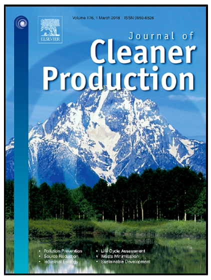

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The spatiotemporal features of Greenhouse Gases Emissions from Biomass Burning in China from 2000-2012

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Abstract

Greenhouse gases emissions from biomass burning have been given a little attention, especially the spatiotemporal features of biomass burning sources and greenhouse gases emissions have not been comprehensively uncovered. This research undertook IPCC bottom-up inventory guideline to estimate Chinese greenhouse gases emissions from biomass burning and applied geographical information system to reveal biomass burning emissions spatiotemporal features. The purposes were to quantify greenhouse gases emissions from various biomass burning sources and to uncover the spatial and temporal emissions features so to deliver future policy implications in China. The results showed that the average annual biomass burning emissions in China from 2000-2012 were 880.66 Mt for CO_2, 96.59 Mt CO_2-eq for CH_4, and 16.81 Mt CO_2-eq for N_2O. The spatial pattern of biomass greenhouse gases emissions showed about 50 % of national emission were in the east and south-central regions. The majority of biomass burning emissions were from firewood and crop residues, which accounted for more than 90 % of national biomass burning emissions. All types of biomass burning emissions exhibited similar temporal trends from 2000-2012, with strong inter-annual variability and fluctuant increase. The large grassland and forest fires induced the significant greenhouse gases emissions peaks in the years of 2001, 2003 and 2006. We found that biofuel burning, with low combustion efficiency, is the major emission source. Open burning of biomass was widespread in China, and east and south-central regions were the major distribution of biomass burning greenhouse gases emission. Optimized design for improving the efficiency of biomass utilization and making emission control policy combination with its spatiotemporal features will be the effective way to reduce the biomass burning emissions.

Keywords: Greenhouse gases emission, Biomass burning, Biofuel, Open burning

1. Introduction

Biomass burning is the burning of living and dead vegetation. It often refers to forest fires, grassland fires, field burning of crop residue, burning of crop residue as fuel and fuel wood (Yan et al., 2006). Biomass burning is a significant source of Greenhouse Gases (GHGs) (Shi and Yamaguchi, 2014), contributing 20-50 % of global GHGs emissions (Yadav et al., 2017), and greatly impacting local, regional and global atmospheric chemistry and climate change (Weldemichael and Assefa, 2016). Biomass burning is also one important reason that induce the inter-annual variability in the growth rate of some trace gases (Langenfelds et al., 2002) and the uncertainty in atmospheric transport simulations of trace gases (Bian et al., 2007). In many policies and regulations, biomass combustion is always considered as “carbon-neutral” due to the released CO_2 refixation by vegetation in the next growth cycle (Searchinger et al., 2009). However, this refixation is not a comforting balance because the short cycle CO_2 cannot be rapidly removed by vegetation regrowth, and biomass burning CO_2 in the atmosphere has been monitored by satellite (Yan et al., 2006). If the burnt ecosystem is not regrown, the liberated CO_2 remain in atmosphere for long time, thereby affecting the global CO_2 budget (Yadav et al., 2017). Together with the relative long cycle of CH_4 and N_2O in atmosphere (Koppmann et al., 2005), the effects of GHGs emissions from biomass burning on global climate change cannot be ignored (Haberl et al., 2012). Accurately evaluating GHGs emissions from biomass burning at both global and regional levels is urgently needed to better understand the interactions between anthropogenic GHGs emissions and climate change (Shi et al., 2015).

Studies on GHGs emissions from biomass burning are limited (Koppmann et al., 2005). Existing studies were mostly focus on open burning of forest fires, grassland fires, and field burning of crop residues (e.g., EDGAR, 2011; Gadde et al., 2009), lacking of biofuel burning. Biofuel burning is popular in countries with rural population, such as China. Biofuel as major energy takes up 54 % of the total rural life energy (Hu, 2008). Short of biofuel burning estimation may dramatically underestimate biomass burning emissions in China. The relevant studies in China are few, and the disparity in the estimates of burned biomass amount and the emission factors have resulted in differences in biomass burning emission inventories (Yan et al., 2006). Streets et al. (2003) estimated that CO_2 and CH_4 emissions from biomass open burning were approximately 300 Mt CO_2-eq. Cao et al. (2005) and Lu et al. (2011) extended biomass burning to biofuel, and the emissions increased to more than 800 Mt CO_2-eq in the same year. Yan et al. (2006) first considered N_2O emission from biofuel and open burning sources, and the GHGs emission was approximately 759 Mt CO_2-eq. Tian et al. (2011) and Zhao et al. (2012) extended the CO_2 and CH_4 emissions from an individual year to temporal changes. The widely available biomass burning emission database of EDGAR v4.2 (2011) provides multi-year GHGs emission inventory; however, the database only focuses on open field biomass burning, lacking the part of biofuel that is important in Chinese rural life energy (Li and Xu, 2010).

