| 172956|
| 30  | 16/45| 278| 29 | 7.32% | 169989| 172895|
| 40  | 31/90| 285| 20 | 5.00% | 172838| 172838|
| 50  | 1/3  | 292| 10 | 2.56% | 175639| 172783|

It can be seen from the information in the table that when the government’s subsidy for farmers is 50 RMB yuan per ton, the government’s subsidy for the biomass power plant will be 1/3 RMB yuan every kilowatt hour. At this time, the planned supply of farmers and farmers is 175,639, and the order of biomass power plants is 172,783. In order to ensure the coordination of supply chain, the surplus goods subsidy should be set at 292 RMB yuan per ton, and the penalty for shortage is 10 RMB yuan per ton. And revenue sharing coefficient is 2.56%. According to Table 1, when the government’s subsidy for a ton of raw materials is fixed at 350 RMB yuan, with the increase of the government’s subsidy for farmers, the subsidies for the actual supply of raw materials exceeding the ordered quantity increase, while the shortage penalty for farmers collected by biomass power plants decreases in case of shortage, and the income sharing coefficient of biomass power plants for farmers decreases continuously. And with the increase of the government’s subsidy for farmers, their willingness to supply increases, and the supply of raw materials increases. The order quantity of the power plant decreases slightly, the difference between the planned supply of farmers and foresters and the order quantity of the power plant is narrowing, and the purchasing cost of the power plant from the spot market reduces. According to the optimal decision variables, the profit of supply chain under different subsidy allocation can be calculated.

From the superficial point of view, with the increase of the subsidy to farmers and foresters, the expected profit of farmers and foresters will increase. However, according to Figure 3, it can be found that when the total subsidy per ton of raw materials is fixed, with the increase of the subsidy to farmers and foresters, the expected profit of farmers and foresters decrease, but the expected profit remain positive. The expected profit of the biomass power plant increases, but the total
When the government’s subsidy for a ton of raw materials is fixed at 200 RMB yuan, the situation under different subsidy combinations are shown in Table 2.

Table 2. Situation under different subsidy distributions when total subsidy value=200

| $r_A$ | $r_B$ | $E(\pi_A)$ | $E(\pi_B)$ | $E(\pi_C)$ | $x$ | $q$ |
|-------|-------|-------------|-------------|-------------|-----|-----|
| 0     | 2/9   | 2999732     | 18998304    | 21998036    | 155921 | 167486 |
| 10    | 19/90 | 2455410     | 18661118    | 21116528    | 158725 | 167310 |
| 20    | 1/5   | 1928749     | 18323116    | 20251865    | 161468 | 167135 |
| 30    | 17/90 | 1419743     | 17983412    | 19403156    | 164153 | 166959 |
| 40    | 8/45  | 928479      | 17641108    | 18569587    | 166783 | 166783 |
| 50    | 1/6   | 455139      | 17295277    | 17750416    | 169359 | 166605 |

With the increase of the government’s subsidy for farmers, the willingness to supply increases, and the order quantity of biomass power plant decreases slightly. The expected profit of farmers decreases, while the expected profit of the biomass power plant increases. The total profit of the supply chain decreases, and expected profits of the members of the supply chain is also positive. Given this situation, the study makes further verification. As shown in Table 6-3, when the government subsidy to the power plant remains unchanged, with the increase of government subsidy to farmers and foresters, the order quantity of the power plant increases, and the planned supply quantity of farmers increases, and the increase rate is higher than that of the order quantity of the power plant. In the process of increasing...
government subsidy to farmers from 0 yuan to 50 yuan, the planned supply of farmers has changed from less than the order of power plants to higher than the order of power plants. On the other hand, when the government subsidy to the power plant remains unchanged, with the increase of government subsidy to farmers, the expected profit of the whole supply chain increases, and the expected profit of biomass power plants increases.

However, the change of farmers’ expected profit is related to the government’s subsidies to the power plant. When \( r_B \) is higher than 0.057 RMB yuan/degree, with the increase of government subsidies to farmers, the expected profit of farmers decreases; when \( r_B \) is equal to 0.057 RMB yuan/degree, with the increase of government subsidies to farmers, the expected profit of farmers increases first and then decreases; when \( r_B \) is equal to 0 yuan/degree, with the increase of government subsidies to farmers, the expected profit of farmers increases. This phenomenon is related to the contract that makes the supply chain coordinate. With the increase of government subsidy to farmers, the supply of farmers increases, the order quantity of the power plant increases, and the generating capacity increases. However, the parameters of revenue sharing contract decrease, and the expected profit of farmers change from increasing to decreasing after \( \lambda \) reaching the critical point. However, when \( r_B \) is less than 0.057 RMB yuan per degree, profits of supply chain members are low, which is not conducive to the development of biomass power generation industry in the long run. Therefore, the government’s subsidy for the biomass power plant should be higher than 0.057 RMB yuan per degree.

