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Estimation of NO_x Emission from Fossil Fuel Consumption in China for the Period 1980-2012

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Abstract. As the largest consumer of fossil fuel, China NOx emission from energy consumption has become a hotspot for studies. In this study, emission inventory was used to analysis the historical variation of NOx emission in china for the period 1980 to 2012. Results indicate that NOx mission of China has increased from 446.45×104t to 2499.72×104t during 1980-2012, electricity, industry and transportation was the main contributor and NOx emission has increased from 145.04×104t, 206.75×104t, 39.44×104t to 1311.6×104t, 479.46×104t, 576.31×104t respectively; from the spatial pattern, high total NOx emission with mainly concentrated in the north of China and the high emission intensity mainly concentrate in eastern China.

1 Introduction

It is now well known that NO_x emissions play an important role in acidification, haze, summer photochemical smog and the increase of tropospheric ozone level [1]. Fossil fuel combustion is identified as one of the main contributors to the escalation of air pollution such as NO_x [2]. China is the largest energy consumer in the world and have contributed amount of various emission during past three decades because of its rapid industrializations and urbanizations. Although China has implement strict environment policy in recent years, NO_x emission still keeps an increase trend all the way. Data from satellite measurements indicated that NO_x vertical column density have increased significantly in East Asia [3].

A systematic emission inventory is helpful for environmental policy maker to understand the essential information of emission source and control air pollution effectively. Several national and provincial level NO_x emission inventories have been presented by several researchers. For instance, D.G.Streets(2000) used emission factor estimate China provincial NO_x emissions of 1995 and forecasted emissions for the year 2020[4]; Tian Hezhong(2001) build up 1980-1998 NO_x emissions inventory of China on the basis of historical energy consumption data and NO_x emission factors[5]; Qing Lu(2013) took use of emission inventory estimate the NO_x emission of Pearl River Delta region and found NO_x emissions went up consistently during 2000-2009 except for a break point in 2008[6]

Yun Shi *et al*. (2014) established a NOx emissions inventory of China from for the period 2000-2010[7]. These study focus more on short period or annual emission and pay no more attention to spatial distribution variation of NO_x emission. As a country with the fast developing speed in the world, China NO_x emission changed greatly over the past years, in this paper we established a bottom-up NO_x emission inventory of China from 1980 to 2012 for different economic sectors and different fuel styles, then, based on the provincial fossil fuel consumption of 2012, we analyses spatial distribution characteristic of NO_x emission in provincial level.

2 Data and methods

Following the approach of Tian Hezhong(2001)[5] and Qing Lu(2013)[6] NOx emission source were classified into seven categories: power plants and heating, industry, construction, transportation, commercial, residential consumption and other resources. Ten fuel types such as coal, coke, crude oil etc, are considered and their emission factors are different for different period. NO_x emission was estimated by an emission factor approach which was implemented by the Equation below:

$$Q_{i,j,f}^{N}(t) = K_{i,j,f}^{N}(t) \times F_{i,j,f}(t) \times (1 - P_{i,j,f}^{N}) \quad (1)$$

$$Q_{i,j}^{N} = \sum_{f} \sum_{j} Q_{i,j,f}^{N}(t) \quad (2)$$

where Q^N is the emission of NO_x, K^N is the emission factors of NO_x weighted by N_2O, F is the fuel consumption, P is the average removal efficiency of NO_x, i, j, f, t represent different province (municipality or Autonomous Region, except Hong Kang, Macau and

Taiwan due to the lack of available data), economic sectors, fuel styles and years respectively.

Emission factor is the basis for inventory, in order to improve the precise and systematic of estimation, we performed an extensive literature reviews on NO_x emission factors and adopted the emission of Tian Hezhong[5] and Zhang Chuying[8]. Considering the technology development of electricity and industry in fact, new factors was used in the two sectors from the year of 2005 and new emission factors of 2005 was marked with * . The unit for all emission factors was expressed by kg/t except for natural gas and coal gas expressed by $kg/10^4{\cdot}m^3$. All emission factors used in this paper were listed in tab.1. Fuel consumption data of different sectors came from national and provincial energy balance table (physical quantity) of National Statistic Yearbook (1985-2013).

