Biomass energy from agriculture in China: Potential and evolutionary trend

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Abstract. This paper aims to quantify the biomass energy potential from agriculture, analyze composition and explore evolutionary trend based on the data of 31 Chinese provinces from 1993 to 2016. The results show that: (1) China's biomass energy potential from agriculture increased from 139.42 million metric tons of coal equivalent (Mtce) in 1993 to 196.51 Mtce in 2016, with an average annual growth of 1.57% during the 24-yr period; (2) In terms of resource composition, biomass energy potential from agriculture mainly derived from the straws of rice, wheat and maize that were as high as 60.97% in all different kinds of biomass energy; (3) In terms of evolutionary trend, the biomass energy potential from agriculture displayed an increasing trend, but disparities among the provinces began widening gradually.

1. Introduction
The essence of low-carbon economy is to improve energy efficiency and increase the proportion of clean energy utilization [1]. Agricultural biomass energy, a renewable energy, is a kind of energy contained in biomass that is characterized by less pollution, easy combustion and low ash [2]. Currently, the annual biomass energy potential all over the world is around 200 EJ to 600 EJ, in which biomass energy from agriculture accounts for the highest proportion [3]. Therefore, it is urgent to develop the industry of agricultural biomass energy in order to achieve sustainable development of low-carbon economy.

Compared with developed countries, the industry of China's agricultural biomass energy is still immature. The China’s 13th Five-Year Plan for Biomass Energy Development pointed out that China's agricultural biomass energy development is facing a number of problems, such as the difficulty of efficient collection of raw materials, the low conversion degree, and the shortage of distributed commercial utilization, which seriously prohibit the development of biomass energy industry. Therefore, it is important to know the basic and decisive information about agricultural biomass energy in China, especially on the biomass energy potential. This article aims to quantify the potential of agricultural biomass energy, analyze its composition and explore temporal and regional changes. This research could provide the corresponding theoretical guide for creating a macro-policy of agricultural biomass energy in China in the future, especially for the sustainable supply of raw materials.
2. Methodology and Data

2.1. Methodology

Crop straw and agricultural processing by-product are the main raw materials to produce agricultural biomass energy. Crop straw refers to the harvest residue of crops that mainly include grain crop, economic crop, industrial raw materials crop, feed crop and medicinal materials crop. In this paper, it quantifies the biomass energy potential from straw based on the yields of grain crop and economic crop, because the last three types of crops have not been fully added up and just account for a small proportion of all crop yields in China. Explicitly, we just focus on the agricultural biomass energy coming from the straw of cereal (including rice, wheat, maize and other cereal), beans, tubers, oil-bearing crops (including peanut, rapeseeds, sesame and other oil-bearing crops), cotton, fiber crops, sugar crops (including sugarcane and beetroots) and tobacco. Agricultural processing by-product refers to the residues produced during the primary processing. The majority of residues of agricultural processing in China are rice hull, corncob, peanut shells, bagasse, beet residue and cottonseed hull. Since there is no official statistical data about the yields of the crop straw and agricultural processing by-product in China, therefore, the potential must be calculated according to the data of crop yields.

2.1.1. Method of estimating biomass energy potential of crop straw. The biomass energy potential of crop straw usually can be estimated in four steps: the theoretical potential of biomass resources of crop straw (Q_a), the available potential of biomass resources of crop straw (Q_b), the available potential for producing biomass energy of crop straw (Q_c), and the potential of biomass energy of crop straw (Q_d):

\[
\begin{align*}
Q_a &= \sum_{i=1}^{n} P_i \cdot RPR_i \\
Q_b &= \sum_{i=1}^{n} Q_a \cdot \lambda_i \\
Q_c &= \sum_{i=1}^{n} Q_b \cdot f_i \\
Q_d &= \sum_{i=1}^{n} Q_c \cdot \eta_i
\end{align*}
\]

where, \(i\) is the kind of crop, \(n\) is all the kinds of crops, \(P_i\) is crop yield, \(RPR_i\) is coefficient of grass-grain ratio, \(\lambda_i\) is coefficient of available potential of biomass resources of crop straw, \(f_i\) is coefficient of available potential for producing biomass energy of crop straw, \(\eta_i\) is the coefficient of coal equivalent. Based on the previous research [4], this paper takes the coefficient of the available potential for producing biomass energy of crop straw as 0.5. All other coefficients are shown in Table 1.

