Supporting information

Title: Field-tested emission factors and temporal allocation factors for air pollutants emitted from industrial sources in China

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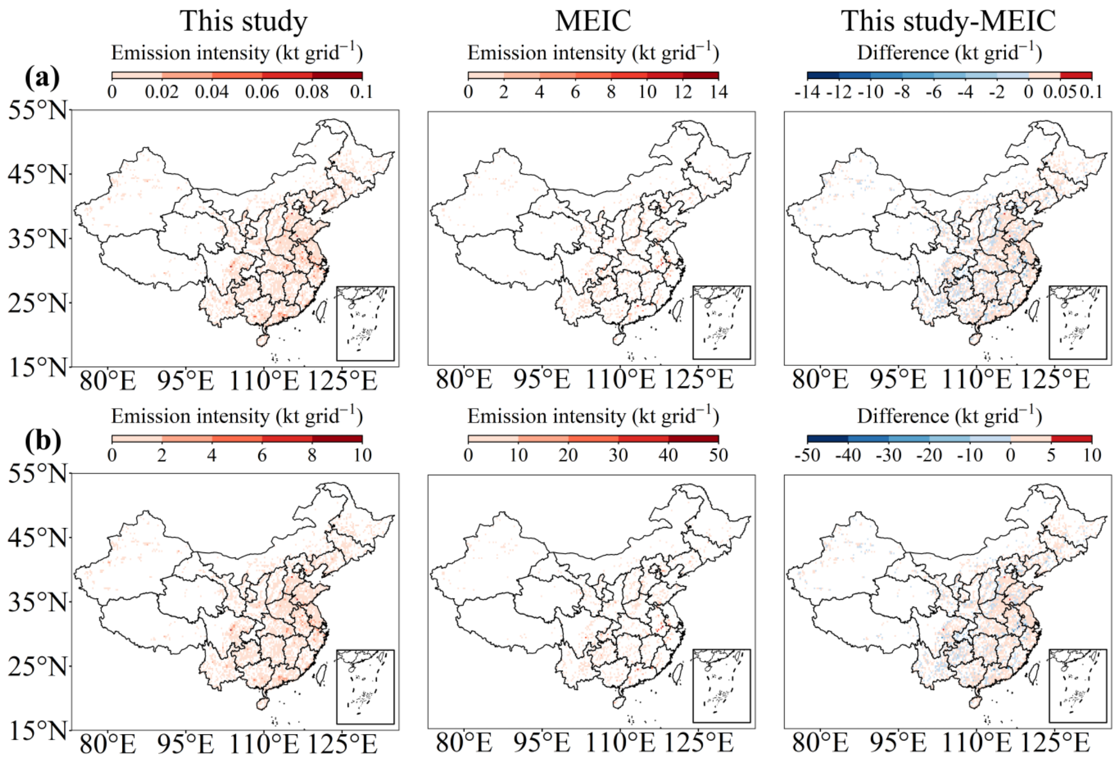

Figure S1. Spatial comparison of cement-related PM_{10} and CO emission intensities between this study and the adjusted MEIC inventory for 2024. Panels (a) and (b) represent PM_{10} and CO, respectively.

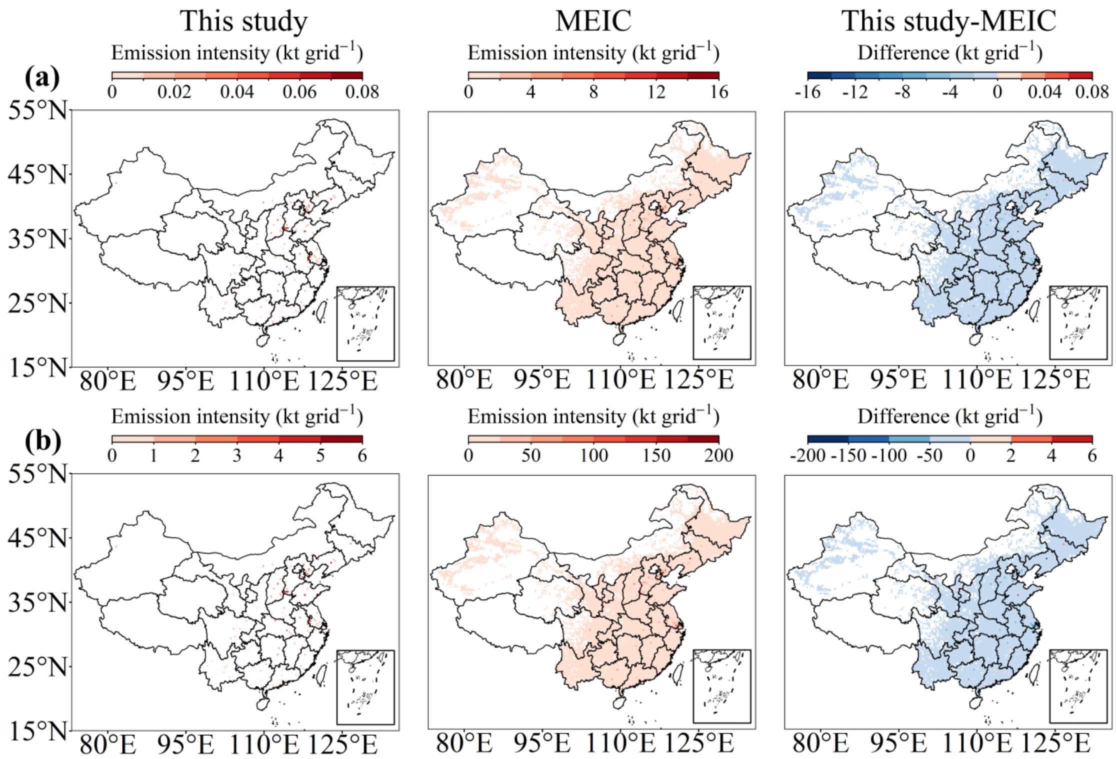

Figure S2. Spatial comparison of iron and steel-related PM_{10} and CO emission intensities between this study and the adjusted MEIC inventory for 2024. Panels (a) and (b) represent PM_{10} and CO, respectively.