Table 1. NOx emission factors for seven sectors and different fossil fuels of China (kg/t).

	Coal	Coke	Crude oil	Gasoline	Kerosene	Diesel	Fuel oil	LPG	Refinery dry gas	Natural Gas[1]	Coal gas[1]
electricity	9.95 6.58*		7.24 5.84*	16.7 5.84*	21.2	7.40	10.06 5.84*	3.74 2.1*	0.75	40.96	13.53
industry	7.5 4*	9.0 4.8*	5.09	16.7	7.46	9.62	5.84	2.63	0.53	20.85	9.5
construction	7.5	9.0		16.7	7.46	9.62	5.84	2.63	0.53	20.85	9.5
transportation	7.5	9.0	5.09	21.2	27.4	36.25	18.1	18.1		20.85	
Commercial	3.75	4.5	3.05	16.7	4.48	3.50	1.58	1.58	0.32	14.62	7.36
Residential	1.88	2.25	1.70	16.7	2.49	1.95		0.88	0.18	14.62	7.36
others	3.75	4.5	3.05	16.7	4.48	3.50	1.58	1.58	0.32	14.62	7.36

3 Results

3.1 Temporal and sector variation of China NO_x emission

Fig. 1 and Fig. 2 illustrate the emissions and contributions of various sources. It can be found that the total NO_x emission from various sources has increased from $446.45{\times}10^4$t to $2499.72{\times}10^4$t and increased 4.6 times from 1980 to 2012, kept the rapid growth in recent 10 years because of energy consumption increase. Electricity was the absolutely dominated contributor of NO_x all the way in the past three decades, NO_x emission from electricity has increased from $145.04{\times}10^4$t to $1311.6{\times}10^4$t and the emission ratio of electricity has increased from 32.48% to 52.47% (Fig. 2). Industry was the second contributor after electricity, NO_x emission from industry has increased from $206.75{\times}10^4$t to $479.46{\times}10^4$t and increased about 1.31 times than that of 1980, however the emission ratio of industry has decreased from 46.31% to 19.18%. Transportation was the fast growing source, NO_x emission has increased from $39.44{\times}10^4$t to $576.31{\times}10^4$t and increased about 13.61 times than that of 1980. NO_x emission from other sectors, including construction, residential, others, was little and takes up less than 5% of emission only.

Although NO_x emission proportion of coal consumption have declined in recent years, coal still was the main contributor of NO_x and NO_x emission of coal combustion has increased from $328.63{\times}10^4$t to $1610.45{\times}10^4$t from 1980 to 2012(Fig.3). NO_x emission of diesel and gasoline combustion has increased from $20.94{\times}10^4$t, $18.50{\times}10^4$t to $430.70{\times}10^4$t $152.53{\times}10^4$t because of rapid increased motor vehicle. Coke was the important component of steelmaking; NO_x emission from coke has increased from $38.54{\times}10^4$t to $181.11{\times}10^4$t and had a stable status in NO_x emission. Other fuel style contributed little NO_x and took no more than 3% of NO_x emission.

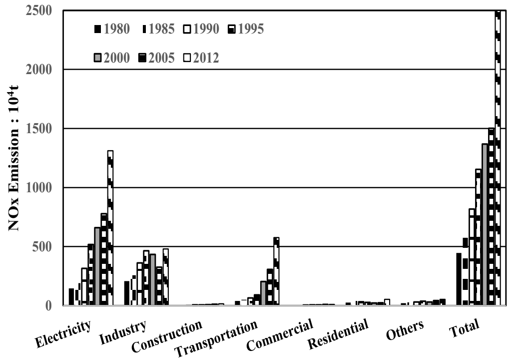

Figure 1. NO_x emission of main sectors from 1980-2012.

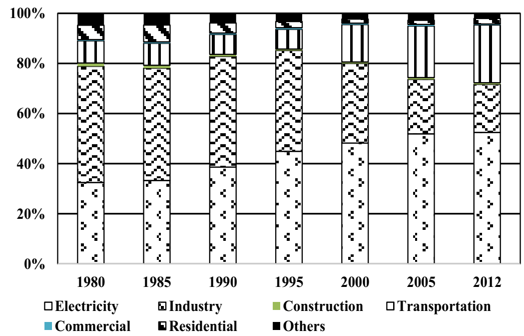

Figure 2. The contribution of main sectors to NO_x emission from 1980-2012.

