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# Potential usage, vertical value chain and challenge of biomass resource: Evidence from China's crop residues

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## HIGHLIGHTS

- China owns large quantity of crop residues to develop the renewable energy.
- Priority of using crop residues should be different across provinces.
- Policy supports are critical for the existence of power generation plant.
- Important to increase power generation efficiency and lower the cost of feedstock.

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## ABSTRACT

China's energy needs and its environment are facing great challenges because of the country's rapid urbanization and industrialization. It is China's strategic choice to exploit renewable energy to guarantee its energy security and reduce $CO_2$ emissions. Crop residue has been identified and targeted by the Chinese government as a promising renewable energy resource. The purposes of this study are to investigate the potential supply of crop residue nationally and regionally, the vertical value chain from the field to final usage of these crop residues, as well as to conduct cost-benefit analysis on power plant-based crop residue. Our results show that the large amount of crop residue in China has great potential to meet the country's demand for renewable energy. Crop residues, however, are distributed unequally across regions. Therefore the use of crop residues to produce energy should be different across provinces, especially with respect to large power generation plants. Government supports right now are critical for power plants based on crop residue to survive. Based on our findings, it is suggested that China should attach more importance to technology innovation and creative policy reforms to improve the overall efficiency of the industry and reduce the cost of feedstock.



## 1. Introduction

China is confronting severe challenges to meet its rapidly increasing demand for energy. It is well known that over the past several decades China has experienced remarkable economic growth. The annual growth rate of gross domestic product (GDP) reached 10.4% between 1979 and 2010 [1]. Along with the rapid economic growth, China's energy consumption rose significantly, increasing annually by 9.1% during 1992–2010, which was much faster than the world average of 2.6% [2]. Although great efforts have been made to improve China's domestic energy supply by carrying out market-oriented reforms and promoting production efficiency, China became a net energy importer in 1992 and even then its energy deficit continued to rise rapidly [1]. The dependence on foreign trade of petroleum and natural gas has exceeded 55% and 24% respectively in 2011 [3]. Exploiting new energy sources has become a strategic choice for China in order to secure a reliable energy supply and maintain its high economic growth [4–7].

Meanwhile, China must deal with a deteriorating environment and face the rising pressure to reduce its carbon dioxide ($CO_2$) emission. China's energy consumption is dominated by coal, accounting for 70.5% of total primary energy consumed in 2010 [2]. The use of coal has dropped continuously in recent years [3]. Despite that, because the combustion of coal is the main source of pollution and $CO_2$ emission, China surpassed the USA in 2005

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and now contributes more $CO_2$ emissions than any other country in the world [8]. The severe and worsening environmental problems in China and increasing pressure worldwide to reduce $CO_2$ emissions precludes China from following previous conventional development patterns and suggests that China should make it a priority to develop and use clean energies [9,10].

Crop residues have proved to be one of the most promising clean energy resources for energy supply in China [11,12]. A large amount of crop residues are available in China [13,14] and the supply is expected to keep rising in the future as agricultural production increases [15,16]. Moreover, the significance of power generation from crop residues is not just as an energy supplement. It has great potential to increase farmers' incomes and resolve the serious air pollution caused by burning crop residues in the open field [17,18]. The development of biomass energy has attracted attention both by energy industrialists and policymakers in China. The bio-energy from crop residues has been targeted in the Twelfth Five-Year Plan for national economic and social development.

Researchers have become interested in analyzing the potential use of crop residues and other biomaterials in China because of the country's energy shortage and widespread concerns about environmental issues. While the estimates vary among studies, it is agreed that large amounts of crop residues are available for energy production in China [13,14,19–21]. For example, Shi estimated that in 2007 about 704 million tons of crop residues were available based on 9 crops[1] [13]. The estimate would increase to 840 million tons when herbs and vegetables were further considered [14]. Furthermore, the use of bio-energy in China could lead to a more efficient use of marginal lands to expand agricultural production [13]. However, the development of bio-energy based on crop or crop residue should be region specific because the supply of agricultural residues is spatially heterogeneous [12,21,22].

Despite the large volume of crop residue in China, the outlook for bio-energy is far from optimistic because of high production costs [18,23,24]. For example, Yu and Tao conducted several case studies by using the 3E Life Cycle Assessment (LCA) approach to evaluate the efficiencies of several biomass-based fuel ethanol projects in China. They concluded the ethanol production based on wheat and corn is not economically viable and second-generation biofuel is even less so [18]. Even with high subsidies, the power plants based on crop residues could not compete with their conventional counterparts [23,24].