Table S1. Basic information of the monitored industrial sectors.

Industry	Product	Production (t yr^{-1})	Fuel	Fuel Consumption yr^{-1}	Control Measure	Dust Removal Efficiency
Cement	Cement	1.0×10^6	Coal	1.3×10^5 t	Electrostatic-fabric filter dust collector	99.9%
Medicine	VB_6	3.7×10^2	Natural gas	2.9×10^6 Nm^3	/	/
Glass	Glass	4.6×10^5	Natural gas	8.8×10^7 Nm^3	Bag dust collector	99%
Textile	Fabrics	1.5×10^3	Anthracite coal	3.5×10^3 t	Bag dust collector	90%
Iron and steel	Steel/iron	3.0×10^6	Coal/coke	1.8×10^5 t	Bag dust collector	98%

Cement: other rotary kilns (ORKs); VB_6: vitamin B6; Nm^3 refers to the volume of gas under standard conditions of 273.15 K and 101.325 kPa, unless otherwise specified.

Table S2. Field monitoring duration, temporal resolution, and valid data coverage for the five industrial sectors.

Industry	Days	Sampling duration	Dilution ratio	Pollutants	Time resolution
Cement	3 d	70 h	20	PM_{10}, $PM_{2.5}$, PM_1, BC; NOx, SO_2, CO	1 min
Medicine	3 d	77 h	20	PM_{10}, $PM_{2.5}$, PM_1, BC; NOx, SO_2, CO	1 min
Glass	3 d	84 h	10	PM_{10}, $PM_{2.5}$, PM_1, BC; NOx, SO_2, CO	1 min
Textile	3 d	84 h	10	PM_{10}, $PM_{2.5}$, PM_1, BC; NOx, SO_2, CO	1 min
Iron and steel	3 d	76 h	10	PM_{10}, $PM_{2.5}$, PM_1, BC; NOx, SO_2, CO	1 min

Note: Temporal resolution refers to the time resolution of the online monitoring data. After data screening, the overall valid data coverage was 94.2% for PM_{10}, $PM_{2.5}$, PM_1 and BC measured using the AE-33 and GRIMM 180 instruments, and 92.1% for NOx, SO_2 and CO measured using the TH-890C instrument.

Table S3. Comparison of hourly allocation factors derived in this study with previously reported temporal profiles for industrial and point sources.

Hour	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
PM_{10}	0.046	0.044	0.051	0.049	0.045	0.042	0.039	0.038	0.045	0.042	0.041	0.041	0.038	0.032	0.036	0.038	0.041	0.045	0.056	0.049	0.047	0.043	0.045	0.026
$PM_{2.5}$	0.045	0.044	0.045	0.043	0.041	0.039	0.038	0.037	0.046	0.050	0.040	0.040	0.037	0.035	0.037	0.041	0.046	0.046	0.055	0.051	0.046	0.044	0.038	0.016
PM_1	0.048	0.048	0.048	0.046	0.043	0.040	0.039	0.038	0.044	0.045	0.040	0.038	0.035	0.034	0.035	0.040	0.045	0.046	0.054	0.052	0.047	0.046	0.045	0.026
BC	0.032	0.033	0.038	0.041	0.039	0.042	0.045	0.052	0.063	0.068	0.066	0.062	0.049	0.043	0.044	0.039	0.040	0.039	0.034	0.032	0.035	0.037	0.030	0.049
NOx	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.043	0.043	0.044	0.044	0.045	0.044	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.043	0.017
SO_2	0.039	0.042	0.042	0.042	0.042	0.042	0.042	0.043	0.044	0.045	0.045	0.045	0.043	0.043	0.042	0.042	0.043	0.042	0.042	0.042	0.042	0.042	0.042	0.021
CO	0.038	0.037	0.037	0.039	0.036	0.037	0.041	0.047	0.057	0.067	0.070	0.063	0.050	0.043	0.042	0.037	0.040	0.039	0.038	0.035	0.033	0.034	0.038	0.049
Major point sources	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
Small points weekday	0.029	0.029	0.029	0.029	0.029	0.029	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.057	0.029	0.029	0.029	0.029	0.029	0.029	0.029
Activity-based industrial facilities	0.02	0.02	0.02	0.02	0.02	0.02	0.025	0.030	0.070	0.075	0.080	0.080	0.080	0.080	0.080	0.075	0.070	0.040	0.03	0.025	0.02	0.02	0.02	0.02
Chinese guideline: industrial sources	0.026	0.007	0.007	0.007	0.007	0.007	0.007	0.029	0.045	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.066	0.063	0.037	0.037	0.037	0.037	0.037
CAMS-TEMPO: manufacturing industry	0.031	0.031	0.032	0.034	0.037	0.040	0.043	0.045	0.048	0.051	0.053	0.054	0.051	0.052	0.052	0.048	0.045	0.042	0.040	0.038	0.035	0.034	0.032	0.031
EPA temporal profile	0	0	0	0	0	0	0	0	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0	0	0	0	0	0	0	0

Note: The data for major point sources and small point sources are from Sowden et al. (2008); data for activity-based industrial facilities are from Pham et al. (2008); data for Chinese guideline-based industrial sources are from MEE (2024); data for CAMS-TEMPO manufacturing industry profiles are from Guevara et al. (2021); data for EPA temporal profiles are from the U.S. EPA (2021). All hourly allocation factors are normalized so that the sum over 24 h equals 1, allowing for rounding differences.