There wasn't official NO_x emission statistic data in China until 2006, in order to verify the data validity of this paper, we contrasted the NO_x emission of relevant literature and listed them in fig.4, among them, data of 2012 was from National Environmental Statistic year book (2013), data of 1980, 1985, 1995 was from Tian hezhong(2005) [5], data of 1990 from Wang wenxing(1996) [9], data of 2000 and 2005 was from Shi Yun (2014) [7]. Although data source and method was different, NO_x emission had same increase trend and had a little difference both in this paper and other researchers, which was less than 10% except data of 2000 and 2005. So we thought the estimation result of this paper was reliable.

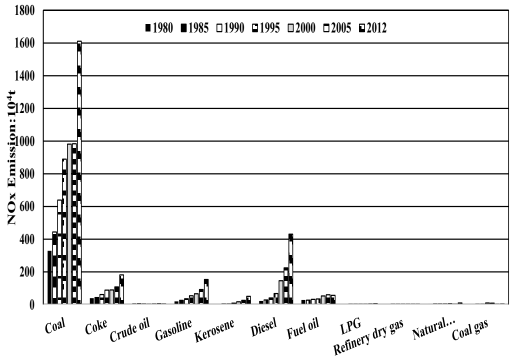

Figure 3. NO_x emission from various fossil fuels (1980-2012).

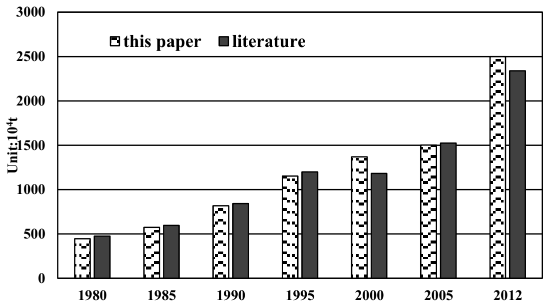

Figure 4. Data contrast from various data source (1980-2012).

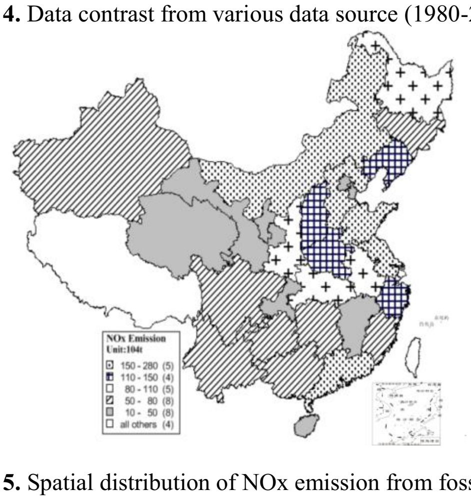

Figure 5. Spatial distribution of NOx emission from fossil fuel combustion for the year 2012.

3.2 Spatial distribution of China NO_x emission

There are great disparities in total NO_x emission from different provinces and mainly lie in north of China for the year 2012 (Fig. 5). Shandong, Inner Mongolia, Jiangsu, Guangdong and Hebei province had a high NO_x emission and their NO_x emission was 279.66×10^4t, 208.74×10^4t, 201.27×10^4t, 177.68×10^4t, and 171.64×10^4t respectively. Provinces with low NO_x emission was relative disperse and showed a polarization phenomenon in emission scale, these province including Qinghai, Hainan, Beijing, Chongqing, Gansu, Ningxia, Jiangxi, Tianjin and their NO_x emission was 10.5×10^4t, 13.61×10^4t, 36.59×10^4t, 39.52×10^4t, 44.15×10^4t, 44.17×10^4t, 45.55×10^4t, 46.02×10^4t respectively in 2012.

Figure 6. Spatial distribution of NOx intensity from fossil fuel combustion for the year 2012.

