Availability of lignocellulose from forestry waste for use as a biofuel in China

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Abstract

Biomass is a very important renewable energy and plays an important role in the energy structure of China. Here, the role of forestry waste in producing energy in China was analyzed and the availability of forestry waste for biofuel production, theoretically collectable amounts of forest biomass, and density of forestry waste were assessed. Agricultural and forestry waste are important biomass resources. The potential for using forestry waste as a low cost substrate for producing fuel ethanol using existing forestry resources and techniques was analyzed, and the feasibility of producing fuel ethanol in different Chinese provinces was assessed using the specific situation for each province. The results showed that 1081.73×10^6 t of forestry waste could be produced in China, and 270.43×10^6 t (25% of the amount that could be collected) could be used to produce fuel ethanol. Assuming 10 t of sawdust could be converted into 1 t of ethanol, 27×10^6 t of ethanol could be produced from forestry waste. Different provinces have different potentials for producing ethanol from forestry waste, Guangdong Province, Guangxi Province, Sichuan Province, and Yunnan Province having higher potentials than the other provinces. It was predicted that 4478×10^6 t of fuel ethanol could be produced from woodcraft waste by 2020, and the provinces with the most potential were found to be Fujian Province, Heilongjiang Province, Jilin Province, Shanxi Province, Sichuan Province, Xinjiang Province, and Yunnan Province. Using forestry waste to produce ethanol could alleviate the energy shortage in China.

Keywords Biomass · Fuel ethanol · Forest waste · Potential analysis · Regional difference

Introduction

Many governments and corporations around the world have become increasingly engaged in the biofuel industry since the early 2000s. The biofuel industry has grown for complex and multidimensional reasons, but the pursuit of energy security is certainly one of the reasons. The demand for fossil fuels continues to grow, and supplies are relatively limited, so governments are searching for every possible way of increasing the amounts of energy their countries can produce. Governments are also interested in biofuels because

they will allow energy consumption to increase without increasing CO₂ emissions to the atmosphere (Wang 2011). The government of Brazil and other major biofuel producers see producing biofuels as a way of supporting the politically powerful farming sector, although the governments of some countries are concerned about the effects of producing biofuels on food prices and, therefore, food security for the poor.

China is energy-poor, so the Chinese government is attempting to develop and expand its biofuel program. Previously, the Chinese biofuel industry mainly produced bioethanol from maize and other grains. Annual bioethanol and biodiesel production in China reached 1.8×10^6 and 0.5×10^6 t, respectively, in 2010. Biofuels are currently mainly used for ground transportation, but demand for aviation biofuel is increasing. The Chinese government annual bioethanol and biodiesel production targets for 2020 are 10×10^6 and 2×10^6 t, respectively.

The global food crisis in 2006–2008 changed the Chinese biofuel development strategy. Concerns about increasing food prices and national food security triggered a moratorium on building new biofuel production plants. The Chinese

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government decided by the end of 2007 to revise its biofuel development strategy, and then decided there should be no trade-off between biofuels and food security, i.e., biofuel production should not compete with the production of grain for consumption.

China has a national biofuel development program that involves developing non-grain feedstocks (Sharma 2013; Zeng et al. 2002). Oil-bearing forest plants and lignocellulose are two major potential sources of biofuel feedstocks. In a recent study we showed that large areas in China are potentially suitable for producing major oil-bearing forest plants but that the areas that could actually be used to produce oil-bearing forest plants do not offer much promise when social and economic constraints and land-use regulations are taken into consideration (Huang and Qiu 2010). The Chinese government has also considered using lignocellulose as a biofuel feedstock (Liu and Shen 2007).

Several issues need to be analyzed and assessed before biofuel production from lignocellulose can be increased. For example, it is important to identify the major potential agricultural and forestry waste sources of lignocellulose and to quantify these potential sources. It is also important to determine the locations of these lignocellulose sources and identify how they are currently used. The availability of each lignocellulose source for use as a biofuel feedstock and the major constraints on the production of biofuel from lignocellulose also need to be determined. This information is critical to appropriate biofuel development programs being developed by decision makers in both the government and industry. This study was designed to provide information to address most of the issues described above.

