A mixed integer programming model based on Biomass Straw Energy Utilization Engineering warehouse logistics site selection

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Abstract. When the scale of biomass straw energy utilization project is relatively large, it is necessary to build a biomass straw storage and logistics center to ensure the stability of the project. By biomass straw lowest total logistics cost as the objective, considering the biomass straw briquette processing, variable cost and fixed cost of biomass straw storage cost and biomass straw warehousing logistics center construction cost to build the mixed integer programming model, to determine the biomass straw warehousing logistics center location, flow rate and maximum capacity. Taking Henan Province as an example, the paper selects the stalk storage and logistics center of biomass straw in Xinyang Jinniu Logistics Industry concentration area, Nanyang River logistics park and Zhoukou Port comprehensive logistics park through model calculation.

1. Introduction
China is rich in biomass straw resources. The total amount of rice, wheat and corn straw resources is nearly 1 billion tons, 20% to 30% of the world's total biomass straw resources. Biomass straw resources are mainly distributed in east China, North China, Northeast China and northwest China. Henan province is a high-yield biomass straw region, accounting for a large part of the national biomass straw resources, with an average annual straw yield of more than 100 million tons (1). However, the distribution of biomass straw resources in Henan province varies greatly from region to region, showing an obvious regional trend of decreasing from southwest to northeast and from south to northwest, concentrated in the central and southern main agricultural areas. The average annual biomass straw resources of Nanyang city, Shangri City, Zhumadian City, Xinyang City and Zhoukou city are over 5 million tons, which are the main locations of biomass straw resources in Henan Province (2). Due to the uneven regional distribution of biomass straw resources and the imbalance between supply and demand, as well as the small density of biomass straw and the difficulty in transportation, the total cost of biomass straw logistics remains high (3). The biomass straw energy utilization engineering logistics system refers to the whole project (4) of the agricultural straw energy utilization engineering after it is harvested from
the field, which goes through a series of links, such as collection, drying, crushing, compression, transportation, storage and distribution, and finally is distributed to the biomass straw energy utilization engineering. In order to facilitate the long-distance transportation and storage of biomass straw and achieve the goal of the lowest total cost of biomass straw logistics, the biomass straw should be lumped. Straw pressing refers to the use of biomass compression equipment, cut corn straw, peanut seedlings, wheat straw and other agricultural and forestry products into cuboid pieces, the density is generally between 0.7--1.3kg/m³, section diameter is generally in 3-10cm, length is generally 2--10 cm (5). The biomass straw storage and logistics center connects the supply point and demand point of biomass straw, and plays a connecting role in the whole biomass straw logistics (6). For biomass straw warehousing logistics center location, flow rate and the maximum capacity of research, this paper considers the biomass straw briquette processing, variable cost and fixed cost of biomass straw storage cost and biomass straw warehousing logistics center construction cost, the establishment of biomass straw warehouse logistics center to make the total cost of biomass straw logistics the lowest. Take Henan Province as an example for analysis.

2. Biomass Saw Storage Ad Lgistics Cnter Panning Mdel Cnstruction

The total cost of biomass straw logistics includes acquisition cost, transportation cost, storage cost, and construction cost of biomass straw storage and logistics center. The biomass straw warehouse and logistics center is built between the biomass straw purchase and storage point and the biomass straw energy utilization project. Under the constraint condition, the geographical location and maximum capacity of the biomass straw warehouse and logistics center are determined to make the total cost of biomass straw logistics the lowest. Due to the biomass straw to be pressed, namely the biomass straw acquisition cost including the biomass straw pressing cost. The storage cost of biomass straw is composed of variable cost and fixed cost.

Figure 1 The biomass straw logistics model

2.1. Description and Hypothesis of Biomass Straw Storage and Logistics Center Planning Model

There are A biomass straw purchasing and storage points, B biomass straw storage and logistics center alternatives, and C biomass straw energy utilization projects in a certain region. \( T_y \) of the B alternative locations of biomass straw storage and logistics centers are selected to minimize the total cost of biomass straw logistics. The biomass straw logistics model is shown in Figure 1. Assumptions:

- The biomass straw purchase and storage point, the alternative site of biomass straw storage and logistics center, and the geographical location of the biomass straw energy utilization project have been determined.
- The transport unit price and distance from the biomass straw purchase and storage point to the alternative site of the biomass straw Storage and logistics Center to the biomass straw energy utilization project are known.
• The average purchase cost of biomass straw storage point is determined.
• The average management cost and average fixed cost of alternative locations of biomass straw storage and logistics center are determined.
• The supply of each biomass straw purchase and storage point and the demand of each biomass straw power generation project are known.
• The quantity of straw required by each alternative site of biomass straw storage and logistics center shall be supplied by multiple biomass straw purchase and storage sites, and each alternative site of biomass straw storage and logistics center shall not supply each other.
• The purchase and storage point of biomass straw can only be provided to the alternative site of biomass straw storage and logistics center. The storage and logistics center of biomass straw can only provide straw for the biomass straw energy utilization project. The purchase and storage point of biomass straw cannot directly provide straw for the biomass straw energy utilization project.
• Biomass straw logistics refers to the transport from the biomass straw purchase and storage point to the alternative site of the biomass straw storage and logistics center and from the alternative site of the biomass straw storage and logistics center to the biomass straw energy utilization project.
• The data involved in the planning model of biomass straw storage and logistics center are in terms of years.

2.2. Model Variables, Parameters and Definitions

Table 1 shows the variables, parameters, and definitions used in the model.

| variables | defines |
|-----------|---------|
| A         | Quantity of biomass straw storage points |
| B         | Number of alternative locations for biomass straw storage and logistics centers |
| C         | Quantity of biomass straw energy utilization projects |
| D<sub>xy</sub> | The transport unit price from the x biomass straw collection and storage point to the y biomass straw storage and logistics center |
| G<sub>yz</sub> | The transport unit price from the alternative site of the y biomass straw storage and logistics center to the z biomass straw energy utilization project |
| F<sub>xy</sub> | The transportation distance between the x biomass straw collection and storage point and the y biomass straw storage and logistics center |
| I<sub>yz</sub> | The transportation distance from the alternative site of the y biomass straw storage and logistics center to the z biomass straw energy utilization project |
| E<sub>xy</sub> | The quantity of transportation from the x biomass straw collection and storage point to the y biomass straw storage and logistics center |
| H<sub>yz</sub> | The transportation quantity from the alternative site of the y biomass straw storage and logistics center to the z biomass straw energy utilization project |
| L<sub>y</sub> | The biomass straw flow rate at the y alternative site of biomass straw storage and logistics center |
| M<sub>y</sub> | The y biomass straw storage and logistics center alternative site of biomass straw maximum capacity |
| N<sub>z</sub> | The z biomass straw energy utilization power generation project biomass straw demand |
| O         | Average purchase cost of biomass straw (including average cost per ton of biomass straw bale) |
| P         | Average management cost of biomass straw |
| Q         | Average fixed cost of biomass straw |
|          | The construction cost of the alternative site for the y biomass straw storage and |
R<sub>My</sub> logistics center

0-1 variables. When \( S_y = 1 \), the y biomass straw storage and logistics center is selected as an alternative. When \( S_y = 0 \), the y alternative location of biomass straw storage and logistics center was not selected

The maximum number of biomass straw storage and logistics center candidates

U Biomass straw effective storage area
V Average height of biomass straw
\( \rho \) Average density of biomass straw

2.3. Objective Function

Taking the total cost of biomass straw logistics \( Z \) as the objective function, a mixed integer programming model was established:

\[
Z = \sum_{x=1}^{A} \sum_{y=1}^{B} D_{xy} E_{xy} F_{xy} + \sum_{x=1}^{A} \sum_{y=1}^{B} C_{y} H_{yx} f_{yx} + \sum_{x=1}^{A} S_{y} R_{My} + UP + UQ
\]

Objective function, the \( \sum_{x=1}^{A} \sum_{y=1}^{B} D_{xy} E_{xy} F_{xy} \) living material straw from purchasing and PM to warehousing logistics center of alternative transportation cost; \( \sum_{y=1}^{B} \sum_{x=1}^{A} C_{y} H_{yx} f_{yx} \) a living material straw from the warehousing logistics center alternative to energy engineering transport costs; \( \sum_{y=1}^{B} S_{y} R_{My} \) for a living material straw alternative to warehousing logistics center construction cost; The average storage cost of biomass straw consists of average variable cost \( P \) and average fixed cost \( Q \).