Table S4. Average measured concentrations of PM_{10}, $PM_{2.5}$, PM_1, BC, NOx, SO_2, and CO across the industrial sectors.

Industry	PM_{10}	$PM_{2.5}$	PM_1	BC	NOx	SO_2	CO
Cement	2.61±0.99	2.21±0.77	1.63±0.44	30.50±18.65	81.36±10.91	-	-
Medicine	5.34±0.88	5.17±0.84	4.96±0.77	41.74±8.41	130.12±6.03	304.23±23.32	10.97±0.99
Glass	0.19±0.13	0.19±0.13	0.19±0.13	1.39±0.48	144.78±10.02	346.83±27.50	10.43±2.40
Textile	1.02±0.45	1.02±0.46	0.97±0.47	10.90±8.50	217.82±5.69	508.50±17.45	26.39±1.96
Iron and steel	0.71±0.28	0.71±0.28	0.69±0.28	7.25±3.63	227.24±5.42	443.97±11.22	20.23±2.35

Note: Concentrations are expressed in mg/m^3 unless otherwise specified; BC is reported in μg m^{-3}. The dash (-) indicates no data.

Table S5. Comparison of measured and literature-reported PM_{10} mass concentrations across different industrial sectors.

Industry	Concentration	Unit	Production process	Sampling location	Reference
Cement	8.76–10.51	mg/m^3	Clinker production	Flue gas at preheater outlet	Liu et al., 2019
Cement	5.64	mg/m^3	Clinker production	Hot air at clinker cooler outlet	Liu et al., 2019
Cement	3.05–19.38	mg/m^3	Clinker production	Kiln tail, kiln head, and coal mill outlets (after FF/ESP)	Guo et al., 2022a
Cement	2.61±0.99	mg/m^3	Clinker production	Kiln tail	This study
Iron and steel	25.2–40.8	mg/m^3	Sintering	Sintering (after FGD + bag filter)	Jia et al., 2018
Iron and steel	0.71±0.28	mg/m^3	Sintering	Sintering flue gas outlet	This study
Medicine	5.34±0.88	mg/m^3	VB_6 production	Exhaust outlet	This study
Glass	0.19±0.13	mg/m^3	Plate glass production	Exhaust outlet	This study
Textile	1.02±0.45	mg/m^3	Fabric production	Exhaust outlet	This study

FF: fabric filter; ESP: electrostatic precipitator; FGD: flue gas desulfurization.

Table S6. Comparison of measured and literature-reported $PM_{2.5}$ mass concentrations across different industrial sectors.

Industry	Concentration	Unit	Production process	Sampling location	Reference
Cement	2.56–5.04	mg/m^3	Clinker production	Flue gas at preheater outlet	Liu et al., 2019
Cement	3.55	mg/m^3	Clinker production	Hot air at clinker cooler outlet	Liu et al., 2019
Cement	0.09–1.64	mg/m^3	Clinker production	Kiln tail, kiln head, and coal mill outlets (after FF/ESP)	Guo et al., 2022a
Cement	2.21±0.77	mg/m^3	Clinker production	Kiln tail	This study
Iron and steel	0.71±0.28	mg/m^3	Sintering	Sintering flue gas outlet	This study
Medicine	5.17±0.84	mg/m^3	VB_6 production	Exhaust outlet	This study
Glass	0.19±0.13	mg/m^3	Plate glass production	Exhaust outlet	This study
Textile	1.02±0.46	mg/m^3	Fabric production	Exhaust outlet	This study

Table S7. Comparison of measured and literature-reported PM_1 mass concentrations across different industrial sectors.

Industry	Concentration	Unit	Production process	Sampling location	Reference
Cement	0.93–2.37	mg/m^3	Clinker production	Flue gas at preheater outlet (after FF1)	Liu et al., 2019
Cement	1.33	mg/m^3	Clinker production	Hot air at clinker cooler outlet (after FF2)	Liu et al., 2019
Cement	1.63±0.44	mg/m^3	Clinker production	Kiln tail	This study
Iron and steel	0.69±0.28	mg/m^3	Sintering	Sintering flue gas outlet	This study
Medicine	4.96±0.77	mg/m^3	VB_6 production	Exhaust outlet	This study
Glass	0.19±0.13	mg/m^3	Plate glass production	Exhaust outlet	This study
Textile	0.97±0.47	mg/m^3	Fabric production	Exhaust outlet	This study

Note: FF1 and FF2 indicates the first and second fabric-filter units, respectively.

Table S8. Comparison of measured and literature-reported BC mass concentrations across different industrial sectors.

Industry	Concentration	Unit	Production process	Sampling location	Reference
Cement	0.02–0.41 (EC)	mg/m^3	Cement production	Coal mill and kiln exhaust	Guo et al., 2022a
Cement	30.50±18.65	μg/m^3	Clinker production	Kiln tail	This study
Iron and steel	1.4–2.3	% of PM_{10}	Sintering, pelletizing, and steelmaking	NR	Jia et al., 2018
Iron and steel	7.25±3.63	μg/m^3	Sintering	Sintering	This study
Medicine	41.74±8.41	μg/m^3	VB_6 production	Exhaust outlet	This study
Glass	1.39±0.48	μg/m^3	Plate glass production	Exhaust outlet	This study
Textile	10.9±8.5	μg/m^3	Fabric production	Exhaust outlet	This study

Note: EC denotes elemental carbon; NR indicates there was no information. Values expressed as % of PM_{10} represent relative mass contribution of PM_{10}.