Given the background described above, the overall goals of this study were to analyze the availability of lignocellulose in forestry waste for use as a biofuel feedstock and to provide appropriate recommendations for the future development of a lignocellulose-based biofuel program in China. The amounts of lignocellulose resources that could be used as biofuel feedstocks and the distributions, allocations, and current uses of these resources were assessed, and the potential for biofuel production in the future was also assessed.

Materials and methods

Measurements and key parameters

Estimating the availability of forestry waste required several steps. The first step was to estimate the forest biomass based on the forest area. The theoretical amount of forest biomass was calculated using the equation $FB_j = A_j \times r_j$, where FB_j is the biomass of forest category j , A_j is the area of forest category j , and r_j is the productivity of forest category j . The second step was to estimate the amount of forestry

waste produced each year in each Chinese province. The total amount of forestry waste produced in China was taken from the National Energy R&D Center for Non-food Biomass website. The proportion of forestry waste in forest biomass can be calculated by dividing the forestry waste mass by the forest biomass. Forestry waste in each province was estimated using the equation $FW_n = FB_n \times P$, where FW_n is the total amount of forestry waste produced in province n . The third step was to calculate the commercial potential of forestry waste by multiplying the total amount of forestry waste produced in each province by the unused share of forestry waste (u). We used collection coefficients of 25 and 50% and unused forestry waste utilization for biofuel production rates of 25, 50, and 75%, meaning we used six groups of data to evaluate the use of forestry waste for biofuel production in China.

A flowchart of the process used to estimate the potential amount of forestry waste that could be used to produce biofuel in China is shown in Fig. 1.

Data description

Several datasets were used to estimate the availability of forestry waste. The areas of major forest categories in each Chinese province were taken from a Chinese forestry biomass energy development document (2011–2020) published by the Chinese State Forestry Administration. This document contained data from the seventh national forestry survey performed between 2004 and 2008. Biomass per unit area data for major Chinese forests were taken from an unpublished study that we performed, and hydrothermal conditions and commercial potential coefficients were taken from previous publications.

Areas of major forest categories in the Chinese provinces

More than 200×10^6 ha are forested in China (Table 1). Inner Mongolia has the highest afforested area (26.34×10^6 ha), followed by Yunnan Province (20.48×10^6 ha), Sichuan Province (20.61×10^6 ha), Heilongjiang Province (19.78×10^6 ha), and Tibet (17.27×10^6 ha). The main forest category in China is broad-leaved forest, which accounts for 64.44% of the afforested land.

Forest productivity

The productivity of a forest depends on the climate zone the forest is in. China has seven climate zones according to Xiao (2005). The climate zones are shown in Supplementary Table S1. Most parts of China are in temperate, warm temperate, and subtropical zones.

Fig. 1 Flowchart of the process used to estimate the availability of forestry waste for use producing biofuel

Table 1 Areas of major forest categories in China (million hectares). Source: (SFA 2013)

Province	Conifers	Broad-leaved forest	Conifers and broad-leaved mixed forest	Bamboo forest	Shrubbery	Total
Hebei	0.46	2.88	0.08	0.00	1.00	4.80
Shanxi	0.23	1.72	0.18	0.00	1.20	3.99
Inner Mongolia	0.10	16.81	0.68	0.00	7.00	26.34
Liaoning	0.61	3.61	0.06	0.00	0.60	5.04
Jilin	0.05	7.27	0.12	0.00	0.20	7.95
Heilongjiang	0.07	19.13	0.16	0.00	0.10	19.78
Jiangsu	0.15	0.74	0.00	0.00	0.00	1.06
Zhejiang	0.57	3.94	0.04	0.80	0.30	5.80
Anhui	0.29	2.71	0.07	0.30	0.40	3.93
Fujian	0.51	5.66	0.09	1.00	0.20	7.93
Jiangxi	0.60	7.68	0.04	0.90	0.20	9.52
Shandong	0.49	1.56	0.07	0.00	0.10	2.54
Henan	0.26	2.83	0.06	0.00	0.60	4.14
Hubei	0.28	5.08	0.12	0.20	1.40	7.43
Hunan	0.79	7.27	0.14	0.60	1.40	11.08
Guangdong	0.65	6.79	0.14	0.40	0.70	8.98
Guangxi	0.99	8.07	0.15	0.30	2.50	12.46
Hainan	0.46	0.84	0.00	0.00	0.00	2.36
Sichuan	0.50	11.65	0.50	0.50	7.30	20.61
Guizhou	0.24	3.98	0.19	0.10	1.30	6.44
Yunnan	0.84	14.72	0.52	0.10	3.80	20.48
Tibet	0.00	8.41	0.29	0.00	8.50	17.27
Shaanxi	0.58	5.67	0.29	0.00	1.80	9.43
Gansu	0.13	2.13	0.17	0.00	3.40	6.54
Qinghai	0.00	0.36	0.07	0.00	3.30	3.82
Ningxia	0.02	0.11	0.02	0.00	0.40	1.01
Xinjiang	0.17	1.69	0.40	0.00	4.60	7.20
Sum of provinces	10.04	153.31	4.65	5.2	52.3	237.9
Percentage in Total (%)	42.2	64.44	1.95	2.19	21.98	100

