GHG mitigation potentials for using urban wastes as the resource for bioenergy with carbon capture and storage (BECCS) in China

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ABSTRACT

Bioenergy with carbon capture and storage (BECCS), as a negative emissions technology, plays an increasingly vital role in the low-carbon energy systems. Urban wastes are the fastest-growing bioenergy resources in recent years. This study aims to provide a high-resolution spatial assessment of GHG mitigation potentials for using urban wastes as the resource for BECCS in China towards 2030. For this evaluation, the domestic urban wastes potential in a 2017 baseline year and three waste to energy (WTE) processes are calculated and proposed. Results show that the collectable potential of urban wastes in 2017 was 1026.53 PJ and its utilizable potential would reach 2191.98 PJ in 2030. If this utilizable potential would be fully realized to displace fossil energy, approximately 151.82 Mt CO_2e of GHG emissions could be reduced. Moreover, WTE process coupled with carbon capture and storage (WTE-CCS) would result in extra negative emissions of 1.83 Mt CO_2e in 2030. Spatially, higher urban wastes potential leads to larger GHG mitigation potentials of WTE-CCS. Compared with less developed regions (e.g. Tibet, Qinghai and Ningxia), the regions with higher densities of population and economy activity (e.g. Guangdong, Jiangsu and Shandong) would have larger GHG mitigation potentials. Our study could provide geographically targeted information on the deployment of WTE-CCS in China.

Keywords: BECCS, Urban wastes, GHG mitigation potentials, China

1. Introduction

Along with the rapid economic development and urbanization process, China's urban wastes, mainly including municipal solid waste (MSW) and organic wastewater (OW) continue to rise in recent years. MSW has been increasing at 10% annually, which is responsible for the expansion of urban wastes [1]. As the processing capacity is relatively outdated, two-thirds of over 600 large and medium cities in China have been surrounded by wastes [2]. Some pilot cities (e.g. Shanghai) are practicing waste sorting to achieve resource recycling. Additionally, China's wastewater discharged reached 78.4 Gt in 2015, which showed an increase of 24.2% from 2000 [3]. The total amount of OW is expected to continue growing in the future.

Waste to energy (WTE) process is capable of reducing wastes volume and producing energy. Currently, MSW sanitary landfill is the most common way of waste disposal, but it occupies the extensive space [4]. MSW incineration power will be a promising treatment method with higher efficiency of reducing dioxin emission [5]. For OW, anaerobic wastewater treatment is a leading technology in converting it into biogas [6, 7]. However, WTE processes still lead to a large amount of GHG emissions, which have a significant impact on the environment [8]. Using urban wastes as bioenergy resource for WTE process with carbon capture and storage (WTE-CCS) can result in negative carbon emissions, which will contribute to alleviating global warming.

Bioenergy with CCS (BECCS), as a negative emissions technology, is an important mitigation option discussed

in the IPCC Fifth Assessment Report. Generally, CO_2 absorbed by photosynthesis during biomass growth can be balanced by CO_2 released to the atmosphere from bioenergy production. If bioenergy combined with CCS, CO_2 will be permanently removed from the atmosphere.

To assess the carbon emission reduction potentials of bioenergy with and without CCS, life cycle assessment (LCA) method has been generally used in previous studies [9-11]. Staples et al. [12] quantified the global life-cycle GHG emissions mitigation of bioenergy to replace fossil fuels in 2050. In the case of urban wastes, Pour et al. [13] estimated the global potential of MSW-based BECCS technologies and analyzed the economic viability of related WTE systems. Wang et al. [14] evaluated the impacts of different climate zones of China on the contribution of WTE to GHG emissions reduction. Nevertheless, China's GHG mitigation potentials of WTE-CCS still need to further explore.

This study evaluates the GHG mitigation potentials of urban wastes-based BECCS in China at a high spatial resolution towards 2030. Three WTE processes are discussed to displace fossil fuels-based conversion. The outcomes could provide valuable information on the regional deployment of WTE-CCS in China.

2. Methodology

2.1 Urban wastes potential estimation

Urban wastes discussed in this study include MSW and OW. Original data of them are from China Statistical Yearbook on Environment [15]. MSW is generated in daily life or related service activities. The organic matter of MSW (e.g. paper, wood, textiles and leather) is the major feedstock of WTE process. The collectable potential of MSW (CP_{MSW}) is defined by Eq. (1).
$$CP_{MSW} = Q \times LHV_{MSW} \tag{1}$$
where Q is the harmless disposed quantity of MSW, kg; LHV_{MSW} is the lower heating value of MSW, 4200 kJ/kg [4].