| Category               | \(RPR\) (%) | \(F\) (%) | \(H\) (kgce/kg) | Category               | \(RPR\) (%) | \(F\) (%) | \(H\) (kgce/kg) |
|------------------------|-------------|-----------|-----------------|------------------------|-------------|-----------|-----------------|
| Rice straw             | 1.04        | 0.83      | 0.429           | Rapeseed straw         | 2.9         | 0.85      | 0.61            |
| Wheat straw            | 1.28        | 0.83      | 0.5             | Sesame straw           | 1.89        | 0.85      | 0.529           |
| Maize straw            | 1.07        | 0.83      | 0.529           | Other oil-bearing crop straw | 2.63       | 0.85      | 0.584           |
| Other cereal straw     | 2.32        | 0.83      | 0.545           | Fiber crop straw       | 1.73        | 0.87      | 0.6             |
| Beans                  | 1.35        | 0.88      | 0.543           | Sugarcane straw        | 0.34        | 0.88      | 0.494           |
| Tubers                 | 0.53        | 0.8       | 0.432           | Beetroots              | 0.37        | 0.88      | 0.205           |
| Cotton stalk           | 2.87        | 0.9       | 0.543           | Tobacco stalk          | 0.66        | 0.9       | 0.55            |
| Peanut straw           | 0.99        | 0.85      | 0.541           |                        |             |           |                 |

2.1.2. Method of estimating biomass energy potential of agricultural processing by-product. Similarly, the biomass energy potential of agricultural processing by-product can also be estimated in four steps,
i.e. the theoretical potential of biomass resources of processing by-product ($Q_a$), the available potential of biomass resources of processing by-product ($Q_b$), the available potential for producing biomass energy of processing by-product ($Q_c$), and the potential of biomass energy of processing by-product ($Q_d$):

$$
Q = Q_1 + Q_2 \sum_{i=1}^{n} p_i \cdot PRI_i \cdot P' \cdot (\frac{1}{\mu} - PRI'_i) \\
Q = \sum_{i=1}^{n} Q_2 \cdot \lambda_i \\
Q = \sum_{i=1}^{n} Q_2 \cdot f_i \\
Q = \sum_{i=1}^{n} Q_2 \cdot \eta_i 
$$

(2)

where, $Q_1$ is the theoretical potential of biomass resources of rice hull, corn cob, peanut shells, bagasse and beet residue, $Q_2$ is the theoretical potential of biomass resources of cottonseed hulls, $i$ is the $i$-th by-product, $n$ is all types of agricultural processing by-product, $P_i$ is the yield of five kinds of crops, $P'$ is ginned cotton yield, $PRI$ is the coefficient of theoretical potential of biomass resources of processing by-product; $PRI'$ is the coefficient of the theoretical potential of biomass resources of cotton husk processing, $\mu$ is the clothing fraction, i.e., the proportion of ginned cotton in seed cotton, $\lambda_i$ is the coefficient of available potential of biomass resources of processing by-product, $f_i$ is coefficient of available potential for producing biomass energy of processing by-product, $\eta_i$ is the coefficient of coal equivalent. Based on the existing research [5], it is thought that $\mu$, $\lambda$ and $f$ are 0.38, 1 and 0.5, respectively. All other coefficients are shown in Table 2.

### Table 2. Coefficients for estimating biomass energy potential of processing by-product.

|                | Rice hull | Corn cob | Cottonseed hull | Peanut shells | Bagasse | Beet residue |
|----------------|-----------|----------|-----------------|---------------|---------|--------------|
| $PRI$ (%)      | 0.18      | 0.16     | 0.47            | 0.27          | 0.16    | 0.05         |
| $\eta$ (kgce/kg) | 0.49     | 0.60     | 0.60            | 0.59          | 0.60    | 0.57         |

### 2.2. Data

The data of crop yield used in this paper were collected from the China Statistical Yearbook, the China Rural Statistical Yearbook and the China National Bureau of Statistics (www.stats.gov.cn). The research period covered from 1993 to 2016, with a total of 24 years.

### 3. Results

#### 3.1. Temporal trend of biomass energy potential from agriculture in China

The potential of biomass energy from agriculture in China demonstrated a slowly increasing trend in the 24-yr period from 1993 to 2016. Although the resource potential was only 139.42 Mtce in 1993, it reached as high as 196.51 Mtce in 2016, with an average annual growth of 1.57%. In general, the temporal trend of biomass energy potential from agriculture in China can be divided into two stages: the inverted U-shaped stage in 1993-2003 and the rapid growth stage in 2003-2016.

During the 11-yr period from 1993 to 2003, the biomass energy potential from agriculture first exhibited a upward trend, and then entered a slow downward stage. Explicitly, it was 139.42 Mtce in 1993, reached 157.19 Mtce in 1998 (the highest point) and then began to decrease gradually, with the lowest point in 2003, 139.87 Mtce. Comparatively, the biomass energy potential from agriculture greatly increased throughout the study period, from 139.87 Mtce in 2003 to 196.51 Mtce in 2016, with an average annual growth of 2.68%.

#### 3.2. Composition of biomass energy potential from agriculture in China

Biomass energy potential from agriculture in China mainly derived from the straw of rice, wheat and maize, which accounted for 60.97% in all kinds of agricultural biomass energy. However, these three
kinds of biomass energy potential from agriculture presented a completely different changing trend. From 1993 to 2016, the biomass energy potential of rice straw and wheat straw, accounting for 40%, displayed a stable increasing trend. In comparison, the biomass energy potential of maize straw exhibited a different trend during this period, i.e., it presented an upward or downward trend before 2003 and rapidly increased from 2003, 27.21 Mtce, to 2016, 51.57 Mtce.

