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Prospects, obstacles and solutions of biomass power industry in China

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ABSTRACT

Biomass power is one of the most important renewable energy sources in China. In order to provide a reference for China's biomass power planning, this paper builds a power sector-planning model using the Long-range Energy Alternatives Planning System (LEAP). The results show that in the base scenario, the installed capacity of agricultural and forestry residues, municipal solid waste and biogas will increase to 22350 MW, 21150 MW, and 4900 MW, respectively by 2030. From the point of view of total volume, biomass supply is not a constraining factor for biomass power source. However, there are some social and economic factors that impede the development of the biomass power industry, some of which may not be addressed in the short term. Therefore, the development of the biomass power industry in China is a long-term process. Some policy suggestions were proposed, including reasonable planning and more subsidies for biomass supply value chain.

1. Introduction

President Trump's decision to withdraw from the Paris Agreement poses a significant threat to climate change mitigation. However, China announced that it would maintain its commitment to reduce emissions and take more responsibility for environmental issues (Yu et al., 2018). The Paris climate agreement aims at keeping the temperature increase to well below 2 °C and countries were encouraged to submit Intended Nationally Determined Contributions outlining their post-2020 climate action (Rogelj et al., 2016). In recent years, China has emerged as a more positive participant in international climate change (Hilton and Kerr, 2017). As the largest energy consuming and carbon dioxide emitting country, China's economy will continue to grow in the coming years (Li and Lin, 2013; Li et al., 2017). World Bank (2018) forecasted that the economic growth rate of China will continue to be higher than 6% before 2020. During 2020–2030 the economic growth rate would be between 4.5% and 6% (Yuan et al., 2017).

In recent years, coal consumption has shown a slight decrease, but coal-fired power still dominates the power generation mix (Li et al., 2015). The Chinese government has announced that it will reduce CO_2 emissions per unit of GDP by 60%–65% from the 2005 level by 2030 and raised the share of non-fossil energy in primary energy consumption to about 20 percent (Hui et al., 2017). Therefore, in order to reduce emissions and guarantee energy security, the development of more renewable energy is required. In China, biomass energy used in the traditional ways (such as rural space heating and cooking) is still higher than that in the modern way (such as biomass power and biofuel) (Pan et al., 2018). Compared with wind and solar energy, there are numerous options for utilizing biomass resources. There are various kinds of biomass materials, such as agricultural and forestry residues, municipal solid waste, animal manure and energy crops. In the rural areas of China, many people still use biomass for cooking and warming homes by direct burning (Song et al., 2018). According to the China Renewable Energy Industry Development Report (2017a), the most common means of industrial utilization of biomass in China is biomass power. As a country with abundant biomass resource, the development of biomass power is part of the actions to fulfill the emissions reduction target. According to the materials and technologies applied, there are different kinds of biomass power technologies, which include agricultural and forestry residue power, biogas power, municipal solid waste power, biomass co-combustion power, and biomass gasification power. The last two technologies, biomass co-combustion power, and biomass gasification have had very little

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application. In China, the common biomass materials for biomass power are agricultural and forestry residues, such as crop straws and wood residues. The biomass power industry is mainly located in the northeast and central China with abundant biomass resources (such as Henan province, Hubei province and Heilongjiang province).

Fig. 1 presents the development of the three main kinds of biomass power in China in recent years. Compared with agricultural and forestry residue power and municipal solid waste power, the total installed capacity of biogas power was relatively low. As a major developing country with an enormous rural population, the development of the biomass power industry in China can boost the rural economy by using agricultural and forestry residues and providing more job opportunities. Except for municipal solid waste and industrial organic waste, most biomass resources are distributed across rural areas. Fig. 2 presents the total amount of main biomass resources in China. All biomass materials had been converted into coal equivalent for easy comparison. Crop straw is the largest biomass resource, reaching320million tons coal equivalent in one year. Municipal solid waste is the least resource, with only 12 million tons coal equivalent.

At the end of the year 2016, China National Energy Administration released “The Thirteenth Five-Year Plan of Biomass Energy Development”, which sought to encourage the development of biomass power in regions with abundant biomass resources. The local government, Henan provincial government invited enterprises to participate in promotional activities, proposed preferential policies and recommended them to invest in the biomass energy industry. Biomass power can use different biomass materials for power generation in an environmentally friendly manner. It can also address the growing need for baseload generation capacity in China. However, the development of biomass power industry might increase the demand for energy crops. The higher requirement for commodity crops may see increased use of monocultures, which involves a small range of high yielding varieties and a reduction in mixed cultures with diverse minor crops and local landraces (Snapp and Pound, 2017). It was found that increased use of monocultures may also lead to a decline in soil quality and biodiversity (Arredondo-Ruiz et al., 2014). Meanwhile, system drainage, boiler supply system drainage or fixed drainage in the project production process may have negative impacts on the local environment. Toxic emissions may also occur during waste-to-energy incineration. Therefore, from the perspective of environmental impacts, there are also some negative aspects to the development of biomass energy.

In previous studies, many scholars have studied biomass power in China from different points of view, such as cost, policies, existing issues, and future prospects. In contrast with other

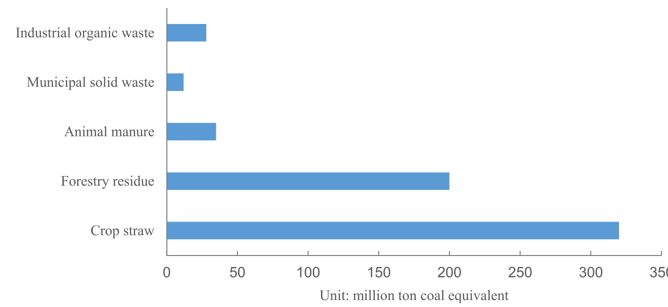

Fig. 2. The amount of available biomass resources in China.

renewable energy sources, the planning of the biomass power industry is more meaningful considering the constraint of materials and the complementarity with other renewable energy sources. Currently, there are many studies on power sector planning in China. However, due to the relatively small total installed capacity and different kinds of biomass power technologies, few studies have focused on biomass power planning. In order to provide support for China's biomass power planning, this paper mainly focuses on different kinds of biomass power technologies in China. According to the simulation results, we can quantitatively analyze the prospects of bioenergy in China's power sector. A few previous studies had analyzed the problems of biomass power industry from different points of view, such as technology, cost-effectiveness, market environment, and policies. These are common issues in most renewable energy technologies. However, the development of biomass energy requires the supply of biomass material, which is related to many social factors, industrial structure, and people's lifestyle. This is different from other renewable energies and has been rarely discussed. Considering the differences between biomass power and other renewable energy sources, the main obstacles to the biomass power industry may not only be technology, cost, and policies. In this paper, we further discuss other factors that affect the development of biomass power and provide some suggestions for the development of the biomass power industry in China.

The rest of the paper is organized as follows. Section 2 is the literature review. Section 3 introduces the data and methodology. Section 4 presents the results. Section 5 consists of further discussions of the results while Section 6 concludes with policy suggestions.

2. Literature review

Since the enforcement of China's Renewable Energy Law in

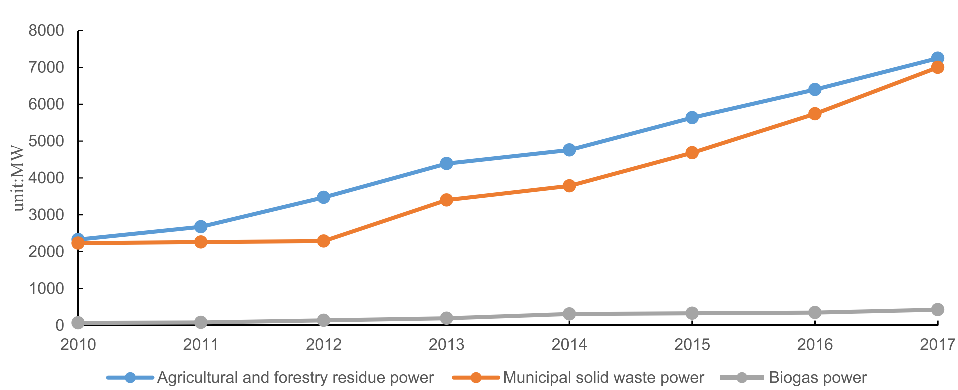

Fig. 1. The development of different kinds of biomass power in China.

