SUPPLEMENTARY

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Table and figure List

Tables

Table S1. The uncertainties of activity levels.

Parameter	Distribution	Sources or methods	Rating[1]
Coal use by power	Normal (CV[2]: 5%)	Unit-based investigation: Zhao et al. (2008)	B
Fossil fuel energy	Normal (CV: 5%)	Subject judgment	D
Industrial production	Normal (CV: 5%)	Subject judgment	D
Vehicle number	Normal (CV: 5%)	Subject judgment	D
Vehicle mileage traveled	Normal (CV: 5%)	Wang et al.(2008); Kioutsioukis et al. (2004)	B
Vehicle fuel economy	Normal (CV: 14%)	Data fitting: CAAM and CATRA (2009)	A
Non-road fuel use	Normal (CV: 16%)	Subject judgment	D
Biofuel consumption	Normal (CV: 20%)	Subject judgment	D
Agriculture production	Normal (CV: 5%)	Subject judgment	D
Waste-to-grain ratio	Uniform (Product dependent)	Lal (2005)	C
Ratio of biomass burning	Normal (Province dependent)	Questionnaire: Wang and Zhang (2008)	B

[1] A: the distribution is obtained through data fitting based on domestic field measurements; B: the distribution is determined according to domestic field measurements; C: the distribution is determined according to foreign studies; D: the distribution is subjectively given (the same below). [2] Coefficients of variation, expressed as the standard deviation divided by the mean. The same below.

Table S2. The uncertainties of penetrations of technologies/emission control devices by sector.

Sector	Technology				Emission control device									
	Technology		Distribution	Rating	Wet-FGD	Other-FGD	FF	ESP	WET	CYC	Stage I	Stage II	Distribution	Rating
CPP	Pulverized	87%	-	-	12%	2%	4%	91%	6%	0%	-	-	-	-
	Grate	6%	-	-	-	-	-	2%	84%	14%	-	-	-	-
	CFB	7%	-	-	-	25%	1%	90%	8%	1%	-	-	-	-
CEM	Precalciner	44% (38-50%)	Triangular	B	-	-	38-56%	NIP[1]	-	-	-	-	Uniform	D
	Other	NIP[1]	NIP[1]	-	-	-	5-7%	32-45%	33-48%	NIP[1]	-	-	Uniform	D
Steel making	Open hearth	0%	-	-	-	-	-	32-48%	NIP[1]	-	-	-	Uniform	D
	Converter	88%	-	-	-	-	40-60%	NIP[1]	-	-	-	-	Uniform	D
	Electric	12%	-	-	-	-	0-10%	25-30%	50-60%	NIP[1]	-	-	Uniform	D
Coke	-		-	-	-	-	-	-	80-100%	-	-	-	Uniform	D
Sinter	-		-	-	-	-	0-10%	55-65%	0-25%	NIP[1]	-	-	Uniform	D
Pig iron	-		-	-	-	-	0-10%	NIP[1]	-	-	-	-	Uniform	D
Casting	-		-	-	-	-	-	16-24%	32-48%	NIP[1]	-	-	Uniform	D
IND coal use	Grate	NIP[1]	NIP[1]	-	4-6%	36-54%	-	-	29-44%	NIP[1]	-	-	Uniform	D
	CFB	8-10%	Uniform	B										
RES coal use	Grate	23-28%	Uniform	D	-	-	-	-	20-25%	45-59%	-	-	Uniform	D
	Furnace	15-19%	Uniform	D	-	-	-	-	-	-	-	-	-	-
	Stove	NIP[1]	NIP[1]	-	-	-	-	-	-	-	-	-	-	-
LDGV	-		-	-	-	-	-	-	-	-	38%	23%	Normal (CV: 20%)	D
LDDV	-		-	-	-	-	-	-	-	-	NIP[1]	40%	Normal (CV: 20%)	D
LDGT/ HDGV	-		-	-	-	-	-	-	-	-	15%	32%	Normal (CV: 20%)	D
LDDT/ HDDV	-		-	-	-	-	-	-	-	-	40%	30%	Normal (CV: 20%)	D
MC	-		-	-	-	-	-	-	-	-	20%	40%	Normal (CV: 20%)	D
Lime	-		-	-	-	-	0-5%	0-10%	0-30%	40-55%	-	-	Uniform	D
Aluminum	-		-	-	-	-	0-5%	0-35%	-	0-60%	-	-	Uniform	D
Al_2O_3 smelt	-		-	-	-	-	48-60%	28-40%	NIP[1]	-	-	-	Uniform	D
Other metal	-		-	-	-	-	20-45%	30-35%	0-5%	0-15%	-	-	Uniform	D
Brick	-		-	-	-	-	-	-	0-10%	35-45%	-	-	Uniform	D
Glass	-		-	-	-	-	0-30%	0-40%	20-30%	NIP[1]	-	-	Uniform	D

[1] Non-independent parameter. The value is calculated as 1 minus the penetrations of other technologies/emission control devices in the sector.