OW consists of domestic wastewater and industrial wastewater. The chemical oxygen demand (COD) of wastewater and its lower heating value are applied to calculate the collectable potential of OW (CP_{OW}), given by Eq. (2).
$$CP_{OW} = CC \times LHV_{COD} \tag{2}$$
where CC is the COD content, g; LHV_{COD} is the lower heating value of COD, 14 kJ /g [16].

2.2 GHG mitigation potentials estimation

China Bioenergy Development Roadmap 2050 [17] formulated the medium- and long-term planning of Chinese biomass availability. The utilizable potential of MSW will up to 2048.9 PJ by 2030, in which 80% of that used for incineration power and 20% used for landfill. As for OW, due to the absence of forecast, we assume that all collectable OW resource will be converted into energy via anaerobic digestion in 2030. For evaluating the GHG mitigation potentials, three WTE processes (i.e., MSW incineration power, MSW sanitary landfill and OW anaerobic digestion) are proposed to fully convert utilizable urban wastes into bioenergy as the replacement of fossil fuels in 2030.

GHG emissions mitigation is determined by the difference between the avoided GHG emissions and life-cycle GHG emissions [18]. Avoided emissions (AE) refer to GHG emissions by offsetting fossil fuels-derived energy carriers. MSW incineration power is used to replace coal-fired power generation, and biogas from MSW sanitary landfill and OW anaerobic digestion is used to substitute natural gas. Life-cycle emissions (LE) mean the GHG emissions of urban wastes feedstock-to-final bioenergy conversion process. Equations of AE and LE estimates are as follows:
$$AE = UP \times CE \times EF \tag{3}$$
$$LE = UP \times CE \times CF \tag{4}$$
where UP is the utilizable potential of urban wastes in 2030, MJ; CE is the conversion efficiency of WTE process; EF is the emission factor of fossil fuel-based conversion, kg CO_2e/MJ; CF is the carbon footprint of WTE processes with and without CCS, kg CO_2e/MJ. The values are shown in Table 1.

Table 1. Key parameters for GHG mitigation potentials estimation.

WTE process	CE	CF (kg CO_2e/MJ)		Fossil fuel-based process	EF (kg CO_2e/MJ)
		Without CCS	With CCS		
MSW incineration power	0.257[4]	0.184[4]	-0.001[13]	Coal-fired power	0.220[19]
MSW sanitary landfill[20]	0.131 m³/kg MSW	0.086	-0.003	Nature gas plant	0.089[21]
OW anaerobic digestion[16]	0.907 m³/kg COD	0.086	-0.003		

3. Results and Discussion

3.1 The collectable potential of urban wastes in 2017

The collectable potential of domestic urban wastes in 2017 was 1026.53 PJ, in which MSW played a dominant role accounted for 86% (883.45 PJ) of the total. Spatially, the regions with higher densities of population and economic activity had larger urban wastes potential, as presented in Fig. 1 (a). For instance, the urban waste potential in Guangdong was the largest (108.83 PJ), followed by Jiangsu (72.86 PJ) and Shandong (66.83 PJ). The collective share of the three provinces corresponded to 31.72% of national urban wastes potential. On the contrary, the least developed regions in northwest China (e.g. Tibet, Qinghai, Ningxia and Gansu) had the lowest urban wastes potential, accounting together for less than 1%. On the other hand, for the density of urban wastes potential, as displayed in Fig. 1(b), the characteristic "east dense and west sparse" was more prominent. The density of urban wastes in the most developed regions such as Shanghai, Beijing, Tianjin, Guangdong and Jiangsu were at the forefront in China (> 4 GJ/hm^2). It means these regions have a great prospect in urban wastes recycling. By contrast, urban wastes of less-developed and unpopulated regions were sparse (< 1 GJ/hm^2), such as Tibet, Qinghai, Sinkiang, Inner Mongolia and Gansu.