Overall, there are few studies on the inventories of GHGs emissions from all types of biomass burning. The existing studies in China only focused on a specific year or a narrow temporal scale, with limited biomass burning sources, lacking detail spatiotemporal information. The underrepresented expression of biomass burning GHGs emissions in China is inevitable (Shi and Yamaguchi, 2014). Comprehensively uncovering the features of biomass burning emissions from the perspectives of complete biomass burning sources and a spatiotemporal scale is essential (Yan et al., 2006). In this study, a bottom-up estimate of biomass burning emission in China using statistical data was conducted. The spatiotemporal features of biomass burning emission analysis were performed by Geographical Information System (GIS). Open burning emissions from forest fire, grassland fire and field burning of crop residues, biofuel burning emissions from crop residues, firewood and livestock excrement, and emissions from biomass-based electricity generation were considered. The outcomes of the study will help to understand Chinese biomass burning GHGs emissions and make a scientific basis for policy implementations.

2. Material and Methods

Biomass burning emission is estimated based on the activity data of burned biomass and emission factors using Eq. (1) (Eggleston et al., 2006). Activity data were calculated from the official statistics Yearbook. Emission factors were based on China's specific values and the default value provided by IPCC bottom-up inventory guideline (Eggleston et al., 2006) (Table 1).

$$Q_i=\sum M_j \cdot EF_{i,j} \cdot 10^{-3} \quad (1)$$

i was the type of GHG (CO_2, CH_4 or N_2O); j was the type of biomass; Q_i was the total amount of i emission each year, t/y; M_j was the amount of j burned biomass each year, t/y or kWh/y; and $EF_{i,j}$ was the i emission factor of biomass j, g/kg or g/kWh.

Biomass burning types include forest and grassland fires, firewood, crop residue burning, livestock excrement burning and biomass-based electricity generation. The activity data calculation methods are listed in the following sections.

2.1 Forest and grassland fires

The amounts of biomass burning from forest and grassland fires are calculated using Eq. (2).

$$M_1=A \cdot D \cdot F \quad (2)$$

M_1 was the amount of burned biomass each year, t/y; A was the burned area each year, m^2/y; D was the biomass density, t/m^2; and F was the burning efficiency.

The burned forest and grassland areas from 2000–2012 for each province were from the China Forestry Yearbook (NFB, 2001-2013) and China Husbandry Yearbook (EBCHY, 2001-2013). Biomass density was estimated by Fang et al. (1996) for forest and by Yan et al. (2006) for grassland. The burning efficiency was 0.33 for forest and 0.95 for grassland (Yan et al., 2006).

2.2 Firewood

Firewood includes energy forest, forestry production logging slash, wood and bamboo manufacturing residues, forest intermediate cutting, civil firewood cutting, and sideway trees (Liu and Shen, 2007). Based on the statistical data from the China Forestry Yearbook (NFB, 2001-2013), the firewood production was calculated using Eq. (3) (Liu and Shen, 2007).

$$M_2=\sum_{i=0}^{n} Qf_i \cdot r_i \cdot m_i \qquad (3)$$

i was the biomass type; M_2 was the actual amount of firewood each year, t/y; Qf_i was the resource amount of wood i each year, and the unit was the volume of m^3/y, area of m^2/y or numbers/y; r_i was the ratio of wood i used as fuel; and m_i was the weight coefficient, t/m^3, m^2/m^3 or t/individual. For the associated parameters, see the study by Liu and Shen (2007).

According to the felling forest data, the forestry production logging slash was approximately 40 % of the forest biomass, including timber forests, shelter forests, and special forests that reach the felling standard. Wood and bamboo processing residues constituted approximately 34.4 % of log and bamboo production. The intermediate cutting times in middle-aged and young trees were approximately 2 to 3 during their growing periods.

2.3 Crop residues burning

Crop residues can be burned as household energy and directly burned in field. The burning amount of crop residues was calculated using Eq. (4) (Lu et al., 2011).

$$M_3=(\sum_{i=0}^{n} P_i \cdot N_i)\cdot C\cdot B\cdot F \qquad (4)$$

i was the crop type; M_3 was the amount of crop residue burning each year, t/y; P_i was crop i production each year, t/y; N_i was the residue/crop ratio of crop i; C was the collected coefficient; B was the burning ratio; and F was the burning efficiency.

Detailed crop production data were collected from the China Statistical Yearbooks (NBSC, 2001-2013). The residue/crop ratios were available from the studies of Lu et al. (2011) and Yevich and Logan (2003). The collected coefficient of crop residues was 0.881 (Yevich and Logan, 2003). The percentage of crop residues burned in the field was 19.4 % (Yan et al., 2006) and 47 % for biofuel (Chen et al., 2017). The burning efficiency for the crop residue was approximately 92.5 % (Lu et al., 2011).

