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Primary Air Pollutant Emissions and Future Prediction of Iron and Steel Industry in China

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ABSTRACT

China is the largest iron and steel producing and consuming country in the world, which leads to enormous quantities of emitted air pollutants. Direct emissions of air pollutants from the iron and steel industry in China were estimated by developing a process and technology-based methodology using information of the proportion of pig iron, crude steel, and rolled steel produced from different processes and technology. Emissions of sulfur dioxide (SO_2), nitrogen oxides (NO_x), particulate matter (PM), volatile organic compound (VOCs), and dioxin (PCDD/Fs) were estimated for the year 2012, and future emissions of major pollutants (SO_2, NO_x, TSP) were projected up to 2030 based on technology developing trends and emission control policies. According to the estimation, 2222 kt of SO_2, 937 kt of NO_x, 1886 kt of TSP, 555 kt of $PM_{2.5}$, 254 kt of VOCs, 618 g I-TEQ of PCDD/Fs was produced in China in 2012. Sintering produced 72.4% of SO_2, 49.4% of NO_x, 22.5% of TSP, 24.0% of $PM_{2.5}$, 69.6% of VOCs and 98.0% of PCDD/Fs, which is the main emission source. Through faithful implementation of closing down outdated production and emission control policies, approximately 77%, 49%, 67% and 64% of SO_2, NO_x, TSP and PCDD/Fs emissions, respectively, could be further reduced in 2012. Emissions in 2020 and 2030 of iron and steel sectors were predicted applying scenario analysis. The removal potential for SO_2 and TSP is larger than NO_x by improvement of removal facilities, and southwest, northwest, and north China has the largest SO_2, NO_x, TSP and PCDD/Fs removal potential respectively.

Keywords: Iron and steel industry; Emission inventory; China; Process and technology-based methodology.

INTRODUCTION

China is the largest iron and steel producing and consuming country in the world. Crude steel production in China was 717 million metric tons in 2012 (NBS, 2013), which accounted for 46% of the world's production (WSA, 2013). The iron and steel industry is the highest in energy consumption, pollution, and consumption of resources-based industries, which leads to enormous quantities of air pollutants emitted, including SO_2, NO_x, PM, VOC, and PCDD/Fs, resulting in significant regional and global environmental problems. In China, the iron and steel industry has been identified as an important source of pollution. For instance, SO_2 and TSP emissions from smelting and pressing of ferrous metals account for 12.6% and 17.6% of all industrial sources (CEYEC, 2012). What's more, iron and other metal production contributed 49% of total national atmospheric PCDD/Fs emissions (Lv *et al.*, 2008).

Since China's iron and steel industry is an important emission source of several types of air pollutants, the systematic and reliable estimation of its emissions is essential for atmospheric modeling and air pollution policy-making. Much research on emission inventories involving the iron and steel industry in China has been done. Some emission inventories of primary air pollutants for China treat the iron and steel industry as a part of the industrial sector, roughly estimating its emissions based on coal and oil consumption (Streets *et al.*, 2003; Ohara *et al.*, 2007). Some emission inventories estimate the emissions of the regional iron and steel industry (Zheng *et al.*, 2009; Tang *et al.*, 2012); some take processes into account, such as the Huabei region emission inventory (Zhao *et al.*, 2012) and national key iron and steel plants emission inventory (Lei *et al.*, 2008). Moreover, there have been many studies measuring or investigating the emissions of iron and steel equipment, including SO_2, NO_x, PM, VOCs, PCDD/Fs (Gong *et al.*, 2008; Lei *et al.*, 2008; Tsai *et al.*, 2008; Lu *et al.*, 2009; Ma *et al.*, 2009; Zou *et al.*, 2012; Yang *et al.*, 2013). In this work, we developed an emission inventory of major air pollutants from China's iron and steel industry based on detailed activity level (provincial production, iron and steel plants location, production technology, production equipment, emission control facilities and so on) for 2012, and we tentatively predict future emissions in 2030 through scenario

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analysis, considering different levels of iron and steel production and control measures; existing and possible future regulations were taken into account as well.

METHODOLOGY AND DATA

Methodology

The study regions covered mainland China including 22 provinces, five autonomous regions and four municipalities (exclusive of Hong Kong, Macau, and Taiwan because of the limited data). Geographical locations of registered iron and steel enterprises in China are shown in Fig. 1.

The emission inventory developed here includes four gaseous air pollutants (SO_2, NO_x, VOCs, and PCDD/Fs) and PM in two different size ranges: $PM_{2.5}$ (particulates with a diameter less than 2.5 µm), and TSP (Total Suspended Particulate). The processes of iron and steel production considered in this study include emissions from sintering, pelletizing, iron-making, steel-making, steel rolling and unorganized emissions, while coking is not included because it is a fuel preparing process rather than a producing process; the producing processes and emission links are shown in Fig. 2.

Emissions from the iron and steel industry of each province in China were calculated based on province-level iron and steel industrial production and emission factors (EFs), and then aggregated to the regional level. Emissions of SO_2, NO_x, PM, VOC, and PCDD/Fs from iron and steel industries at the provincial level were calculated using Eqs. (1)–(5) respectively:

$$E_{SO_2,i} = \sum_k \sum_m A_{i,k,m} EF_{SO_2,k,m} \sum_n C_n (1 - \eta_{SO_2,n,k,m}) \quad (1)$$

$$E_{NO_x,i} = \sum_k \sum_m A_{i,k,m} ef_{NO_x,i,k,m} \quad (2)$$

$$E_{PM_y,i} = \sum_k \sum_m A_{i,k,m} EF_{PM_y,k,m} f_{PM_y} \sum_n C_n (1 - \eta_{PM_y,n,k,m}) \quad (3)$$

$$E_{VOC,i} = \sum_k \sum_m A_{i,k,m} ef_{VOC,i,k,m} \quad (4)$$

$$E_{PCDD/Fs,i} = \sum_k \sum_m A_{i,k,m} ef_{PCDD/Fs,i,k,m} \quad (5)$$

where subscripts *i, k, m, n* and *y* stands for province, production process, production technology, emission control technology and particulate size; *A* is the production; *EF* is the emission factor without control; *ef* is the real emission factor; *C* is the application rate of emission control technology; *η* is the removal efficiency of emission control technology; and *f* is the particulate fraction by size.