(a) Urban wastes potential (PJ)
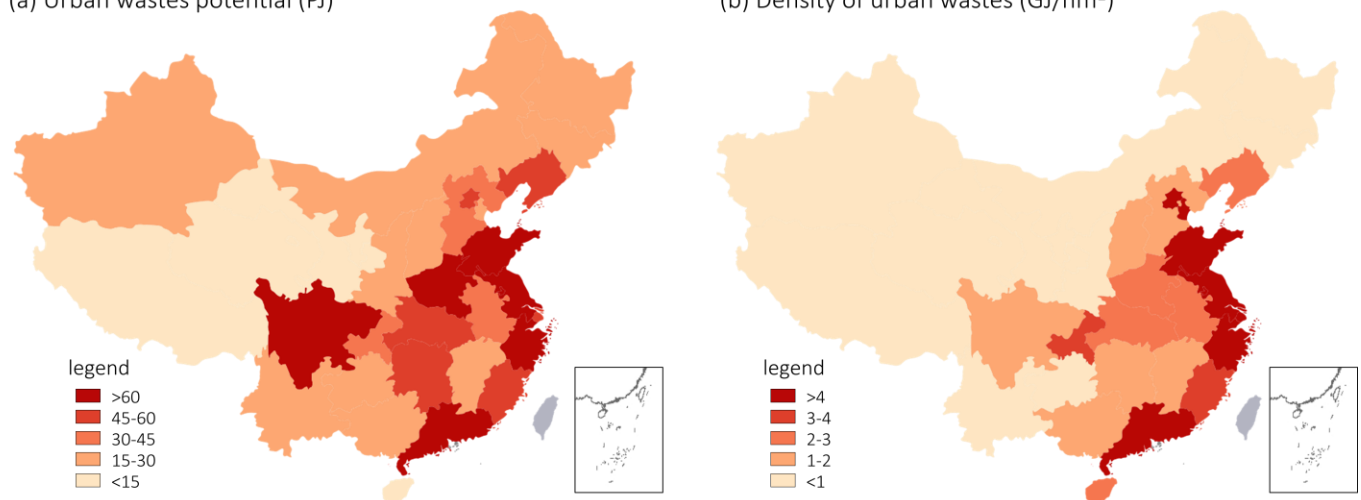
(b) Density of urban wastes (GJ/hm^2)

Fig. 1. Spatial distribution of collectable urban wastes in 2017.

3.2 GHG mitigation potentials in 2030

Given the large-scale deployment of BECCS in the future, we set two scenarios for evaluating the GHG mitigation potentials of urban wastes: WTE process coupled without CCS (S1) and with CCS (S2). S1 is used as a reference to illustrate the environmental benefits of large-scale BECCS.

The utilizable potential of China's urban wastes in 2030 would reach 2191.98 PJ as mentioned before. Based on this potential, we calculate the energy production of WTE processes and the associated GHG mitigation potentials of S1 and S2 in 2030. The results on a national level are shown in Table 2.

It is estimated that incineration power generation would up to 117.08 TWh (421.49 PJ) in 2030. Simultaneously, it would be the main contributor to reducing GHG emissions, accounting for 92% in S1 and 65% in S2. Additionally, biogas production would amount to 22.03 Gm^3 (671.04 PJ) in 2030. Wherein SS anaerobic digestion would contribute 57% of total biogas production. Biogas process with CCS would result in 52.53 Mt CO$_2$e of GHG emissions mitigation, which has more significant emission reduction benefits than the process without CCS. On the whole, the total GHG mitigation potentials of WTE-CCS would amount to 151.82 Mt CO$_2$e.

Table 2. GHG mitigation potentials of WTE processes.

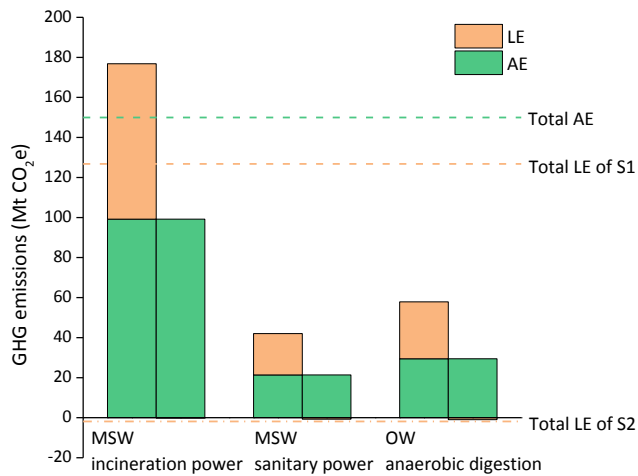|	Final carrier	Energy production	Mitigation potential (Mt CO$_2$e)	
			S1	S2
MSW incineration power	Electricity	117.08 TWh	21.50	99.28
MSW sanitary landfill		9.27 Gm^3	0.72	22.10
SS anaerobic digestion	Biogas	12.76 Gm^3	0.99	30.43
Total			23.22	151.82

Fig. 2. Scenario analysis of GHG emissions mitigation.

The structure of GHG mitigation potentials of three WTE processes is depicted in Fig. 2 using scenario analysis. If MSW incineration power would totally realize to replace coal-fired power in 2030, 99.17 Mt CO_2e of AE could produce, corresponding to 66% of total AE. MSW sanitary landfill and SS anaerobic

digestion by replacing natural gas-based conversion would have 50.82 Mt CO_2e of AE. Furthermore, compared with the positive LE of S1, WTE-CCS would result in extra GHG emissions of 1.83 Mt CO_2e in 2030. Biogas process with CCS would have larger negative LE potential than MSW incineration power with CCS.

