Optimization of biomass collection, transportation and storage processes empowered by blockchain technology

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Abstract: As an important renewable alternative energy source, one of the most critical aspects that can be used reasonably is the improvement of the biomass energy supply chain. In view of the uncontrollable transportation process in the biomass energy supply chain, Blockchain technology (BT) is introduced to optimize the biomass energy collection, transportation, and storage processes. On this basis, the game model is applied to analyze the impact of BT on the members of the biomass supply chain and the overall profit of the supply chain. Research shows that the application of BT is beneficial to increase the profits of biomass energy supply chain members within the threshold range, and for the overall benefit of the supply chain, the overall benefit of the supply chain under centralized decision-making is the highest.

1. Introduction
In recent years, Chinese biomass energy industry has made great progress, but there is still a problem of high production costs. In the biomass energy supply chain, transportation costs, storage costs and collection costs associated with transportation issues account for a large part of production costs. Therefore, in order to attract industrial participants' interest and more investment in biomass-based industries, how to save transportation costs and improve the profitability of biomass power generation has become the key to promoting the sustainable development of the biomass power generation supply chain. BT has technical advantages such as decentralization, non-tampering, distributed sharing, asymmetric encryption, and smart contracts [1]. In recent years, the successful application of the supply chain in many industries has had a great impact. This is biomass The further development of the energy generation industry provides new ideas.

2. Biomass energy supply chain
Nunes Leonel J. R. et al. [2] think that by developing a logistics management system of biomass storage Park, there are two different biomass storage parks to solve the internal logistics problem in the process of biomass power generation. Amin mirkoue et al. [3] proposed an energy supply chain , the results show that hybrid supply chains can improve the sustainability performance of traditional supply infrastructure by reducing costs (up to 24%) and environmental impact (up to 5%). Zahraee SM et al. [4] are committed to studying the impact of improving efficiency by changing transportation technology and production technology on the environmental sustainability of palm oil. Nunes et al. [5] compiled a literature review on biomass fuel research and summarized the research of different scholars on the biomass supply chain, mainly focusing on three aspects. Sangpil Ko et al. [6] established a mixed integer programming model and concluded that external (social and environmental) costs accounted for a considerable part of the total transportation cost (about 26-37%). Yesim Gital Durmaz et al. [7] combined geographic information system, analytic hierarchy process and
MILP model, and proposed a multi-stage solution method. Su Shiwei et al. [8] summarized the literature at home and abroad, and obtained the research on the impact of the special properties of raw material fuel raw materials and the uncertain factors in the transportation collection process on the logistics cost, which is the conclusion of the possible research directions of domestic scholars in the future[9].

3. Application of blockchain in biomass energy supply chain

3.1. Application of blockchain in demand management

Power plant companies will write demand for biomass energy into the demand block. Each purchase station obtains the biomass energy demand from the demand block, summarizes it, retrieves the current storage situation of the power plant, and then reasonably determines the demand content of the storage in the power plant and the needs of the purchase station based on the purchase station's own situation and the situation of other purchase stations. Complete the demand goal to complete the demand[10].

3.2. Application of blockchain in procurement management

The acquisition station determines the storage content, that is, the type, quantity, supply time limit, quality status, etc., when the demand cannot be met, the acquisition station completes the acquisition of biomass energy in accordance with the requirements of the procurement procedures, and writes the acquisition content into the procurement blockchain to facilitate responsibility. People organize collection[11].

3.3. Application of blockchain in contract management

The purchase station maps the biomass energy purchase and storage conditions with the demand of power plant companies, and writes the mapping results into the contract block. After the delivery process is completed, the acquisition station and the power plant company will include the delivery process in their respective receiving block and supply block to ensure that other companies in the supply chain can supervise the entire process.