2006, biomass power has experienced rapid growth. The most studied field is the assessment of the industry. The major advantages of the biomass power industry are its resources, R&D, investment, demand, price, and subsidies, whereas the major disadvantages are cost, financing channel, core technology, industries coordination, excessive competition (Zhao and Yan, 2012). Using the SWOT analysis, Cui and Wu (2012) assessed the strengths, weaknesses, opportunities, and threats of the industry. Also, Liu et al. (2015) analyzed power structure, resource distribution, investment strength, and policy environment of the biomass power industry and provided several suggestions for future development on the relevant areas, such as cost, strategic planning, and policy. Using Michael Porter's Five Forces Model, Zhao et al. (2016a) assessed the competitive environment and situation of the industry. The results show that the profitability of biomass power projects was comparatively low and the policy support such as financial subsidies, tax benefits, and tariff concessions have played a vital role in promoting the development of the biomass power industry. From the perspective of the recycling industry, Xu and Chen (2018) analyzed the technical efficiency of biomass energy and found that the industrial level and the economic level have positive impacts on technical efficiency. Considering the importance of policies on biomass power industry, some studies have concentrated on related policies. Zhang et al. (2014) reviewed China's biomass power policies from 2006 to 2012 and suggested that biomass power should be developed steadily in China but without further fiscal supports. In order to explain why some biomass projects in China are making little profits or incurring losses, Liu et al. (2015) explored the challenges and future obstacles to China's biomass power industry and proposed that further support policies should be focused on each stage of the supply chain. By estimating the emissions reduction and subsidies of the three main renewable energy power sources (wind power, solar power, and biomass power) in China, Lin and He (2017) found that emission reductions of biomass power plant are more effective than wind and solar plants given the same installed capacity.

Other studies also focused on the optimal strategy for biomass power projects. Zhao and Li (2016) developed a bi-objective 0–1 integer programming model for optimal locations and corresponding feedstock supply chain designs of biomass power plants. Additionally, Cheng et al. (2014) developed a methodology for evaluating the agricultural biomass potential for a biomass power plant based on multi-factor analysis that influences the agricultural biomass potential. The study of Tan et al. (2017) focused on the fuel supply chain of the biomass project. They used a nonlinear multi-objective optimization model to determine the optimal quantity of electricity generation, the ideal blending ratio, and acquisition quantity. As the cost of biomass power in China is relatively high, Lin and He (2016) applied an improved learning curves model to explain the factors influencing the cost of biomass power and found that installed capacity expansion has led to significant cost reduction. Similarly, Wang et al. (2018a) used a learning curves model to empirically estimate the learning rates of China's biomass direct combustion power and found the overall learning rate is 4.54% over the period 2006–2014.

The supply of biomass materials is the main obstacle for biomass power in China. Chen (2016) developed a mathematical programming model to evaluate the economic potentials of crop residue supply and the estimation results showed that China can produce 174.4–248.6 million tons of crop residues a year. He et al. (2016) estimated households' willingness to accept compensation in terms of agricultural waste recycling and calculated the compensation standard for households' participation in agricultural waste recycling. Based on an investigation in northeast China, the study of Wang and Watanabe (2016) revealed the influencing factors that impact farmers' risk perceptions on straw supply activities. These were policy guidance factors, economic factors, and trust factors.

To have a better understanding of biomass power generation in China, Wang et al. (2015) used a typical Salix direct-fired power generation system (SDPGS) as a case study. The development of biomass power may also lead to a negative impact on the environment. Thus, the utilization of biomass power technologies must be systematically and scientifically evaluated to avoid secondary pollution generation and pollutant transformation (Xu et al., 2016). According to previous studies, we found that the competitiveness of biomass power was relatively weak and the supporting government policies have promoted the development of the industry. There are still some policy-related problems in the industry that remain unsolved. Fuel supply is vital for the successful operation of biomass projects and more reasonable fuel supply modes may increase the profitability of biomass power.

With the development of renewable energy in China, increasing intermittency of renewable power has increased uncertainties in the power system. There is an increasing interest in the status and optimal planning of China's power sector. Zhou et al. (2015) presented development status of China's electric power industry, including the total power generating capacity and proportions of different kinds of power, as well as the situation of renewable energy power. Yang et al. (2016) placed more attention on the historical and current status of China's renewable energy industry and discussed challenges and strategies for China's renewable energy goals for 2050.

To provide a supporting framework for power sector planning in China, many scholars applied different models to investigate the industry. Cheng et al. (2015) proposed a multi-region optimization model to analyze the long-term development planning of China's power sector that could minimize the total cost of the power sector. To enhance the investment and operational planning of power sector, Chen et al. (2016) developed a deterministic linear programming model for China's power planning for the period 2015–2030 and determine the optimal development roadmap for the sector. Duan et al. (2018) developed a stochastic energy-economy-environment integrated model, to assess China's energy and climate targets in 2030. Using a multi-region dispatch model in optimal choices for the development of China's electricity sector, Guo et al. (2017a) confirmed the importance of considering even short-term temporal variations when planning the long-term development of electricity systems. Dong et al. (2016) established a large-scale and fine-resolution Bayesian interval robust energy system optimization (BIRESO) approach for sustainable energy system planning in Qiqihar City, China.

Some studies mainly focused on the impact of policies on power sector planning. Based on the multi-period optimization model, Zhang et al. (2013) analyzed the impact of two typical types of carbon tax policies on optimal power sector planning. Guo et al. (2017b) confirmed that clean energy targets have played an important role in promoting the development of renewable energy. Yi et al. (2016) quantitatively analyzed the optimum inter-regional power transmission planning under various policy scenarios and estimated the environmental impacts. Wang et al. (2018b) examine the optimal power mix in Hebei Province in China via the introduction of environmental and carbon taxes.

From the aforementioned review on power sector planning in China, we observed that although some studies considered biomass power in the optimization model of the power sector, most of them investigated one kind of biomass power technology. Even when biomass power was included in the models, it attracted little attention in the analysis. It is well known that different kinds of biomass power technologies have different biomass fuels and equipment requirements. Therefore, separately considering different biomass power generation systems can provide more insights into power sector planning and enhance support for decision-making.

3. Data and methodology

The main objective of this paper is to investigate the role of biomass in China's power sector. The Long-range Energy Alternatives Planning System (LEAP) model was used. It has been extensively adopted in many studies to project energy supply and demand, predict the environmental impact of energy policies, and identify possible challenges in the future (Emodi et al., 2017). Similar, studies such as Nikolaev and Konidari (2017) adopted the LEAP model for renewable energy in Bulgaria. The LEAP model was also used in some city-level case studies, such as Shanghai (Chang et al., 2017).

3.1. Methodology

The LEAP model used in this paper is the current version which support optimization modeling: allowing for the construction of least-cost models of electric system capacity expansion and dispatch, potentially under various constraints, which is an integrated, scenario-based modeling tool that can be used to track energy consumption, production and resource extraction of an economy (Heaps, 2016). It is usually used to analyze national energy systems, which provides various accounting and simulation methodologies as well as optimization methodologies that are good for modeling electric sector generation and capacity expansion planning (Connolly et al., 2010). Following this common framework, the main goal of the model in this paper is to minimize emissions and total costs to accommodate the government's plan for the power sector and environmental constraints in China. The LEAP model used in this paper is useful to realize the importance of different biomass power technologies to China's power sector. However, although biomass power is the area of interest in this paper, LEAP optimization model generally analyzes the electricity generation planning in a national framework. For example, in recent years, intermittent renewable energy sources, such as wind power and solar power have experienced rapid development. Biomass power could be used to augment electricity supply in general as well as serve as backup capacity. Hence, to determine an optimal structure for the final electricity generation and consumption, other electricity generation technologies are also included in the simulation model. Fig. 3 gives the framework of the model used in this paper. The costs of generating electricity, including the capital, operating costs, maintenance costs and fuel costs of these technologies and the externality costs of environmental emissions are included in electricity generation and capacity expansion planning in China.

