Environment for Development

Discussion Paper Series April 2015 ■ EfD DP 15-06

Assessment of the Potential Biomass Supply from Crop Residues in China

Xiaoguang Chen

Sida

EfD
Environment for Development

RESOURCES
FOR THE FUTURE

Environment for Development Centers

Central America
Research Program in Economics and Environment for Development in Central America
Tropical Agricultural Research and Higher Education Center (CATIE)
Email: centralamerica@efdinitiative.org

Chile
Research Nucleus on Environmental and Natural Resource Economics (NENRE)
Universidad de Concepción
Email: chile@efdinitiative.org

China
Environmental Economics Program in China (EEPC)
Peking University
Email: china@efdinitiative.org

Ethiopia
Environmental Economics Policy Forum for Ethiopia (EEPFE)
Ethiopian Development Research Institute (EDRI/AAU)
Email: ethiopia@efdinitiative.org

Kenya
Environment for Development Kenya
University of Nairobi with
Kenya Institute for Public Policy Research and Analysis (KIPPRA)
Email: kenya@efdinitiative.org

South Africa
Environmental Economics Policy Research Unit (EPRU)
University of Cape Town
Email: southafrica@efdinitiative.org

Sweden
Environmental Economics Unit
University of Gothenburg

Email: info@efdinitiative.org

Tanzania
Environment for Development Tanzania
University of Dar es Salaam
Email: tanzania@efdinitiative.org

USA (Washington, DC)
Resources for the Future (RFF)
Email: usa@efdintiative.org

The Environment for Development (EfD) initiative is an environmental economics program focused on international research collaboration, policy advice, and academic training. Financial support is provided by the Swedish International Development Cooperation Agency (Sida). Learn more at www.efdinitiative.org or contact info@efdinitiative.org.

Assessment of the Potential Biomass Supply from Crop Residues in China

Xiaoguang Chen

Abstract

Using a mathematical programming model, we estimated the potential biomass supply from crop residues in China at various exogenously-given biomass prices and identified the areas that are likely to produce crop residues. Our analysis indicated that China can potentially produce about 153.0–244.2 million dry metric tons of crop residues per year when biomass prices are larger than $90 per metric ton. Rice straw is expected to account for about 47% of total residue production across the different biomass prices and residue production scenarios that we considered. Corn stover and wheat straw contribute 28% and 25%, respectively, to total biomass production in China.

Key Words: biomass supply, crop residues, spatial distribution, China

Contents

Assessment of the Potential Biomass Supply from Crop Residues in China

Xiaoguang Chen*

1. Introduction

To fuel its rapidly expanding economy, China's demand for energy increased more than four-fold during the past 30 years. At present, the primary energy source consumed in China is coal, which represents about 66% of China's domestic energy consumption, while crude oil and natural gas account for 19% and 6%, respectively [1]. The remainder (about 9%) of the demand for energy is mainly met by hydropower and renewable energy, including wind, solar PV, and bioenergy. China's heavy reliance on coal as the primary energy source has led to China becoming the world's largest emitter of sulfur dioxide and greenhouse gases (GHG). Currently, China is responsible for about 26% of annual global GHG emissions[1]. Coal combustion in boilers has released a large amount of air pollutants, particularly particulate matter that can be extremely harmful to human health [2-4].

To reduce over-reliance on coal for power and heat generation and to mitigate associated environmental and health problems, China has implemented a series of regulatory policies. The Renewable Energy Law was enacted in 2005, and seeks to promote the utilization of renewable energy so as to reduce coal consumption. The Renewable Energy Law also has a particular focus on the production/consumption of cellulosic biomass that can be co-fired with coal for power generation purposes. In 2012, China published the report *12th Five-Year Plan for Renewable Energy Development*. This report established the goals of meeting 11% of its primary energy consumption from non-fossil fuel sources by 2015, and 15% by 2020, again emphasizing the utilization of cellulosic biomass for electricity generation.[2]

Cellulosic biomass can be derived from agricultural sources, such as crop residues and perennial energy grasses, and forest sources, such as forest residues and woody biomass. Crop

---

* Research Institute of Economics and Management, Southwestern University of Finance and Economics, No 55 Guanghuacun Street, Chengdu, Sichuan 610074 CHINA. Email: cxg@swufe.edu.cn. Financial support from the World Bank and the EfD Initiative of the University of Gothenburg through Sida is gratefully acknowledged.