4. Construction of game model

The parameters are set as follows:

| Parameter | Description |
|-----------|-------------|
| \( c_m \) | The unit production cost of the power plant enterprise; |
| \( c_t \) | The transportation cost of the acquisition station; |
| \( c_p \) | The acquisition cost of the acquisition station; |
| \( c_e \) | The implementation cost of BT; |
| \( q_s \) | The market demand of power plant enterprises; |
| \( q_p \) | The purchase volume of the purchase station; |
| \( w \) | The unit price that the power plant company buys back from the recycling station; |
| \( z_s^j \) | Is the profit function of the acquisition station under different decision-making modes, \( j \in \{S, D, N\} \); Same below; |
| \( z_p^j \) | It is the profit function of power plant enterprises under different decision-making modes; |
| \( z^j \) | It is the overall profit function of the supply chain under different decision-making modes; |

The market demand of the power plant company is \( q_s = a - bp + ne \), \( a \) is the basic market demand of the power plant company, \( b \) is the price elasticity, \( p \) is the market price set by the power plant company, \( n \) is the elasticity of BT, and \( e \) is the degree of BT capability. The acquisition cost of the acquisition station is \( c_p = gk^2/2 \), \( g \) is the sensitivity coefficient of the acquisition cost, \( k = 1/l \), and \( l \) is the conversion rate of the repurchased product. \( K \) is acquire capabilities. Therefore, the acquisition volume of the acquisition station is \( q_p = qsk \). The transportation cost of the acquisition station is
\[ ct = \frac{mr^2}{2}, \]  
where \( m \) is the sensitivity coefficient of the acquisition radius to the transportation cost, and \( r \) is the acquisition radius. The implementation cost of BT is \[ ce = \frac{he^2}{2}, \]  
where \( h \) is the sensitivity coefficient of BT capability to implementation cost, and \( e \) is the degree of BT capability.

### 4.1. Decentralized decision model construction

The model under decentralized decision-making is represented by "S". Under decentralized decision-making, power plant enterprises and purchase stations form a secondary biomass energy supply chain. The profits of power plant companies, purchase stations and the overall supply chain are as follows:

- The profit function is:
  \[ f_{ab} = z_S = \frac{w}{wp} - \left( ct + cp \right) \]

First of all, by bringing in the cost function, using Stackelbe rg game theory analysis, the optimal purchase price and sales price can be obtained as follows:

- Purchase price:
  \[ p_S = bne + \frac{he^2 + 2cm}{4} + \frac{en}{2} + \frac{bkmr^2}{4b^2} \]
- Sales price:
  \[ w_S = k\left[ a - \frac{bhe^2 + 2cm}{4} + \frac{en}{2} + \frac{bkmr^2}{4b^2} \right] \]

Secondly, by bringing \( w_S \) and \( p_S \) into \( qs_S \) and \( qp_S \), it can be seen that the optimal acquisition and sales are as follows:

- Acquisition volume:
  \[ qs_S = a - b\left( h + \frac{2cm}{4} \right) + \frac{en}{2} - \frac{bkmr^2}{4b^2} \]
- Sales volume:
  \[ qp_S = k\left[ \frac{a}{2} - \frac{bhe^2 + 2cm}{4} + \frac{en}{2} - \frac{bkmr^2}{4b^2} \right] \]

Finally, \( w_S, p_S, qs_S, qp_S \) are brought into the profit function, we can see that the optimal supply chain members and the overall profit are:

- Optimal supply chain profit:
  \[ z_S = \frac{3\left( bhe^2 - 2ne + bgk^3 + bkmr^2 - 2a + 2bcm \right)^2}{64b} \]

### 4.2. Centralized decision model building

Under centralized decision-making, use "D" to indicate that under centralized decision-making, power plant enterprises and purchase stations form a secondary biomass energy supply chain as a system as a whole, so the overall profit of the supply chain is:

\[ z_D = -\left( \frac{h}{2} + cm - p\right)(a - bp + en) - k\left( \frac{gk^2}{2} + \frac{mr^2}{2} \right)(a - bp + en) \]

First, using Stackelberg game theory analysis, the best selling price can be obtained as:

\[ p^D = \frac{2a + b(h^2 + 2cm) + 2en + bk(gk^3 + mr^2)}{4b} \]

Secondly, by bringing \( p^D \) in \( qs^D \) and \( qp^D \), we can see that the optimal purchase volume and sales volume are:

- Purchase volume:
  \[ qs^D = a - \frac{b(h^2 + 2cm)}{4} + \frac{en}{2} - \frac{bgk^3 + mr^2}{4} \]
- Sales volume:
  \[ qp^D = k\left[ \frac{a}{2} - \frac{bhe^2 + 2cm}{4} + \frac{en}{2} - \frac{bkmr^2}{4b^2} \right] \]

Finally, by bringing \( w^D, p^D, qs^D, qp^D \) into the profit function, we can see that the optimal supply
chain members and overall profit are: 

\[ z^D = \frac{(bhe^2 - 2ne + bgk^3 + bmkr^2 - 2a + 2bcm)^2}{16b}; \]