Table S9. Comparison of measured and literature-reported NOx mass concentrations across different industrial sectors.

Industry	Concentration	Unit	Data source	Process/source	Reference
Cement	80–171	mg/m^3	CEMS	Rotary kiln (after DeNOx)	Guo et al., 2022a
Cement	81.36±10.91	mg/m^3	Field measurement	Clinker production, kiln tail	This study
Iron and steel	≤ 217.28	mg/m^3	Stack measurement	Coking, reheating furnace, power boiler	Sun et al., 2019
Iron and steel	100–150	mg/m^3	CEMS-based calculation	Sintering	Bo et al., 2020
Iron and steel	95–200	mg/m^3	CEMS-based	Sintering head	Yi et al., 2021
Iron and steel	130–150	mg/m^3	CEMS-based calculation	Sintering, pelletizing, coking, blast furnace, BOF, EAF, and rolling	Bo et al., 2021
Iron and steel	153.7	mg/m^3	CEMS with O_2 correction	NR	Liu et al., 2022
Iron and steel	100–150	mg/m^3	CEMS-based	Sintering head	Wang et al., 2022
Iron and steel	53.43	mg/m^3	CEMS real-time monitoring	All processes	Tang et al., 2025
Iron and steel	227.24±5.42	mg/m^3	Field measurement	Sintering	This study
Medicine	130.12±6.03	mg/m^3	Field measurement	VB6 production, exhaust outlet	This study
Glass	144.78±10.02	mg/m^3	Field measurement	Plate glass production, exhaust outlet	This study
Textile	217.82±5.69	mg/m^3	Field measurement	Fabric production, exhaust outlet	This study

Note: CEMS-continuous emission monitoring system; BOF-basic oxygen furnace; EAF-electric arc furnace; O_2 correction-oxygen-content correction.

Table S10. Comparison of measured and literature-reported SO_2 mass concentrations across different industrial sectors.

Industry	Concentration	Unit	Data source	Process/source	Reference
Cement	0–4.96	mg/m^3	CEMS	Rotary kiln	Guo et al., 2022a
Iron and steel	≤ 138.26	mg/m^3	Stack measurement	Sintering, ironmaking, power boiler	Sun et al., 2019
Iron and steel	100–150	mg/m^3	CEMS-based calculation	Sintering	Bo et al., 2020
Iron and steel	100	mg/m^3	CEMS-based calculation	Sintering	Bo et al., 2020
Iron and steel	30–120	mg/m^3	CEMS-based	NR	Yi et al., 2021
Iron and steel	40–120	mg/m^3	CEMS-based calculation	Sintering, pelletizing, coking, blast furnace, BOF, EAF, and rolling	Bo et al., 2021
Iron and steel	66.30	mg/m^3	CEMS with O_2 correction	Sintering head	Liu et al., 2022
Iron and steel	60–150	mg/m^3	CEMS-based	Sintering head	Wang et al., 2022
Iron and steel	20.79	mg/m^3	CEMS real-time monitoring	All processes	Tang et al., 2025
Iron and steel	443.97±11.22	mg/m^3	Field measurement	Sintering	This study
Medicine	304.23±23.32	mg/m^3	Field measurement	Exhaust outlet	This study
Glass	346.83±27.50	mg/m^3	Field measurement	Exhaust outlet	This study
Textile	508.50±17.45	mg/m^3	Field measurement	Exhaust outlet	This study

Table S11. Comparison of measured and literature-reported CO mass concentrations across different industrial sectors.

Industry	Concentration	Unit	Data source	Process/source	Reference
Cement	12–146	mg/m^3	CEMS	Rotary kiln	Guo et al., 2022a
Iron and steel	20.23±2.35	mg/m^3	Field measurement	Sintering	This study
Medicine	10.97±0.99	mg/m^3	Field measurement	Exhaust outlet	This study
Glass	10.43±2.40	mg/m^3	Field measurement	Exhaust outlet	This study
Textile	26.39±1.96	mg/m^3	Field measurement	Exhaust outlet	This study

Table S12. Average emission factors (EF) for seven primary pollutants across the five typical industrial sources in this study.

Industry	Basis	PM_{10} (mg kg^{-1} or mg m^{-3})	$PM_{2.5}$ (mg kg^{-1} or mg m^{-3})	PM_1 (mg kg^{-1} or mg m^{-3})	BC (mg kg^{-1} or mg m^{-3})	NOx (g kg^{-1} or g m^{-3})	SO_2 (g kg^{-1} or g m^{-3})	CO (g kg^{-1} or g m^{-3})
Cement	Product-based	11±3.9	8.8±3.1	6.5±1.7	0.12±0.07	0.32±0.04	0.25	1
Glass	Product-based	0.45±0.3	0.45±0.3	0.44±0.3	0.0032±0.001	0.33±0.02	0.80±0.06	0.024±0.006
	Fuel-based	2.3±1.6	2.3±1.6	2.3±1.6	0.017±0.006	1.75±0.12	4.18±0.33	0.13±0.03
Medicine	Product-based	6030±990	5840±950	5600±870	47±10	146.88±6.81	343.43±26.33	12.39±1.13
	Fuel-based	780±130	750±120	720±110	6±1.0	18.91±0.88	44.21±3.39	1.59±0.15
Textile	Product-based	49±22	48±22	47±23	0.52±0.4	10.44±0.27	24.38±0.84	1.27±0.09
	Fuel-based	21±9	21±9	20±10	0.23±0.18	4.50±0.12	10.51±0.36	0.55±0.04
Iron and steel	Product-based	2.8±1.0	2.7±1.0	2.7±1.0	0.028±0.014	0.88±0.015	1.72±0.04	0.078±0.009

Note: Glass and medicine used natural gas as fuel, and their fuel-based emission factors are expressed as mg m^{-3} or g m^{-3}. Cement, textile, and iron and steel used coal or coke as fuel, and their fuel-based emission factors are expressed as mg kg^{-1}.