3.2. Data sources

The data on the cost of different power technologies, such as investment cost, operation, and maintenance cost, were obtained from BRIIC and CREC (2014) and IEA (2015). Following Chen et al. (2016), the externality costs of environmental emissions of electricity were divided into carbon emissions cost and non-carbon emissions cost. The non-carbon emissions cost in this paper mainly come from Chen et al. (2016). The carbon emissions cost is estimated by multiplying the carbon emission factor by the carbon price. The data on carbon prices in each planning period were obtained from the China National Renewable Energy Center (2017b). Generally, different scenarios would be considered in the simulation model, including base scenario without any policy constraints, the scenario with government intervention, the scenario with CO_2 emissions constraint and the scenario with both constraints. However, governments play a vital role in the power industry in China. Some planning of power technologies already exists, such as wind power and solar power in a certain period.[1] The role of government in power industry could not be ignored in the analysis. In China, the power transmission and distribution enterprises are operated by two state-owned enterprises (State Grid Corporation of China and China Southern Power Grid Company Limited) (Wang et al., 2017). Most energy prices in China are controlled by the government at the central or local levels, which have non-market characteristics (Andrews-Speed and Xu, 2017; Du et al., 2017). Therefore, to be simplified, the scenario without policy constraint was not considered as the base scenario. In the analysis, the scenario with government's policy constraint was set as the base scenario. Meanwhile, 2 °C CO_2 emissions constraint was also considered as another scenario in the model, which was set at CO_2 constraint scenario (CO_2 constraint + policies constraint). The data were collected from IEA (2016).

4. Result

Based on the power sector planning model proposed in section 3, the simulation results of the installed capacity of each power source were obtained. Fig. 4 gives the log value of the installed capacity of main power technologies in China, such as coal power, natural gas power, and wind power and biomass power. Since the main interest of this paper is biomass power, the results of the total capacity of the three kinds of biomass power (agricultural and forestry biomass, municipal solid waste, and biogas) in each planning year will be discussed further in Figs. 5 and 6. From Fig. 4, we can see that renewable energy power, such as wind and solar power and biomass power involve a significant increase up to the year 2030. The forecasted log value of installed capacity of coal power (6.81) under the CO_2 constraint scenario in 2030 is less than that of the base scenario (6.87). Similar to coal power, natural gas power is thermal power, not renewable power. However, the log value of the total installed capacity of natural gas power under the CO_2 constraint scenario is 4.91 in 2030, which is higher than that of the base scenario (4.55). This indicated that although natural gas power is not renewable power, the emissions are relatively small compared to coal power and benefited more in CO_2 constraint scenario. Further attention would be given to each biomass power in the subsequent session.

As shown in Fig. 5, the total installed capacity of agricultural and forestry biomass power, municipal solid waste power and biogas power will increase in the base scenario. Among the three kinds of biomass power technologies, agricultural and forestry power prove to be the most valuable source of biomass power generation, which increased from 6,463 MW to 22,350 MW in the whole period. Municipal solid waste power also witnessed a rapid growth during the period, as it increased from 5,488 MW to 21,150 MW. The difference in the growth rate of these two biomass power technologies is not as large as the annual growth rate of agricultural and forestry power and municipal solid waste power which are 9.27% and 10.11% respectively. Compared with the other two biomass power technologies, the total installed capacity of biogas power is small in the whole period, which is 350 MW in 2016 and would be 4,900 MW by 2030. However, the growth rate of biogas power is relatively high in each planning period with the annual growth rate being 20.74%.

[1] These informations are mainly from “China's National Plan for Climate Change (2014–2020)”; “13th Five-Year Plan for Development of Biomass Energy”.

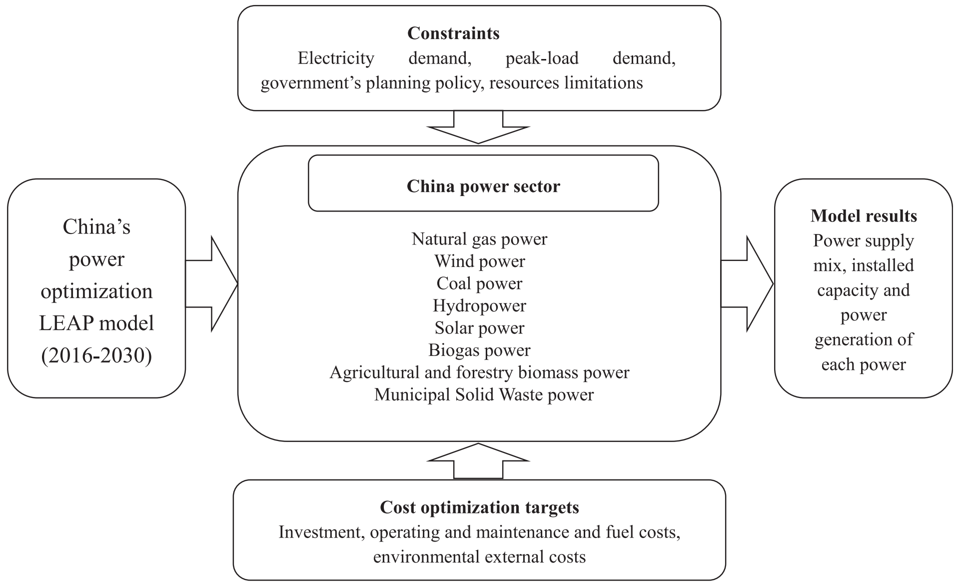

Fig. 3. The framework for China's power optimization LEAP model.

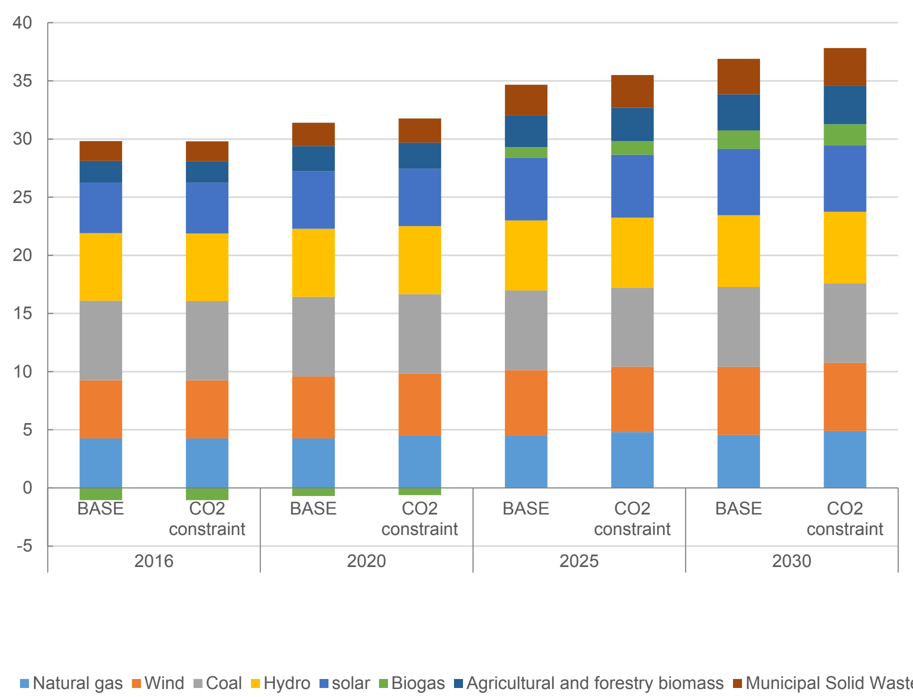

Fig. 4. The total installed capacity of power technologies under BASE scenario and CO_2 constraint scenario (log value of thousand MW).

The difference in the increasing trend of biomass power between the base scenario and the CO_2 constraint scenario is not significant. The total installed capacity of each biomass power is larger than that of the base scenario. In the CO_2 constraint scenario, the total installed capacity of agricultural and forestry power, municipal solid waste power and biogas power would be 26,920 MW, 25,970 MW, and 6,240 MW, respectively by 2030. This showed that the biomass power industry has more advantages under the CO_2 constraint scenario.