To sum up, from the perspective of decision variables, increasing government subsidies to farmers can enhance their willingness to supply, increase the planned supply of raw materials, and also promote the biomass power plant to upgrade the order level, which is conducive to the utilization of agricultural and forestry wastes such as straws and branches. From the perspective of supply chain profit, increasing government subsidy to farmers and foresters can increase the profit of the biomass power plant and the profit of the whole supply chain, but will reduce the profit of farmers. According to the data in Table 3, considering the quantity of raw materials and the profit of supply chain, it is suggested that the government set a subsidy of 20-30 RMB yuan per ton for farmers. The study now sets \( r_A = 20 \). So, \( r = 1900/7 \), \( b = 800/21 \) and \( \lambda = 9.5\% \). The study analyses the impact of government subsidies on the income \( R(\pi_B) \), cost \( C(\pi_B) \), profit \( E(\pi_B) \) and profit rate \( p \) of the power plant. When the government provide farmers 20 RMB yuan for each ton of raw materials, the situation under different subsidies are shown in Table 4.

According to Table 4, it is found that the profit rate of the biomass power plant increases from negative to positive with the increase of government subsidy from 0 to 0.357. The profit rate of the biomass power plant can reach more than 10% when the price of electricity on the grid is 0.55 RMB yuan/degree, that is, the government subsidy is 0.157 RMB yuan/degree, and the profit rate of the biomass power plant can reach a higher level in the industry. Through the field survey, it is found that there is a large gap in subsidy funds for biomass power generation. In addition, the government only subsidizes biomass power plant, there is no government subsidy for raw material suppliers. Based on the calculation of government subsidy in this study, the following suggestions are put forward:

(1) The government should provide subsidies to farmers who supply raw materials for biomass power generation. There are abundant raw materials for biomass power in our city, but the supply of raw materials cannot meet the large-scale development
Table 3. Situation under different subsidy distribution policies

| $r_A$ | $r_B$ | $E(\pi_A)$ | $E(\pi_B)$ | $E(\pi_C)$ | $x$ | $q$ |
|-------|-------|-------------|-------------|-------------|-----|-----|
| 0     | 0     | -1407826    | -8916234    | -10324060   | 144216 | 154913 |
| 10    | 0     | -1116079    | -8482206    | -9598285    | 147293 | 155260 |
| 20    | 0     | -843398     | -8012288    | -8855686    | 150340 | 155617 |
| 30    | 0     | -592460     | -7504496    | -8096956    | 153361 | 155983 |
| 40    | 0     | -366136     | -6956586    | -7322722    | 156358 | 156358 |
| 50    | 0     | -167527     | -6366028    | -6533555    | 159334 | 156743 |
| 0     | 0.057 | -310685     | -1967673    | -2278359    | 148015 | 158994 |
| 10    | 0.057 | -178318     | -1355214    | -1533532    | 151145 | 159321 |
| 20    | 0.057 | -73484      | -698095     | -771579     | 154244 | 159658 |
| 30    | 0.057 | 496         | 6284        | 6780        | 157314 | 160003 |
| 40    | 0.057 | 40045       | 760846      | 800891      | 160357 | 160357 |
| 50    | 0.057 | 41286       | 1568873     | 1601059     | 163376 | 160719 |
| 0     | 0.157 | 1675358     | 10610602    | 12285960    | 153230 | 164596 |
| 10    | 0.157 | 1518248     | 11538885    | 13056933    | 156431 | 164893 |
| 20    | 0.157 | 1318612     | 12526818    | 13845431    | 159597 | 165198 |
| 30    | 0.157 | 1072002     | 13578691    | 14650692    | 162729 | 165511 |
| 40    | 0.157 | 773601      | 14698425    | 15472027    | 165831 | 165831 |
| 50    | 0.157 | 418174      | 15890630    | 16308805    | 166905 | 166159 |
| 0     | 0.257 | 3712806     | 23514436    | 27227242    | 157182 | 168841 |
| 10    | 0.257 | 3257909     | 24760109    | 28018018    | 160434 | 169112 |
| 20    | 0.257 | 2745391     | 26081216    | 28826607    | 163647 | 169390 |
| 30    | 0.257 | 2169674     | 27482542    | 29652217    | 166824 | 169675 |
| 40    | 0.257 | 1524706     | 28969420    | 30494127    | 169967 | 169967 |
| 50    | 0.257 | 803889      | 30547792    | 31351681    | 173080 | 170266 |
| 0     | 0.357 | 5783661     | 36629858    | 42413519    | 160282 | 172171 |
| 10    | 0.357 | 5025561     | 38194268    | 43219829    | 163572 | 172420 |
| 20    | 0.357 | 4194682     | 39849485    | 44044167    | 166820 | 172676 |
| 30    | 0.357 | 3284320     | 41601399    | 44885719    | 170031 | 172937 |
| 40    | 0.357 | 2287187     | 43456554    | 45743741    | 173205 | 173205 |
| 50    | 0.357 | 1195321     | 45422232    | 46617553    | 173479 | 173479 |