[1] http://cdiac.ornl.gov/trends/emis/tre_coun.html

[2] The Chinese-language version of the report is available online at: http://www.cnrec.info/zcfg/2013-01-24-2463.html

residues mainly include corn stover, wheat straw, and rice straw. Given that crop residues are by-products of crop production, the collection of crop residues does not compete with food crops for land. Thus, the negative impacts of cellulosic biomass production from crop residues on food prices can be expected to be small. Although cellulosic feedstocks differ substantially in their environmental performance [5], they can offer greater potential for various environmental benefits when compared with the coal they will displace [6]. China is a major producer of corn, wheat, and rice. It produced about 20% of the world's corn and wheat, and 26% of the world's rice, in 2010 [7]. Therefore, China has the potential to produce a large amount of crop residues, which can reduce China's reliance on coal as a major energy source.

Because there are spatial differences in the yields of corn, rice, and wheat, the yields and production costs of corn stover, rice straw, and wheat straw can be expected to differ across regions. Sheehan et al. [8] estimated that there is a 1:1 grain-to-residue relationship between the dry matter of crop grain and the dry matter of crop residues. Harvestable crop residues per unit of land also depend on regional-specific crop production practices. The costs of producing crop residues include fertilizer costs, harvesting costs (such as mowing, baling, and staging) and storage costs, all of which are expected to differ across regions.

Several studies have assessed the technical feasibility of crop residue production in China. Jiang et al. [9] used a GIS-based approach to examine the availability of crop residues in China. They considered residues derived from various crops, including corn, beans, rice, wheat, and others, and showed that China has the potential to supply about 506 million dry metric tons (MT) of crop residues per year. Qiu et al. [10] used remote-sensing data and found that China had 729 million MT of harvestable crop residues in 2010, of which about 147-334 million MT could be used to replace coal, depending on regional competition with the traditional uses of crop residues. Liu et al. [11] discovered that, during the period 1995-2005, about 630 million MT of crop residues could be harvested per year. The difference in the estimated technical availability of crop residues mentioned in these studies can be attributed to several factors, including the set of crops considered, assumptions made about crop-to-residue ratios and residue collection technology, and the data utilized. When estimating the technical potential of crop residues production, the studies mentioned above did not consider the production costs of crop residues and biomass prices. In reality, farmers' willingness to collect crop residues depends critically on the yields and production costs of crop residues as well as on the biomass prices provided in the market. Specifically, the biomass prices offered must cover the costs of collecting crop residues.

In this paper, we first examine the potential supply of each type of crop residue in China at various exogenously-given biomass prices, and then estimate the aggregate supply of crop residues at these prices. As regards crop residues, we consider corn stover, wheat straw, and rice straw. Because of the yield and cost uncertainty, we derive the supply curves of crop residues using alternative assumptions about the production costs of crop residues and residue collection technology. We also examine the spatial mix of crop residues production.

We developed a multi-market, price-endogenous, nonlinear mathematical programming model which we call the Chinese Agricultural Sector Model. The model determines the optimal land allocation among various food/feed crops, crop production and prices in agricultural commodity markets, and the quantity and mix of crop residues that are likely to be produced in China at various exogenously-given biomass prices. In the model, each county is treated as a decision unit for regional land use and crop and biomass production. Land availability, yields and production costs of crops and crop residues are specified differently for each county.

2. Materials and Methods

The numerical simulation model used in this analysis is a multi-market, multi-period, nonlinear mathematical programming model. The model takes into consideration the Chinese agricultural sector and incorporates the trade of agricultural commodities with the rest of the world (ROW). The model considers the markets for primary crop commodities (such as corn, wheat, rice, cotton, etc.) and processed crop commodities (such as vegetable oil, sugar, etc.) and cellulosic biomass derived from crop residues. The key endogenous variables determined in the model are domestic consumption, the international trade of crop commodities, regional land allocation among various crops, and the quantity and mix of crop residues produced. The market equilibrium is determined by maximizing the sum of consumers' and producers' surpluses in the agricultural sector, subject to market clearing conditions and resource availability constraints, assuming that agricultural markets in China are perfectly competitive.

2.1 Algebraic Illustration of the Agricultural Sector Model

For the sake of convenience, in the following model illustration, exogenously-given parameters/data are denoted using lower-case symbols, while endogenously-determined variables are represented by upper-case symbols. The objective function in (1) represents the sum of discounted consumers' and producers' surpluses in the agricultural sector over a planning horizon of T with a discount factor ρ. The consumers' and producers' surpluses are obtained from production, consumption, and international trade of various agricultural commodities:

$$Max:\sum_{0}^{T}e^{-\rho t}\{p_b BMS_t+\sum_i\int_0^{DEM_{t,i}}f^i(.)d(.)+\sum_i\int_0^{EXP_{t,i}}g^i(.)d(.)-\sum_i\int_0^{IMP_{t,i}}h^i(.)d(.)$$
$$-\sum_{r,i}rc_{r,i}LA_{t,r,i}-\sum_{r,i}rs_{r,i}LAR_{t,r,i}\} \qquad (1)$$