To present the role of biomass power in China power sector, Figs. 7 and 8 present the proportion of installed capacity of biomass power in the power grid in each planning year under the two scenarios. In the base scenario, the penetration of all biomass power increases significantly from 0.76% to 1.98%. Agricultural and forestry power and municipal solid waste power accounted for the most part of the increase. The proportion of agricultural and forestry power and municipal solid waste power in 2030 would be 0.92% and 0.87%, respectively. Under the CO_2 constraint scenario, the proportion of total biomass power in the power grid would increase to 2.42% by 2030. Although the total installed capacity of biomass power is small compared to wind or solar power, it consistently keeps a steady growth and constitutes an important part of renewable energy in China.

The results of Figs. 9 and 10 show the contribution of biomass

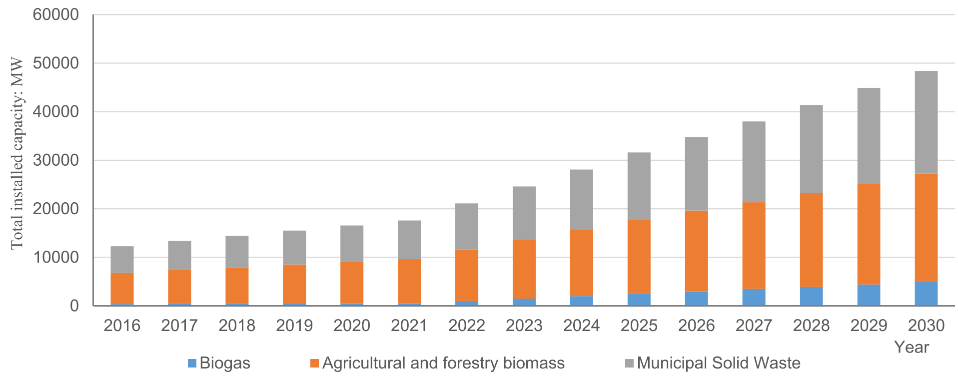

Fig. 5. Total capacity of biomass power installed under Base scenario (MW).

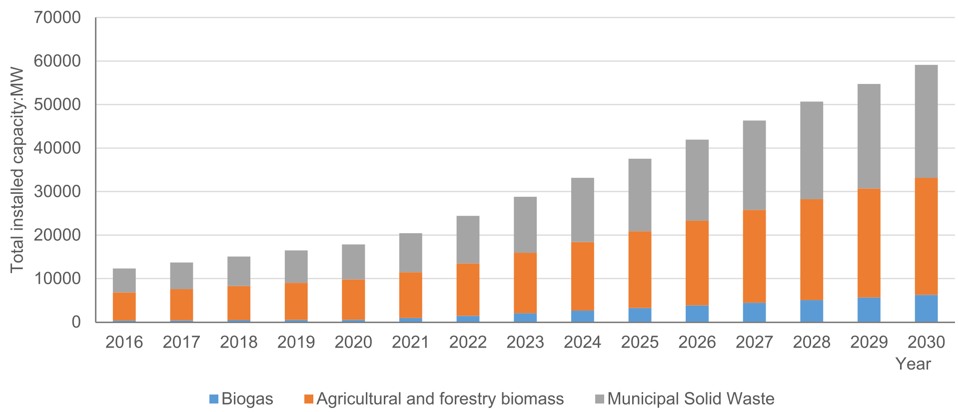

Fig. 6. Total capacity of biomass power installed under CO_2 constraint scenario (MW).

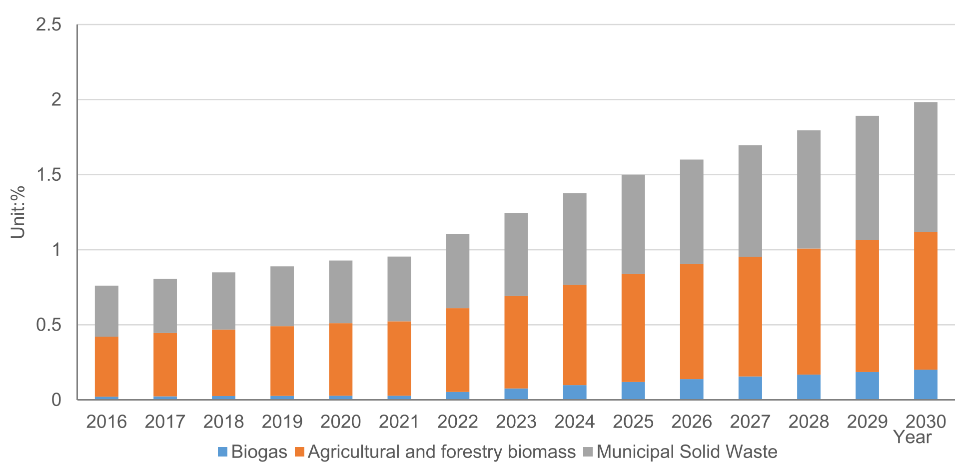

Fig. 7. The proportion of biomass power installed capacity in the power grid under Base scenario (%).

power technologies to increase in power generation. Similar to total installed capacity, agricultural and forestry biomass power and municipal solid waste power accounted for the most part of the increase. In the base scenario, the power generation of agricultural and forestry biomass power increased from 32,670 GW h to 188,589 GW h during the whole period. The power generation of municipal solid waste power is a little smaller than agricultural and forestry biomass power, which are 29,280 GW h and 178,464 GW h in 2016 and 2030, respectively. The power generation of biogas power is relatively smaller, which would be 41,346 GW h in 2030. Biomass power generation in the CO_2 constraint scenario was a little bigger than in the base scenario. The power generation of agricultural and forestry biomass power, municipal solid waste power and biogas power would be227,145 GW h, 219,129 GW h, and 52,652 GW h, respectively in 2030.

Similar to installed capacity, Figs. 11 and 12 provide the proportion of biomass power generation in the total power generation in China. The increasing trend of power generation of each biomass power is generally the same. Agricultural and forestry power constitutes the most stable contributor to power generation among all

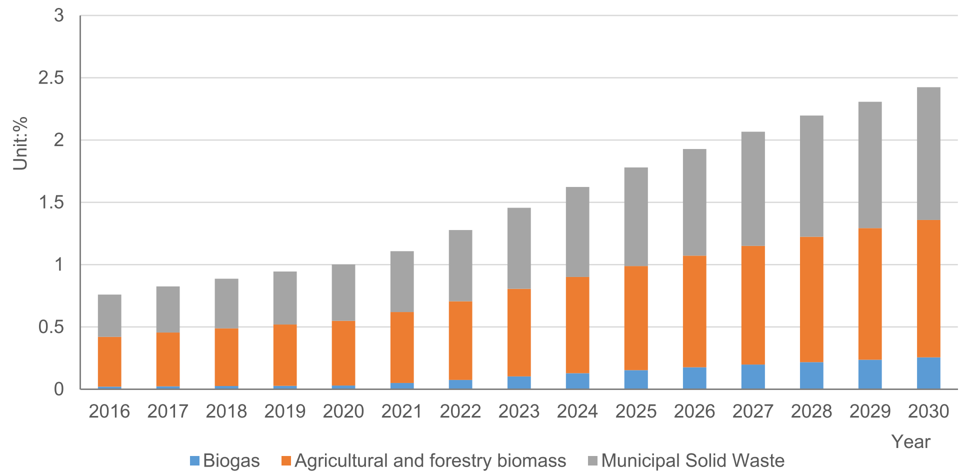

Fig. 8. The proportion of biomass power installed capacity in the power grid under CO_2 constraint scenario (%).