The productivities of different forest categories in different provinces are shown in Supplementary Table S2. Generally speaking, the better the hydrothermal conditions the higher the productivity of a forest. Cold–warm coniferous forests, including larch forests and spruce and fir forests, are mainly found in southwest and northeast China, where soil moisture conditions are suited to such forests. Such forests can have biomass productivities of 4–15 t/(ha a). Warm coniferous forests are adapted to the semi-arid and semi-humid conditions found in northwest China and can have productivities of 4–13 t/(ha a). Warm coniferous and mixed broad-leaved forests, mainly represented by Korean pine and broad-leaved forests, are found in the Changbai Mountains and Lesser Khingan Mountains in northeast China. These forests can have productivities of 14–16 t/(ha a). Warm coniferous forests are often found in subtropical hilly and mountainous areas with good hydrothermal conditions and can have productivities of 17–20 t/(ha a). The hydrothermal conditions in subtropical and tropical regions are the best conditions for forests in China, and the dominant forest categories in such areas are evergreen broad-leaved forests and rainforests, and mangrove forests in coastal areas. These forests have the highest productivities, of 19–26 t/(ha a).

Amount of forestry waste produced in China as a whole

Data from the National Energy R&D Center for Non-food Biomass (<http://necb.cau.edu.cn/>) (Supplementary Table S3) suggest that the total amount of forestry waste produced through wood processing could be $131.17 \times 10^6 \text{ m}^3$, equivalent to $113.6 \times 10^6 \text{ t}$. Branches and other waste produced during forest harvesting are likely to be the main components of forestry waste. It has been found that $>900 \times 10^6 \text{ t}$ of forestry waste is produced during tree felling. About $68.13 \times 10^6 \text{ t}$ of forest resources can be obtained through urban landscaping and commercial forest management. In total, $1081.73 \times 10^6 \text{ t}$ of forestry waste is produced in China each year. It is not possible to collect all of the forestry waste because more than half of the waste may be difficult to collect. We therefore used collection coefficients of 25 and 50%.

Forestry waste collection coefficients

Wang (2007) found that 35–45% of forestry waste is unused (Supplementary Table S4) and that 5–8% of collectable forest biomass is used as panels by industry and in agriculture, 10–15% is used for energy, 42–48% is used for making paper, and 6–10% is used as a raw material. The unused forestry waste could be available for producing biofuel. We used three scenarios, 75, 50, and 25% of the unused share, when calculating the availability of forest biomass.

Results and discussion

Theoretically available and collectable amounts of forest biomass

A total of about $2490 \times 10^6 \text{ t}$ of forest biomass is produced in China each year (Table 2). The biomass is mainly produced in Guangdong Province, Guangxi Province, Sichuan Province, and Yunnan Province, which together account for 53.14% of the biomass produced in China. A little less biomass is produced in Hunan Province, Inner Mongolia, and Jiangxi Province, and all seven provinces together produce 68.78% of the biomass produced in China.

Total and collectable amounts of forestry waste

The amount of forestry waste produced in each province is shown in Table 3. Most of the forestry waste is produced in Guangdong Province, Guangxi Province, Hunan Province, Inner Mongolia, Jiangxi Province, Sichuan Province, and Yunnan Province.

The amount of collectable forestry waste produced in each province is also shown in Table 3. Not all forestry waste can be collected and used, more than half of forestry waste being difficult to collect. Using collection coefficients of 50% and 25%, This article estimated that 540.87×10^6 and $270.43 \times 10^6 \text{ t}$, respectively, of collectable forestry waste is produced each year in China.