Table S13. PM_{10} emission factors reported in the literature for different industrial sectors in China.

Industry	EF	Unit	Process/source	Reference
Cement	0.65	g/kg cement	Cement production	Hua et al., 2016
Cement	1.27	g/kg cement	New dry process kiln	Liu et al., 2018
Cement	1.24	g/kg cement	Shaft kiln	Liu et al., 2018
Cement	1.41	g/kg cement	Ordinary rotary kiln	Liu et al., 2018
Cement	0.017–0.031	g/kg clinker	Flue gas (preheater and FF1)	Liu et al., 2019
Cement	0.005	g/kg clinker	Hot air (clinker cooler and FF2)	Liu et al., 2019
Cement	8.05	g/kg product	Cement production	Zhou et al., 2019
Cement	1.95 (TSP-based)	g/kg cement	Cement production	Zheng et al., 2021
Cement	0.58–15.83	g/kg cement	Clinker calcination, grinding and fugitive (unit-based inventory)	Liu et al., 2021
Cement	0.0015–0.018	g/kg clinker	Kiln tail, kiln head, and coal mill (after FF/ESP)	Guo et al., 2022a
Cement	0.61–3.09	g/kg clinker	Kilns equipped with FF	Guo et al., 2022b
Cement	3.74–5.36	g/kg cement	Grinding station	Liu et al., 2024
Cement	2.5–30	g/kg clinker	NR	Yan et al., 2024
Cement	8	g/kg product	Grinding	MEE, 2024
Iron and steel	0.40–2.07	g/kg product	Sintering/BF/BOF/EAF	Wang et al., 2016
Iron and steel	8.42	g/kg product	Sintering	Liu et al., 2018
Iron and steel	1.92/0.78/0.61/0.47	g/kg product	Coke making/blast furnace/basic oxygen furnace/electric arc furnace	Liu et al., 2018
Iron and steel	23.98/14.27/10.55/8.7	g/kg product	Sintering/BF/BOF/EAF	Wang et al., 2019
Iron and steel	0.72	g/kg product	Ironmaking	Zhou et al., 2019
Iron and steel	0.67	g/kg product	Steelmaking	Zhou et al., 2019
Iron and steel	3.58	g/kg product	Steel processing	Zhou et al., 2019
Iron and steel	Organized: 0.027–14.68; Unorganized: 0–1.22	g/kg product	Sintering, pelletizing, BF, BOF/EAF, rolling (by scale)	Gao et al., 2019
Iron and steel	0.003–0.113	g/kg product	All processes	Chen et al., 2023
Iron and steel	5.81/5.81/8.43/14.63/8.12	g/kg product	Sintering/pelletizing/ironmaking/BOF steelmaking/EAF steelmaking	MEE, 2024
Glass	0.58	g/kg product	Flat glass	Zhou et al., 2019
Glass	0.99	g/kg product	Glass product	Zhou et al., 2019
Glass	8.27/11.16/3.07/0	g/kg product	Float glass/vertically drawn glass/glass products/glass fiber	MEE, 2024
Medicine	1.32/1.59/2.6	g/kg product	Chinese herbal decoction pieces	MEE, 2017
Textile	0.41	g/kg product	Chemical processing and shaping	MEE, 2017

Note: TSP-total suspended particulate matter; BF-blast furnace.

Table S14. $PM_{2.5}$ emission factors reported in the literature for different industrial sectors in China.

Industry	EF	Unit	Process/source	Reference
Cement	0.005–0.015	g/kg clinker	Flue gas (preheater + FF1)	Liu et al., 2019
Cement	0.003	g/kg clinker	Hot air (clinker cooler + FF2)	Liu et al., 2019
Cement	0.249	g/kg cement	Cement production	Hua et al., 2016
Cement	0.8	g/kg cement	New dry process kiln	Liu et al., 2018
Cement	0.75	g/kg cement	Shaft kiln	Liu et al., 2018
Cement	0.88	g/kg cement	Ordinary rotary kiln	Liu et al., 2018
Cement	0.23–1.17	g/kg clinker	Cement kilns (PC/SK/OR) with FF	Guo et al., 2022b
Cement	3.40	g/kg product	Cement	Zhou et al., 2019
Cement	0.16–2.48	g/t clinker	Kiln tail/head/coal mill (after FF/ESP)	Guo et al., 2022a
Cement	20.44–23.38	g/t clinker	Kiln tail	Liu et al., 2024
Cement	0.96–1.37	g/kg cement	Grinding station	Liu et al., 2024
Cement	0.3–6.0	g/kg clinker	PM fraction×$PM_{2.5}$ EF	Yan et al., 2024
Cement	8	g/kg product	Grinding	MEE, 2024
Iron and steel	0.35–1.9	g/kg product	Sintering/BF/BOF/EAF	Wang et al., 2016
Iron and steel	4.12	g/kg product	Sintering	Liu et al., 2018
Iron and steel	0.84	g/kg product	Coke making	Liu et al., 2018
Iron and steel	0.32	g/kg product	Blast furnace	Liu et al., 2018
Iron and steel	0.29	g/kg product	Basic oxygen furnace	Liu et al., 2018
Iron and steel	0.21	g/kg product	Electric arc furnace	Liu et al., 2018
Iron and steel	1.76/4.69/16.89/8.92	g/kg product	Sintering/BF/BOF/EAF	Wang et al., 2019
Iron and steel	0.45/0.60/1.75/1.70	g/kg product	Ironmaking/Steelmaking/Coking/Steel processing	Zhou et al., 2019
Iron and steel	Organized: 0.031–10.5; Unorganized: 0–0.73	g/kg product	Sintering, pelletizing, BF, BOF, EAF, rolling (by scale)	Gao et al., 2019
Iron and steel	2.82/0.7/0.17/0.04	g/kg product	Sintering/Pelletizing/Ironmaking/BOF	Zhang et al., 2023
Iron and steel	2.52/2.52/5.27/10.45/6.02	g/kg product	Sintering/Pelletizing/Ironmaking/BOF/EAF	MEE, 2024
Iron and steel	0.21–0.54	g/kg product	Sintering/steelmaking	Zheng et al., 2024
Glass	0.55	g/kg product	Flat glass	Zhou et al., 2019
Glass	0.94	g/kg product	Glass product	Zhou et al., 2019
Glass	7.92/10.69/2.94/0	g/kg product	Float glass/vertically drawn glass/glass products/glass fiber	MEE, 2024