Activity Level

National iron and steel industry production in 2012 was 809.9 Mt of sinter ore, 135.6 Mt of pellets (CMISI, 2012), and 663.5 Mt of pig iron, 723.9 Mt of crude steel, 955.8 Mt of rolled steel, maintaining 15% growth rate since the year of 2000 (NBS, 2012), as shown in Fig. 3. Fig. 4 shows an imbalance of production among provinces and regions,

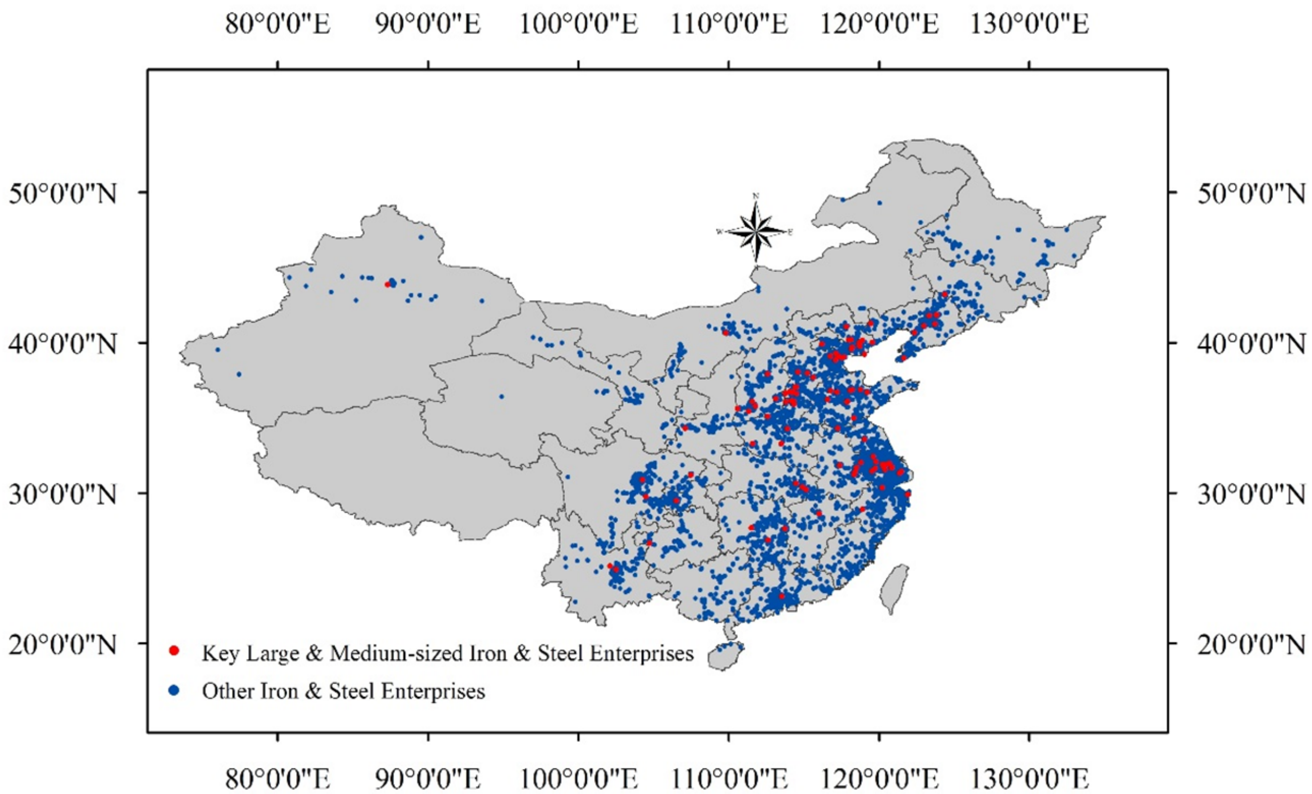

Fig. 1. Geographical locations of the 10 839 iron and steel enterprises in China.

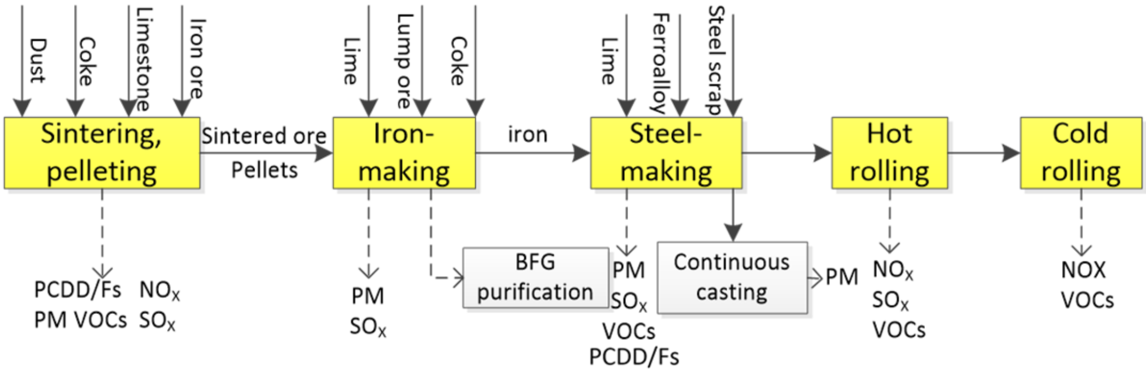

Fig. 2. Processes and emission links of iron and steel industry.