Table S3. The uncertainties of unabated emission factors for stationary sources.

	SR/EF_{SO2} (kg/t)[1, 2]			EF_{NOX} (kg/t)[2]			AR/EF_{PM} (kg/t)[1, 2]		
	Value	Distribution	Rating	Value	Distribution	Rating	Value	Distribution	Rating
CPP: pulverized	90%	Beta	A	Technology dependent	Technology dependent	A	69%	Beta	A
Grate boiler	85%	Beta	A	4.7	Lognormal (GSD^3:1.8)	A	13%	Logistic	A
CFB boiler	60%	Beta	B	3.0(2.5-3.4)	Triangular	B	48-60%	Uniform	B
Hot water system	80%	Beta	A	1.8	Gamma	A	1.8	Lognormal (GSD:2.3)	A
Small stove	80%	Beta	D	0.9(0.1-3.9)	Triangular	B	11	Beta	A
IND: oil combustion	-	-	-	5.3-16.7	Uniform	B	0.50-0.90	Uniform	B
IND: gas combustion	-	-	-	1.9-3.5	Uniform	B	0.14-0.20	Uniform	B
RES: oil combustion	-	-	-	0.2-16.7	Uniform	B	0.10-0.90	Uniform	B
RES: gas combustion	-	-	-	0.1-3.3	Uniform	B	0.10-0.20	Uniform	B
Biofuel: waste	0.05	Lognormal (GSD:3.1)	A	1.5	Gamma	A	4.0[4]	Beta	A
Biofuel: firewood	0.004	Gamma	A	1.4	Logistic	A	3.1(0.0-9.7)[4]	Triangular	A
Open burning	0.6 (0.0-2.0)	Uniform	B	3.8 (0.7-7.9)	Uniform	B	9.6(0.7-13.7)[4]	Uniform	B
CEM precalciner				13.7 (3.0-23.8)	Triangular	B	117	Beta	A
CEM shaft	85%	Beta	A	18.1 (10.8-22.1)	Triangular	B	85	Lognormal (GSD:3.0)	A
CEM rotary				3.2 (1.7-8.5)	Triangular	B	30 (13-91)	Triangular	A
CEM other processes	-	-	-	-	-	-	140 (62-235)	Triangular	B
Coking	0.7	Normal (CV: 20%)	D	-	-	-	5	Normal (CV: 20%)	D
Sintering	2.7	Lognormal (GSD:1.5)	A	0.64 (0.50-0.76)	Triangular	B	47	Uniform	A
Pig iron	-	-	-	-	-	-	48.8	Lognormal (GSD: 1.3)	A
Pig iron: fugitive	-	-	-	-	-	-	16	Weibull	A
Steel: open hearth	-	-	-	-	-	-	20.2	Logistic	A
Steel: converter	-	-	-	-	-	-	40	Weibull	A
Steel: electric	-	-	-	-	-	-	12.2	Triangular	A
Casting	-	-	-	-	-	-	10	Normal (CV: 20%)	D
Casting: fugitive	-	-	-	-	-	-	5.8	Normal (CV: 20%)	D

Table S3. The uncertainties of unabated emission factors for stationary sources (continued).