Availability of forestry waste for biofuel production

The availabilities of forestry waste in each province under each of the three scenarios are shown in Table 4. About $216 \times 10^6 \text{ t}$ of forestry waste could be collected assuming a collection coefficient of 50%, and $108 \times 10^6 \text{ t}$ of forestry waste could be collected assuming a collection coefficient of 25%. However, it is unreasonable to assume that all collected unused forestry waste could be used for biofuel production. We therefore performed further calculations assuming that 75, 50, or 25% of the unused forestry waste was used for biofuel production. Six groups of data were therefore produced. The groups with the highest, lowest, and median values were used in the density calculations.

Density of forestry waste for use producing biofuel in China

The density data for forestry waste for use producing biofuel in China are shown in Table 5. The mean densities for groups C1, C2, and C3 for the whole of China were 68.21, 34.10, and 11.37 t/km^2 , respectively. Group C2 would therefore be

Table 2 Amount of forest biomass for major categories in China (million tons). Source: author's conclusion

Province	Conifers	Broad-leaved forest	Conifers and broad-leaved mixed forest	Bamboo forest	Shrubbery	Total
Yunnan	10.1	382.7	8.3	2.6	98.8	502.5
Sichuan	5.0	174.8	6.5	7.5	109.5	303.3
Guangxi	14.9	209.8	2.4	7.8	65.0	299.9
Guangdong	9.8	176.5	2.2	10.4	18.2	217.1
Jiangxi	6.0	115.2	0.4	13.5	3.0	138.1
Hunan	7.9	109.1	1.7	9.0	0.0	127.6
Inner Mongolia	0.3	84.1	4.1	0.0	35.0	123.4
Heilongjiang	0.2	95.7	1.0	0.0	0.5	97.3
Guizhou	2.9	63.7	2.9	1.6	20.8	91.8
Hubei	2.8	61.0	1.2	2.4	16.8	84.2
Fujian	7.7	50.9	1.4	9.0	1.8	70.8
Tibet	0.0	33.6	1.7	0.0	34.0	69.4
Shaanxi	2.9	39.7	2.3	0.0	12.6	57.5
Anhui	3.5	27.1	1.0	3.0	4.0	38.6
Jilin	0.2	36.4	0.7	0.0	0.0	37.3
Gansu	0.7	12.8	0.0	0.0	20.4	33.8
Xinjiang	0.5	8.5	0.0	0.0	23.0	32.0
Hebei	2.3	20.2	0.0	0.0	7.0	29.5
Henan	1.3	19.8	0.5	0.0	4.2	25.9
Liaoning	3.1	18.1	0.0	0.0	3.0	24.1
Hainan	0.0	21.8	0.0	0.0	0.0	21.8
Shanxi	1.2	12.0	0.0	0.0	8.4	21.6
Qinghai	0.0	1.4	0.0	0.0	13.2	14.6
Shandong	2.5	10.9	0.6	0.0	0.7	14.6
Jiangsu	1.5	10.4	0.0	0.0	0.0	11.9
Ningxia	0.1	0.6	0.0	0.0	0.0	0.6
Zhejiang	0.0	0.0	0.0	0.0	0.0	0.0
Total	86.97	1796.54	38.97	66.8	499.9	2489.2

ideal, meaning that the ideal collection coefficient was 25% and the percentage of unused forestry waste available for biofuel production was 75%.

For the ideal situation C2, the provinces of China could be divided into five groups according to the density of forestry waste for use producing biofuel. Group 1 contained very high-density areas ($> 70 \text{ t/km}^2$), which included Guangdong Province, Guangxi Province, and Yunnan Province. Group 2 contained high-density areas ($40\text{--}70 \text{ t/km}^2$), which included Guizhou Province, Jiangxi Province, and Sichuan Province. Group 3 contained medium-density areas ($20\text{--}30 \text{ t/km}^2$), which included Anhui Province, Fujian Province, Hainan Province, Hebei Province, Henan Province, Hubei Province, Hunan Province, and Jiangsu Province. Group 4 contained low-density areas ($15\text{--}20 \text{ t/km}^2$), which included Gansu Province, Heilongjiang Province, Inner Mongolia, Jilin Province, Liaoning Province, Shaanxi Province, Shandong Province, and Shanxi Province. Group 5 contained extremely low-density areas ($< 15 \text{ t/km}^2$), which included

Ningxia Province, Qinghai Province, Tibet, Xinjiang Province, and Zhejiang Province.