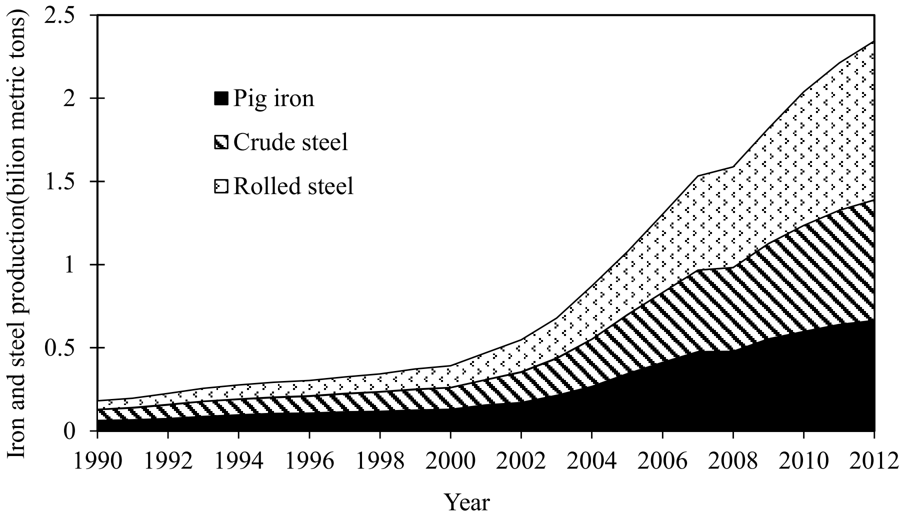

Fig. 3. Iron and steel production in China from 1990 to 2012.

Hebei had the largest iron and steel production (NBS, 2012). There are no statistical data for provincial sinter ore and pellets production, therefore, they were estimated from the provincial pig iron production. The pelleting production technology (3% of shaft furnace, 35% of grate-kiln, and 62% of belt roaster pelleting) rate was estimated from the 2009 rate data (MPI, 2009). Steel-making production (converter and electric furnace steel) for each province in 2012 was estimated from the historical provincial capacity of converter and electric furnace steel. A breakdown of national rolled steel production in 2012 is available (ASKCI, 2012). The national scale distribution of production devices in 2012 refers to *China Steel industry Yearbook 2012*.

Sintering and Pelleting

Belt sintering technology was the only technology applied in the sintering process, and pellets producing was divided into three technologies: shaft furnace, grate-kiln, and belt roaster pelleting. Almost all of China's long process iron and steel enterprises produce sinter ore for their own iron-making, and there was no significant difference in the amount of sinter ore consumed per pig iron production; the amount of sinter ore and pig iron production was positively correlated (Lei, 2008). Pellets are also required iron-making raw materials; generally, 20% to 30% ratio is considered reasonable (Du *et al.*, 2011).

During the "Eleventh Five-Year" period, China's sintering capacity above 90 m^2 rose from 67.9% to 85.2%. With the development of the large-scale blast furnace, the quality of shaft furnace pellets gradually cannot meet the needs of blast furnace iron-making, under this situation, so grate-kiln pellet production technology has developed rapidly, and its capacity increased to 61.7% in 2009 (MPI, 2012).

Iron-Making

Iron-making technologies can be divided into blast furnace technology, direct reduction iron (DRI) technology, smelting reduction iron-making (COREX), and so on. Blast furnace iron production produced in China increased from 23% to nearly 60% of the worldwide from 2000 to 2010, while the DRI production was less than 1% (Qi *et al.*, 2013).

Steel-Making

The BOF (basic oxygen furnace) steelmaking and EAF (electric arc furnace) steelmaking methods are the two main steelmaking processes. The proportion of EAF steel production fluctuated around 10% due to lack of resources and a shortage of electricity scrap, and there is a large gap

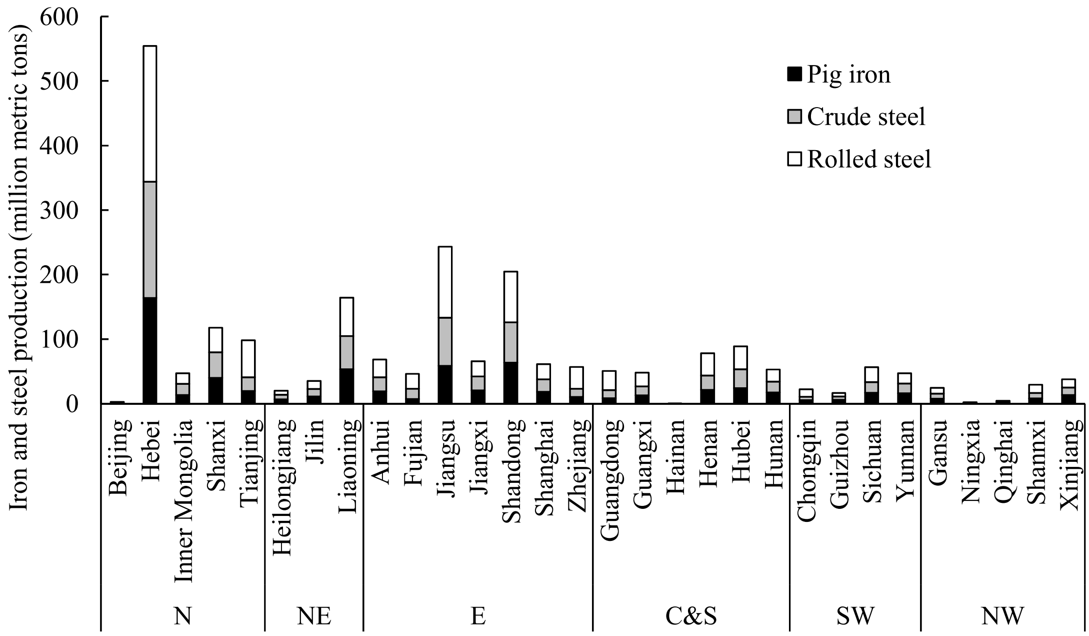

Fig. 4. Iron and steel production by region (N: North China, NE: Northeast, E: East China, C&S: Center and South China, SW: Southwest China, and NW: Northwest China).

compared with the proportion of the world's 30% EAF steel. China's EAF steel production was 64.5 million tons in 2012, accounting for 8.9% of total crude steel production. The EAF steel production of each province was estimated according to total output and provincial EAF steel capacity, for lack of statistical data.

Steel Rolling

Hot rolling and cold rolling are both steel-rolling technologies. In recent years, China's steel enterprises have made remarkable progress in the modernization of rolling equipment. China's rolled steel production was up to 955.78 million tons, with every type shown in Fig. 5 (ISA, 2013).

