Life Cycle Assessment of Straw Solid Particle Molding Fuel Manufacturing Process

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Abstract. Taking a 500,000 t/a straw briquette fuel plant in Baoding area of Hebei Province as an example, this paper establishes a life cycle energy consumption and environmental emission analysis model of straw solid fuel. Based on this model, the energy saving and greenhouse gas emission reduction potential of straw solid particles as typical briquette fuels are quantitatively analyzed. Secondly, the life cycle energy consumption and environmental emissions are analyzed. Finally, from the point of view of energy consumption and environmental emissions, the potential value of environmental impact is calculated by standardization and sensitivity analysis is carried out. The results show that the energy consumption of straw granulation stage (compression molding stage) accounts for the largest proportion in the solid particle manufacturing life cycle, reaching 32.30%. Compared with fossil fuels, solid particles have a large emission reduction advantage, which provides basic data for the utilization of straw solid granular forming fuel.

1. Introduction
China is rich in crop straw resources and forest resources. According to statistics, the annual output of crop straw is about 600 million tons, equivalent to 300 million tons of standard coal, and the forestry residue is about 150 million tons\textsuperscript{[1]}. How to efficiently and comprehensively utilize biomass energy such as crop straw and forestry residues has become an important research topic in various countries.\textsuperscript{[2]} Biomass fuels have the dual characteristics of renewability and environmental friendliness, and are considered as an important energy source in the future sustainable energy system. They can be regarded as a green energy source and a new clean energy source. The biomass processed into solid briquette fuel has the advantages of easy storage and transportation, wider application range, 20\% higher combustion efficiency and less soot pollution. (Use the status quo). For example, Hebei Province is an important commodity grain production base in China, and the high yield of crops brings about the production of a large number of straws. Now Hebei has leapt to the fourth largest straw producing area in China, with a total amount of about 80 million tons, but nearly half of the straw are directly used as fertilizer for returning to the field, only 2\% of which is used as straw energy\textsuperscript{[3]}. It can be seen that the utilization of straw are not mature enough.

In this paper, the life cycle assessment (LCA) method is used to establish the analysis model of straw solid pellet briquette fuel. Aiming at the technology and energy utilization of straw solid briquette fuel in Baoding area, the energy balance relationship and greenhouse gas emissions of straw solid briquette fuel converted into biomass solid briquette fuel are quantitatively evaluated, and the environmental
emission of straw pellet during its life cycle is analyzed. The environmental emissions of straw particles in different stages of their life cycle were analyzed, and the influence of key parameters on the accounting results was determined by sensitivity analysis, thus providing a reference for the correct evaluation of the energy sustainability of biomass solid briquette fuels in China.

2. Modeling

2.1. Formatting the title
Take a biomass solid forming granule factory in Baoding as an example. Its fuel engineering design pellets 2000 t per day (water content 9.91%) and 500,000 t per year. In autumn, the moisture content of straw is 30% - 70% (50% of the middle of the project.). Under the regulation of 2000 tons, 4 000 tons of straw per day and 1 million tons per year are needed. Because a certain amount of straw will be consumed in the actual production pretreatment stage, the consumption of straw is estimated at 110% ratio (based on the life cycle assessment of the environmental impact assessment of biomass energy engineering). The daily consumption of straw is 4400 tons, and the annual demand of straw is 1.1 million tons.

Referring to the actual working conditions of the plant, the LCA boundary division is shown in Figure 1. The life cycle system from straw transportation stage to biomass solid pellet briquette fuel application stage is divided into three stages: straw transportation stage from field to plant transportation stage, biomass solid pellet fuel processing and briquetting stage and biomass solid pellet briquette fuel transportation stage. The boundary is divided as follows:

| A (Straw transportation) | B (Screening) | C (Dry) | D (Crushing and crushing) | E (Screening) | F (Material transportation) | J (screening) | G (Pelletizing) | K (Finished goods bagging) | H (Particle transport) | L (Burning) |
|--------------------------|--------------|---------|---------------------------|--------------|----------------------------|--------------|----------------|-----------------------------|-----------------------|-------------|