Distribution of factories corresponding to the biomass resources available for biofuel production

The density data for forestry waste available for biofuel production allowed the suitability of each Chinese province for siting biofuel production facilities to be assessed. The best provinces in which to site factories were Guangdong Province, Guangxi Province, and Yunnan Province. The eleven provinces in medium- or high-density areas (Anhui Province, Fujian Province, Guizhou Province, Hainan Province, Hebei Province, Henan Province, Hubei Province, Hunan Province, Jiangsu Province, Jiangxi Province, and Sichuan Province) are suitable for siting factories. Gansu Province, Heilongjiang Province, Inner Mongolia, Jilin Province, Liaoning Province, Shaanxi Province, Shandong Province,

Table 3 Total and collectable amount of forest wastes (million tons). Source: author's conclusion

Province	The amount of forest wastes	Collectable amount of forest wastes under the following assumptions	
		50% ^a	25%
Hebei	12.80	6.40	3.20
Shanxi	9.38	4.69	2.35
Inner Mongolia	53.64	26.82	13.41
Liaoning	10.47	5.24	2.62
Jilin	16.20	8.10	4.05
Heilongjiang	42.29	21.15	10.57
Jiangsu	5.15	2.58	1.29
Zhejiang	0.00	0.00	0.00
Anhui	16.76	8.38	4.19
Fujian	30.78	15.39	7.70
Jiangxi	60.03	30.02	15.01
Shandong	6.36	3.18	1.59
Henan	11.23	5.62	2.81
Hubei	36.57	18.29	9.14
Hunan	55.46	27.73	13.87
Guangdong	94.36	47.18	23.59
Guangxi	130.32	65.16	32.58
Hainan	9.49	4.75	2.37
Sichuan	131.78	65.89	32.95
Guizhou	39.90	19.95	9.97
Yunnan	218.38	109.19	54.60
Tibet	30.15	15.08	7.54
Shaanxi	24.99	12.50	6.25
Gansu	14.70	7.35	3.68
Qinghai	6.36	3.18	1.59
Ningxia	0.27	0.13	0.07
Xinjiang	13.89	6.94	3.47
Total	1081.73	540.87	270.43

^aCollection coefficients are assumed by the author

and Shanxi Province just met the basic requirements for siting factories. The densities in the remaining provinces were too low for forestry waste to be used effectively to produce biofuel.

Potential production of bioethanol under the C2 conditions

The analysis described above indicated that it would be appropriate to establish factories in Anhui Province, Fujian Province, Guangdong Province, Guangxi Province, Guizhou Province, Hainan Province, Hebei Province, Henan Province, Hubei Province, Hunan Province, Jiangsu Province, Jiangxi Province, Sichuan Province, and Yunnan Province. The amount of forestry waste available for producing biofuel

in each province is shown in Table 6. About 1 t bioethanol can be refined from 10 t of forestry waste using current techniques. The potential bioethanol yield is, therefore, one-tenth of the amount of forestry waste available for biofuel production. The data shown in Table 6 suggest that about 6.40×10^6 t of bioethanol could be produced each year in China and that more bioethanol could be produced in Yunnan province than in the other Chinese provinces.

The fossil fuel supply crisis and ecosystem deterioration have caused developed countries to start changing their energy supply strategies from being based on fossil fuels to being based on bioenergy. The development and use of bioenergy will also allow the energy supply crisis and environmental pollution in China to be addressed (Bai et al. 2007). Bioenergy is expected to become one of the key energy resources that will be used in future to mitigate global warming and produce energy as fossil fuel resources become exhausted. Various bioenergy production techniques have been developed in China in recent decades, but different techniques are used to very different degrees (Wu et al. 2010). A wide range of biomass is available in China, and biomass can be divided into three categories, agricultural residues, firewood and manure, and organic matter (Zhang and Lei 1997).