2.4 Livestock excrement burning

Livestock excrement burned as fuel in China is small and only distributes in the pastoral and semi-pastoral areas of Inner Mongolia, Xinjiang, Tibet, Qinghai and Ningxia provinces. The amount of livestock excrement burning was calculated using Eq. (5) (Lu et al., 2011).

$$M_4=(\sum_{i=0}^{n} S_i \cdot Y_i)\cdot C\cdot R \qquad (5)$$

Where i was the large livestock type; M_4 was the amount of livestock excrement burning each year, t/y; S_i was the numbers of large livestock i at the end of the year; Y was the excrement production per one large livestock i during its feeding period (approximately 365 d), t/individual/y; C was the large livestock excrement dry matter content; and R was the ratio of livestock excrement direct burned as fuel.

The numbers of large livestock were collected from the China Statistical Yearbooks (NBSC, 2001-2013). The excrement coefficients of large livestock were estimated by He (2012). The dry matter content of large livestock excrement was 18 %, and its direct burning as fuel was 20 % (Tian et al., 2011).

2.5 Biomass-based electricity generation

The development of biomass-based electricity generation in China is late, and the available data began in 2006. From the Clean Development Mechanism project database and methodology (AM0006) (CDM, 2014), we can obtain the estimated average GHGs reduction (CO_2-eq, t/y), the approved date, the location, and the calculation method of GHGs reduction. According to the GHGs reduction coefficient of 1.79 kg CO_2-eq/kWh (Shafie et al., 2014), the electricity generation was calculated using Eq. (6).

$$M_5 = R_{GHG} /1.79 \quad (6)$$

M_5 was the biomass-based electricity generation each year, kWh/y; and R_{GHG} was the GHGs emission reduction each year, kg/y.

3 Results and Discussions

3.1 The GHGs emissions from biomass burning on national scale

Biomass burning GHGs emissions showed increase trend from 822.69 Mt CO_2-eq in 2000 to 1,088.18 Mt CO_2-eq in 2013, with an average annual growth rate of 2.4 %. CO_2 was the overwhelmingly largest contributor (88 %), followed by CH_4 (10 %) and N_2O (2 %) (Table 2). The three types GHGs presented similar variations with strong inter-annual variability and fluctuant increase over time, even though their emission magnitudes differed greatly (Table 2). The contributions of biomass burning sources were similar for the three GHGs types (Fig. 1). Crop residues burned as fuel was the biggest contributor. Biofuel of firewood and crop residues burned in field were the other two major emission sources. The top three biomass burning sources accounted for approximately 86-98 % of the total biomass burning emissions (Fig. 2), which was consistent with other study (Lu et al., 2011). The remaining biomass burning emissions (approximately 2-14 %) was mainly from forest fires, with small peaks in 2003 and 2006. The contribution of grassland fires was small, while its peak amount in 2001 increased its share to 11 % (Fig. 2). The decreased biomass burning amount from forest and grassland fires over time indicated that more attention to control of wildfires had a good effect (Yan et al., 2006). Livestock excrement burned as fuel was the least contributor of biomass burning.

Biomass burning as life energy was the dominant burning type in rural China (Yevich and Logan, 2003). In this study, biofuel burning emission (crop residues, firewood and livestock excrement burned as fuel) was the main biomass burning GHGs emissions in China, taking up approximately 77-81 % of the total emissions. Biomass open burning emission (field burning of crop residue and forest and grassland fires) constituted only 25 % of biofuel burning. Its temporal change was consistent with biofuel emissions but fluctuated more moderately. The annual average of open field burning of crop residues was 162 Tg CO_2-eq, which was consistent with other study (Li et al., 2016). Compared to crop residues, emissions from forest and grassland fires were small, but the obvious peak emissions resulted from large grassland and forest fires cannot be neglected (Fig. 2). Biomass-based electricity generation emission was not large, while it increased obviously from 2006 to 2012 (with annual 73 % growth rate). The swift increases were derived from its ability of energy saving and GHGs emission reduces as well as government promotion (Xu et al., 2016). The development of new and efficient biomass-to-electricity technologies and consideration of logistical component of biomass should be promoted to improve the economic and GHGs emissions reduction outcomes (Liu et al., 2017).

3.2 The spatiotemporal GHGs emissions from biomass burning on regional scale

Biomass burning emissions were mainly distributed in east and south-central regions of China (Table 2; Fig. 4), accounting for half of the total emissions. The southwest region, northeast region, and north-central region separately took up approximately 10-15 %, with less than 10 % in the northwest region. The regional GHGs emissions presented various temporal changes, with a fluctuating decrease in east and south-central regions, a parabolic increase and then decrease in southwest region, a rapid increase in northeast region, and a steady increase in north-central region. The national GHGs emission peaks in 2001, 2003, and 2006 due to large grassland and forest open fires (Fig. 2) were mainly distributed in the south-central region and northeast region. The large open fires separately caused GHGs to take up 35-54 % and 32-53 % of the regional emissions.

The contribution of biomass burning source to regional GHGs emissions was different (Fig. 3). In the north-central, northeast, and east regions, crop residues burned as fuel were the largest contributor, accounting for more than 50 % of the regional GHGs emissions. In the south-central and northwest regions, crop residues burned as fuel and firewood separately took up approximately 30% of the regional emissions. Since three (Xinjiang, Qinghai and Ningxia provinces) of the five pastoral and semi-pastoral areas are in northwest region, livestock excrement played an important role in GHG emissions, especially for the N_2O emission (constituting 37 % of the regional emission). In the southwest region, firewood became the largest contributor. The different biofuel utilization among various regions depends on local natural resources and economy (Wang and Feng, 2004). The different biomass burning type contribution to regional GHGs emissions indicated that the mitigation potential and related strategies and policies should be different in various regions.