Emission Factors (EFs)

SO_2

About 50% of SO_2 comes from the oxidation of sulfur in coal and coke (Hu *et al.*, 2008) in the sintering and pelleting process, therefore, we correct provincial SO_2 emissions combined with sulfur content of coal and iron ore for each province (Zhao *et al.*, 2008; MPI, 2012), as shown in Fig. 6. In a sintering machine and pellet furnace, exhaust gas contained with SO_2 is emitted, while in the blast furnace, most of the sulfur is absorbed in the slut by reaction. Since sintering and pelleting are the main SO_2 emission processes, sulfur removal equipment is mainly adopted in these processes, while sintering and pelleting gas desulfurization was started in 2012, and the national average efficiency was 38.6% (MEP, 2013). Sulfur removal equipment put into operation was 389 of sintering and 44 of pelleting, respectively, in 2012 (MEP, 2013).

By 2012, the proportion of WFGD of the sintering process reached 73.1%, and limestone-gypsum FGD was the most popular technology applied, which occupied nearly half of all FGD, as shown in Fig. 7 (MEP, 2013).

NO_x

For sintering and pelleting processes, generation of NO_x is mainly formed by reaction of nitrogen from the solid fuel or raw material and oxygen from the air at high temperature; and for the exhaust gas from the heating furnace of iron-making and steel rolling processes, it is highly dependent on temperature and oxygen availability. Until 2012, few NO_x removal equipment was put into operation in iron and steel industries because of the high emission limit; we therefore dismiss NO_x emission control.

PM

The EFs of PM are dependent on both the characteristics of uncontrolled emissions from the overall production processes and the effectiveness of PM emission control devices, and the uncontrolled emissions are dependent on the type and scale of production devices. *Dedusting Engineering Technical Specification of Iron and Steel Industry* (MEP, 2008) was released in 2008, which explicitly specifies system and installation of dedusting devices in almost every PM emission node. In this study, we assume dedusting facilities were adopted in the mentioned processes of every iron and steel industries.

VOCs

The EFs of VOCs of the iron and steel industry were mainly gained from domestic research (Lei, 2008; Tsai, 2008). In general, the sintering process, the heating furnace, and the BF are the major VOCs sources.

PCDD/Fs

For iron and steel industries, PCDD/Fs is formed in

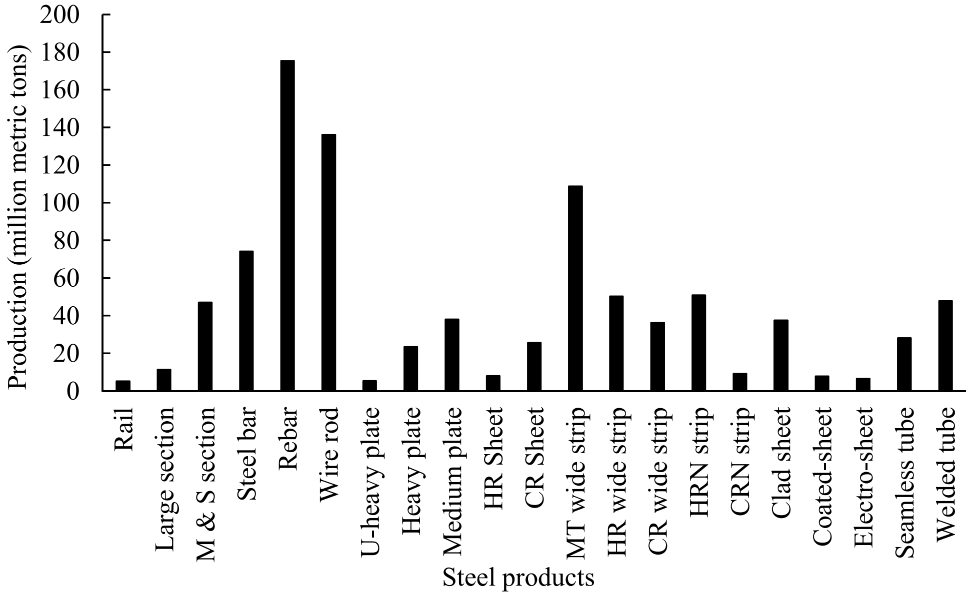

Fig. 5. Steel production in 2012 in China.

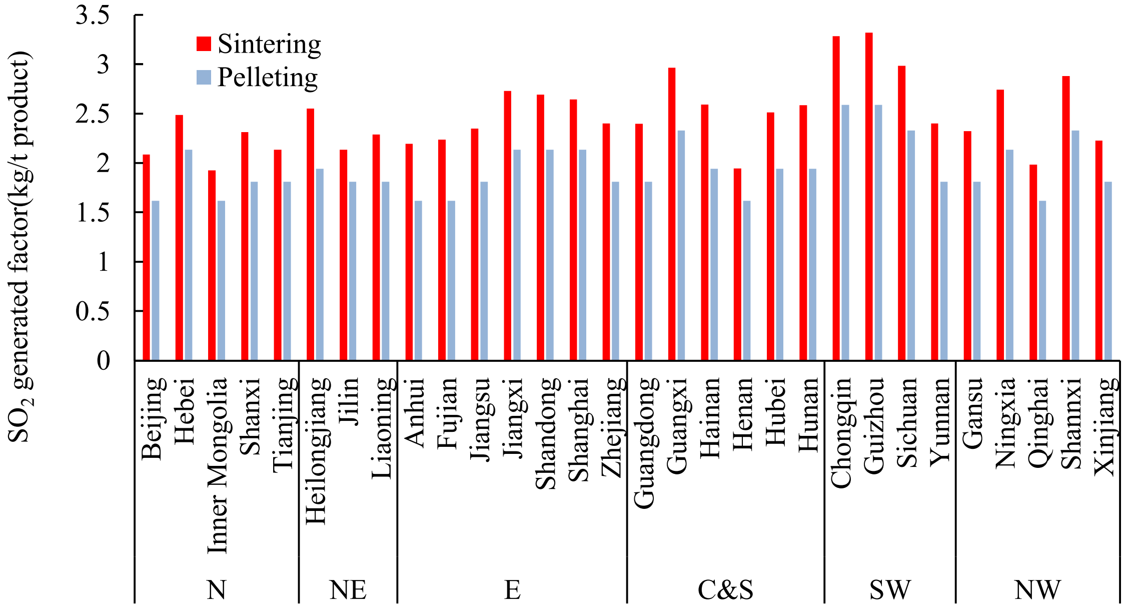

Fig. 6. Corrected SO_2 generated factor for each province.

sintering and electric steelmaking processes. The EFs were given in quite a few studies measuring PCDD/Fs concentration in sintering and electric furnace gas in China (Gong, 2007; Lu, 2009; Zou, 2012).