Due to difference in land area, the spatial distribution of NO_x intensity took a distinct feature of zonality in eastern, middle and western China (Fig.6). Shanghai, Tianjin and Beijing, Jiangsu, Shandong and Zhejiang, had the highest emission density of NOx due to their concentration of population and industry polluted area, their NOx intensity reached to 131.8t/km^2, 40.72 t/km^2, 21.28 t/km^2, 19.62 t/km^2, 18.01 t/km^2 and 12.05 t/km^2 respectively, which were similar to data via satellite monitoring[1]. NOx intensity of western China such as Qinghai, Xinjiang, Gansu, Sichuan, Yunnan, Inner Mongolia, Heilongjiang provinces was low owing to their broader land area, whose NOx intensity only 0.15 t/km^2, 0.43 t/km^2, 0.97 t/km^2, 1.65 t/km^2, 1.66 t/km^2, 1.74 t/km^2, 1.78 t/km^2 respectively.

3.3 NO_x speciation by provinces

Fig.7 showed the NO_x speciation by provinces for the year of 2012. The profile for provinces were somewhat similar, mainly electricity and industry. However, some differences can be seen, for example, transportation was predominant in Shanghai, Beijing and Hainan, industry was predominant in Sichuan, Chongqing, Hubei and Hunan province. The contribution of economic sector indicated that NOx emission control policy should be suited to local condition.

4 Discussion and conclusions

Using the inventory method on based emission factor, we estimated the NO_x emission of China from 1980 to 2012 and provincial distribution for the year 2012 for the first time. Results indicated that NO_x had increased 4.6 times during the past 32 years and had an apparent upward trend in recent years, because of rapid fossil fuel consumption. Electricity has exceeded industry and become the main contributor of NO_x emission. Because of its rising ratio in NO_x emission, electricity is the key sector for NO_x emission control in the future. Industry was the important contributor for its gigantic total NO_x emission although its emission ratio has declined, improving industrial energy consumption efficiency and enforcing pollution control was the only way for NO_x emission. Transportation was the fast growing contributor for NO_x emission and the public transport system should be as a priority measures to reducing the growth of NOx emission. From the perspective of energy structure, coal as the main energy source for NO_x emission and the promotion of green energy would be significant to decrease the NO_x emission. The spatial patterns of NOx emission in China energy consumption were primary concentrated in eastern of China because of their dense population and industrialization.

A long time series NO_x emission inventory was developed for the first time. Although different in data source and the method, the estimation of this paper had little difference to official data and other researchers, so the estimation results was reliable. To further improve the emission inventory, local emission factors and technology change should be considered in the future.

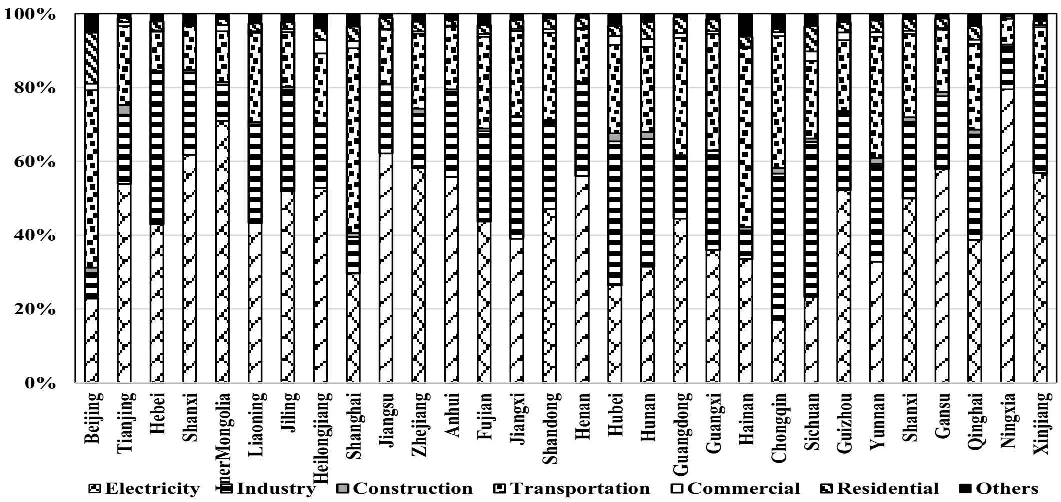

Figure 7. NOx speciation by provinces for the year 2012.

Acknowledgments

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