	SR/EF_{SO2} (kg/t) [1]			EF_{NOX} (kg/t)			AR/EF_{PM} (kg/t) [1]		
	Value	Distribution	Rating	Value	Distribution	Rating	Value	Distribution	Rating
H_2SO_4 production	3.4	Logistic	A	-	-	-	-	-	-
Lime	1.0	Normal (CV: 20%)	D	1.6	Normal (CV: 20%)	D	30-100	Uniform	B
Aluminum smelt	-	-	-	-	-	-	41.4	Weibull	A
Al_2O_3 smelt	-	-	-	-	-	-	1651 (685-2164)	Triangular	B
Copper smelt	212	Weibull	A	-	-	-	290	Weibull	A
Lead smelt	80 (43-146)	Triangular	B	-	-	-	250 (237-452)	Triangular	B
Zinc smelt	80 (43-146)	Triangular	B	-	-	-	196 (135-369)	Triangular	B
HNO_3 production	-	-	-	7.1	Gamma	A	-	-	-
Brick production	-	-	-	0.3	Normal (CV: 20%)	D	3.7	Normal (CV: 20%)	D
Glass production	-	-	-	-	-	-	10.6 (7.4-13.1)	Triangular	B

[1] The values with and without a "%" indicate the SR/AR and *EF*, respectively. [2] The emission factors for processes, iron and steel, and PM emission factors for cement are expressed as kg/t-product, and others are expressed as kg/t-fuel. [3] Geometric standard deviation. [4] Emission factor for $PM_{2.5}$.

Table S4. The emission factors with uncertainties for mobile sources.

	NO_X (kg/t-fuel)			$PM_{2.5}$ (kg/t-fuel)			Rating
	Pre-stage I	Stage I	Stage II	Pre-stage I	Stage I	Stage II	
LDGV	22.0	3.9	2.3	0.30	0.17	0.12	B
LDDV	17.4	16.6	16.6	4.67	2.35	1.22	B
LDGT1	25.5	7.4	3.5	0.25	0.14	0.14	B
LDGT2	15.8	2.8	1.6	0.40	0.22	0.07	B
LDDT	30.8	29.4	30.8	4.25	2.32	1.15	B
HDGV	21.5	3.9	2.3	0.40	0.22	0.07	B
HDDV	77.6	57.4	56.1	3.00	2.26	0.93	B
MC	6.9	6.6	6.6	6.00	1.95	1.20	B
Railway	32.5	-	-	3.00	-	-	D
Shipping	42.9	-	-	1.10	-	-	D
Construction machine	17.5	-	-	6.70	-	-	D
Tractor	48.5	-	-	13.30	-	-	D
Rural vehicle	48.5	-	-	6.10	-	-	D
Rural machine	17.5	-	-	4.40	-	-	D
Probability distribution	Lognormal (CV: 36%)	Lognormal (CV: 36%)	Lognormal (CV: 17%)	Lognormal (CV: 59%)	Lognormal (CV: 59%)	Lognormal (CV: 34%)	

Table S5. The uncertainties of size distribution and carbonaceous fractions of PM