The first term in the first line of the objective function (1) represents the revenues from collecting crop residues (BMS_t) at a market biomass price p_b . Biomass price is given exogenously to induce the collection of crop residues. The second integral term denotes the sum of the areas under the demand functions from which consumers derive surplus from the consumption of crop commodities. $f^i(.)$ represents the inverse domestic demand function for crop *i*. $DEM_{t,i}$ denotes the endogenous domestic demand for crop *i* in year *t*. The third integral term represents the areas under the demand functions for exported crops (denoted by $EXP_{t,i}$), while $g^i(.)$ denotes the inverse demand function for exported crop *i* from the ROW. The last integral term in this line accounts for the area under the supply functions for imported crops (represented by $IMP_{t,i}$). The import supply function for crop *i* is represented by $h^i(.)$. We assume that the domestic demand functions, export demand functions, and import supply functions for individual crops are linear and separable. These specifications lead to a quadratic objective function. For simplicity, in the stylized model we do not consider processed goods (such as sugar) which are incorporated into the numerical simulation model. We also do not consider transportation of crops to consumers; thus, crop prices solved by the model represent producer prices at the farm-gate.

The second line in the objective function (1) includes the costs of producing crops and collecting crop residues. The land allocated to crop *i* in county *r* and year *t* is denoted by $LA_{t,r,i}$. The parameter that denotes the production costs of crop *i* in this county is $rc_{r,i}$. A Leontief production function is assumed for crop production. The second term in this line represents the costs of collecting crop residues, where $rs_{r,i}$ and $LAR_{t,r,i}$ denote residue collection costs per unit land and the land under which crop residues are collected, respectively.

$$DEM_{t,i}+EXP_{t,i}\le\sum_r y_{i,r}LA_{t,r,i}+IMP_{t,i} \quad \text{for all } t,i \qquad (2)$$

Constraint (2) is the material balance constraint for each crop, indicating that the sum of domestic and export demands is restricted to the total supply of that crop, which is the sum of domestic production and imports from the ROW. The symbol $y_{i,r}$ denotes the yield of crop *i* per unit of land in county *r*. For simplicity, we assume that crops are homogenous in quality. Therefore, a crop can either be imported from the ROW, or can be exported to the ROW from China.

$$BMS_t \leq \sum_{i,r} yr_{i,r} LAR_{t,r,i} \quad \text{for all } t \tag{3}$$

Constraint (3) relates the total production of crop residues to the regional supply of crop residues. We use $yr_{i,r}$ to denote the yield per hectare of crop residue under crop *i* in county *r*.

$$\sum_{i} LA_{t,r,i} \leq l_r \quad \text{for all } r, t \tag{4}$$

$$LAR_{t,r,i} \leq LA_{t,r,i} \quad \text{for all } t, r, i \tag{5}$$

Constraint (4) states that the sum of land allocated to different food/feed crops in a county ($\sum_{i} LA_{t,r,i}$) cannot exceed total land availability in that county (represented by l_r).

Constraint (5) requires that the land from which crop residues are harvested cannot exceed the amount of land allocated to the crop which produces that particular type of crop residue.

Lastly, constraint (6) below requires that all endogenous variables should be non-negative.

$$BMS_t, DEM_{t,i}, EXP_{t,i}, IMP_{t,i}, LA_{t,r,i}, LAR_{t,r,i} \geq 0 \tag{6}$$

The model defined by (1)-(6) is a nonlinear (quadratic) mathematical program with linear constraints. Following Chen and Önal [12], we also impose historical crop mix constraints to avoid extreme specialization in regional land use and crop production.

2.2 Model Specification

The empirical model includes ten major crops produced in China (corn, soybeans, wheat, cotton, peanuts, rice, sugarcane, sugar beets, potatoes, and rapeseed) and various processed crop products (such as vegetable oil, sugar, soy meal, etc.). It also considers several types of crop residues (corn stover, rice straw, and wheat straw) as cellulosic biomass. Primary crops can be consumed domestically, traded with the ROW, or processed into final products.

The model considers each county to be a decision unit for crop and biomass production. Each county is represented by a profit-maximizing producer who allocates available production resources (such as land) among a specified set of production activities to maximize the total net returns from producing various crops and crop residues. Row crops can be produced in various rotations with other row crops (such as continuous corn and corn-soybean rotations). The model considers land as the only limited resource endowment, while other inputs for crop and crop residue production can be purchased from markets at fixed market prices.