All the selected emission factors are shown in Table 1.

RESULTS AND DISCUSSION

Regional Emissions in 2012

Emissions inventories of SO_2, NO_x, TSP, $PM_{2.5}$, VOCs, and PCDD/Fs of the iron and steel industry in 2012 were calculated based on the provincial activity data and emission factors. Fig. 8 show contributions of each iron and steel production processes.

SO_2 emission from the iron and steel industry was estimated to be 2,222 kt. As listed in Table 2, five provinces emitting over 100 kt each were Hebei, Shandong, Jiangsu, Liaoning, Shanxi, emitting a total 1,237 kt (56% of nationwide emissions of iron and steel industries). Sintering and pelleting were the main processes emitting SO_2, contributing 84% to the total emissions. Large SO_2 emissions are attributed to three factors: high sulfur content of solid fuel and iron ore; undistributed desulfurization facilities of sintering machine (50% of national sintering machine area applying desulphurization) and low desulfurization efficiency.

NO_x emission from the iron and steel industry was estimated to be 937 kt. Hebei, Jiangsu, Shandong, Liaoning, and Shanxi each emitted over 50 kt, emitting a total of 521 kt

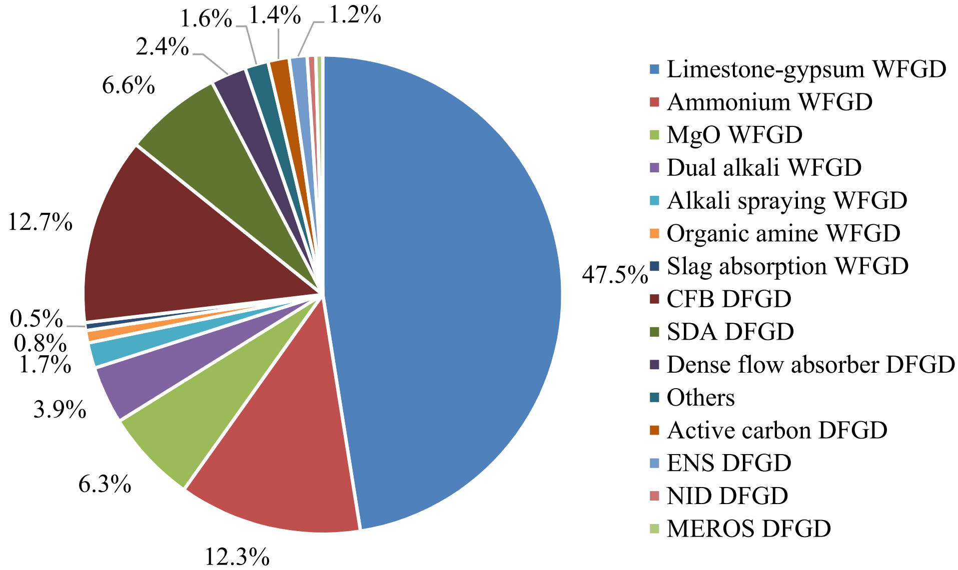

Fig. 7. Proportion of FGD technologies of sintering in 2012.

Table 1. Emission factors of air pollutants from China's iron and steel industry.

Process	Equipment	Scale	PF/kg·ton^{-1}				EF/kg·ton^{-1}	/ng I-TEQ·ton^{-1}
			SO_2	NO_x	$PM_{2.5}$	TSP	NMVOC	PCDD/Fs
Sintering	Belt sintering	180 m^2	2.400[a*]	0.522[a]	0.211[abc]	0.402[a]	0.219[e]	704[f]
		50–180 m^2	2.600[a*]	0.584[a]	0.274[abc]	0.523[a]	0.219[e]	864[fg]
		< 50 m^2	2.800[a*]	0.612[a]	0.540[bc]	1.590[b]	0.219[e]	1024[g]
Pelleting	Shaft furnace	≥ 8 m^2	2.000[a*]	0.143[a]	0.134[bc]	0.442[a]	ND	ND
	Belt roaster	All	1.750[a*]	0.500[a]	0.134[bc]	0.443[a]	ND	ND
	Grate-kiln	All	2.000[a*]	0.261[a]	0.103[bc]	0.316[a]	ND	ND
Iron-making	BF	≥ 2000 m^2	0.109[a]	0.150[a]	0.066[bc]	0.350[a]	ND	ND
		400–2000 m^2	0.131[a]	0.170[a]	0.114[bc]	1.030[a]	ND	ND
Steel-making	BOF	≥ 150 t	ND	0.003[d]	0.139[ab]	0.160[a]	0.060[e]	ND
		50–150 t	ND	0.003[d]	0.230[ab]	0.267[a]	0.060[e]	ND
	EAF	≥ 50 t	0.004[d]	0.034[d]	0.351[ab]	0.386[a]	0.060[e]	187[h]
		30–50 t	0.006[d]	0.037[d]	0.762[abc]	0.853[a]	0.060[e]	198[f]
Steel rolling	Hot rolling	All	0.267[a]	0.280[a]	0.027[ab]	0.034[a]	0.020[e]	ND
	Cold rolling	All	0.135[a]	0.080[a]	0.010[ab]	0.012[a]	0.062[e]	ND
A Sintering		All	ND	ND	0.073[ab]	0.398[ab]	ND	ND
Iron-making		All	ND	ND	0.055[ab]	0.524[ab]	ND	ND
Steel rolling		All	0.003[a]	ND	0.086[ab]	0.285[ab]	ND	ND

[a] The first national pollution census leading group office, 2010; [b] Lei *et al.*, 2008; [c] Ma *et al.*, 2009; [d] Yang *et al.*, 2013; [e] Tsai *et al.*, 2008; [f] Zou *et al.*, 2012; [g] Gong *et al.*, 2007; [h] Lu *et al.*, 2009.
A: unorganized; PF: pollutants-producing factor; EF: emission factor; BF: blast furnace; BOF: basic oxygen furnace; EAF: Electric arc furnace; ND: Not detected.
* National average SO_2 EFs.