	Size fraction						Carbonaceous fractions/*EF* (kg/t-fuel)[1]					
	$PM_{2.5}$			$PM_{2.5-10}$			BC			OC		
	Value	Distribution	Rating	Value	Distribution	Rating	Value	Distribution	Rating	Value	Distribution	Rating
CPP: PC	6%	Lognormal (GSD:1.19)	A	16%	Beta	A	0-4%	Uniform	C	-	-	-
Grate boiler	3-25%	Uniform	B	3-23%	Uniform	B	0-22%	Uniform	B	1-23%	Uniform	B
CFB boiler	5-10%	Uniform	B	21-24%	Uniform	B	0-23%	Uniform	B	-	-	-
Hot water system	32-48%	Uniform	D	24-36%	Uniform	D	6-50%	Uniform	C	6-40%	Uniform	C
Small stove	NIP[2]	NIP[2]	NIP[2]	3%	Lognormal (GSD:1.25)	A	2.8 (0-12.7)	Uniform	B	6.3 (0-17)	Uniform	B
IND oil combustion	-	-	-	-	-	-	13-30%	Uniform	C	9-13%	Uniform	C
RES oil combustion	-	-	-	-	-	-	14-50%	Uniform	C	9-20%	Uniform	C
Gas combustion	-	-	-	-	-	-	6-13%	Uniform	C	10-50%	Uniform	C
Biofuel: waste	-	-	-	-	-	-	0.4	Lognormal (GSD: 2.5)	A	2.2	Lognormal (GSD: 2.2)	A
Biofuel: firewood	-	-	-	-	-	-	1.5	Lognormal (GSD: 2.2)	A	1.2	Lognormal (GSD: 1.9)	A
Open burning	-	-	-	-	-	-	0.2-0.7	Uniform	B	0.5-7.3	Uniform	B
CEM kiln: precalciner	14-22%	Uniform	D	19-29%	Uniform	D						
CEM kiln: shaft	7-14%	Uniform	C	17-21%	Uniform	C	0.6-1.0%	Uniform	C	1-3%	Uniform	C
CEM kiln: rotary	7-11%	Uniform	C	17-20%	Uniform	C						
CEM processes	1-13%	Uniform	C	8-26%	Uniform	C						
Coking	7-60%	Uniform	C	2-38%	Uniform	C	30-50%	Uniform	C	28-42%	Uniform	D
Sintering	5-9%	Uniform	D	6-10%	Uniform	D	0.8-1.2%	Uniform	D	4-6%	Uniform	D
Pig iron	10-23%	Uniform	C	6-27%	Uniform	C	10-28%	Uniform	C	2-5%	Uniform	C
Pig iron: fugitive	6-14%	Uniform	C	4-11%	Uniform	C	0-10%	Uniform	C	0-2%	Uniform	C
Steel: open hearth	48-72%	Uniform	D	18-28%	Uniform	D	-	-	-	-	-	
Steel: converter	23-65%	Uniform	C	2-23%	Uniform	C	-	-	-	16-24%	Uniform	C
Steel: electric	38-48%	Uniform	D	12-18%	Uniform	D	-	-	-	1.6-2.4%	Uniform	D
Casting	58-71%	Uniform	C	6-29%	Uniform	C	-	-	-	2-4%	Uniform	D
Casting: fugitive	19-29%	Uniform	D	20-30%	Uniform	D	-	-	-	2-4%	Uniform	D
Lime	1.6-2.4%	Uniform	D	8-12%	Uniform	D	1.6-2.4%	Uniform	D	1-6%	Uniform	C
Aluminum smelt	18-44%	Uniform	C	15-24%	Uniform	C	-	-	-	-	-	-
Al_2O_3 smelt	14-22%	Uniform	D	5-7%	Uniform	D	-	-	-	-	-	-
Other metal smelt	66-88%	Uniform	D	8-12%	Uniform	D	-	-	-	-	-	-
Brick production	6-8%	Uniform	D	10-16%	Uniform	D	40-50%	Uniform	C	35-40%	Uniform	C

Table S5. The uncertainties of size distribution and carbonaceous fractions of PM (continued)

	Size fraction						Carbonaceous fractions/*EF* (kg/t-fuel)[1]					
	$PM_{2.5}$			$PM_{2.5-10}$			BC			OC		
	Value	Distribution	Rating	Value	Distribution	Rating	Value	Distribution	Rating	Value	Distribution	Rating
Glass production	73-95%	Uniform	D	3-5%	Uniform	D	-	-	-	-	-	-
On-road: gasoline	-	-	-	-	-	-	2-81%	Uniform	C	3-65%	Uniform	C
On-road: diesel	-	-	-	-	-	-	43%	Gamma	A	37%	Logistic	A
Non-road: diesel	-	-	-	-	-	-	4-84%	Uniform	C	1-32%	Uniform	C

[1] The values with and without a "%" indicate the fraction and *EF*, respectively. [2] Non-independent parameter. The value is calculated as 1 minus the PM fractions of other sizes.

Table S6. The uncertainties of removal efficiencies of emission control devices (%).

	$PM_{2.5}$			$PM_{2.5-10}$			PM>10			SO_2		
	Value	Distribution	Rating	Value	Distribution	Rating	Value	Distribution	Rating	Value	Distribution	Rating
FF	99.3 (99.00-99.70)	Triangular	B	99.7 (99.5-99.9)	Triangular	B	99.95 (99.90-99.99)	Triangular	B	-	-	-
ESP	92.31	Lognormal (GSD:1.0)	A	96.97	Lognormal (GSD:1.0)	A	99.46	Normal (SD[1]:0.1)	A	-	-	-
WET (power)	67.40 (37.50-71.73)	Triangular	B	85.74 (78.57-90.00)	Triangular	B	96.51 (94.37-98.65)	Triangular	B	20 (10-30)	Uniform	D
WET (industry)	56.96 (37.50-71.73)	Triangular	B	84.01 (78.57-90.00)	Triangular	B	96.49 (94.37-98.65)	Triangular	B	-	-	-
CYC	13.33 (10.00-65.12)	Triangular	B	75 (70.00-77.78)	Triangular	B	90 (72.00-95.00)	Triangular	D	-	-	-
wet-FGD	53.74	Normal (SD: 2.5)	A	81.21	Normal (SD: 2.8)	A	92.63	Normal (SD: 0.7)	A	75 (55-95)	Triangular	B
Other-FGD	-	-	-	-	-	-	-	-	-	30 (10-60)	Triangular	B

[1] Standard deviation. The same below.