2.3 Data

County-specific total crop production and historical planted acres of major crops for the years 2000 through 2010 were obtained from the National Bureau of Statistics of China (NBS), which covers 2,570 Chinese counties. Crop yields were computed as total county-level production divided by the respective planted acres in each county. We used ten-year (2001-2010) average crop yields for each county as the representative crop yields for that county. We computed the sum of the planted acres of major crops in 2010 as the total land availability for each county. The costs of crop production were obtained from the crop budgets compiled by the NBS and were used to construct county-level crop production costs. Crop production costs include the costs of inputs such as seeds, inorganic and organic fertilizers, and chemicals; the costs of irrigation, machinery, fuels, and repairs; interest payments for loans; and labor costs.

Yields and the production costs of crop residues differ across regions. County-specific crop residue yields were computed based on the grain-to-residue ratios of the dry matter of crop grains to the dry matter of crop residues, grain moisture content, and residue collection rates, which are dependent on tillage practices. The grain-to-residue ratio is assumed to be 1:1 for corn stover and 1:1.5 for wheat straw and rice straw. We assume that the moisture content of the grain is 15%, which is similar to the assumption made in Sheehan et al.[8] and Graham et al. [13]. Following Malcolm [14], we assume that 50% of the residues can be collected if conservation tillage is practiced, and 30% of the residues can be removed from the soil if conventional tillage is practiced. Because the removal of crop residues from the soil may lead to the loss of nutrients and soil organic matter, collecting crop residues results in additional costs for fertilizer. Residue collection also involves harvesting and storage costs. Given the lack of relevant information on crop residue production costs in China, we used the average crop residue production costs for the U.S. as reported in Chen et al. [15] as the benchmark assumption. We consider alternative scenarios regarding the production costs of crop residues to test the robustness of our results to this assumption.

Domestic and export demand functions and import supply functions are specified differently for each crop, and are assumed to be linear. These demand and supply functions were calibrated using prices, consumption, exports, and imports of crop commodities in 2010. We compiled the data on crop prices, consumption, and trade from various sources, including the U.S. Foreign Agricultural Service[3] and the China Customs Statistics Yearbook in 2010, while elasticities were obtained mainly from China's Agricultural Policy Simulation Model [16].

Table 1. Simulated and observed land allocation in 2010 (million hectares)

	Observed	Simulated	% deviation
Corn	29.4	25.0	-15.2
Soybeans	9.3	9.7	4.1
Wheat	22.0	21.5	-2.0
Rice	25.4	24.9	-2.1
Cotton	4.1	4.2	2.6
Peanuts	5.4	6.0	11.8
Sugar beets	0.2	0.2	2.6
Sugarcane	1.6	1.6	0.1
Potatoes	6.3	6.2	-1.1
Rapeseed	7.4	7.6	3.4

3. Results

Before proceeding to examine the potential supply of crop residues, we first validated the mathematical programming model by comparing model results for land allocated to different crops in China with observed values for 2010. As shown in Table 1, we found that the model can accurately simulate farmers' land use decisions. The percentage differences between simulated and observed land allocation for major crops are typically less than 5%, with exceptions for corn and peanuts, where the percentage differences are -15.2% and 11.8%, respectively.

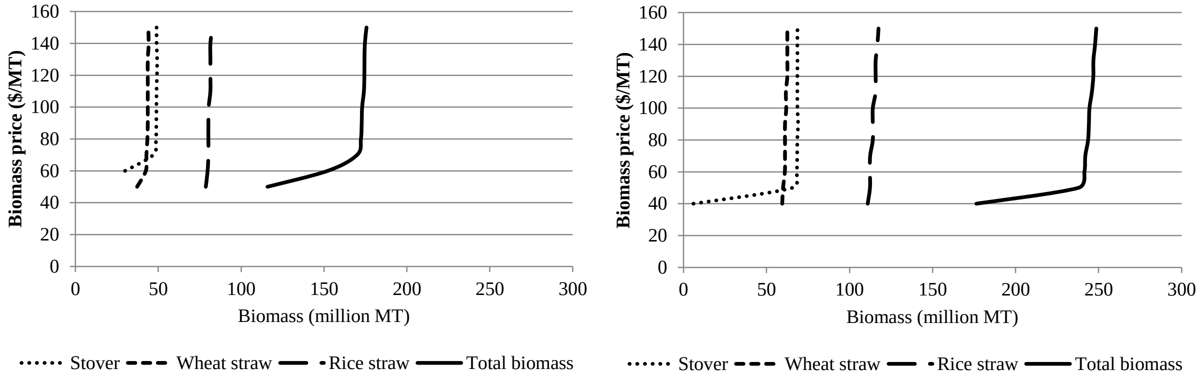
We then estimated the supply of crop residues in four different scenarios at various biomass prices that are exogenously given and range from \$20/MT to \$150/MT. Specifically, in Scenario (1), we first considered a case with low production costs of crop residues, as described in Chen et al. [15]. In Scenario (2), we considered a scenario with high residue collection rates.