**Figure 1 Boundary Division**

2.2. Raw Material Transportation Phase
Straw is mainly transported by diesel trucks with an average fuel consumption of 0.08L/(t.km). The distance of bicycle transportation is calculated by collecting radius model. The calculation method is as follows:

Straw Collection = Total Collection Area × Output of Straw per Unit Planting Area × Ratio of Planting Area to Total Area × Ratio of Straw for Energy

The project is located in Baoding City, Hebei Province, with a total area of 22,100 km²; the maize planting area of 4,613 km²; the total amount of straw collected for the project is 1.1 million tons; and the proportion of straw used for energy is 43% [4]. Reference formula can be obtained, R is the collection radius of straw, m; M is the total amount of straw collected per year, kg; M₀ is the total amount of straw waste per unit area, kg/m²; A is the proportion of crop planting area; and beta is the proportion of straw waste used for energy. The radius of collection is about 10 km. From (1) it can be calculated that the annual diesel consumption in the transportation process is as follows:

\[
R^2 = \frac{M}{\pi M_0 \alpha}
\]

\[
1100000t/a0.08L/(t.km) \times 78.1km = 6872800L/a
\]
2.3. Stage of Straw Production

In the process of solid particle production, it is divided into straw raw material screening, straw drying, straw crushing, straw screening, material transportation, granulation, particle transportation, cooling, particle screening, finished product bagging/warehousing. The energy consumption is calculated by using the corresponding models.

| Machine Type | Motor Power | Production Efficiency |
|--------------|-------------|----------------------|
| GXP130—100   | 220KW       | 5t/h                 |

According to the total amount of straw required and the production efficiency of the high-efficiency crusher, it can be calculated that two equipment are needed to support the operation of the equipment when the equipment is running all year round. Equipment power consumption can be calculated by formula: equipment power consumption = motor power × equipment operation time.

The annual power consumption of the two equipments is 143 x 10^5kWh.

The content of other steps in the straw production process is similar. It is possible to calculate the power consumption of one step and not repeat it again.

3. The energy consumption in each stage of summary

According to the calculation in the table above, the proportion of energy consumption in each stage of straw production is as shown in Table 2.

As shown in Table 2, we can see that in the life cycle of solid particle manufacturing, the proportion of energy consumption in the straw granulation stage (compression molding stage) is the largest, reaching 32.30%, and the proportion in the straw screening stage is the smallest, only 0.05%.

![Figure 2 Proportion of Energy Consumption in Stages of Straw](image)

The final total emission of pollutants is calculated according to the emission coefficients of different materials. The emission coefficients of materials and energy pollutants in this study are as follows:
According to the above table, the total discharge of pollutants can be calculated according to the following formula:

Total emission of pollutants = total amount of materials × corresponding emission coefficient of materials (2).

### Table 3. Total discharge of pollutants (kg / year)

| Project          | CO₂  | SO₂  | CH₄  | NOₓ  | CO  | VOC | PM10 | N₂O |
|------------------|------|------|------|------|-----|-----|------|-----|
| Transport stage  |      |      |      |      |     |     |      |     |
|                          2×10⁵  | 6.5  | 1.7×10⁵ | 4.25×10⁵ | 1.05×10⁵ | 3.25×10⁵ | 1.32×10⁶ | /    |
| Straw             | 6.95×10⁷ | 6.50×10⁷ | 1.70×10⁶ | 4.25×10⁵ | 1.05×10⁵ | 3.25×10⁵ | 1.32×10⁶ | /    |
| The process       | 7.05×10⁷ | 6.50×10⁷ | 1.70×10⁶ | 4.25×10⁵ | 1.05×10⁵ | 3.25×10⁵ | 1.32×10⁶ | 10.45 |

### 4. Environmental impact assessment

The main impact assessment is to identify the environmental impact of quantitative or qualitative evaluation, thus the impact of its external environment to determine the resources consumption and pollutant discharge of the research system.

#### 4.1 Stage of Straw Production

Environmental impact potential (EIP) is the sum of the effects of all similar environmental emissions in the whole system. The environmental impact potential of the same kind of pollutants is converted to the reference substance by equivalent coefficient (Table 4). The environmental impact potential is calculated according to the different types of pollutants.