3.3 The GHGs emissions from biomass burning on provincial scale

From the provincial GHGs emissions during 2000-2012 period (Fig. 4), we found that more than 40 Mt CO_2-eq emissions were major in Jiangsu, Anhui, Shandong, Henan, Hubei, Hunan, Hebei, Heilongjiang, Sichuan, and Guangxi provinces. High population density, increased consumption of firewood and crop residue as life energy, and serious crop residues burned in the field were the main cause of large emissions (Cao et al., 2008). The lower GHGs emissions were mostly in Beijing, Tianjing, Shanghai, Hainan, Tibet, Qinghai, and Ningxia provinces (Fig. 4). Beijing, Tianjing and Shanghai municipalities have rapid urbanization, while Hainan, Tibet, Qinghai, and Ningxia provinces have smaller population. The demand of biomass burning as life energy in these areas was relatively lower (Cao et al., 2008).

From the temporal changes during 2000-2012 period (Fig. 4), the relative emission growth rates in some interior provinces, including Jilin, Heilongjiang, Inner Mongolia, Ningxia, and Xinjiang provinces, were obviously higher than those of coastal provinces in the east and south-central regions, although the absolute emissions in these interior provinces were generally small. The smallest emission growth rate appeared in Shanghai, then the coastal provinces of Jiangsu, Zhejiang, Guangdong and Hainan provinces. The disparity in the provincial emission growth rates mainly resulted from different energy structure (Cao et al., 2008). In the less-developed rural areas of the west region and the abundant biomass resource of northeast provinces, the inexpensive and easily obtained firewood and crop residues were consistently important energy (Yevich and Logan, 2003). In contrast, in the developed coastal provinces, other high-grade energy sources, such as gas, coal, and electricity were used widely. Making related mitigation strategies and policies should consider not only high GHGs emission provinces but also include higher emission growth rate provinces.

3.4 Chinese biomass burning GHGs emission contribution

In this study, the annual GHGs emissions from biomass burning in China during 2000-2012 period were 993 Mt CO_2-eq/y, equivalent to approximately 10 % of the national total GHGs emissions from fossil fuel combustion and cement production. The biomass burning GHGs emissions in China accounted for approximately 8 % of global (Watson et al., 2001), 22 % of developing world, and 34 % of Asia biomass burning GHG emissions (Yevich and Logan, 2003). The emissions of CH_4 and N_2O accounted for approximately 7 % of the global biomass burning non-CO_2 GHGs emissions (Montzka et al., 2011). Annual open biomass burning GHGs emissions were approximately 210 Mt CO_2-eq/y, taking approximately 17 % of Asia (Streets et al., 2003) and 2-3 % of the world open biomass burning emissions (Van der Werf et al., 2006). Compared to other main contributors of open biomass burning emission in Asia (Yevich and Logan, 2003), this study was lower than the estimated 238-688 Mt CO_2-eq/y in India (Venkataraman et al., 2006) and 240 Mt CO_2-eq/y in Southeast Asia (Shi and Yamaguchi, 2014) but significantly higher than the 58 Mt CO_2-eq/y in Indonesia (Permadi and Oanh, 2013).

3.5 Emission uncertainties

Biomass burning emissions were associated with the amount and types of biomass burning and related emission factors. It was true that some types of biomass burning were very little known. This inventory in such cases relied heavily on inferences of activity data from statistical information and the emission factors. According to previous studies, the activity data of each biomass type was within an uncertainty range of approximately ±50 % around the mean value (Saatchi et al., 2011), and the typical uncertainty of related emission factor was on the order of 20-30 % (Hoelzemann et al., 2004). Based on the IPCC guidelines for national greenhouse gas inventories (2006) and the method of Streets et al (2003), we estimated the uncertainty of biomass burning emissions, and considered seven types of burning sources and three chemical species. The estimated emission ranges were 264.20-1,585.19 Mt CO_2 /y, 28.98-173.86 Mt CO_2-eq /y for CH_4, and 5.04-30.26 Mt CO_2-eq /y for N_2O.

3.6 Policy implication

Biomass resources in China are abundant (Chen et al., 2017). Rational utilization of biomass resources can significantly reduce GHGs emissions and alleviate both energy and air quality concerns (Weldemichael and Assefa, 2016). Based on above findings, several policy implications should be raised for a health and environmental policy interventions:

It is urgent to promote efficient biomass energy utilization in Chinese rural areas. Biomass as an important life energy in rural China will not change in the near future. Considering rural resident preference for conventional energy usages, it is important to develop clean and efficient combustion technologies for household use. Widely disseminating clean-burning household stove use accompanied by some subsidy programs can be piloted in the high biomass use as life energy region and then promoted nationwide. Appropriate bioenergy planning according to regional conditions is crucial. In the abundant biomass regions such as east and south-central, biomass power generation may be a good choice for governments to fulfill emissions reduction considering comprehensive benefits. Optimizing biomass power plant layout and minimizing logistics costs should be paid to insure biomass power under a good operation status (Liu et al., 2017). The market of biomass-based clean and efficient energy (such as power generation, biomass briquettes, biogas production) should be expanded to rural areas to thoroughly address rural conventional energy structure. Strengthening the awareness of rural residents on their willing to choose and use such clean biomass energy efficiently for air pollution reduction is also in demand (Sun et al., 2016).