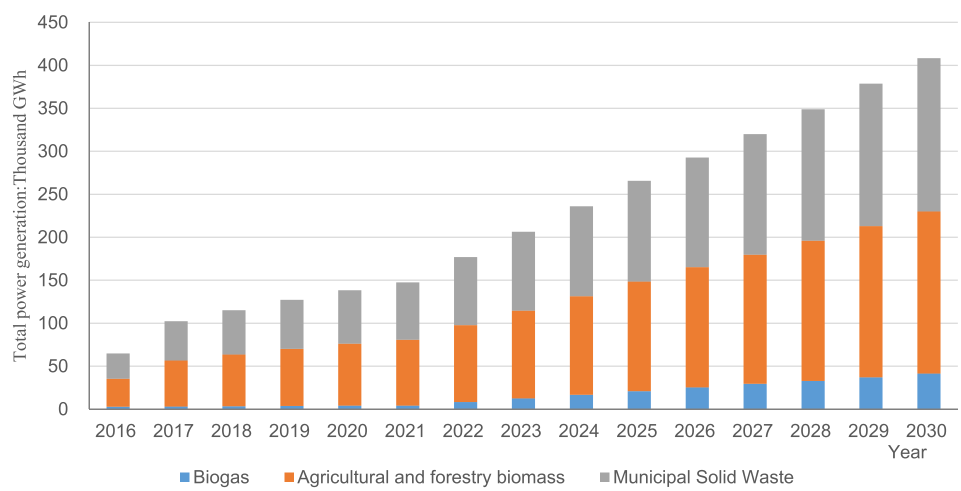

Fig. 9. Total biomass power generation under Base scenario (Thousand GWh).

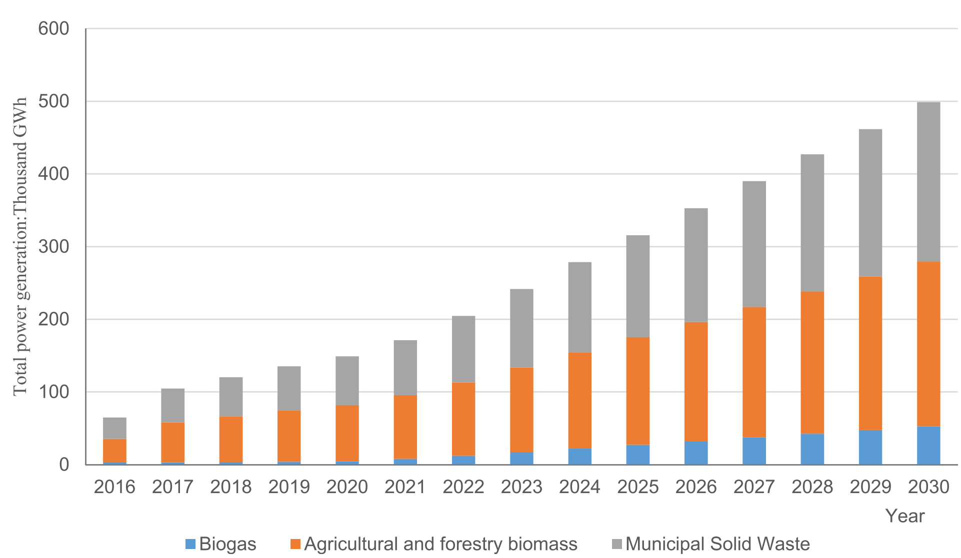

Fig. 10. Total biomass power generation under CO_2 constraint scenario (Thousand GWh).

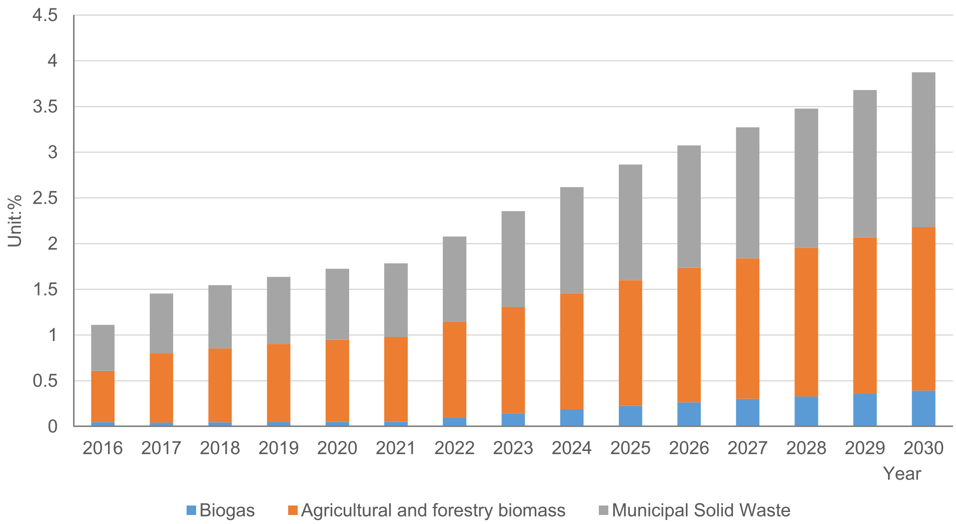

Fig. 11. The proportion of biomass power generation in the total power generation in China under Base scenario (%).

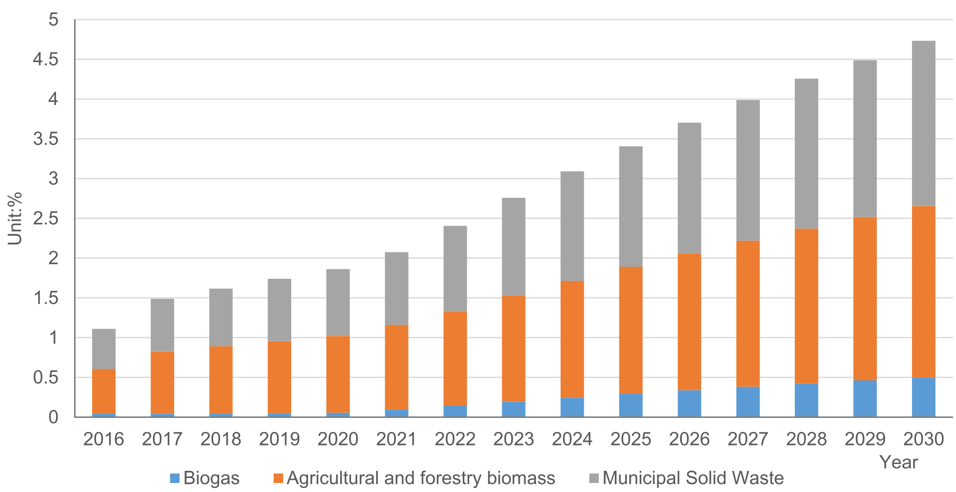

Fig. 12. The proportion of biomass power generation in the total power generation in China under CO_2constraint scenario (%).

biomass power, increasing from 0.56% to 1.79%in the whole period under the base scenario. The proportion of municipal solid waste power increased from 0.50% to 1.69%, while that of biogas power increased from 0.05% to 0.39%. Similarly, the proportion of power generation of each biomass technology under the CO_2constraint scenario is higher than that of the base scenario. By 2030, the proportion of agricultural and forestry biomass power, municipal solid waste power and biogas power would be 2.15%, 2.08%, and 0.50%, respectively. Comparing the power generation with installed capacity, it was found that the proportion of power generation of each biomass power technology is greater than their proportion in the installed capacity. This could be because the annual operation time of biomass power is usually longer than intermittent energy sources, such as wind power. This confirms the fact that biomass power is a more reliable renewable energy source.

5. Discussion

According to the results, agricultural and forestry residues power, municipal solid waste power, and biogas power will experience future growth. The adequate supply of biomass fuels is a requirement for the development of the biomass power industry. Considering the importance of biomass supply forth biomass power industry, biomass resources constraint was not put in the simulation. Instead, the influence of biomass materials supply will be discussed in this section according to the simulation results. Based on the results of the power sector planning model, the estimation of biomass materials required in each planning period was calculated.

The required biomass materials estimate shows the demand for each biomass fuel in different years (Table 1). For agricultural and forestry residues and organic waste, the estimation of biomass supply of each period is not provided because their supply is not a problem. According to the China Renewable Energy Industry Development Report (2017a), the available agricultural and forestry residues and organic waste were 750 and 840 million tons, respectively, which are greater than the amount of biomass that would be required by 2030 (158.12 and 172.13 million tons in the base scenario for agricultural and forestry biomass power and biogas power, respectively). Comparing the demand and supply of each biomass fuel, it was found that there is a guaranteed supply of biomass materials for the biomass power industry. In other words, from the point of view of total volume, biomass supply is not a constraining factor for biomass power.