This article calculated the maximum potential for forest residues to be used to produce fuel ethanol using only current conditions. This article used assumed forestry waste collection coefficients, and the commercial potential recovery factors were taken from previous publications. The data may be biased because of the local hydrothermal conditions used and because of factors such as land type and traffic, but the bias will generally have had little effect on the conclusions. The geographical distribution of biomass resources and the quantities of biomass produced will depend mainly on the relationship between agricultural zones and climatic conditions (Shen et al. 2010).

There have been many constraints on the development and use of biofuels in China. Appropriate policy guidance and restrictions are required, and research into new biofuel production techniques needs to be performed. Biomass resources are not uniformly distributed in China, and the qualities of the resources are also not uniformly distributed. A great deal of biomass is not used to produce energy, although the amount used to produce energy varies between regions. Measures therefore need to be taken to develop biofuel industries in each part of China to suit the local conditions to allow the resources to be used sustainably. Resource use and biofuel production techniques will need to be improved to achieve this. In summary, China has great potential biomass resources, but relatively little biomass is used to produce biofuel because biomass offers little in the way of technical and economic advantages. It has therefore been suggested that the most appropriate biofuel

Table 4 Forestry wastes for biofuel production in China (million tons). Source: author's conclusion

Province	Unused forest wastes		Availability of forestry wastes under the following assumptions					
	50% ^a	25% ^a	75% ^b		50% ^b		25% ^b	
			50% ^{ac}	25% ^{ac}	50% ^a	25% ^a	50% ^a	25% ^{ac}
Hebei	2.56	1.28	1.92	0.96	1.28	0.64	0.64	0.32
Shanxi	1.88	0.94	1.41	0.71	0.94	0.47	0.47	0.24
Inner Mongolia	10.73	5.36	8.05	4.02	5.36	2.68	2.68	1.34
Liaoning	2.10	1.05	1.57	0.79	1.05	0.52	0.52	0.26
Jilin	3.24	1.62	2.43	1.22	1.62	0.81	0.81	0.41
Heilongjiang	8.46	4.23	6.35	3.17	4.23	2.11	2.12	1.06
Jiangsu	1.03	0.52	0.77	0.39	0.52	0.26	0.26	0.13
Zhejiang	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anhui	3.35	1.68	2.51	1.26	1.68	0.84	0.84	0.42
Fujian	6.16	3.08	4.62	2.31	3.08	1.54	1.54	0.77
Jiangxi	12.01	6.00	9.01	4.50	6.00	3.00	3.00	1.50
Shandong	1.27	0.64	0.95	0.48	0.64	0.32	0.32	0.16
Henan	2.25	1.12	1.69	0.84	1.12	0.56	0.56	0.28
Hubei	7.32	3.66	5.49	2.74	3.66	1.83	1.83	0.91
Hunan	11.09	5.55	8.32	4.16	5.55	2.77	2.77	1.39
Guangdong	18.87	9.44	14.15	7.08	9.44	4.72	4.72	2.36
Guangxi	26.06	13.03	19.55	9.77	13.03	6.52	6.52	3.26
Hainan	1.90	0.95	1.43	0.71	0.95	0.47	0.48	0.24
Sichuan	26.36	13.18	19.77	9.89	13.18	6.59	6.59	3.30
Guizhou	7.98	3.99	5.99	2.99	3.99	1.99	2.00	1.00
Yunnan	43.68	21.84	32.76	16.38	21.84	10.92	10.92	5.46
Tibet	6.03	3.02	4.52	2.26	3.02	1.51	1.51	0.75
Shaanxi	5.00	2.50	3.75	1.88	2.50	1.25	1.25	0.63
Gansu	2.94	1.47	2.21	1.10	1.47	0.74	0.74	0.37
Qinghai	1.27	0.64	0.95	0.48	0.64	0.32	0.32	0.16
Ningxia	0.05	0.03	0.04	0.02	0.03	0.01	0.01	0.01
Xinjiang	2.78	1.39	2.08	1.04	1.39	0.69	0.69	0.35
Total	216.35	108.17	162.26	81.13	108.17	54.09	54.09	27.04

^aThe collection coefficients assumed by the author^bThe utilization of the forestry wastes for biofuel production^cThe selected groups for density calculation

production techniques should be identified, that research and development of biofuel production techniques should be promoted, and that management of the biofuel industry should be improved (Zhang et al. 2009).