Table S7. Uncertainties of Chinese emission inventory by sector in 2005. The estimated emissions are expressed as kilo metric tons (kt). The percentages in the parentheses indicate the 95% CI around the central estimate.

	SO_2	NO_X	PM	PM_{10}	$PM_{2.5}$	BC	OC
CPP	16258 (-16%, 20%)	6730 (-19%, 16%)	2768 (-19%, 39%)	1859 (-19%, 49%)	912 (-27%, 80%)	16 (-69%, 378%)	2 (-73%, 2367%)
CEM	1364 (-32%, 24%)	1274 (-37%, 50%)	7316 (-31%, 99%)	4960 (-40%, 97%)	2756 (-55%, 119%)	22 (-59%, 112%)	55 (-65%, 157%)
ISP	1155 (-51%, 102%)	232 (-19%, 18%)	3624 (-7%, 127%)	2088 (-17%, 58%)	1585 (-22%, 52%)	225 (-49%, 93%)	234 (-40%, 79%)
IND	7489 (-33%, 23%)	3684 (-48%, 161%)	3028 (-61%, 118%)	1730 (-59%, 151%)	1030 (-62%, 227%)	112 (-81%, 356%)	37 (-64%, 1288%)
PRO	1514 (-45%, 36%)	1106 (-28%, 31%)	11836 (-39%, 26%)	3055 (-28%, 33%)	1554 (-21%, 56%)	242 (-42%, 51%)	245 (-52%, 25%)
TRA (on road)	54 (-18%, 51%)	2356 (-25%, 45%)	133 (-35%, 53%)	133 (-35%, 53%)	133 (-35%, 53%)	43 (-52%, 126%)	37 (-91%, 121%)
TRA (non road)	187 (-30%, 48%)	2368 (-32%, 81%)	457 (-38%, 58%)	444 (-38%, 60%)	419 (-39%, 64%)	195 (-87%, 86%)	65 (-84%, 120%)
RES (fossil fuel)	2957 (-50%, 21%)	667 (-34%, 103%)	1788 (-64%, 133%)	1383 (-77%, 160%)	1261 (-68%, 198%)	336 (-80%, 347%)	930 (-92%, 114%)
RES (biomass)	107 (-71%, 296%)	1369 (-53%, 115%)	3710 (-58%, 95%)	3562 (-58%, 95%)	3451 (-58%, 95%)	505 (-60%, 281%)	1598 (-57%, 226%)
Total	31085 (-14%, 12%)	19785 (-10%, 36%)	34659 (-10%, 36%)	19214 (-12%, 42%)	13100 (-16%, 52%)	1698 (-23%, 130%)	3203 (-37%, 117%)

Figures

Fig. S1.