Table 1
The required biomass materials in each planning period (Unit: million tons).

	Biomass power technology	2020	2025	2030
Required biomass materials	Agricultural and forestry biomass power	57.13	106.94	158.12
	Municipal solid waste power	142.12	265.43	402.32
	Biogas power	17.56	61.48	172.13
Estimation of biomass supply	Municipal solid waste	323	370.98	409

Date sources: Report on the development of renewable energy industry; https://www.qianzhan.com/analyst/detail/220/20120516-b690599e0a686e73.html

From the literature review section, it is clear that the biomass power industry faces problems of ineffective support policies. However, besides the problems mentioned above, some other social and economic factors may also affect the development of biomass power. Due to differences in biomass power technologies, the obstacles of each biomass power industry may be unique.

5.1. Main obstacles for agriculture and forestry biomass power

Agriculture and forestry biomass power experienced a relatively rapid growth in the early stages. However, the growth trend has slowed in the past two years. Some biomass power enterprises are not economically viable without government subsidies (Zhao et al., 2016a). Unlike photovoltaic and wind power, the operation of biomass power plant requires more labor. Meanwhile, the biomass fuels for biomass power, such as crop straws, require high human labors to collect and transport. Because farmers in China typically have less farmland than farmers in other countries, agricultural biomass resources are decentralized and it is difficult to collect agricultural residues (Tan et al., 2017). The high proportion of income of many Chinese farmers comes from non-agricultural employment. In the busy farming season, farmers want to finish the harvest of crops in the shortest time and continue to focus on non-agricultural activities. However, the collection and transportation of crop straws take a lot of time and energy. The price of agricultural and forestry residues is not high. In terms of economic interests, a collection of straws are not compensating. Therefore, many farmers choose to discard or burn them. This led to the high cost of fuel for biomass power. It was found that straw collection costs accounted for 64% of the total cost of straw biomass power generation (Tan et al., 2014). Similarly, Zhao et al. (2015) showed that the annual profit of the biomass power plant will drop by 10% for each 10% increase in the fuel price. The logistics system of a biomass power plant plays an important role in reducing costs, improving efficiency, and increasing market competitiveness (Zhao and Li, 2016). Another study found that the price of straw increased by nearly 100% from the point of purchase to where it is eventually put into the furnace (Liu et al., 2015). The high cost of biomass materials supply is the main problem. However, the subsidies of biomass power are mainly focused on the production process, while biomass collection and transportation are neglected. Different from wind and solar power, there is competition for the purchase of biomass materials between adjacent biomass power plants. Due to inappropriate planning in some provinces, biomass plants are built near each other, leading to competition and difficulties in purchasing biomass. Some enterprises even expand the collection radius of fuels to over 200 km regardless of the incremental costs (Wang et al., 2015). In China, the Feed-in-Tariff for agricultural and forestry biomass power generation is 0.75 CNY per kW has determined in 2010 and was calculated according to the labor cost at that time. In recent years, labor costs have increased considerably. Therefore, the current benchmark price is not sufficient for biomass power generation in many areas. At the end of 2016, the National Development and Reform Commission issued "The Adjustment of New Energy Benchmarking Feed-in Tariff Notification (Draft)", which proposed that after January 2017 the provincial governments have the right to set the price of Feed-in-Tariff for biomass power, including agriculture and forestry biomass power, waste incineration power and biogas power, according to local conditions. Currently, most provinces have not yet introduced a clear policy for biomass power. In view of the overall trend of agricultural development in China, farmers' income will continue to increase, and the opportunity cost of collecting straw will increase accordingly. Therefore, agricultural and forestry biomass power generation costs are unpredictable and regional specific conditions are different. For enterprises, investment in biomass power generation also faces great uncertainty.

Biomass power enterprises not only burn boilers, steam turbines, generators, and other equipment but also require more relevant supporting facilities. Agriculture and forestry biomass power enterprises usually occupy more land because a larger space is required for warehouse storage. Such fuel storage-requirement is too large to be manageable (Zhao et al., 2016a). Meanwhile, biomass pre-treatment technologies need extra investments, which small farmers and small-scale fuel companies cannot afford (Liu et al., 2015). From the stability of the supply of raw materials, both crop straw and forestry waste have great uncertainty. Some natural environmental impacts may also affect the supply of raw materials. Therefore, the uncertainty of biomass power projects is higher than other renewable energy sources, and there is insufficient enthusiasm for the enterprise to invest in biomass power generation.

5.2. Main obstacles for municipal solid waste power

Unlike agricultural and forestry residues, it is more convenient to collect and transport municipal solid waste. The problem of municipal solid waste is that the classification is not realized and the composition is more complex, which is not suitable for power generation. Due to the differences in economic status and lifestyle across regions, the composition of municipal solid waste varies widely.

Many cities do not implement garbage classification recycling. Many urban residents do not have a sense of garbage classification, which makes the heat value of MSW generally low and MSW is usually dominated by components of high moisture (Zhao et al., 2016b). For example, electronic waste, building materials, and waste food are contained in municipal waste. In this case, the various components of municipal waste are basically mixed, and it is difficult to separate at a later time. At the same time, many useful resources in municipal waste are wasted. The pre-treatment equipment and methods are different due to the different composition of raw materials before combustion. Both operators and authorities lack data on the compositions of MSW and harmful gas emissions generated in the combustion process and measuring pollutant concentrations and the cleaning process is usually given less attention (Lu et al., 2017).

China's MSW power has been opposed by local residents in many cities because of concerns that waste incineration may emit toxic gases, which can be harmful to health. Huang et al. (2015)

showed that around 70% of respondents supported MSW incineration technology in general, but Opposed the projects being located in the vicinity of their residential areas regardless of how good the technology is. In order to save cost, some enterprises did not follow the production process and caused toxic gas emissions, which results in environmental degradation. Public opposition and improper operation are the top risk factors for the assessment of China's MSW incineration projects (Wu et al., 2018). In some countries, waste incineration has little impact on the surrounding environment. Many plants were built near residential areas, and there is no opposition from local residents.

For example, in Switzerland, Lausanne waste incineration power was built around residential areas, and Thun waste power located in scenic areas. Both waste power projects were not opposed by the local residents. Similar to agricultural and forestry power, the feed-in-tariff policy of municipal solid waste power in many provinces have not been decided. Besides renewable energy, waste power is also a way of dealing with waste, and many local governments pay for waste disposal according to the amount of waste they dispose of. However, the waste disposal fee varies widely across cities. This lead to a lack of competitiveness for some waste power enterprises with lower waste disposal fee.

5.3. *Main obstacles for biogas power*

The biomass materials for China's biogas power are mainly industrial organic waste and breeding industrial organic waste. Similar to agriculture and forestry biomass power, biogas power also has problems of immature technology and relatively high cost. The efficacy of biogas power systems was lower than that of traditional coal and natural gas power plants (Wang et al., 2014). Similar to agricultural and forestry power, the supply of biomass materials is the main constraint to biogas power.

The main materials for biogas power are mainly the byproduct of agricultural production and some industrial production processes. These biomass materials are not easy to collect and the cost is relatively high. China's breeding industry is mainly scattered in rural areas, with a relatively small scale. As one of the main raw materials of biogas power, it is difficult to collect waste materials. Lack of labor force in rural areas is also a problem as more than 70% of the young labor force work and do business out of home (Yin et al., 2017). Meanwhile, some of the biogas produced is used for domestic fuel for animal farms and neighboring farmers, and only a small part of it goes into electricity generation (Deng et al., 2017).

According to the above analysis, the problem of biomass power generation, unlike wind power and solar power generation, is the supply of biomass materials. The support policies for the development of biomass power are mainly concentrated in the process of power generation, and the support for the collection and transportation of raw materials is relatively small.

6. Conclusion and policy implications

As a major source of carbon emissions, the power sector bears a large part of the socioeconomic burden of emission reductions. In this case, planning the development of China's power sector is of great significance to long-term strategic decisions. This paper presents an optimal power-planning model in China and focuses on biomass power. The simulation results showed that biomass power would potentially become one of the major renewable energy options in China in the next few years and has a projected 48,400 MW total installed capacity by 2030. According to the estimation results of biomass materials, biomass supply is not a limiting factor for the biomass power industry. This paper further discussed the main obstacles impeding biomass power from the perspective of social custom, industrial structure and so on.