---

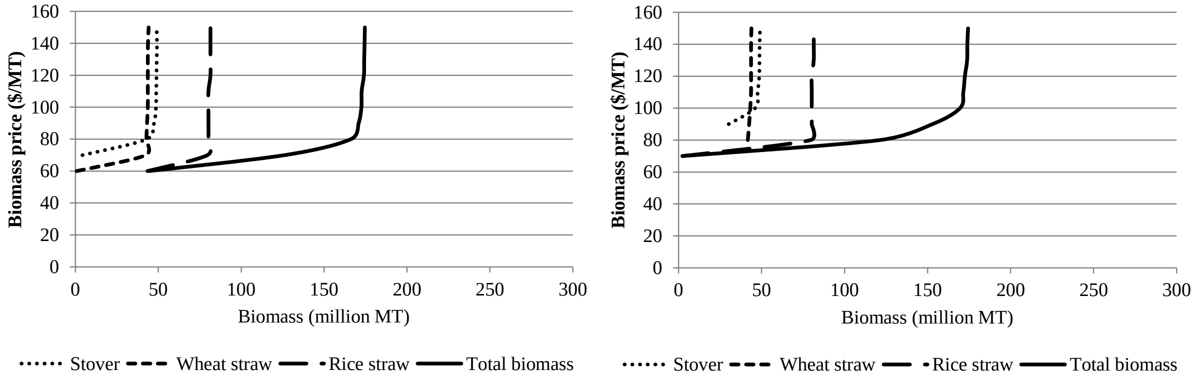
[3] http://www.fas.usda.gov/regions/china

We assumed that 50% of corn stover can be collected if conventional tillage is practiced and that 70% of corn stover can be collected if conservation tillage is used. Residue collection rates for wheat straw and rice straw were assumed to be 70% in this scenario. In Scenarios (3) and (4), we assumed that residue production costs were 25% and 50%, respectively, higher than what was assumed in Scenario (1). Figure 1 shows the aggregate supply and mix of crop residues that are likely to be collected in 2010 at various biomass prices in different scenarios.

Figure. 1 Supply of crop residues under different scenarios and different biomass prices



(a) Low production costs of crop residues (b) High residue collection rates



(c) 25% higher production costs (d) 50% higher production costs

3.1 Supply of Crop Residues under Different Scenarios

Figure 1 shows that biomass prices of $40-70/MT would be needed to induce Chinese farmers to collect crop residues, depending on the scenario. In Scenario (1), with low production costs of crop residues, the production of crop residues is expected to be economically viable at a biomass price of $50/MT. In Scenario (2), with assumed high residue collection rates, a biomass price of $40/MT would be required to trigger residue collection. In Scenarios (3)-(4), where crop residue production becomes very costly, biomass prices of $60-70/MT would be needed to make the collection of crop residues economically viable.

China can potentially supply about 175.6 million MT of crop residues per year, consisting of corn stover, wheat straw, and rice straw at a biomass price of $150/MT in Scenario (1). At the same biomass price, total residue production would increase by 42%, relative to Scenario (1), to 248.6 million MT in Scenario (2) with high residue collection rates. When considering pessimistic views about the production costs of crop residues in Scenarios (3)-(4), total residue availability would decrease slightly (less than 1%) to 174.6 and 174.4 million MT, respectively, compared with Scenario (1). That is the case because the economic returns from the collection of crop residues are considerably larger than the associated residue production costs at a biomass price of $150/MT, despite assumed high production costs in these two scenarios.

As shown in Figure 1, we find that, once it becomes economically viable to produce crop residues, the supply of crop residues does not change much as biomass price increases. For instance, when the biomass price increases from $50/MT to $150/MT, rice straw production only increases from 78.7 to 82.7 million MT in Scenario (1), while wheat straw production increases from 37.2 to 44.0 million MT in that scenario. Rice straw and wheat straw represent about 47% and 25%, respectively, of the total biomass production in this scenario. In comparison with wheat straw and rice straw, corn stover is more costly to produce; a biomass price of $60/MT would be required to make it economically viable. Corn stover production ranges between 30.0-49.0 million MT when the biomass price increases from $60/MT to $150/MT, accounting for roughly 28% of the total biomass production after it becomes economically viable to produce.