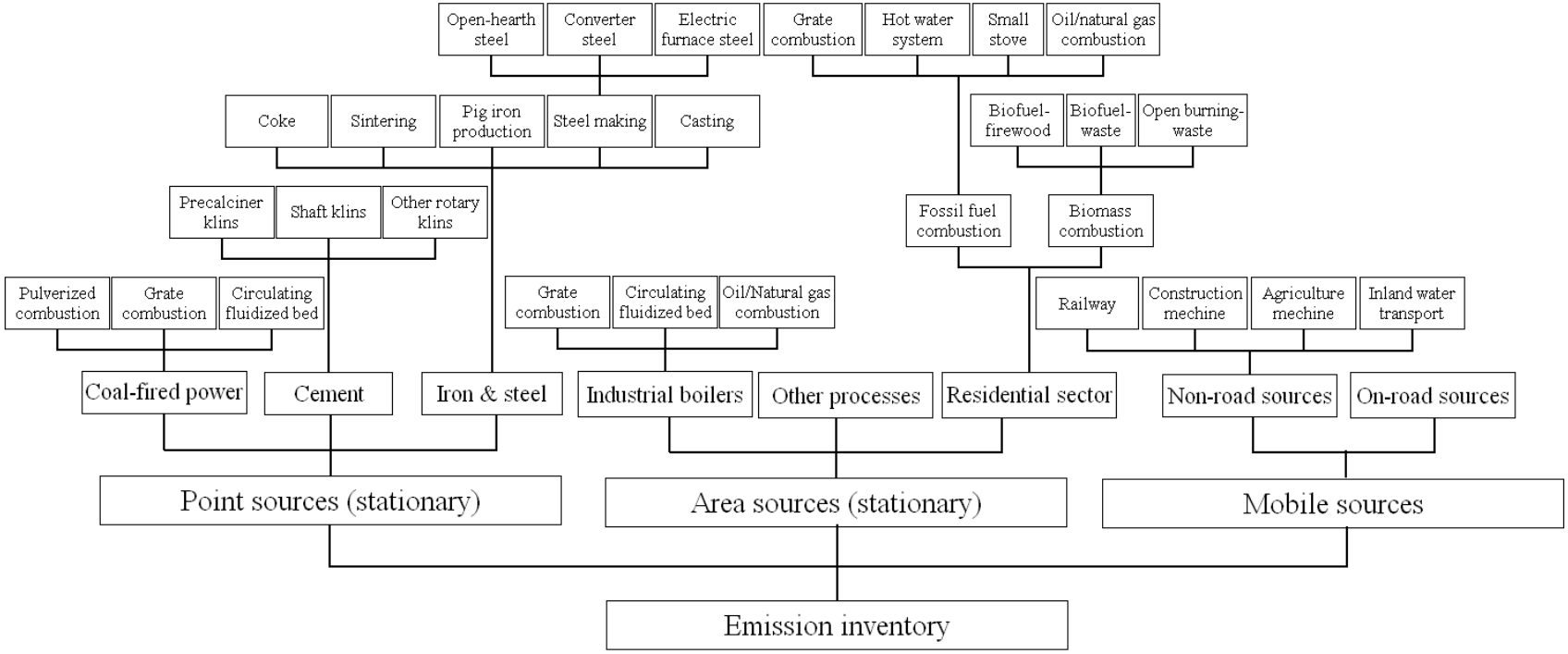
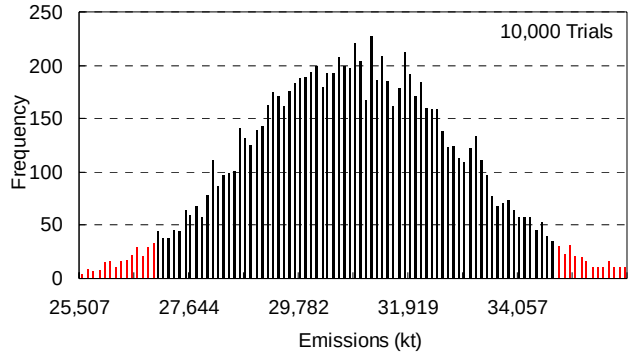


Fig. S2.



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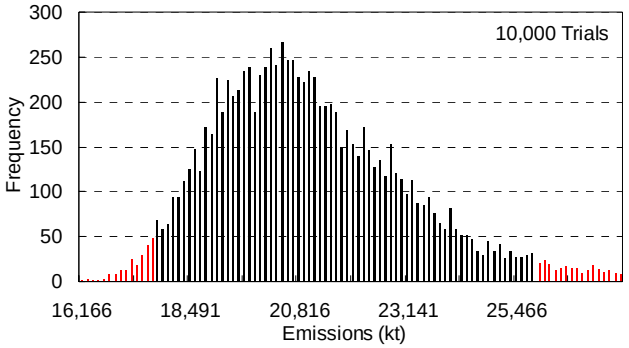

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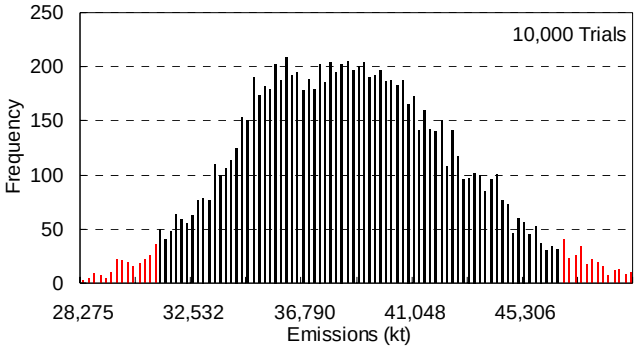