Note: PC-a precalciner kiln; SK-a shaft kiln; OR-other rotary kilns.

Table S15. PM_1 emission factors reported in the literature for different industrial sectors in China.

Industry	EF	Unit	Process/source	Reference
Cement	0.002–0.007	g/kg clinker	Flue gas (preheater + FF1)	Liu et al., 2019
Cement	0.001	g/kg clinker	Hot air (clinker cooler + FF2)	Liu et al., 2019

Table S16. BC emission factors reported in the literature for different industrial sectors in China.

Industry	EF	Unit	Process/source	Reference
Cement	0.23	$BC/PM_{2.5}$ mass fraction	New dry process kiln	Liu et al., 2018
Cement	0.27	$BC/PM_{2.5}$ mass fraction	Shaft kiln	Liu et al., 2018
Cement	0.13	$BC/PM_{2.5}$ mass fraction	Ordinary rotary kiln	Liu et al., 2018
Cement	0.0204	g/kg product	Cement (f_{BC} = 0.006)	Zhou et al., 2019
Iron and steel	0.22	$BC/PM_{2.5}$ mass fraction	Sintering	Liu et al., 2018
Iron and steel	0.30	$BC/PM_{2.5}$ mass fraction	Coke making	Liu et al., 2018
Iron and steel	0.25	$BC/PM_{2.5}$ mass fraction	Blast furnace	Liu et al., 2018
Iron and steel	0.21	$BC/PM_{2.5}$ mass fraction	BOF	Liu et al., 2018
Iron and steel	0.126	g/kg product	Ironmaking (f_{BC} = 0.28)	Zhou et al., 2019
Iron and steel	0.84	g/kg product	Coking (f_{BC} = 0.48)	Zhou et al., 2019
Iron and steel	30.60/1.60/1.60/10.60/1.18/14.19/1.18	BC fraction of $PM_{2.5}$ (%)	Coking/sintering/pelletizing/blast furnace/BOF/EAF/hot rolling	Tang et al., 2020
Iron and steel	0.003/0.003/0.53/0	g/kg product	Sintering/pelletizing/ironmaking/steelmaking (BOF, EAF)	MEE, 2024
Glass	0.0003276	g/kg product	Flat glass production (f_{BC} = 0.0006)	Zhou et al., 2019
Glass	0.0005622	g/kg product	Glass production (f_{BC} = 0.0006)	Zhou et al., 2019

Note: f_{BC}-the $BC/PM_{2.5}$ mass ratio.

Table S17. NOx emission factors reported in the literature for different industrial sectors in China.

Industry	EF	Unit	Process/Source	Reference
Cement	10.61	g/kg coal	Cement kilns	Hua et al., 2016
Cement	10.9	g/kg cement	New dry process kiln	Liu et al., 2018
Cement	1.2	g/kg cement	Shaft kiln	Liu et al., 2018
Cement	15.6	g/kg cement	Ordinary rotary kiln	Liu et al., 2018
Cement	13.1	g/kg product	Cement	Zhou et al., 2019
Cement	1.57	g/kg cement	Kilns + electricity	Zheng et al., 2021
Cement	0.68–1	g/kg cement	Kilns + LNB + SNCR (dynamic penetration)	Liu et al., 2021
Cement	1.2–13.8	g/kg clinker	Kilns + SNCR/SCR	Guo et al., 2022b
Cement	10.9	g/kg coal	Precalciner kiln, unabated EF	Liu et al., 2024
Cement	1.2	g/kg coal	Shaft kiln, unabated EF	Liu et al., 2024
Cement	1.27–1.57	g/kg clinker	New dry-process kiln tail	Liu et al., 2024
Cement	1.2–6.5	g/kg clinker	Cement kilns (GAINS model)	Yan et al., 2024
Iron and steel	0.1–0.6	g/kg product	Sinter/BF/BOF/EAF	Wang et al., 2016
Iron and steel	1.68	g/kg product	Sintering	Liu et al., 2018
Iron and steel	0.41	g/kg product	Coke making	Liu et al., 2018
Iron and steel	0.35	g/kg product	Blast furnace	Liu et al., 2018
Iron and steel	0.09	g/kg product	Ironmaking	Zhou et al., 2019
Iron and steel	0.02	g/kg product	Coking	Zhou et al., 2019
Iron and steel	0.6/0.08	g/kg product	Sintering/BF	Wang et al., 2019
Iron and steel	0.09–0.61	g/kg product	Sintering, pelletizing, BF, BOF, EAF	Gao et al., 2019
Iron and steel	0.068	g/kg product	Sintering	Bo et al., 2020
Iron and steel	0.369–0.404	g/kg product	Sintering head	Yi et al., 2021
Iron and steel	0.7–1	g/kg raw steel	Sintering, pelletizing, coking, blast furnace, BOF, EAF, rolling	Bo et al., 2021
Iron and steel	0.30–0.49; 0.078–0.53	g/kg product	Sintering head	Wang et al., 2022
Iron and steel	0.48 (national avg)	g/kg product	NR	Liu et al., 2022
Iron and steel	0–0.849	g/kg product	All processes	Chen et al., 2023
Iron and steel	2.44/1.1/0.25/ 0.1	g/kg product	Sintering/Pelletizing/Ironma king (BF)/BOF	Zhang et al., 2023
Iron and steel	0.55/0.5/0.17/ 0/0	g/kg product	Sintering/pelletizing/ironmak ing/steelmaking (BOF/EAF)	MEE, 2024
Iron and steel	0.52–0.61	g/kg product	Sintering and pelleting	Zheng et al., 2024
Iron and steel	0.101	g/kg raw steel	All processes	Tang et al., 2025
Glass	7.74	g/kg product	Float glass	MEE, 2024