We find that the supply curves of crop residues are very steep in other scenarios as well. Rice straw production increases from 112.3 million MT to 117.5 million MT when the biomass price increases from $50/MT to $150/MT in Scenario (2). With the same level of biomass price increase, wheat straw production increases from 60.0 million MT to 62.5 million MT, while corn stover production increases from 65.6 million MT to 68.7 million MT. The residue production in Scenario (2) is about 40% larger than the corresponding residue production in Scenario (1). In Scenarios (3)-(4), which feature high production costs for the crop residues, we find that biomass prices of $60-70/MT would be needed to induce farmers to collect crop residues. However, when biomass prices exceed $100/MT, the quantities of each type of crop residue collected in these two scenarios are quite close to residue production in Scenario (1).

3.2 Land Requirements for Crop Residue Production at Different Biomass Prices

Table 2 shows land used for residue collection when biomass prices are $60/MT and $100/MT. At a biomass price of $60/MT, about 44.2 million hectares of land under corn, wheat, and rice can be expected to be utilized for collecting crop residues in Scenario (1). As compared to Scenario (1), the land used for residue collection would increase by 24% to 54.7 million hectares in Scenario (2) with high residue collection rates. When the production costs of crop residues are high in Scenario (3), only 8.5 million hectares of the land under corn, wheat, and rice would be used for residue collection at a biomass price of $60/MT. It is not economically viable to collect crop residues in Scenario (4) at a biomass price of $60/MT. When biomass price is $100/MT, the differences in land used for collecting crop residues under different scenarios become small, ranging between 52.7 and 55.6 million hectares.

The amount of crop residues produced varies substantially across the scenarios considered here when the biomass price is $60/MT. In Scenario (1), total biomass production is 115.6 million MT. In Scenario (2), about 241.5 million MT of crop residues would be supplied, whereas collecting crop residues is not economically feasible in Scenario (4) with assumed high production costs for residues. In Scenario (3), total biomass production is 44.2 million MT at the biomass price of $60/MT.

Table 2. Land used for crop residues collection under various production conditions

	Biomass price ($/MT)	Scenario(1)	Scenario(2)	Scenario(3)	Scenario(4)
Corn stover	60	12.1	22.0	0.0	0.0
(million hectares)	100	22.3	22.4	22.0	20.2
Wheat straw	60	13.7	14.1	0.2	0.0
(million hectares)	100	14.1	14.3	14.1	14.0
Rice straw	60	18.5	18.6	8.3	0.0
(million hectares)	100	18.6	18.9	18.6	18.6
Total biomass	60	152.3	241.5	44.2	0.0
(million MT)	100	173.0	244.5	172.5	169.5

3.3 Spatial Distribution of Crop Residue Production

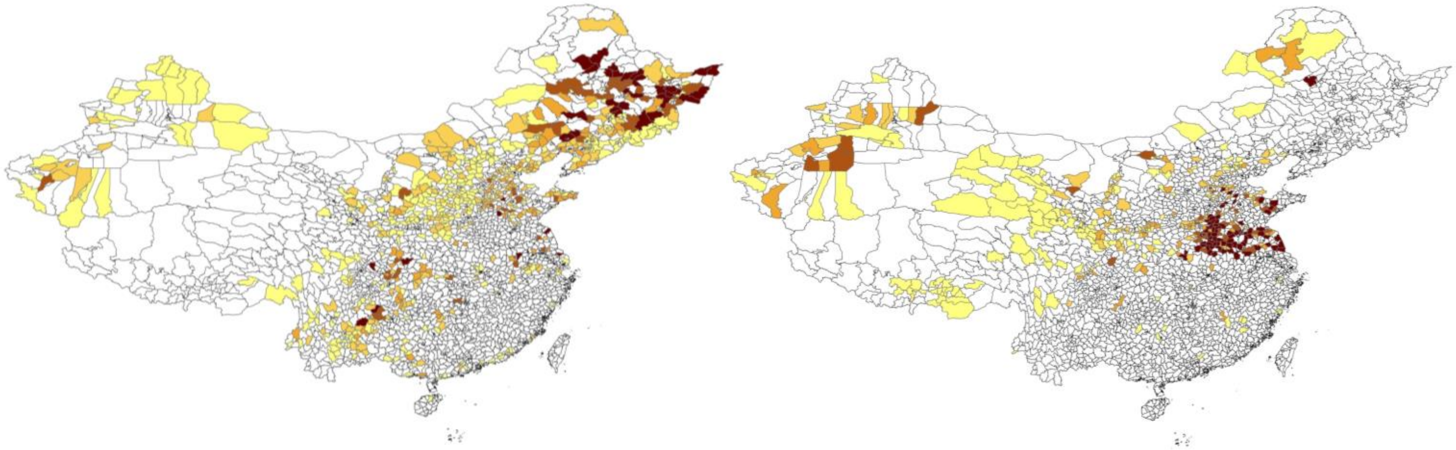
Figure 2 shows the spatial distribution of crop residue collection in Scenario (1) when biomass price is $100/MT. As shown in Figure 2(a), three northeastern provinces (Heilongjiang, Jilin, and Liaoning) and Central China are likely to be the main areas for corn stover collection, because of cost and yield advantages. These regions account for about 60% of total corn stover production at the biomass price of $100/MT. Figure 2(b) shows that the production of wheat straw is fairly concentrated in Central China and the Northwest inland area (including the Xinjiang Uygur Autonomous Region, Shan'xi, and Gansu). More than 80% of total wheat straw is produced in these regions. Figure 2(c) shows that the collection of rice straw is expected to occur in regions with yield and cost advantages for the production of rice, primarily in the southern part of the country and Heilongjiang (a major rice-producing region in the northeastern China). Therefore, considering corn stover, wheat straw, and rice straw as cellulosic biomass, the regional supply of cellulosic biomass in China is expected to be widely distributed across the country (see Figure 2(d)).