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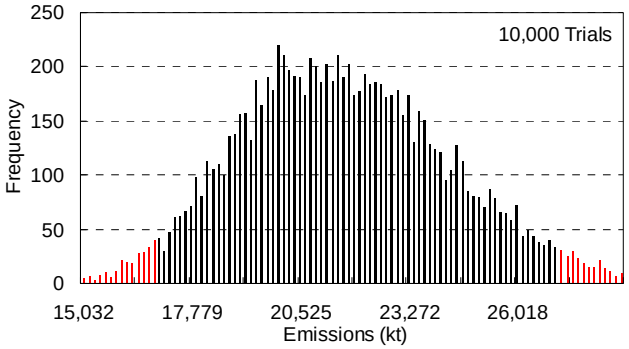

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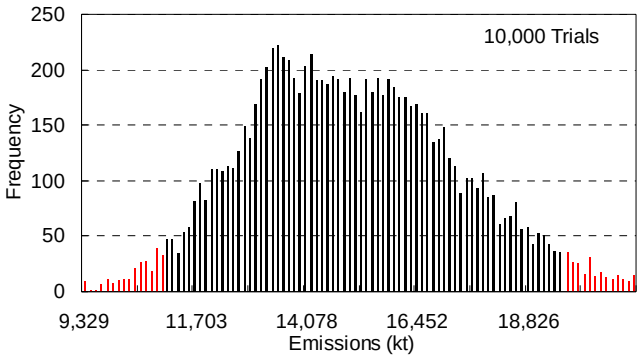

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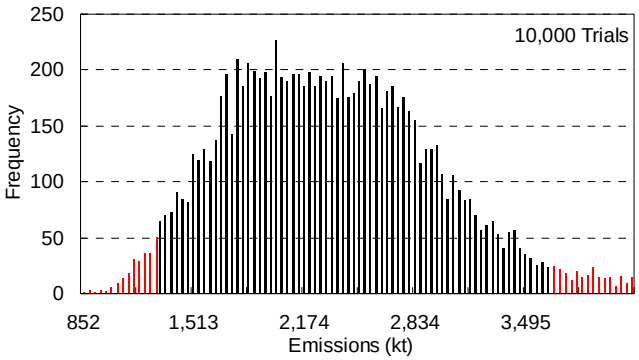

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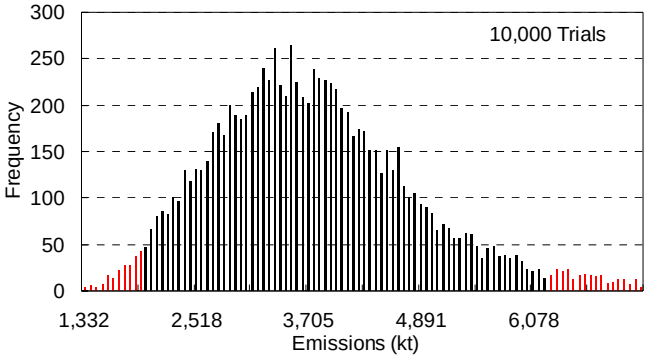

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References

China Association of Automobile Manufacturers (CAAM) and China Automotive Technology & Research Center (CATRA): Evaluation report of automobile energy saving in China, 2009 (in Chinese). Available at http://caam.org.cn/files/file/0906/zhyh.pdf

Kioutsioukis, I., Tarantola, S., Saltelli, A., and Debora, G.: Uncertainty and global sensitivity analysis of road transport emission estimates, Atmos. Environ., 38, 6609-6620, 2004.

Lal, R.: World crop residues production and implications of its use as a biofuel, Environ. Int., 31, 575-584, 2005.

Wang, H, K., Chen, C. H., Huang, C., and Fu, L. X.: On-road vehicle emission inventory and its uncertainty analysis for Shanghai, China, Sci. Total. Environ, 398, 60-67, 2008.

Wang, S. X., and Zhang, C. Y.: Spatial and temporal distribution of air pollutant emission from open burning of crop residues in China, Sciencepaper online, 3, 329-333, 2008 (in Chinese).

Zhao, Y., Wang, S.X., Duan, L., Lei, Y., Cao, P.F., and Hao, J.M.: Primary air pollutant emissions of coal-fired power plants in China: current status and future prediction. Atmos. Environ., 42, 8442-8452, 2008.