4.3. Nash decision model construction

Under the Nash decision, "N" means that under the Nash equilibrium decision, the power plant company and the purchase station form a secondary biomass energy supply chain. Both are in the same decision-making position. The sales price is the unit marginal profit of the power plant company. Then the supply chain The profits of the members and the overall supply chain are as follows:

\[ i = a - b(u + w) + en \cdot z^N = -k\left(\frac{2gk}{2} + \frac{mr^2}{2} - w\right)j \cdot z^N = \frac{1}{2}(en - w) - kO \]

\[ z^N = z^S + z^P \]

First, using Nash equilibrium game theory analysis, the optimal purchase price and sales price can be obtained as follows:

\[ p^N = \frac{bne + 2ne + bgk^3 + bmkr^2 + 2ak + 2a + 2bcm}{2(2 + k)} \]
\[ w^N = \frac{-bhe^2 + 2ne + 2bgk^2 + 2hmr^2 + 2a - 2bcm}{2(2 + k)} \]

Secondly, by bringing \( w^N \) and \( p^N \) into \( qs^N \) and \( qP^N \), we can see that the optimal purchase volume and sales volume are:

\[ qs^N = \frac{-bhe^2 + 2ne + bgk^2 + bmkr - 2a + 2bcm}{2(2 + k)} \]
\[ qP^N = \frac{-bhe^2 + 2ne + bgk^3 + bmkr^2 - 2a + 2bcm}{2(2 + k)} \]

Finally, by bringing \( w^N, p^N, qs^N \) and \( qP^N \) into the profit function, we can see that the optimal supply chain members and overall profit are:

\[ j = bhe^2 - 2ne + bgk^3 + bmkr^2 - 2a + 2bcm \]

\[ z^S = \frac{kj^2}{4b(k + 2)} \]
\[ z^P = \frac{j^2}{4b(k + 2)} \]
\[ z^N = \frac{(k + 1)j^2}{4b(k + 2)} \]

4.4. Case analysis

Combined with the actual situation of the case, set the parameters \( n = 0.4, b = 2, a = 10, cm = 1, k = 0.6, m = 0.2, r = 1, e = [0, 2] \) and analyze the influence analysis of the BT on the equilibrium results such as the sales price and the purchase price, as shown in Figure 1 - Figure 7.

![Figure 1](image1.png)  
**Figure 1. Analysis of the impact of BT on sales prices**

![Figure 2](image2.png)  
**Figure 2. Analysis of the impact of BT on the repurchase price**

Under the three different decision-making modes, the results of the analysis of the influence of BT on the sales price and repurchase are shown in Figure 1 to Figure 2.
Analysis of the impact of BT on sales volume and repurchase volume under three different decision-making modes. As shown in Figure 3-Figure 4, with the enhancement of BT, sales and repurchase volumes show a trend of increasing first and then decreasing, indicating that there is a threshold, so that the enhancement of BT capabilities within the threshold is beneficial to the improvement in sales.

With the enhancement of BT capabilities, under different decision-making modes The profits of supply chain members all show a trend of first increasing and then decreasing, indicating that the technical capabilities of the blockchain are within the threshold range, which is conducive to increasing the profits of the biomass energy supply chain members and bringing higher profits to the supply chain as a whole. However, if the threshold is exceeded, improving the technical capabilities of the blockchain will affect the income of the supply chain members and reduce the overall profit of the supply chain. Therefore, considering the company's own capabilities, the implementation of BT should be controlled within a certain threshold. The profit of the acquisition station is higher than the profit under the Nash equilibrium decision under the decentralized decision, and the profit of the power plant enterprise is higher than the profit of the acquisition station under the Nash equilibrium decision.

5. Conclusions
This article separately discusses the current status of biomass energy transportation and the current development of BT, and innovatively combines the two, expounds the application of BT to the biomass energy supply chain, which is important for the collection, transportation, and transportation of biomass energy. Optimization of storage process. Using the game model, it shows that the BT is within the threshold range, which is beneficial to increase the profits of the members of the biomass energy supply chain and improve the overall efficiency of the supply chain. Among them, it is more...
advantageous for power plant companies to choose Nash equilibrium decision. For the overall income of the supply chain, the overall income of the supply chain under centralized decision-making is the highest.

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