By determining the geographical location and maximum capacity of the biomass straw storage and logistics center to minimize the total cost \( Z \) of biomass straw logistics as the objective function, a mixed integer programming model was established:

\[
\text{Min} Z = \sum_{x=1}^{A} \sum_{y=1}^{B} D_{xy} E_{xy} F_{xy} + \sum_{x=1}^{A} \sum_{y=1}^{B} C_{y} H_{yx} f_{yx} + \sum_{x=1}^{A} S_{y} R_{My} + UP + UQ
\]

2.4. Constraints

- The total quantity of biomass straw from the x biomass straw collection and storage point to the y alternative site of biomass straw storage and logistics center is equal to the demand of biomass straw for the z biomass straw power generation project.

\[
\sum_{x=1}^{A} \sum_{y=1}^{B} E_{xy} = \sum_{z=1}^{C} N_z
\]

- The total amount of biomass straw from the alternative site of the y biomass straw storage and logistics center to the z biomass straw energy Utilization project is equal to the demand for biomass straw of the z biomass straw power generation project.

\[
\sum_{y=1}^{B} \sum_{z=1}^{C} H_{yz} = \sum_{z=1}^{C} N_z
\]

- The first x a biomass straw purchase points to the first y a biomass straw warehousing logistics center of the alternative is equal to the first y a total biomass straw biomass straw warehousing logistics center alternative to the z a total biomass straw biomass engineering in the energy utilization of straw and not more than the first y biomass straw warehousing logistics center alternative to biomass straw maximum capacity.

\[
\sum_{x=1}^{A} \sum_{y=1}^{B} E_{xy} = \sum_{y=1}^{B} \sum_{z=1}^{C} H_{yz} \leq \sum_{y=1}^{B} S_{y} M_{y}
\]

- The total quantity of biomass straw from the x biomass straw collection and storage point to the y biomass straw storage and logistics center is equal to the biomass straw flow from the y biomass straw storage and logistics center.

\[
\sum_{x=1}^{A} E_{xy} = S_{y} M_{y} \quad y = 1, 2, ..., B
\]
• The total quantity of biomass straw from the x biomass straw collection and storage point to the alternative site of the y biomass straw storage and logistics center shall not exceed the maximum capacity of biomass straw from the alternative site of the y biomass straw storage and logistics center.

\[ \sum_{x=1}^{A} E_{xy} - S_y M_y \leq 0 \quad y = 1, 2, \ldots, B \]  

(8)

• The biomass straw flow rate of the alternative site of the y biomass straw storage and logistics center is equal to the biomass straw demand of the z biomass straw energy utilization project.

\[ \sum_{y=1}^{B} S_y H_{yz} = N_x \quad z = 1, 2, \ldots, C \]  

(9)

• The biomass straw flow in the alternative site of the y-th biomass straw storage and logistics center is less than the maximum capacity of the biomass straw in the alternative site of the y-th biomass straw storage and logistics center.

\[ \sum_{y=1}^{B} S_y L_y - \sum_{y=1}^{B} S_y L_y \geq 0 \]  

(10)

• The maximum capacity of the biomass straw at the alternative site of the y-th biomass straw storage and logistics center is not less than the biomass straw flow at the alternative site of the y-th biomass straw storage and logistics center.

\[ M_y \geq L_y \quad y = 1, 2, \ldots, B \]  

(11)

• The construction cost of the alternative site of the y-th biomass straw storage and logistics center.

\[ R_{M_y} = \begin{cases} 12000000 & M_y \leq 850000 \\ 15000000 & M_y > 850000 \end{cases} \]  

(12)

• The maximum number of biomass straw storage and logistics center is selected.

\[ T_y \leq B \]  

(13)

• The variables involved in the model are all non-negative.

\[ \begin{cases} A, B, C, D_{xy}, E_{xy}, F_{xy}, G_{yz}, \\ H_{yz}, I_{yz}, L_y, M_y, N_x, O, \\ P, Q, R_{M_y}, S_y, T, U, V \end{cases} \geq 0 \]  

(14)

\[ x = 1, 2, \ldots, A \\
 y = 1, 2, \ldots, B \\
z = 1, 2, \ldots, C \]  

(15)

0-1 variables.

\[ S_y = \begin{cases} 1 \\ 0 \end{cases} \]  

(16)

When \( S_y = 1 \), the y biomass straw storage and logistics center was selected as an alternative. When \( S_y = 0 \), the y alternative location of biomass straw storage and logistics center was not selected.