Table 4. Profit statement of biomass power plant under different subsidies when $r_A=20$

| $r_B$ | $r_B + p_B$ | x | Q | $R(\pi_B)$ | $C(\pi_B)$ | $E(\pi_B)$ | p  |
|-------|-------------|---|---|-------------|-------------|-------------|----|
| 0     | 0.393       | 150340 | 155617 | 57988171  | 66000459    | -8012288 | -13.82% |
| 0.007 | 0.4         | 150862 | 156157 | 59200760  | 66326206    | -7125446 | -12.04% |
| 0.057 | 0.45        | 154244 | 159658 | 67808514  | 68506609    | -69895  | -1.03%  |
| 0.107 | 0.5         | 157120 | 162635 | 76338929  | 70475997    | 5862932  | 7.68%   |
| 0.157 | 0.55        | 159596 | 165198 | 84805198  | 72278380    | 12526818 | 14.77%  |
| 0.207 | 0.6         | 161753 | 167430 | 93218692  | 73947086    | 19271606 | 20.67%  |
| 0.257 | 0.65        | 163647 | 169390 | 101586998 | 75505782    | 26081216 | 25.67%  |
| 0.307 | 0.7         | 165324 | 171127 | 109917862 | 76974277    | 32943585 | 29.97%  |
of the biomass power generation industry. Two main reasons account for this phenomenon. First, raw material production is dispersed, which causes difficulty to the storage and transport. Second, the raw materials purchasing price is not high enough to arouse farmers’ enthusiasm to collect. Therefore, to encourage farmers to supply raw materials such as agricultural and forestry wastes to biomass power plants or the middles, the government should give some subsidies to the farmers while setting the subsidy of on-grid electricity price. It can solve the problem of shortage of raw materials for biomass power generation, and reduce air pollution caused by the direct combustion of agricultural and forestry residues so that agricultural and forestry residues can be used efficiently and environmentally. The government may entrust middles and power plants to grant subsidies to farmers.

(2) The government should ensure that the biomass power generation subsidy fund is distributed on time and in quantity. The government needs to set up a special fund for renewable energy to ensure the healthy development of the biomass power generation industry. In particular, there are at least three points that need to make clear. First, give priority to the enterprises that use agricultural and forestry wastes for biomass power generation. Second, improve the management measures of the special fund for renewable energy. Finally, update the list of subsidy projects for biomass power generation dynamically. According to above, biomass power generation industry can develop steadily, farmers can increase income and get rid of poverty, and the role of biomass power generation in optimizing energy structure and developing green and low-carbon economies can be highlighted.

(3) According to the market environment of raw materials, farmers are allowed 20-40 RMB yuan per ton of raw materials supply subsidies. According to the above calculation results, the combination contract parameters of risk-sharing contract and revenue-sharing contract on the two-level supply chain that are not linear with the government subsidy amount for farmers. And the impact of government subsidies for farmers on the expected profits of supply chain members is affected by the government subsidy amount for biomass power plants. It is estimated that the government subsidy amount for biomass power plants should be higher than 0.057 RMB yuan/kWh. Considering the quantity of raw materials and the profit of supply chain, it is suggested that the amount of government subsidies to farmers should be set at 20-30 yuan/ton, and the government can entrust biomass power plants to distribute them on its behalf.

(4) In the early stage, the government should maintain stable subsidies. With the maturity of biomass power generation industry, the price can be reduced to 0.5-0.6 RMB yuan per kilowatt-hour, that is, the subsidy amount is 0.107-0.207 RMB yuan/kWh. In the secondary supply chain, the government’s supply subsidy for farmers is set as 20 RMB yuan/ton. When the on-grid price is 0.55 RMB yuan/kWh, that is, the government subsidy is 0.157 RMB yuan/kWh, the profit rate of biomass power plants can reach more than 10%, reaching a high level in the industry.

6. Conclusion. The biomass direct-fired power generation is helpful to build a clean, low-carbon, and green energy system. At present, the shortage of raw materials, the rising raw materials price, and the unprofitability of biomass power plants hinder the healthy development of the biomass power generation industry. Therefore, based on the reality, supply chain management theory, and contract coordination theory, the study establishes a two-level supply chain model of biomass
direct-fired power generation, and designs contracts to solve the discoordination. At the same time, according to the data obtained from the field survey, the numerical example and analysis of the government subsidy strategy are carried out. The planned supply of farmers is random, and the generation efficiency of biomass power plant is random. Under decentralized decision-making, farmers and the power plant aim at maximizing their own profits, which makes the total profit of the supply chain unable to reach the maximum profit. Therefore, this study designs a combination contract of risk-sharing contract and revenue-sharing contract. It has been proved that the combination contract can share the risk of supply chain members in both directions, and can reasonably distribute the profits among the supply chain members. Finally, the validity of the contract is verified by an example analysis based on the data obtained from field survey. Based on contract coordination, the government subsidy strategy is analyzed. The government should ensure that the biomass power generation subsidy fund is issued on time and in accordance with the amount. At the same time, the farmers who supply raw materials should be given a certain subsidy. It is suggested that the subsidy for farmers should be set at 20-30 RMB yuan/ton. And the price of electricity on the grid should be set at 0.55 RMB yuan/ton. This study has a certain theoretical significance in the field of supply chain contract coordination and has a certain practical significance in promoting the development of the biomass power generation industry. In the future, more accurate supply functions can be calculated through continuous data collection. In addition, the multi-supplier biomass power supply chain model is also the future research content.

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