It is critical to put forward effective measures to prohibit open field burning of crop residues. Now, central and local governments have recognized the negative effects of crop resides field burning and took some control actions to ban open field burning of crop residues (MEP, 1999). For instance, to define the government responsibility, to monitor fire spots by meteorological and environmental satellite, to strengthen the inspection of illegal activities, etc. (Zhang et al., 2017). The key point is strengthening the enforcement of these good regulations in the northeast, east and south-central regions. In addition to administrative control measures from the government, the integrated utilization of crop resides initiatives such as returning straw to soil to increase soil texture and fertility (Sun et al., 2016), making crop residue as efficient energy by advanced technology to partially replace fossil energy (Zhang et al., 2017), and using straw as feed supply to animal and raw material to plate-making and charcoal making (Zhang et al., 2017) are another valid control measures. The crop residues utilization efficiency improvement needs government supports from aspects of fund, policy, technology, education, etc..

It is important to consider spatiotemporal features when making biomass burning GHGs emission control policy. The key control areas are in east and south-central regions, especially for the contributions of biofuel of crop residues in east region and biofuel of crop residues and firewood in south-central region. Mitigation strategies and policies should consider both provinces with high biomass burning GHGs emission and provinces with higher emission growth rate. The provinces with high biomass burning emission potential can reduce the emissions by increasing biomass in energy structure optimization and adopting advanced biomass technology. The forest and grassland open fire control have had a good effect on biomass burning GHGs emissions reduction in recent years. Government should continue to strengthen the monitoring and preventing of anthropogenic forest and grassland fires, especially in the south-central region and northeast region.

4. Conclusions

The GHGs emissions from biomass burning increased in China from 2000 to 2012. The majority of biomass burning emissions were from firewood, crop residues burned as fuel, and crop residues field burning, which accounted for more than 90 % of the national biomass burning emissions. The large grassland and forest open fires resulted in obvious emission peaks in several years. The obvious emission peaks resulted from large grassland and forest fires mainly distributed in the south-central region and northeast region. Half of biomass burning GHGs emissions were mainly distributed in the east and south-central regions. The biomass burning GHGs emissions in coastal provinces were higher than the interior provinces, while the relative emission growth rates presented a contrary trend. Future research on obtaining more accurate biomass burning data, improving the quality of statistics as well as combination of model simulation and prediction would be definitely necessary for feature identification of regional and global biomass burning GHGs emissions and policy making.

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Table 1 Emission factors for biomass burning in China

Emission factors (g/kg)	Field burning			Biofuel			Electricity generation
	forest fire	grassland fire	crop residue	firewood	crop residue	livestock excrement	biomass-based (g/kWh)
CO_2	1,599.3[1]	1,613[1]	1,445.76[1]	1,658[2]	1,437.97[3]	1,060[4]	3,602[5]
CH_4	4.7[1]	2.3[1]	3.90[1]	5.2[2]	5.2[2]	4.14[4]	16.32[5]
N_2O	0.26[6]	0.21[6]	0.07[7]	0.0624[6]	0.12[8]	0.3132[6]	0.2862[5]

Note: superscript numbers indicate references. [1] indicates Lu et al., 2011; [2] indicates Yan et al., 2006; [3] indicates Zhao et al., 2012; [4] indicates Tian et al., 2011; [5] indicates Koppmann et al., 2005; [6] indicates Eggleston et al., 2006; [7] indicates Gadde et al., 2009; [8] indicates Liu, 2011.

Table 2 The inventories of GHGs emissions from biomass burning during 2000-2012 period (Mt CO_2-eq)