3. Model Application

In Henan province, Nanyang City, Shangqiu City, Zhumadian City, Xinyang City and Zhoukou City are used to collect and store biomass straw for the convenience of calculation and consideration of biomass straw resources. In 2015, the General Office of Henan Provincial People’s Government named 21 parks as Demonstration logistics parks of Henan Province. Xinyang Jinniu Logistics Industry Cluster, Nanyang Dongshen Pharmaceutical Logistics Park, Nanyang Nanli River Logistics Park and Zhoukou Port Comprehensive Logistics Park are all located in the city where the four biomass straw purchase and storage points are located. Xinyang Jinniu Logistics Industry Cluster, Nanyang Dongshen Pharmaceutical Logistics Park, Nanyang River Logistics Park, Zhoukou Port Comprehensive Logistics Park are selected as alternative sites for biomass straw storage and logistics center. Because the establishment of biomass straw storage and logistics center in the logistics park can get strong support from the policy and infrastructure construction, so as to achieve the lowest total cost of biomass straw logistics. It is required to choose no more than 3 alternative locations of the above 4 biomass straw storage and logistics centers to achieve the lowest total cost of biomass straw logistics.
According to the report of Henan Development and Reform Commission on the progress monitoring of new energy projects in Henan Province in the first quarter of 2019, there are 25 biomass straw energy utilization projects that have been put into production in Henan Province, of which 6 are located in the cities of the 5 biomass straw purchasing and storage sites selected. See Table 2. Select these 6 biomass straw power generation projects, facilitate the transport of biomass straw.

The transport distance (km) from the biomass straw purchase and storage point to the alternative site of the biomass straw storage and logistics center and the supply of the biomass straw purchase and storage point (10,000 tons) are shown in Table 3.

The transportation distance (km) from the alternative site of biomass straw storage and logistics center to the biomass straw energy utilization project is shown in Table 4.

The above transportation distance data can be seen from the query of Aude map, and the data with short time is the transportation distance data. The supply of biomass straw purchasing point, transportation distance and the demand of biomass straw power generation project are all rounded. The transport unit price of biomass straw is set at 0.5 yuan/ton. The purchase cost of biomass straw (including the average cost of biomass straw block) is 500 yuan/ton.

### Table 2  Energy Utilization engineering of biomass straw

| Project Name                          | Installed capacity (10,000 kW) | Straw demand (tons) |
|---------------------------------------|-------------------------------|--------------------|
| Luyi County Biomass Straw Energy Utilization Project | 2.5                           | 20                 |
| Zhoukou Fugou County Biomass straw Energy Utilization Project | 1.2                           | 15                 |
| Gushi County biomass straw energy Utilization project | 1.2                           | 13                 |
| Zhoukou Shenqiu County biomass straw Energy Utilization Project | 1.2                           | 14                 |
| Zhenping County Biomass straw Energy Utilization Project | 2.4                           | 20                 |
| Suixian County biomass straw energy utilization project | 3                             | 30                 |

### Table 3  Transportation distance (km) from the biomass straw purchase and storage point to the biomass straw storage and logistics center and the supply of the biomass straw purchase and storage point (10,000 tons)

| Biomass straw collection and storage point | Biological straw storage and logistics center | Biomass straw purchase and storage point supply |
|-------------------------------------------|----------------------------------------------|-----------------------------------------------|
|                                           | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_{total}$ |
| $A_1$                                    | 207   | 9     | 8     | 247   | 60          |
| $A_2$                                    | 356   | 371   | 382   | 160   | 30          |
| $A_3$                                    | 116   | 200   | 198   | 123   | 20          |
| $A_4$                                    | 6     | 205   | 203   | 226   | 40          |
| $A_5$                                    | 213   | 236   | 247   | 15    | 90          |

### Table 4  Transportation distance (km) from biomass straw storage and logistics center to biomass straw Energy Utilization Project

| Biological straw storage and logistics center | $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ | $C_6$ |
|----------------------------------------------|-------|-------|-------|-------|-------|-------|
| $B_1$                                        | 318   | 269   | 188   | 314   | 238   | 314   |
| $B_2$                                        | 339   | 241   | 376   | 334   | 44    | 335   |
| $B_3$                                        | 345   | 247   | 375   | 340   | 40    | 341   |
| $B_4$                                        | 122   | 85    | 277   | 117   | 291   | 118   |
Lingo program is applied to solve the problem, because lingo can solve the integer programming problem better.