Given the importance, potential future prospects and many controversial issues, the development of bio-energy based on crop residue in China needs deeper and more systematic study to address development problems, efficient strategies and needed policy supports. Current literature mainly focuses on the availability of crop residues in China. Few studies analyze key factors undermining development. A number of questions remain unanswered. For example, how will the spatial heterogeneity of resources among provinces influence the capacity of power generation? How will it be affected by storage and transportation costs? What are the benefit and cost comparisons of biomass power plants? What are the main constraints and challenges of the development of biomass power plants? Answering these questions has important policy implications for sustainable agricultural and renewable energy economies in China.

The study seeks to determine what key elements affect the development of power generation from crop residues and what technologies and policies would be most effective. To meet our objectives, the paper is organized as follows: Section 2 estimates the potential availability of crops residues nationally and regionally; Section 3 describes the value chains of supplying crop-derived biomass from the crop field to power generation plants; Section 4 uses cost-benefit analysis and sensitivity analysis to highlight key points related to the development of power generation plants from crop residues; and Section 5 provides research conclusions and suggests policy implications.

## 2. The potential of crop residues used for biomass energy

The availability of substantial crop residues provides important opportunities for China to develop biomass energy. Since no official statistics exist on the crop residues and their coal equivalent, China's biomass potential can be estimated from the crop output in two steps. First, the amount of crop residue is estimated by transforming the crop output weighted by residue ratio for each of crops [11,12]. Second, there is evidence that crop residue is discounted depending on the crop because of different collection costs, which are measured by the collection ratio of residue and which vary by 10% across crops from 0.80 for yam to 0.90 for cotton (Table 1). This suggests that the previous estimation of Chinese biomass resources without taking the collection residue ratio into consideration will overestimate the biomass potential [28].

Using the above procedures, the calculated potential of crop residue in China is shown in Table 1. This approach shows 729 million tons of crop residues produced in China in 2010, an estimate that is similar to those produced by Shi [13], Wang and Zhang [19] and Zhang et al. [21]. This amount of crop residue is equivalent in terms of energy content to 364.39 mmt standard coal (Table 1).

The energy stored within agricultural residue is potentially an important resource to increase the energy supply in China. Fig. 1 presents the potential biomass of coal equivalent and coal consumption in the past three decades. Chinese biomass potential is substantial given that the coal equivalent of biomass increased at the annual growth rate of 2.7% from 1978 to 2010 [1]. As discussed previously, this growth rate is expected to be stable and may even increase in the future [29]. While the ratio of potential energy from crop residues to total energy consumption dropped a little bit as the higher growth of energy consumption in 1978–2010, the biomass in China could still supply a large amount of energy, accounting for 11.3% of total energy consumption in 2010 (Fig. 1).

The output and distribution of crop residues, which is highly correlated with crop production structure and cropping intensity, is geographically heterogeneous both across and within provinces [26,30]. As shown in Panel A of Fig. 2, crop residues are mainly concentrated in regions of Northeast (Heilongjiang, Jilin, Inner Mongolia), Central (Hebei, Henan, Shandong, Jiangsu, Anhui and Hubei) and Southwest (Sichuan) China. Interestingly, it is found that many severe energy-deficit regions overlap with regions which have a rich supply of crop residues. As shown in Panel B of Fig. 2, there is an energy shortage in the Eastern and Southern coastal areas (i.e., Hebei, Shandong, Zhejiang, Jiangsu, Fujian and Guangdong) as well as in the Central area (Hubei and Hunan) and in Southwest area (Sichuan) [1,31]. There are obvious overlaps in regions of Hebei, Shandong, Jiangsu, Hubei and Sichuan. No doubt, the bio-energy development provides opportunities both to alleviate the energy deficit and increase farmers' incomes in those regions. Regions in Northeast China with plenty of crop residue and a balanced supply and demand for energy still could increase their energy production to mitigate the overall energy-deficit situation for the entire country.

## 3. The vertical value chain from field to power generation

This section will analyze the vertical value chain of crop residues from field to power generation plants. The entire chain

[1] It includes rice, wheat, maize, other grains, beans, tuber crops, oilseeds, cotton and sugar cane.