Regions	Year												
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
CO_2													
North-central	68.54	76.81	78.40	92.84	87.29	90.93	95.15	91.93	97.05	94.62	98.11	102.35	103.45
Northeast	75.79	86.09	89.23	121.34	106.79	103.05	122.04	104.45	117.04	116.40	127.80	139.97	146.29
East	209.20	213.25	232.01	217.89	229.87	200.21	208.14	207.69	225.83	231.77	228.26	229.63	236.22
South-central	208.99	303.94	196.44	189.56	217.26	222.56	240.87	232.43	236.68	236.30	234.81	236.24	236.79
Southwest	104.56	152.78	159.12	162.78	133.80	149.56	137.15	129.56	137.31	129.48	130.09	124.42	128.39
Northwest	50.09	66.64	55.94	53.53	63.39	58.65	63.91	66.52	71.57	73.06	71.72	77.09	78.19
National	729.01	898.43	824.77	890.00	858.85	849.70	902.31	854.92	909.67	907.84	914.77	939.40	961.11
CH_4 (CO_2-eq)													
North-central	7.72	8.62	8.83	10.31	9.84	10.24	10.75	10.44	11.08	10.79	11.33	11.89	12.17
Northeast	8.59	9.75	10.19	13.32	12.06	11.70	13.68	12.07	13.67	13.52	15.08	16.59	17.47
East	23.39	23.84	25.81	24.19	25.60	22.44	23.39	23.60	25.70	26.53	26.16	26.35	27.45
South-central	23.01	26.95	21.62	20.82	23.84	24.44	26.47	25.56	26.20	26.31	26.28	26.55	26.79
Southwest	11.73	16.82	17.53	17.91	14.86	16.54	15.16	14.38	15.22	14.41	14.46	13.88	14.36
Northwest	5.71	5.92	6.36	6.11	7.18	6.70	7.25	7.56	8.11	8.28	8.15	8.74	8.88
National	79.91	91.84	90.21	96.35	93.73	92.81	98.49	94.25	100.81	100.87	102.24	105.39	108.75
N_2O (CO_2-eq)													
North-central	1.55	1.60	1.67	2.21	1.88	2.04	2.19	2.03	2.18	2.13	2.21	2.33	2.40
Northeast	1.60	1.91	1.90	3.54	2.39	2.28	3.05	2.19	2.47	2.55	2.70	2.98	3.13
East	4.14	4.11	4.29	3.98	4.41	3.98	4.12	4.12	4.46	4.58	4.47	4.56	4.71
South-central	3.72	7.66	3.52	3.43	3.96	4.00	4.17	4.13	4.32	4.29	4.27	4.30	4.35
Southwest	2.01	2.58	2.65	2.79	2.43	2.67	2.48	2.36	2.65	2.45	2.56	2.29	2.39
Northwest	1.39	1.40	1.49	1.48	1.61	1.61	1.65	1.66	1.72	1.75	1.76	1.84	1.89
National	13.77	18.66	14.81	18.36	16.08	15.97	17.58	15.79	17.06	17.18	17.23	17.73	18.32

Note: North-central including Beijing and Tianjin municipalities, Hebei, Shanxi, and Inner Mongol provinces; Northeast including Liaoning, Jilin and Heilongjiang provinces; East including Shanghai municipality, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi and Shandong provinces; South-central including Henan, Hubei, Hunan, Guangdong, Guangxi and Hainan provinces; Southwest including Chongqing municipality, Sichuan, Guizhou, Yunnan and Tibet provinces; Northwest including Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang provinces.

Figure captions

Fig. 1. The contribution of biomass burning types to greenhouse gases emissions during 2000-2012 period

Fig. 2. The biomass burning amount changes in China during 2000-2012 period

Fig. 3. The relative percentage of different biomass burning types to average regional greenhouse gases emissions during 2000-2012 period

Fig. 4. Spatial distribution of China's biomass burning greenhouse gases emissions (Mt CO_2-eq) during 2000-2012 period and the relative emission growth rate from 2000 to 2012.

Fig. 1

CO_2
electricity generation
livestock excement
grassland fire
forest fire
crop residue in field
firewood
crop residue as fuel
The structure of contribution(%)
100%
80%
60%
40%
20%
0%
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
CH_4
The structure of contribution (%)
N_2O
The structure of contribution (%)
Date (year)