Conclusions

China is facing two serious problems, energy shortage and environmental pollution, as are developed countries. These problems are affecting the development of the Chinese economy and improvements in living conditions. However, China has huge biomass resources (NDRC 2014). This article found that unused agricultural and forestry waste account

for 51.9 and 45.8% of total waste available for use producing energy in China (Sharma 2013).

There could be as much as 1081.73×10^6 t of forestry waste produced in China each year. This is 46.87% of total forest biomass. As much as 270.43×10^6 t of forestry waste could be used to produce fuel ethanol assuming that a collection coefficient of 25% can be achieved. Assuming 10 t of sawdust can be converted into 1 t of ethanol, 27×10^6 t of fuel ethanol could be produced each year. About 2490×10^6 t of forest biomass is produced each year in China. Factories for producing biofuels from forestry waste will be best established in Anhui Province, Fujian Province, Guangdong Province, Guangxi Province, Guizhou Province, Hainan Province, Hebei Province, Henan Province, Hubei Province, Hunan Province, Jiangsu Province, Jiangxi Province,

Table 5 The density of forestry wastes for biofuel production in China (t/km²). Source: author's conclusion

Province	Density of forestry wastes for biofuel production		
	C1	C2	C3
Hebei	40.00	20.00	6.67
Shanxi	35.26	17.67	5.89
Inner Mongolia	30.55	15.27	5.09
Liaoning	31.19	15.60	5.20
Jilin	30.57	15.28	5.09
Heilongjiang	32.08	16.03	5.34
Jiangsu	73.02	36.51	12.17
Zhejiang	0.00	0.00	0.00
Anhui	63.97	31.98	10.66
Fujian	58.22	29.13	9.71
Jiangxi	94.60	47.30	15.77
Shandong	37.56	18.78	6.26
Henan	40.72	20.36	6.79
Hubei	73.85	36.90	12.30
Hunan	75.08	37.55	12.52
Guangdong	157.62	78.81	26.27
Guangxi	156.89	78.44	26.15
Hainan	60.38	30.13	10.04
Sichuan	95.91	47.96	15.99
Guizhou	92.93	46.44	15.48
Yunnan	159.95	79.98	26.66
Tibet	26.20	13.10	4.37
Shaanxi	39.77	19.88	6.63
Gansu	33.72	16.88	5.63
Qinghai	24.97	12.49	4.16
Ningxia	3.86	2.08	0.69
Xinjiang	28.92	14.46	4.82
National average	68.21	34.10	11.37

Sichuan Province, and Yunnan Province. Bioethanol production of 6.40×10^6 t/a could be achieved in China using forestry waste from these provinces, in which 53.14% of all Chinese forestry waste is produced. Only slightly less forestry waste is produced in Hunan province, Inner Mongolia, and Jiangxi Province than in the provinces just mentioned. Seven provinces together account for 68.78% of the forestry waste produced in China. Not all forestry waste can be collected and used, and more than half of the forestry waste produced is difficult to collect. Collecting and using forestry waste effectively is therefore a problem. Solving this would play a part in relieving the energy crisis in China and to a certain extent decrease atmospheric pollution.

The National Development and Reform Commission of China has set bioenergy development goals with three deadlines (2010, 2015, and 2020). The bioethanol production goal for 2015 was 4×10^6 t, and the goal for 2020 is 10×10^6 .

Table 6 The potential production of bioethanol in provinces suitable for factories. Source: author's conclusion

Province	Forest wastes for biofuel production (million tons)	Potential production of bioethanol (million tons)
Yunnan	16.38	1.64
Guangdong	7.08	0.71
Guangxi	9.77	0.98
Sichuan	9.89	0.99
Jiangxi	4.5	0.45
Guizhou	2.99	0.30
Hunan	4.16	0.42
Hubei	2.74	0.27
Jiangsu	0.39	0.04
Anhui	1.26	0.13
Hainan	0.71	0.07
Fujian	2.31	0.23
Henan	0.84	0.08
Hebei	0.96	0.10
Total	63.98	6.40

The 2015 was not achieved, and with current progress in developing biofuel production the 2020 goal is going to be difficult to reach. Large amounts of forestry waste are available for producing biofuel, but collecting forestry waste from remote mountainous areas is difficult because of a lack of transportation and increasing labor costs.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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