There were two characteristics of the changing trend of other types of biomass energy potential from agriculture: First, all of them demonstrated a stable trend. There was no obvious increase or decrease from 1993 to 2016. Second, the potential of most kinds of agricultural biomass energy increased gradually, but others decreased. Explicitly, the agricultural biomass energy potential of straw of beans, fiber crops, beetroots and beet residue gradually decreased in the 24-yr period, while other biomass energy potential from agriculture presented an upward trend.

In order to further analyze the composition of biomass energy potential from agriculture in China, this article calculated the average proportion of different types of biomass energy potential from agriculture throughout the study period. As seen in figure 1, the proportion of biomass energy potential of maize straw, up to 21.62%, was the highest, followed by the biomass energy potential of rice straw at 21.57%. The third one was the biomass energy of wheat straw, accounting for 17.78%. Overall, these three kinds of biomass energy potential accounted for 60.97% totally.

In terms of the proportion of other biomass energy potential of crop straw, there was little disparity. Specifically, according to the proportion from the highest to the lowest, they were rapeseed straw (5.37%), sugarcane straw (4.29%), beans (3.78%), other cereals straw (3.70%), cotton stalk (2.37%), tubers (1.87%), peanuts straw (1.91%), other oil-bearing crops straw (1.03%), tobacco stalk (0.2%), beetroots (0.21%), fiber crops straw (0.17%) and sesame straw (0.17%). Furthermore, the biomass energy potential of agricultural processing by-product accounted for 13.88% on average in all the biomass energy potential from agriculture. Explicitly, the biomass energy of rice hull, corncob, bagasse, peanut shells, cottonseed hull and beet residue accounted for 5.14%, 4.42%, 2.79%, 0.67%, 0.78% and 0.09%, respectively.

![Figure 1. Proportion of biomass energy potential from agriculture in 1993-2016.](image)

### 3.3. Regional changes of biomass energy potential from agriculture in China

The method of kernel density was used to analyze regional changes of biomass energy potential across 31 provinces of China. The kernel density curve with five years -1993, 1998, 2004, 2010 and 2016 - was exhibited in figure 2. Based on the curve, the following characteristics were found.

First, the kernel density curve presented a trend of double-peak distribution that the first and second peaks were obvious in five curves. In terms of the kernel density, the values corresponding to the first and second main peak were very low, respectively. Furthermore, the disparity of biomass energy potential between the first and second main peak was not wide. Both of these distribution fully indicated that the biomass energy potential from agriculture in most provinces were similar each other.
Second, the kernel density curve shifted from the left to the right as the time changed. The curve in 1993, 1998, 2010, 2016 shifted to the right obviously that fully denoted that the potential of agricultural biomass energy in China was gradually increasing. Comparatively, the curve in 2004 shifted slightly to the left, but it did not move too much. The reason was that China's government adjusted the supporting policy in the field of agriculture in 2003. On the whole, China’s biomass energy potential from agriculture gradually increased at all the time across all 31 provinces.

Third, the kernel density of the first peak decreased over the five study years. It indicated that the disparity of biomass energy potential from agriculture among all the provinces were gradually widening. In addition, the right parts of five curves became smooth as the time changed. Although the agricultural biomass energy potential of most provinces were slowly increasing, the resource potential in other provinces increased greatly, such as Shandong, Henan, Guangxi, Sichuan, Heilongjiang, Jiangsu. That was the reason for the increasing disparity of biomass energy potential from agriculture among all the provinces.

![Kernel density curve of biomass energy potential from agriculture.](image)

**Figure 2.** Kernel density curve of biomass energy potential from agriculture.

### 4. Conclusion

By analyzing the statistical data in the 24-yr period from 1993 to 2016, we found that: (1) The total biomass energy potential from agriculture increased from 139.42 Mtce in 1993 to 196.51 Mtce in 2016, with an average annual growth of 1.57% and an increase of 40.95% in the past 24 years; (2) In terms of composition, biomass energy potential from agriculture mainly derived from the straw of rice, wheat and maize, accounting for 60.97% in all types of biomass energy; (3) In terms of evolutionary trend, the agricultural biomass energy potential of most provinces showed a gradual increasing trend from 1993 to 2016, while the disparity among all the provinces were gradually widening. Overall, there is a plentiful potential of agricultural biomass energy in China and the resource potential continues to increase steadily. The resources of China's agricultural biomass lay a good foundation for the development of agricultural biomass energy industry. Therefore, it is urgent to establish a long-term and stable supply mechanism according to the total resource potential in the region in order to realize the interactional development between agricultural biomass energy and fossil energy.

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