4. Conclusions

In this paper, we developed a mathematical programming model to evaluate the potential supply of crop residues in China. Our results indicated that the supply of crop residues in China depends on biomass prices and crop residue production conditions. We find that China can produce 174.4-248.6 million MT of crop residues annually at a biomass price of $150/MT. Total residue production increases significantly with higher residue collection rates. Among the chosen set of crop residues considered in the model, rice straw is likely to be the main biomass type, representing about 47% of total residue production across the various biomass prices and production conditions considered. Corn stover and wheat straw can potentially contribute 28% and 25%, respectively, to total biomass production in China.

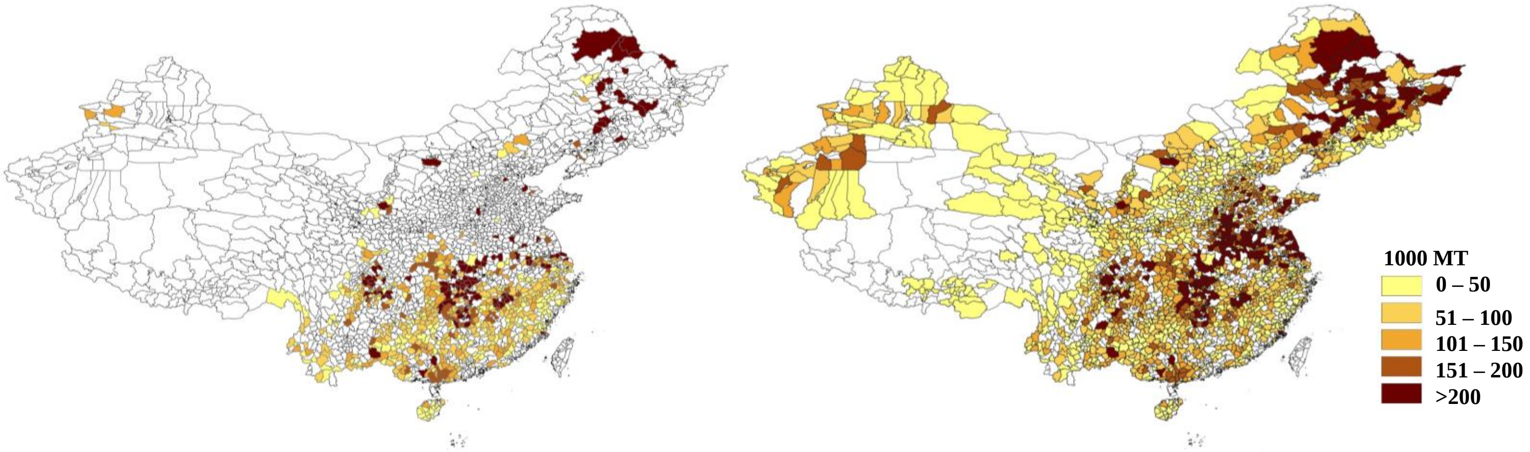
To incentivize Chinese farmers to collect crop residues for bioenergy purposes, biomass prices of $40-50/MT would be required under the baseline production conditions. When the production costs of crop residues are assumed to be high, considerably higher biomass prices (about $60-70/MT) would be needed to induce crop residue collection, which are consistent with the findings in studies which have analyzed cellulosic biomass supply in other countries [17-20].

Figure. 2 Spatial distribution of crop residues at the biomass price of $100/MT in Scenario (1) (Unit: 1000 MT)



(a) Corn stover

(b) Wheat straw



(c) Rice straw

(d) Total production of crop residues

When estimating the potential supply of crop residues in China, our analysis uses the production costs of crop residues in the U.S. as the baseline and considers scenarios with higher residue production costs. Because production conditions of crop residues are expected to differ substantially between the U.S. and China, our estimates of total residue availability might turn out to be larger or smaller than the estimated residue production in Scenario (1). We find that supply curves of crop residues are fairly steep and the differences in estimated total biomass availability across scenarios differ only modestly (except for Scenario (2)), which suggests that our results are not very sensitive to the assumptions made about residue production costs.