Fig. 2

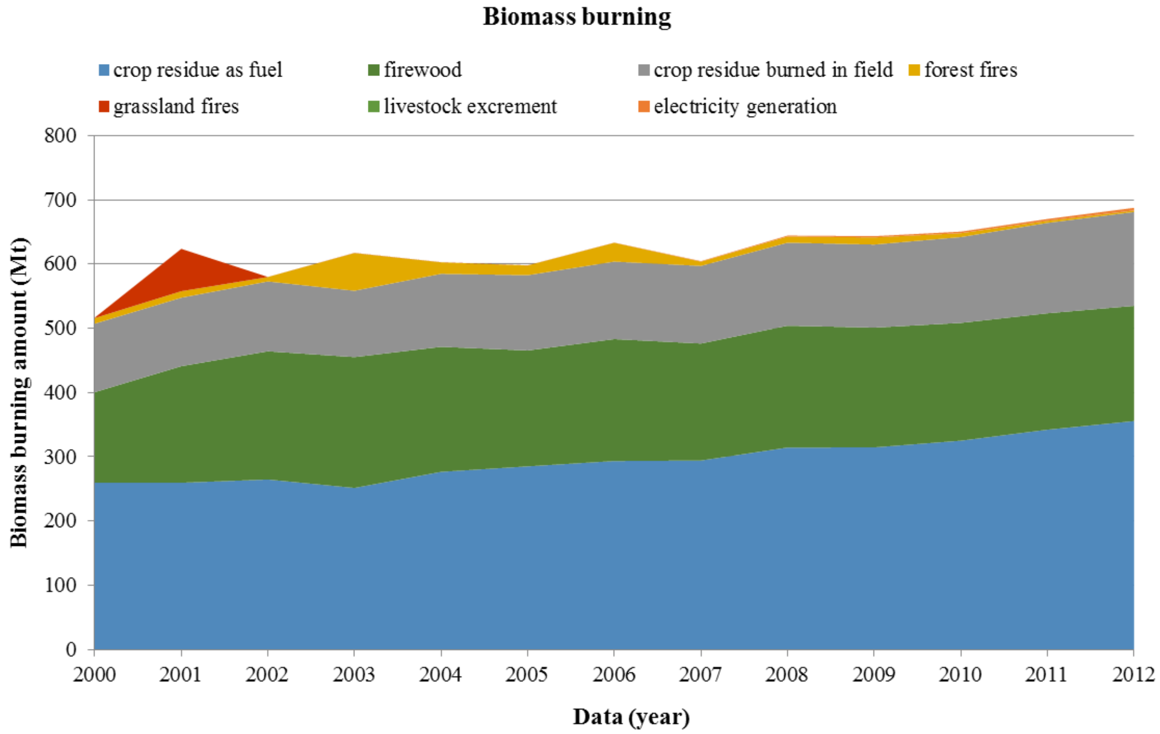

Biomass burning
crop residue as fuel
firewood
crop residue burned in field
forest fires
grassland fires
livestock excrement
electricity generation
Biomass burning amount (Mt)
0
100
200
300
400
500
600
700
800
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
Data (year)