The result is:
The quantity of biomass straw transportation is respectively (ten thousand tons):
E (1, 3) = 20; E (4, 1) = 13; E (5, 4) = 79;
H (1, 3) = 13; H (3, 5) = 20; H (4, 1) = 20;
H (4, 2) = 15; H (4, 4) = 14; H = 30 (4, 6);

Alternative locations for biomass straw storage and logistics centers are as follows:
S (1) = 1; S (2) = 0;
S (3) = 1; S (4) = 1;
Maximum capacity of biomass straw storage and logistics Center (ten thousand tons):
M (1) = 85; M (3) = 85; M (4) = 85;
Construction cost of Biomass Straw Storage and LogisticsCenter (ten thousand yuan):
R (1) = 1200; R (3) = 1200; R (4) = 1200;

Considering the construction cost of biomass straw bales and biomass straw storage and logistics center, the paper selected xinyang Jinniu Logistics Industrial cluster, Nanyang River logistics park and Zhoukou Port comprehensive logistics park as biomass straw storage and logistics center through model calculation.

Xinyang Jinniu Logistics Industry Cluster area biomass straw storage logistics center construction cost of 12 million yuan; The construction cost of the raw material straw storage and logistics center in Nanyanli River Logistics Park is 12 million yuan. The construction cost of biomass straw storage and logistics center in Zhoukou Port comprehensive logistics Park is 12 million yuan. The biomass straw collection and storage point of Nanyang City provided 200,000 tons of biomass straw to Nanyang River Logistics Park. The biomass straw collection and storage point of Xinyang city provides 200,000 tons of biomass straw to Xinyang Jinniu Logistics Industry agglomeration area. The biomass straw collection and storage point of Zhoukou city provided 200,000 tons of biomass straw to Zhoukou Port comprehensive logistics Park.

The biomass straw storage and logistics center of Xinyang Jinniu Logistics Industry Cluster area provided 130,000 tons of biomass straw for the biomass straw energy utilization project in Gushi County. The biomass straw storage and logistics Center in Nanyanli River Logistics Park provided 200,000 tons of biomass straw for the biomass straw energy utilization project in Zhenping County. The biomass straw storage and logistics Center of Zhoukou Port Comprehensive Logistics Park provides 200,000 tons of biomass straw for the energy utilization project of biomass straw in Luyi County. The biomass straw storage and logistics Center of Zhoukou Port Comprehensive Logistics Park provides 150,000 tons of biomass straw for the biomass straw energy utilization project in Fugou County, Zhoukou City. The Biomass straw Storage and Logistics Center of Zhoukou Port Comprehensive Logistics Park provided 140,000 tons of biomass straw for the biomass straw Energy Utilization project in Shenqiu County, Zhoukou City. The biomass straw storage and logistics center in Zhoukou Port comprehensive logistics Park provides 300,000 tons of biomass straw for the biomass straw energy utilization project in Suxian County.

4. Conclusions
A mathematical model of biomass straw logistics was established in a certain region, and the total cost of biomass straw logistics was targeted at the lowest, taking into account the acquisition cost of biomass straw blocks, transportation cost and the construction cost of storage and logistics center. An example is given to verify the feasibility of the model.

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References

[1] Yong Cheol, P., Tae Hyun, K., Jun Seok, K. (2017) Effect of organosolv pretreatment on mechanically pretreated biomass by use of concentrated ethanol as the solvent. J. Biotechnology and Bioprocess Engineering. commun., 22(4).

[2] Rodrigo Morales, V., Renata, B., Rick, G. (2015) Synergistic effects of mixing hybrid poplar and wheat straw biomass for bioconversion processes. J. Biotechnology for Biofuels. commun., 8(1).

[3] Vera Rodrigo, M., Bura, R., Gustafson, R. (2015) Synergistic effects of mixing hybrid poplar and wheat straw biomass for bioconversion processes. J. Biotechnology for biofuels. commun., 8.

[4] Kumar Adepu, K., Parikh Bhumika, S., Pravakar, M. (2016) Natural deep eutectic solvent mediated pretreatment of rice straw: bioanalytical characterization of lignin extract and enzymatic hydrolysis of pretreated biomass residue. J. Environmental science and pollution research international. commun., 23(10).

[5] Adepu, K.K., Bhumika, S., Parikh, Mohanty, P. (2016) Natural deep eutectic solvent mediated pretreatment of rice straw: bioanalytical characterization of lignin extract and enzymatic hydrolysis of pretreated biomass residue. J. Environmental Science and Pollution Research. commun., 23(10).

[6] Xiangqun, X., Zhiqi, X., Song, S., Mengmeng, L. (2017) Lignocellulose degradation patterns, structural changes, and enzyme secretion by Inonotus obliquus on straw biomass under submerged fermentation. J. Bioresource Technology. commun., 241.