(56% of nationwide emissions of iron and steel industries). Sintering and pelleting were still the main processes emitting NO_x, contributing 57% of the total emission. DeNO_x facilities were few, which largely depended on high emission standard limits.

The primary TSP emission was 1,886 kt from the iron and steel industry, approximately 15% of the total eissions. Three provinces emitting over 150 kt each were Hebei, Shandong, Shanxi, emitting a total of 703 kt (37% of nationwide emissions of iron and steel industries). Although clear dedusting specification was published in 2008 and PM removal facilities were popularized in 2012, TSP emission was high because the dedusting effect of plenty of iron and steel plants was still to be improved, and there were still some gaps compared with international, advanced steel plants. Annual $PM_{2.5}$ emissions were 555 kt from iron and steel industry, approximately 29% of the total particles.

VOCs emissions were 254 kt from the iron and steel industry. Hebei, Jiangsu, and Shandong emitted 43% of VOCs from the iron and steel industry.

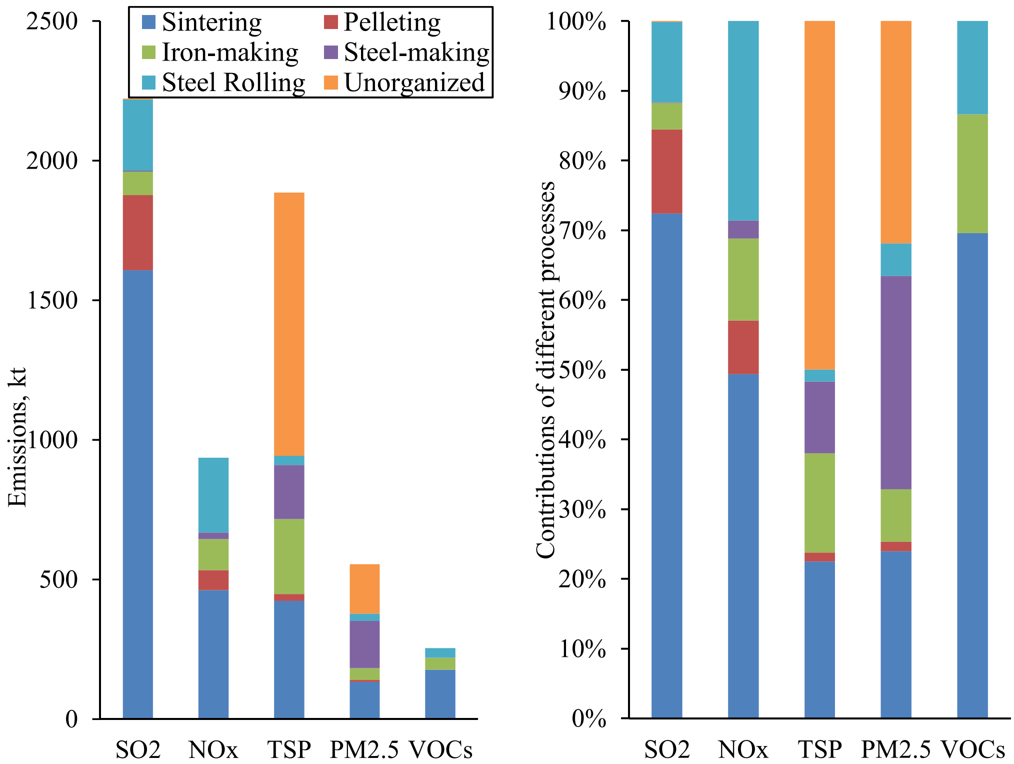

Fig. 8. Regional emission inventory of (a) different processes and (b) contributions of different processes.

PCDD/Fs emissions were 618 g I-TEQ (the scheme of TEF values agreed by NATO (1988), known as the International Scheme).

Iron and steel enterprises from east and north China emitted more than 60% of mentioned atmospheric pollutants nationwide.

Spatial Distribution of Emissions

The comparison each region of air pollutants emissions showed that north and east China were the main sources, accounting for 61.0% of SO_2, 62.8% of NO_x, 58.4% of $PM_{2.5}$, 59.5% of TSP, 63.0% of VOCs, and 61.0% of PCDD/Fs.

FUTURE EMISSIONS AND MITIGATION POTENTIAL

Accurate emission projections are necessary since emissions from China's national iron and steel industry were a main source of air pollutants. In this study, both iron and steel production and emission control strategies of the iron and steel industry in 2020–2050 were evaluated through scenario analysis for future emission projection.

Production Forecast

Owing to total amount control and implementation of emission control policy, the emissions of iron and steel production should be further restrained in the future. In this study, base (B), normal (N), and strict (S) emission control scenarios were assumed in 2012–2030. We selected the production data of crude steel from *Medium and long-term research and development strategy on energy in China* (CAE, 2011) in 2020 and 2030, and extrapolate production of pig iron and rolled steel equal proportion to the year of 2012, as shown in Table 3.

The share of EAF is still low in China (about 10% in 2012) because of the limitation of scrap and electricity. However, EAF has many advantages, such as low investment and low emission, which means it has development potential in the future. As the steel demand decreases, the scarp of China will show a rapid growth, which would result in rapid growth of the share of EAF (Hu *et al.*, 2009). We assume in 2020 the share of EAF will increase to 20%, and then increase to 30% in 2030, which is also close to the average OECD level. The share change of EAF and BOF is listed in Table 3.

Emission Control Policy

The key features of technology and scale of the iron and steel industry are projected based on the existing policies on industry structure (NDRC, 2011; MIIT, 2010).