On a provincial level, the regions with greater urban wastes potential would have higher GHG mitigation potentials of WTE-CCS. In other words, the GHG mitigation potentials in developed regions (e.g. Guangdong, Jiangsu, Shandong and Zhejiang) would be higher than that in less developed regions (e.g. Tibet, Qinghai and Ningxia) in China. From the scenario analysis perspective, the GHG mitigation potentials of WTE-CCS would significantly exceed than that of S1. There would be no regions with GHG mitigation potential higher than 3 Mt CO_2e in S1, but 14 regions in S2. Accordingly, the environmental benefits of BECCS in regional scale is also superior.
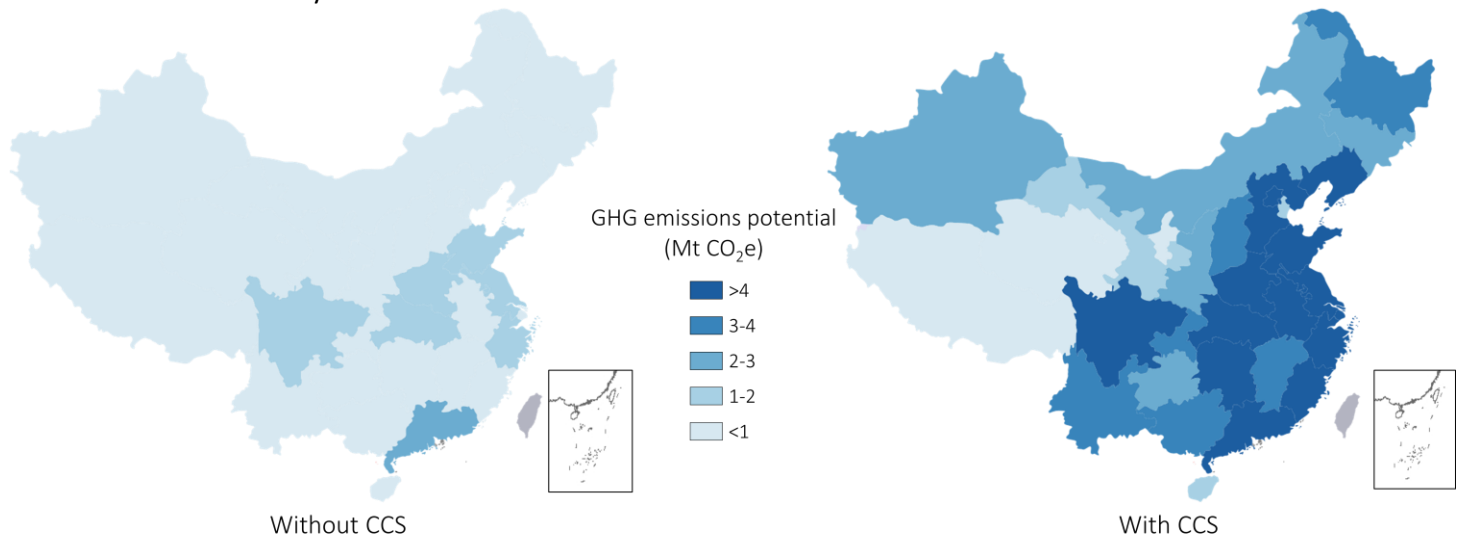

Fig. 3. Spatial distribution of GHG mitigation potentials in 2030.

3.3 Discussion

Under the threat of garbage siege and global warming, it is imperative to recycle urban wastes and reduce the GHG emissions of WTE processes. For China, there are remarkable provincial disparities on economic development and wastes distribution. This study provides a high-resolution spatial assessment for GHG mitigation potentials of urban wastes-based BECCS technology in China. The findings could help decision-makers to identify the suitable regions of the urban wastes-based BECCS deployment in China.

4. Conclusions

This study is the first time to evaluate the GHG mitigation potentials of urban wastes-based BECCS in China with a high spatial resolution. It is estimated that the domestic collectable potential of urban wastes was 1026.53 PJ in 2017 and the utilizable potential would reach 2191.98 PJ in 2030. Three WTE processes (i.e., MSW incineration power, MSW sanitary landfill and OW anaerobic digestion) would fully convert the utilizable urban wastes into bioenergy to displace fossil fuels in 2030. Approximately 151.82 Mt CO_2e of GHG emissions from WTE-CCS could be reduced. Compared with WTE

processes without CCS, WTE-CCS would result in extra GHG emissions of 1.83 Mt CO_2e. Spatially, higher urban wastes potential leads to larger GHG mitigation potentials of WTE-CCS. The regions with higher densities of population and economy activity (e.g. Guangdong, Jiangsu and Shandong) would have larger GHG mitigation potentials and also have a great prospect in the development of urban wastes-based BECCS technology.

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