References

EIA. 2014. Independent Statistics & Analysis.

Chen, Y., A. Ebenstein, M. Greenstone, and H. Li. 2013. Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China's Huai River Policy. Proceedings of the National Academy of Sciences.

Dockery, D.W., C.A. Pope, X. Xu, J.D. Spengler, J.H. Ware, M.E. Fay, et al. 1993. An Association between Air Pollution and Mortality in Six U.S. Cities. *New England Journal of Medicine*. 329: 1753-9.

Chen, Z., J.-N. Wang, G.-X. Ma, and Y.-S. Zhang. 2013. China Tackles the Health Effects of Air Pollution. *The Lancet* 382: 1959-60.

Chen, X., H. Huang, and M. Khanna. 2012. Land-use and Greenhouse Gas Implications of Biofuels: Role of Technology and Policy. *Climate Change Economics* 3: 1250013.

Loeffler, D., and N. Anderson. 2014. Emissions Tradeoffs Associated with Cofiring Forest Biomass with Coal: A Case Study in Colorado, USA. *Applied Energy* 113: 67-77.

FAO. 2012. FAOSTAT-Agriculture. Food and Agricultural Organizations of the United Nations. Available online at: http://www.fao.org/corp/statistics/en/. Food and Agricultural Organizations of the United Nations.

Sheehan, J., A. Aden, K. Paustian, K. Killian, J. Brenner, M. Walsh, et al. 2003. Energy and Environmental Aspects of Using Corn Stover for Fuel Ethanol. *Journal of Industrial Ecology* 7: 117-46.

Jiang, D., D. Zhuang, J. Fu, Y. Huang, and K. Wen. 2012. Bioenergy Potential from Crop Residues in China: Availability and Distribution. *Renewable and Sustainable Energy Reviews* 16: 1377-82.

Qiu, H., L. Sun, X. Xu, Y. Cai, and J. Bai. 2014. Potentials of Crop Residues for Commercial Energy Production in China: A Geographic and Economic Analysis. *Biomass and Bioenergy* 64: 110-23.

Liu, H., G.M. Jiang, H.Y. Zhuang, and K.J. Wang. 2008. Distribution, Utilization Structure and Potential of Biomass Resources in Rural China: With Special References of Crop Residues. *Renewable and Sustainable Energy Reviews* 12: 1402-18.

Chen, X., and H. Önal. 2012. Modeling Agricultural Supply Response Using Mathematical Programming and Crop Mixes. *American Journal of Agricultural Economics* 94: 674-86.

Graham, R.L., R. Nelson, and J. Sheehan.2007. Current and Potential U.S. Corn Stover Supplies. *Agronomy Journal* 99: 1-11.

Malcolm, S. 2008. Weaning Off Corn: Crop Residues and the Transition to Cellulosic Ethanol. The Transition to a BioEconomy: Environmental and Rural Development Impact. St. Louis, MO.

Chen, X., H. Huang, M. Khanna, and H. Onal. 2014. Alternative Transportation Fuel Standards: Welfare Effects and Climate Benefits. *Journal of Environmental Economics and Management* 67: 241-57.

Huang, J., Y. Jun, Z. Xu, S. Rozelle, and N. Li. 2007. Agricultural Trade Liberalization and Poverty in China. *China Economic Review* 18: 244-65.

Egbendewe-Mondzozo, A., S.M. Swinton, R.C. Izaurralde, D.H. Manowitz, and X. Zhang. 2013. Maintaining Environmental Quality while Expanding Biomass Production: Sub-regional U.S. Policy Simulations. *Energy Policy* 57: 518-31.

Egbendewe-Mondzozo, A., S.M. Swinton, C.R. Izaurralde, D.H. Manowitz, and X. Zhang. 2011. Biomass Supply from Alternative Cellulosic Crops and Crop Residues: A Spatially Explicit Bioeconomic Modeling Approach. *Biomass and Bioenergy* 35: 4636-47.

Khanna, M., X. Chen, H. Huang and H. Onal. 2011. Supply of Cellulosic Biofuel Feedstocks and Regional Production Pattern. *American Journal of Agricultural Economics* 93: 473-80.

Chen, X., and L. Li. 2014. Supply of Cellulosic Biomass in Illinois and Implications for the Conservation Reserve Program. *GCB BioEnergy* (forthcoming).