Fig. 3

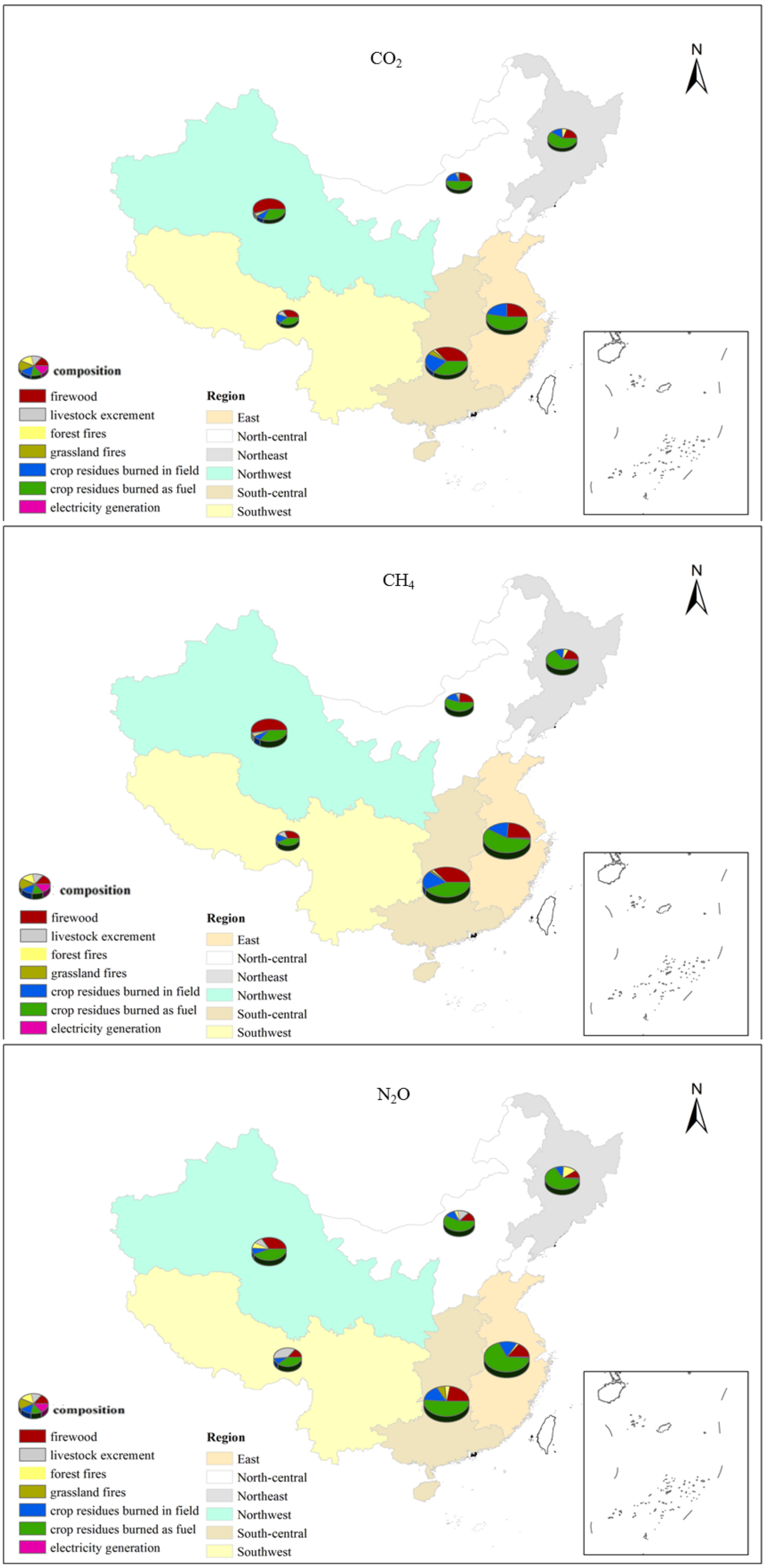
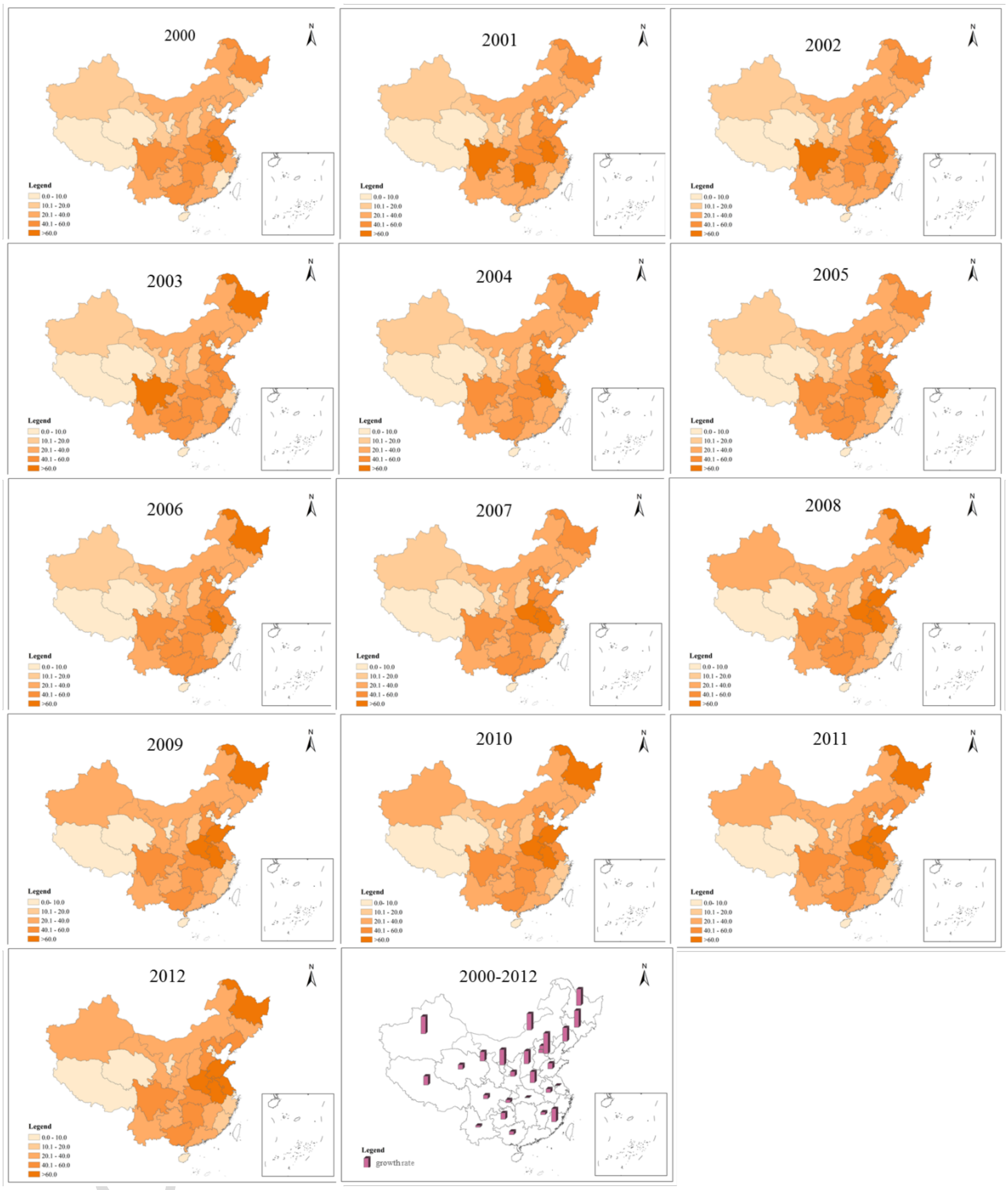

CO2
N
composition
firewood
livestock excrement
forest fires
grassland fires
crop residues burned in field
crop residues burned as fuel
electricity generation
Region
East
North-central
Northeast
Northwest
South-central
Southwest
CH4
N
composition
firewood
livestock excrement
forest fires
grassland fires
crop residues burned in field
crop residues burned as fuel
electricity generation
Region
East
North-central
Northeast
Northwest
South-central
Southwest
N2O
N
composition
firewood
livestock excrement
forest fires
grassland fires
crop residues burned in field
crop residues burned as fuel
electricity generation
Region
East
North-central
Northeast
Northwest
South-central
Southwest

Fig. 4



2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2000-2012
N
Legend
0.0 - 10.0
10.1 - 20.0
20.1 - 40.0
40.1 - 60.0
>60.0
growth rate