With the development of biomass energy industry, more energy crops might be cultivated in the future. Meanwhile, bigger agricultural companies will engage in this field, with incentives typically focusing on short-term profits. This may lead to an increase in monocultures which will impede the agricultural production in rural regions. For a country with a large rural population, sustainable forms of land use and efficient agricultural production are necessary. Considering the shortage of farmlands in China, sand land, saline-alkali land, and other marginal land will be an attractive option for biomass production. A large quantity of rural labor benefits from land reclamation. Currently, the main raw materials are crop straw, forestry waste, etc. The total amount of changes in agricultural acreage in China is not large and so is the possibility of a large increase in the forest production area. Given the potential of future increases in energy crops on marginal land, the amount of biomass raw materials used to generate electricity will increase. The subsidies and support for biomass production should be more targeted towards small farmers for their relative weakness in competing with big companies.

It is necessary to handle the relationship between the development of the biomass industry and environmental protection, and the relationship at the local and national levels. Enterprises should focus on strengthening the awareness of compliance with environmental law and sense of social responsibility. The development of biomass energy is related to farmers so that farmers can benefit from and the poor can increase their income. Based on the analysis, several policy recommendations are proposed as follows.

Agricultural and forestry biomass power is one of the main directions of the biomass energy industry in China. The development of agricultural and forestry power needs reasonable price support and other preferential tax policies. To ensure that enterprises can obtain certain profits through reasonable economic management, the local governments should adjust the feed-in tariff and establish the dynamic adjustment mechanism according to the local specific circumstances, such as flexible changes in prices of raw materials under the guidance of the National Development and Reform Commission. The central government can also provide guidance on the overall planning, and the national renewable energy fund can provide some subsidies to improve the enthusiasm of local governments to develop biomass power. The construction of biomass power plant must be based on reasonable planning to avoid concentration in the same area. Too many projects in an area will cause vicious competition for biomass materials, which may lead to a shortage.

Many aspects of biogas power are similar to that of agricultural and forestry biomass power. For biogas power whose biomass fuels are industrial organic waste, the raw materials are mainly concentrated in industrial areas. In the planning or reconstruction of industrial sewage treatment, organic waste should be a key factor. The scale of biogas power should be determined according to the amount of the biomass materials. In rural areas, the main biomass material of biogas power is breeding industrial organic waste. Biogas could be built in areas where the breeding industry is relatively concentrated to ensure adequate biomass materials. For rural areas with relatively few biomass materials, it is possible to consider building smaller power generation equipment, which can be adopted for self-use. This will ensure the efficient use of raw materials and increase the income of farmers without loss of investment.

The main problem of municipal solid waste power is that garbage classification is not realized. Solving the problem of garbage classification is a gradual process. In addition to relevant policies and regulations, it also dependent on the improvement of public environmental awareness. Some developed countries pay great attention to garbage classification education. In the future, China will also need to increase the awareness of garbage classification, which should not only include formal education but also make use of the community platform. Since change in the living habits of residents is a long-term process, corresponding measures should also be taken in the short term. The collection of garbage from centralized recycling, such as the community, shopping malls, restaurants, etc., could also be initiated. For instance, the government can determine the charging standard according to whether the garbage is classified or not. At the same time, the government should pay attention to the role of urban informal garbage collectors. They indirectly contribute to urban garbage disposal. Therefore, supporting these people in garbage classification and recycling can help to solve the problems of low-income urban residents and promote the recycling of urban garbage at the same time. In the future, the government should strengthen the supervision and control of waste gas and wastewater discharge which will prevent accidents. Enterprises themselves should also raise the standards for safety production and welcome the supervision of neighboring residents.

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References

Andrews-Speed, P., Xu, X., 2017. Non-Geological Constraints to Coalbed Methane Production in China: Developments from the 1990s to 2014. http://esi.nus.edu.sg/docs/default-source/doc/non-geological-constraints-to-coalbed-methane-production-in-china.pdf. (Accessed 5 August 2018).

Arredondo-Ruiz, F., García-Montero, L., Valverde-Asenjo, I., Menta, C., 2014. Soil-Quality Indicators for Forest Management. CRC Press Taylor & Francis Group, Boca Raton, FL, USA.

Bank, W., 2018. Global Economic Prospects, June 2018: the Turning of the Tide? Washington, DC. World Bank, Washington, DC.

BRIIC, CREC, (Beijing Rightsky International Information Cons Co and China Renewable Energy Center), 2014. China Renewable Energy Technology Catalogue, Beijing.

Chang, Z., Wu, H., Pan, K., Zhu, H., Chen, J., 2017. Clean production pathways for regional power-generation system under emission constraints: a case study of Shanghai, China. J. Clean. Prod. 143, 989–1000.

Chen, H., Tang, B.-J., Liao, H., Wei, Y.-M., 2016. A multi-period power generation planning model incorporating the non-carbon external costs: a case study of China. Appl. Energy 183, 1333–1345.

Chen, X., 2016. Economic potential of biomass supply from crop residues in China. Appl. Energy 166, 141–149.

Cheng, R., Xu, Z., Liu, P., Wang, Z., Li, Z., Jones, I., 2015. A multi-region optimization planning model for China's power sector. Appl. Energy 137, 413–426.

Cheng, S., Li, Z., Gao, R., Wang, X., Mang, H.-P., 2014. Methodology development of evaluating agricultural biomass potential for biomass power plant in China. Energy Procedia 61, 13–16.

China National Renewable Energy Center, 2017a. China Renewable Energy Industry Development Report. China Economic Publishing House, Beijing.

China National Renewable Energy Center, 2017b. China Renewable Energy Outlook 2017. Beijing. http://www.cnrec.org.cn/cbw/?pi=1.

Connolly, D., Lund, H., Mathiesen, B.V., Leahy, M. , 2010. A review of computer tools for analysing the integration of renewable energy into various energy systems. Appl. Energy 87 , 1059–1082.

Cui, H., Wu, R., 2012. Feasibility analysis of biomass power generation in China. Energy Procedia 16, 45–52.

Deng, L., Liu, Y., Zheng, D., Wang, L., Pu, X., Song, L., Wang, Z., Lei, Y., Chen, Z., Long, Y., 2017. Application and development of biogas technology for the treatment of waste in China. Renew. Sustain. Energy Rev. 70, 845–851.

Dong, C., Huang, G., Cai, Y., Cheng, G., Tan, Q., 2016. Bayesian interval robust optimization for sustainable energy system planning in Qiqihar City, China. Energy Econ. 60, 357–376.

Du, Q., Li, Y., Bai, L., 2017. The energy rebound effect for the construction industry: empirical evidence from China. Sustainability 9 (5), 803.

Duan, H., Mo, J., Fan, Y., Wang, S., 2018. Achieving China's energy and climate policy targets in 2030 under multiple uncertainties. Energy Econ. 70, 45–60.

Emodi, N.V., Emodi, C.C., Murthy, G.P., Emodi, A.S.A., 2017. Energy policy for low carbon development in Nigeria: a LEAP model application. Renew. Sustain. Energy Rev. 68, 247–261.

Guo, Z., Cheng, R., Xu, Z., Liu, P., Wang, Z., Li, Z., Jones, I., Sun, Y., 2017a. A multi-region load dispatch model for the long-term optimum planning of China's electricity sector. Appl. Energy 185, 556–572.

Guo, Z., Ma, L., Liu, P., Jones, I., Li, Z., 2017b. A long-term multi-region load-dispatch model based on grid structures for the optimal planning of China's power sector. Comput. Chem. Eng. 102, 52–63.

He, K., Zhang, J., Zeng, Y., Zhang, L., 2016. Households' willingness to accept compensation for agricultural waste recycling: taking biogas production from livestock manure waste in Hubei, PR China as an example. J. Clean. Prod. 131, 410–420.

Heaps, C.G., 2016. Long-range Energy Alternatives Planning (LEAP) System. Stockholm Environment Institute, Somerville, MA, USA [Software version: 2018.1.8]. https://www.energycommunity.org.