Note: LNB-low-NOx burner; SNCR-selective non-catalytic reduction; SCR-selective catalytic reduction. GAINS-the Greenhouse Gas–Air Pollution Interactions and Synergies model.

Table S18. SO_2 emission factors reported in the literature for different industrial sectors in China.

Industry	EF	Unit	Process/source	Reference
Cement	3.46	g/kg coal	Cement kilns	Hua et al., 2016
Cement	2.9	g/kg cement	New dry process kiln	Liu et al., 2018
Cement	12.3	g/kg cement	Shaft kiln	Liu et al., 2018
Cement	12.3	g/kg cement	Ordinary rotary kiln	Liu et al., 2018
Cement	4.8	g/kg product	Cement	Zhou et al., 2019
Cement	0.28–2.10	g/kg cement	Kilns (PC, SK, OR), sulfur balance	Liu et al., 2021
Cement	0.65	g/kg cement	Kilns + power	Zheng et al., 2021
Cement	0.5–1.5	g/kg clinker	Kilns (coal + raw material sulfur)	Guo et al., 2022b
Cement	0.198	g/kg clinker	New dry-process kiln tail	Liu et al., 2024
Cement	0.2–1.8	g/kg clinker	Sulfur mass balance (GAINS model)	Yan et al., 2024
Iron and steel	0.003–3.2	g/kg product	Sinter/BF/BOF	Wang et al., 2016
Iron and steel	2.23/1.56	g/kg product	Sintering/coke making	Liu et al., 2018
Iron and steel	0.3	g/kg product	Ironmaking	Zhou et al., 2019
Iron and steel	2.01	g/kg product	Coking	Zhou et al., 2019
Iron and steel	0.02–1.02	g/kg product	Sintering, pelletizing, BF, BOF, EAF, rolling	Gao et al., 2019
Iron and steel	0.157	g/kg product	BF	Wang et al., 2019
Iron and steel	0.033	g/kg product	Sintering	Bo et al., 2020
Iron and steel	0.028	g/kg product	Sintering	Bo et al., 2020
Iron and steel	0.111–0.144	g/kg product	NR	Yi et al., 2021
Iron and steel	0.3–0.6	g/kg raw steel	Sintering, pelletizing, coking, blast furnace, BOF, EAF, rolling	Bo et al., 2021
Iron and steel	0.19 (avg)	g/kg product	Sintering head	Liu et al., 2022
Iron and steel	0.14–0.29; 0.048–0.175	g/kg product	Sintering head	Wang et al., 2022
Iron and steel	0.75/0.3/0.15/0.02	g/kg product	Sintering/pelletizing/ironmaking (BF)/BOF	Zhang et al., 2023
Iron and steel	0–0.453	g/kg product	Coking, Pellets, Sinter, BF, Converter, Rolling	Chen et al., 2023
Iron and steel	2.4–2.8	g/kg product	Sintering (belt sintering, scale-dependent)	Zheng et al., 2024
Iron and steel	1.34/1.34/0.14/0/0	g/kg product	Sintering/pelletizing/ironmaking/steelmaking (BOF/EAF)	MEE, 2024
Iron and steel	0.043	g/kg product	All processes	Tang et al., 2025
Glass	3.4	g/kg product	Float glass	MEE, 2024

Table S19. CO emission factors reported in the literature for different industrial sectors in China.

Industry	EF	Unit	Process/source	Reference
Cement	12.9/135.4/17.8	g/kg cement	New dry process kiln/shaft kiln/ordinary rotary kiln	Liu et al., 2018
Cement	40.2	g/kg product	Cement	Zhou et al., 2019
Cement	1.47–19.4	g/kg cement	Kilns (technology-dependent)	Liu et al., 2021
Cement	3.71	g/kg clinker	New dry-process kiln tail	Liu et al., 2024
Cement	1–20	g/kg clinker	Cement kilns (GAINS model)	Yan et al., 2024
Iron and steel	2.96–23.7	g/kg product	Sinter/BF/BOF/EAF	Wang et al., 2016
Iron and steel	21.3/9.8	g/kg product	Sintering/coke making	Liu et al., 2018
Iron and steel	40.5/9/0.64	g/kg product	Ironmaking/steelmaking/coking	Zhou et al., 2019
Iron and steel	1.61/226/0.064/22.36/35.26/91	g/kg product	Coking/sintering/pelletizing/blast furnace/BOF/EAF	Tang et al., 2020
Iron and steel	1.6/16/0.06/15.29/8.75/9/1/28	g/kg product	Coking/sintering/pelletizing/blast furnace/BOF/EAF/steel rolling	Chen et al., 2023
Iron and steel	21.8/56.66/9.32	g/kg product	Sintering/ironmaking (BF)/BOF	Zhang et al., 2023
Iron and steel	16/16/15.29/8.75/9	g/kg product	Sintering/pelletizing/ironmaking/steelmaking (BOF/EAF)	MEE, 2024

Table S20. Uncertainty estimates for national PM_{10}, $PM_{2.5}$, NOx, and SO_2 emissions from the cement and iron and steel industries using Monte Carlo simulation.