After 2010, the iron and steel industry has become an important emission control source. According to *Iron and Steel Industry in the Twelfth Five Year Plan*, sintering and pelleting equipment must be equipped with FGD before 2016. In this study, base, normal, and strict scenarios were designed to describe different emission control policies or emission limits. The base scenario is a pessimistic one in which the production status and emission control for all the species would remain at the same proportion. The normal scenario emphasizes the implementation of closing and substitution of small plants capacity, and the improvement

Table 2. Emission estimate by region in 2012.

Region	SO_2 (kt)	NO_x (kt)	TSP (kt)	$PM_{2.5}$ (kt)	VOCs (kt)	PCDD/Fs (g I-TEQ)
Northern	**670**	**296**	**512**	**154**	**82**	**188**
Beijing	1	1	1	0	0	0
Hebei	511	223	385	114	62	143
Inner Mongol	31	15	39	11	4	11
Shanxi	57	23	37	12	7	17
Tianjin	71	35	50	17	9	17
Northeastern	**276**	**120**	**267**	**77**	**33**	**80**
Heilongjiang	70	31	74	22	8	20
Jilin	168	70	146	41	19	49
Liaoning	38	18	47	14	5	12
East	**759**	**316**	**627**	**187**	**85**	**207**
Anhui	63	27	55	16	7	21
Fujian	23	14	29	10	4	7
Jiangsu	203	90	132	43	24	52
Jiangxi	82	27	45	13	8	18
Shandong	219	85	167	47	23	58
Shanghai	137	51	151	42	14	41
Zhejiang	33	20	48	15	5	11
Central & southern	**248**	**103**	**199**	**59**	**27**	**72**
Guangdong	33	17	30	10	4	8
Guangxi	52	19	36	10	5	13
Hainan	0	0	0	0	0	0
Henan	20	9	32	9	2	6
Hubei	85	35	57	17	9	24
Hunan	58	23	45	12	6	21
Southwestern	**164**	**60**	**152**	**43**	**16**	**39**
Chongqing	25	9	14	4	2	5
Guizhou	24	7	16	4	2	5
Sichuan	57	23	50	14	6	15
Yunnan	59	21	72	20	6	14
Northwestern	**106**	**42**	**128**	**36**	**11**	**31**
Gansu	27	10	17	5	3	8
Ningxia	3	1	5	1	0	1
Qinghai	5	2	9	3	1	2
Shaanxi	32	12	19	5	3	7
Xinjiang	38	17	77	21	5	12
Total	**2222**	**937**	**1886**	**555**	**254**	**618**

Table 3. Iron and steel production change from 2012 to 2030.

	2012	2020	2030
Crude steel(Mt)	724	610	570
Pig iron(Mt)	664	559	522
Rolled steel(Mt)	956	805	753
Share of EAF (%)	10	20	30
Share of BOF (%)	90	80	70

of emission removal efficiency. Based on the normal one, the strict scenario is an optimistic one, which greatly promotes the application rate of emission control technologies and average removal efficiency, average removal efficiency close to current maximum removal efficiency or the emission concentration reached the world advanced level. The projected removal efficiency and emission concentration is summarized in Table 4.

Emissions Projection

Current emission standards have promoted the use of various emission control technologies in each process; however, the level of emission control in China's iron and steel industry is still lower than that of advanced countries. There is potential to substantially reduce the emission of air pollutants from the iron and steel industry in China if advanced control technologies are used.

SO_2 emission is now the major focus of air pollution control from the iron and steel industry in China. According to *Twelfth Five Year Plan of Iron and Steel Industry*, desulfur facilities should be equipped by all sintering machines before 2015, and all sintering machines are required to meet an emission standard of 200 mg/m^3 flue gas, as of 2015 (SEPA, 2012), which equates to a SO_2 EF for the whole

Table 4. The average removal efficiency and emission concentration in 2020 and 2030.

	2020			2030		
	Base	Normal	Strict	Base	Normal	Strict
SO_2 (%)	38.6	50.0	80.0	38.6	55.0	90.0
NO_x (%)	0.0	15.0	50.0	0.0	30.0	75.0
TSP (%)	98.8	98.9	99.2	98.8	99.0	99.6
Unorganized TSP (%)	25.0	30.3	42.0	25.0	36.0	59.5
PCDD/Fs for Sinter/EAF(ng I-TEQ/m^3)	0.24/0.17	0.2/0.15	0.15/0.13	0.24/0.17	0.15/0.13	0.1/0.1

Table 5. The iron and steel sector emissions during 2012–2030 under different scenarios.

	2012			2020			2030		
	Base	Normal	Strict	Base	Normal	Strict	Base	Normal	Strict
SO_2 (kt)	2222	2222	2222	2610	1973	972	2517	1561	576
NO_x (kt)	937	937	937	1100	835	640	1061	758	546
TSP (kt)	1886	1886	1886	2214	1667	1289	2136	1384	701
PCDD/Fs (g I-TEQ)	618	618	618	544	454	342	517	356	220

production process of approximately 0.64 g/kg sinter ore. This emission level could be even lower, if all of China's sintering machines of the iron and steel industry were equipped WFGD facilities, and the average SO_2 EF could drop to 0.25 g/kg sinter ore. According to our estimates (Table 5), during 2012–2030, SO_2 would decrease by 30%–74%. In 2030, SO_2 emissions would decrease by 578.5 kt and 662.6 kt under the strict control scenario compared with the base control scenario in north China and east China, which are the main emission areas.

Until now, few NO_x removal equipment was put into operation in the iron and steel industries. Integrated treatment technologies for sintering flue gas desulfurization and denitrification are widely studied in iron and steel industry in China. While SCR and SNCR $DeNO_x$ are widely used in advanced countries, NO_x was reduced by 60%–80% (SEPA, 2007). During 2012–2030, NO_x should decrease by 19%–42%. In 2030, NOx emissions should decrease by 162.8 kt and 172.5 kt under the strict control scenario compared with the base control scenario in north China and east China.

PM emission control is paid abundant attention according to *Dedusting Engineering Technical Specification of Iron and Steel Industry* (MEP, 2008), which explicitly specifies a system and installation of dedusting devices in almost every PM emission node. During 2012-2030, TSP should decrease 27%–63%. In 2030, TSP emission should decrease by 412.0 kt and 492.4 kt under the strict control scenario compared with the base control scenario in north China and east China.