Hilton, I., Kerr, O., 2017. The Paris Agreement: China's 'New Normal'role in international climate negotiations. Clim. Policy 17 (1), 48–58.

Huang, Y., Ning, Y., Zhang, T., Fei, Y., 2015. Public acceptance of waste incineration power plants in China: comparative case studies. Habitat Int. 47, 11–19.

Hui, J., Cai, W., Wang, C., 2017. Achieving China's INDC: biomass development and competition for land. Energy Procedia 105, 3521–3526.

IEA, 2015. Projected Costs of Generating Electricity, 2015 Edition. OECD, Paris. https://webstore.iea.org/projected-costs-of-generating-electricity-2015.

IEA, 2016. Energy Technology Perspectives Paris. OECD. http://www.iea.org/etp/etp2016/.

Li, A., Lin, B., 2013. Comparing climate policies to reduce carbon emissions in China. Energy Policy 60, 667–674.

Li, A., Peng, D., Wang, D., Yao, X., 2017. Comparing regional effects of climate policies to promote non-fossil fuels in China. Energy 141, 1998–2012.

Li, J., Zhang, J., Gong, L., Miao, P., 2015. The spatial and temporal distribution of coal resource and its utilization in China—based on space exploration analysis technique ESDA. Energy Environ. 26 (6–7), 1099–1113.

Lin, B., He, J., 2016. Learning curves for harnessing biomass power: what could explain the reduction of its cost during the expansion of China? Renew. Energy 99, 280–288.

Lin, B., He, J., 2017. Is biomass power a good choice for governments in China? Renew. Sustain. Energy Rev. 73, 1218–1230.

Liu, L., Ye, J., Zhao, Y., Zhao, E., 2015. The plight of the biomass power generation industry in China – a supply chain risk perspective. Renew. Sustain. Energy Rev. 49, 680–692.

Lu, J.-W., Zhang, S., Hai, J., Lei, M., 2017. Status and perspectives of municipal solid waste incineration in China: a comparison with developed regions. Waste Manag. 69, 170–186.

Nikolaev, A., Konidari, P., 2017. Development and assessment of renewable energy policy scenarios by 2030 for Bulgaria. Renew. Energy 111, 792–802.

Pan, X., Chen, W., Wang, L., Lin, L., Li, N., 2018. The role of biomass in China's long-term mitigation toward the Paris climate goals. Environ. Res. Lett. 13 (12), 124028.

Rogelj, J., Den Elzen, M., Höhne, N., Fransen, T., Fekete, H., Winkler, H., Schaeffer, R., Sha, F., Riahi, K., Meinshausen, M., 2016. Paris Agreement climate proposals need a boost to keep warming well below 2 C. Nature 534 (7609), 631.

Snapp, S., Pound, B., 2017. Farming Systems for Sustainable Intensification, Agricultural Systems, second ed. Elsevier, pp. 93–122.

Song, C., Bilsborrow, R., Jagger, P., Zhang, Q., Chen, X., Huang, Q., 2018. Rural household energy use and its determinants in China: how important are influences of payment for ecosystem services vs. Other factors? Ecol. Econ. 145, 148–159.

Tan, Q., Wang, T., Zhang, Y., Miao, X., Zhu, J., 2017. Nonlinear multi-objective optimization model for a biomass direct-fired power generation supply chain using a case study in China. Energy 139, 1066–1079.

Tan, Q., Yang, H., Zhang, X., Deng, Y., Wei, Y., 2014. Measurement model and empirical analysis of fuel collection cost for biomass power generation. Forum Sci. Technol. China. https://doi.org/10.13580/j.cnki.fstc.

Wang, B., Liu, L., Huang, G., Li, W., Xie, Y., 2018b. Effects of carbon and environmental tax on power mix planning-A case study of Hebei Province, China. Energy 143, 645–657.

Wang, C., Zhang, L., Chang, Y., Pang, M., 2015. Biomass direct-fired power generation system in China: an integrated energy, GHG emissions, and economic evaluation for Salix. Energy Policy 84, 155–165.

Wang, C., Zhou, K., Yang, S., 2017. A review of residential tiered electricity pricing in China. Renew. Sustain. Energy Rev. 79, 533–543.

Wang, L., Watanabe, T., 2016. Factors affecting farmers' risk perceptions regarding biomass supply: a case study of the national bioenergy industry in northeast China. J. Clean. Prod. 139, 517–526.

Wang, T., Huang, H., Yu, C., Fang, K., Zheng, M., Luo, Z., 2018a. Understanding cost reduction of China's biomass direct combustion power generation—a study based on learning curve model. J. Clean. Prod. 188, 546–555.

Wang, X., Chen, Y., Sui, P., Gao, W., Qin, F., Wu, X., Xiong, J., 2014. Efficiency and sustainability analysis of biogas and electricity production from a large-scale biogas project in China: an emergy evaluation based on LCA. J. Clean. Prod. 65, 234–245.

Wu, Y., Xu, C., Li, L., Wang, Y., Chen, K., Xu, R., 2018. A risk assessment framework of PPP waste-to-energy incineration projects in China under 2-dimension linguistic environment. J. Clean. Prod. 183, 602–617.

Xu, C., Hong, J., Chen, J., Han, X., Lin, C., Li, X., 2016. Is biomass energy really clean? An environmental life-cycle perspective on biomass-based electricity generation in China. J. Clean. Prod. 133, 767–776.

Xu, X.-l., Chen, H.H., 2018. Examining the efficiency of biomass energy: evidence from the Chinese recycling industry. Energy Policy 119, 77–86.

Yang, X.J., Hu, H., Tan, T., Li, J., 2016. China's renewable energy goals by 2050. Environ. Dev. 20, 83–90.

Yi, B.-W., Xu, J.-H., Fan, Y., 2016. Inter-regional power grid planning up to 2030 in China considering renewable energy development and regional pollutant control: a multi-region bottom-up optimization model. Appl. Energy 184, 641–658.

Yin, D., Liu, W., Zhai, N., Wang, Y., Ren, C., Yang, G., 2017. Regional differentiation of rural household biogas development and related driving factors in China. Renew. Sustain. Energy Rev. 67, 1008–1018.

Yu, S., Zheng, S., Li, X., 2018. The achievement of the carbon emissions peak in China: the role of energy consumption structure optimization. Energy Econ. 74, 693–707.

Yuan, X.-C., Wei, Y.-M., Mi, Z., Sun, X., Zhao, W., Wang, B., 2017. Forecasting China's regional energy demand by 2030: a Bayesian approach. Resour. Conserv. Recycl. 127, 85–95.

Zhang, D., Liu, P., Ma, L., Zheng, L., 2013. A multi-period optimization model for planning of China's power sector with consideration of carbon dioxide mitigation—the importance of continuous and stable carbon mitigation policy. Energy Policy 58, 319–328.

Zhang, Q., Zhou, D., Fang, X., 2014. Analysis on the policies of biomass power generation in China. Renew. Sustain. Energy Rev. 32, 926–935.

Zhao, X.-g., Li, A., 2016. A multi-objective sustainable location model for biomass power plants: case of China. Energy 112, 1184–1193.

Zhao, X.-G., Tian-Tian, F., Yu, M., Yi-Sheng, Y., Xue-Fu, P., 2015. Analysis on investment strategies in China: the case of biomass direct combustion power generation sector. Renew. Sustain. Energy Rev. 42, 760–772.

Zhao, X., Jiang, G., Li, A., Wang, L., 2016b. Economic analysis of waste-to-energy industry in China. Waste Manag. 48, 604–618.

Zhao, Z.-y., Yan, H., 2012. Assessment of the biomass power generation industry in China. Renew. Energy 37 (1), 53–60.

Zhao, Z.-Y., Zuo, J., Wu, P.-H., Yan, H., Zillante, G., 2016a. Competitiveness assessment of the biomass power generation industry in China: a five forces model study. Renew. Energy 89, 144–153.

Zhou, K., Yang, S., Shen, C., Ding, S., Sun, C., 2015. Energy conservation and emission reduction of China's electric power industry. Renew. Sustain. Energy Rev. 45, 10–19.