Sector	Pollutant	Mean emission (kt)	95% CI (kt)	Uncertainty
Cement	PM_{10}	20.08	6.30–33.99	–68.6% to +69.3%
Cement	$PM_{2.5}$	16.06	4.86–27.08	–69.8% to +68.6%
Cement	NOx	584.08	439.31–730.58	–24.8% to +25.1%
Cement	SO_2	456.31	436.83–475.56	–4.3% to +4.2%
Iron and steel	PM_{10}	2.81	0.82–4.78	–70.7% to +70.1%
Iron and steel	$PM_{2.5}$	2.71	0.73–4.67	–73.2% to +72.4%
Iron and steel	NOx	884.48	827.69–942.22	–6.4% to +6.5%
Iron and steel	SO_2	1728.76	1606.03–1856.15	–7.1% to +7.4%

Note: 95% CI-the 95% confidence interval.

Table S21. Literature-reported uncertainties of PM_{10} emissions from the cement and iron and steel sectors.

Industry	Year	Uncertainty	Reference
Cement	2012	±30% to ±50% (95% CI)	Hua et al., 2016
Cement	2012	–55% to +75%	Liu et al., 2018
Cement	2015	–16% to +17%	Liu et al., 2021
Cement	2021	±15% to ±30%	Guo et al., 2022a
Cement	2012–2020	–36% to +43%	Guo et al., 2022b
Cement	2020	–4.93 % to +4.99 %	Liu et al., 2024
Cement	1990–2020	–22% to +21%	Yan et al., 2024
Iron and steel	2012	–55% to +75%	Liu et al., 2018
Iron and steel	2010–2015	–28% to +52%	Wang et al., 2019
Iron and steel	2019	–3.1% to 3.0%	Chen et al., 2023

Table S22. Literature-reported uncertainties of $PM_{2.5}$ emissions from the cement and iron and steel sectors.

Industry	Year	Uncertainty	Reference
Cement	2012	±35% to ±55% (95% CI)	Hua et al., 2016
Cement	2012	–55% to +75%	Liu et al., 2018
Cement	2015	–20% to +22%	Liu et al., 2021
Cement	2012–2020	–38% to +45%	Guo et al., 2022b
Cement	2020	–4.93 % to +4.99%	Liu et al., 2024
Cement	1990–2020	–22% to +21%	Yan et al., 2024
Cement	2021	±20% to ±40%	Guo et al., 2022a
Iron and steel	2012	–55% to +75%	Liu et al., 2018
Iron and steel	2010–2015	–34% to +63%	Wang et al., 2019

Table S23. Literature-reported uncertainties of BC emissions from the cement and iron and steel sectors.

Industry	Year	Uncertainty	Reference
Iron and steel	2012	±28.72%	Tang et al., 2020

Table S24. Literature-reported uncertainties of NOx emissions from the cement and iron and steel sectors.

Industry	Year	Uncertainty	Reference
Cement	2012	±20% to ±40%	Hua et al., 2016
Cement	2012	–55% to +75%	Liu et al., 2018
Cement	2015	–20% to +21%	Liu et al., 2021
Cement	2012–2020	–25% to +30%	Guo et al., 2022b
Cement	2020	–3.91% to +3.98%	Liu et al., 2024
Cement	1990–2020	–15% to +14%	Yan et al., 2024
Iron and steel	2012	–55% to +75%	Liu et al., 2018
Iron and steel	2010–2015	–41% to +19%	Wang et al., 2019
Iron and steel	2014–2018	±4.0%	Bo et al., 2021
Iron and steel	2019	± 4.5%	Chen et al., 2023
Iron and steel	2023	±0.18%	Tang et al., 2025

Table S25. Literature-reported uncertainties of SO_2 emissions from the cement and iron and steel sectors.

Industry	Year	Uncertainty	Reference
Cement	2012	±25% to ±45%	Hua et al., 2016
Cement	2012	–55% to +75%	Liu et al., 2018
Cement	2015	–27% to +30%	Liu et al., 2021
Cement	2012–2020	–12% to +15%	Guo et al., 2022b
Cement	2020	–3.96% to +3.99%	Liu et al., 2024
Cement	1990–2020	–17% to +15%	Yan et al., 2024
Iron and steel	2012	–55% to +75%	Liu et al., 2018
Iron and steel	2010–2015	–5% to +11%	Wang et al., 2019
Iron and steel	2014–2018	±4%	Bo et al., 2021
Iron and steel	2023	±0.20%	Tang et al., 2025

Table S26. Literature-reported uncertainties of CO emissions from the cement and iron and steel sectors.

Industry	Year	Uncertainty	Reference
Cement	2012	±30% to ±50% (95% CI)	Hua et al., 2016
Cement	2012	–55% to +75%	Liu et al., 2018
Cement	2015	–18% to +19%	Liu et al., 2021
Iron and steel	2012	±28.72%	Tang et al., 2020
Iron and steel	2019	–4.9% to +4.9%	Chen et al., 2023

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