PM removal device is also effective for PCDD/Fs removal because of high share of particle-phase PCDD/Fs, while solutions must be sought to avoid the emission of not only the particle-phase but also the gas-phase PCDD/Fs. In our normal and strict scenarios, during 2012–2030, PCDD/Fs should decrease by 42%–64%. In 2030, PMTSP emission should decrease by 99.8 g I-TEQ and 92.3 g I-TEQ under the strict control scenario compared with the base control scenario in east China and north China.

The emission of SO_2, NO_x, TSP and PCDD/Fs under different scenarios in 2030 are shown in Fig. 9.

To sum up, the potential for SO_2 TSP mitigation was larger than NO_x because of the improvement of removal facilities, and the potential for PCDD/Fs emission reduction was considerable compared with world advanced level. It implies that the implementation of control policies in north China and east China would have a significant influence on emissions, while the closing and substitution of small plants capacity would produce little effect.

CONCLUSIONS

The iron and steel industry plays an important role in emissions of many air pollutants in China. We estimated the emissions of primary air pollutants from the iron and steel industry based on information on the development of production technologies and equipment scale, pollutants removal situation, and rising emission standards in China's iron and steel industry. The emissions inventory indicated that sintering was the main emission source which produced 72.4% of SO_2, 49.4% of NO_x, 22.5% of TSP, 24.0% of $PM_{2.5}$, 69.6% of VOCs, and 98.0% of PCDD/Fs of the entire iron and steel industry in China in 2012. Our analysis shows that SO_2 and TSP emissions of the iron and steel industry could be effectively controlled with the measures of the wide application of FGD and high-efficiency PM control facilities; and the implementation of control policies in north China and east China would have a significant influence on emissions. There were few $DeNO_x$ facilities due to the high emission limit; NO_X control policies being followed through in the future will reduce NO_x emissions greatly in the iron and steel industry. Due to the scenario analysis, southwest, northwest, and north China has the largest SO_2, NO_x, TSP and PCDD/Fs removal potential, respectively.

On the other hand, the direct cause of air pollution in the steel industry is mainly dependent on coal and coke energy, and while the DRI industry is able to reduce reliance on coke, it is an energy-saving, low-emission iron-making technology and has good development prospects in China.

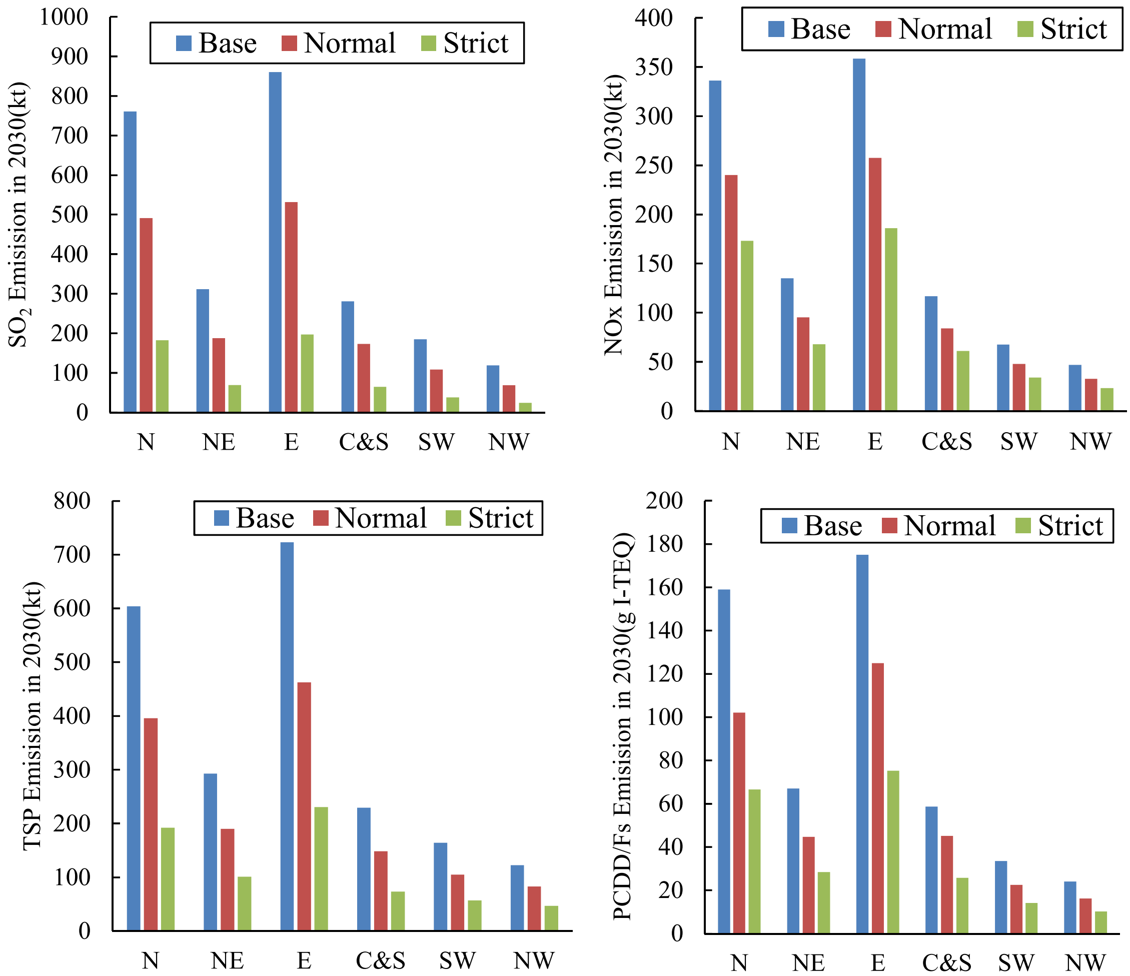

Fig. 9. The emissions of (a)SO_2, (b)NO_x, (c)TSP and (d)PCDD/Fs by region under different scenarios in 2030.

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