### Table 4. Major environmental impact types and impact potential

| Impact type          | Material | Impact potential/kg | Impact type          | Material | Impact potential/kg |
|----------------------|----------|---------------------|----------------------|----------|---------------------|
| Global warming       | CH₄      | 21                  | Photochemical pollutants | CO       | 0.03                |
| NOₓ                  | 310      |                     |                      | CH₄      | 0.007               |
| N₂O                  | 290      |                     |                      | VOC      | 0.416               |
Formula for calculating environmental impact potential:
\[ EP(m) = \sum EP(m) n = \sum [Q(m) n EF(m) n] \]  

(3)

Formula (3): EP (m) is the mth environmental impact potential in the product life cycle; EP (m) n is the mth environmental impact potential of the nth emissions; Q (m) n is the nth emissions; EF (m) n is the mth environmental impact equivalent factor of the nth emissions[5]. Potential impacts of various environmental impacts are shown in Table 5.

### Table 5. Emission factors (kg/year)

| Environmental Load Types | Global Warming | Acidification | Photochemical Smoke | Aerosol | Eutrophication | Human Toxicity |
|--------------------------|----------------|---------------|---------------------|---------|----------------|----------------|
| Environmental impact potential | \(2.605 \times 10^8\) | \(9.475 \times 10^7\) | \(1.3954 \times 10^4\) | \(1.32 \times 10^6\) | \(4.25 \times 10^3\) | \(3.32 \times 10^5\) |
| kg/a                     | kg/a           | kg/a          | kg/a                | kg/a    | g/a            | g/a            |

#### 4.2 Sensitivity Analysis

When each process is changed, the impact of energy consumption and environment varies, but it is difficult to quantitatively and qualitatively analyze the specific changes. In this study, the sensitivity analysis is based on the radius of straw transportation and the power data of various straw processing machines (+10%). Based on this, the sensitivity factors in the life cycle of the system are determined. The sensitivity of each data to the results can be obtained by comparing the environmental impact changes caused by the fluctuation of each data. Here, the Sensitivity S formula is set here as follows: 

\[ S = \frac{(\text{evaluation results after changing inventory data}) - (\text{original evaluation results})}{(\text{original evaluation results})} \]

Firstly, the sensitivity of straw gas direct supply scenario was analyzed, and the life cycle assessment was carried out by changing the data of each stage. The results showed as shown in table 10: when the transportation radius changed from 78.1 km to 85.91 km, the change ratio of global warming capacity was 0.09%, and when the power consumption increased by 10%, the change ratio of global warming capacity was 232.56%. The results show that the change ratio of manufacturing process is much larger than that of transportation process, so it is an important problem to solve the problems of energy saving and emission reduction and environmental impact in the manufacturing process before the biomass solid forming technology.

### Table 6. Environmental impact changes before and after changes in parameters (global warming capacity)

| The Stage of Variable Parameters | Parametric Change Items | Range of parameter variation | Parameter unit | Act of Pre-change Environmental Change (Global Warming Capacity) | Impact of post-change environmental change (global warming capacity) | Change ratio (%) |
|----------------------------------|-------------------------|------------------------------|----------------|---------------------------------------------------------------|------------------------------------------------------------------|---------------|
5. Conclusion
1) In the life cycle evaluation of straw solid pellet briquette fuel, the transportation of straw and the screening of straw all need to consume energy. Although the energy consumption of the straw granulation stage (compression molding) is the largest, the volume of the compressed briquette fuel is reduced by 6-8 times, the fuel density is 1.0-1.4 t/m³, the energy density is equivalent to the medium bituminous coal, which improves the transport and storage capacity, facilitates storage and transportation, and can be used efficiently. At the same time, the pollution caused by straw burning in situ is reduced and fossil fuels such as coal are saved.

2) When the parameters change, the straw transportation has less impact on the environment, but it is the most human consumption stage in the whole process of the system; in the straw production stage, after changing the parameters, the impact on the environment is very large. No change is recommended.

3) There is still much room for the development of biomass pellet fuel products, focusing on the research and development of straw granulation technology to improve fuel calorific value.

4) According to the GWP coefficient of global warming potential, the ability of biomass solid particles to global warming is also reduced.

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