atmosphere

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Supplementary Materials: Air Pollutants and CO2 Emissions in Industrial Parks and Evaluation of Their Green Upgrade on Regional Air Quality Improvement: A Case Study of Seven Cities in Henan Province

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Table S1. The information of leading industry in 13 industrial parks.

Type of IP	Name of industrial parks	Leading industry
Energy-intensive IP	Puyang Park	Chemical and equipment manufacturing
	Hongqiqu Park	Equipment manufacturing, auto parts processing industry
	Xinxiang ET Park	Chemical fiber textile, automobile and auto parts industry
	Jiaozuo Park	Equipment manufacturing, new materials industry
	Huanglong Park	Agricultural products processing, logistics
	Anyang Steel Park	Iron and steel production
Emerging IP	Kaifeng ET Park	auto parts and agricultural by-product
	Hebi Park	Quality improvement of metallic magnesium industry and Plastic products industry
Mixed IP	Zhengzhou ET Park	Automobile and equipment manufacturing industry, modern logistics industry
	Zhengzhou HA Park	Electronic information, new energy industry
	Anyang HA Park	Equipment manufacturing, electronic information industry
	Xinxiang HA Park	Electronic appliances and new biological medicine industry
	Zhengzhou AP Park	Electronic information industry, logistics industry

Table S2. Emission factors of power plant and industry boiler [51].

Sector	Fuel type			SO_2	NO_x	CO	PM_{10}	$PM_{2.5}$	VOCs	NH_3
Power plant	Raw coal	Pulverized coal stove	CS	A	2[h]	46[h]	12[h]	0.15[h]	0.02[g]	
		fluidized-bed furnace	CS	1.5[c]	2.1[c]	1.54B[c]	0.45B[c]	0.15[h]	0.02[g]	
		Garbage/bio mass		2.67[a]	1.54[a]	3.6[e]	10.28[a,e]	5.88[a,e]	5.3[f]	0.04[b]
		Natural gas	CS	9.82[a]	1.3[h]	0.24[h]	0.17[h]	0.12[c]	0.05[g]	
Industry Boiler	Raw coal	layer burning stove	CS	4[h]	15[h]	5.4[h]	1.89[h]	0.18[h]	0.02[g]	
		Pulverized coal stove	CS	4.72[a]	2[c]	3.51B[a]	0.22B[a]	0.18[h]	0.02[g]	
		fluidized-bed furnace	CS	7.5[h]	2[h]	28.08[h]	5.04[h]	0.18[h]	0.02[g]	
		Fuel type		SO_2	NO_x	CO	PM_{10}	$PM_{2.5}$	VOCs	NH_3
		coke	CS	4.8[c]	6.6[c]	0.29[c]	0.15[c]	0.04[c]	0.02[g]	
		Natural gas	CS	2.09[d]	1.3[h]	0.24[h]	0.17[h]	0.18[h]	0.05[g]	
		Diesel	20S	9.62[h]	0.6[h]	0.5[h]	0.5[h]	0.15[h]	0.13[g]	

Note: The gas unit is g/m^3, and the remaining units are kg/t. The value of C depends on the installed capacity and fuel combustion method. When the installed capacity is less than 100 MW without low nitrogen combustion (LNB) technology, A=10.5; when 100 MW ≤installed capacity ≤300 MW and no

LNB A=8.85, if there has LNB A=5.85; when the value of installed capacity is >300MW and there is LNB, A=5.55. The value of B is the average value of coal based ash.
[a] MEE [52]; [b] Pham et al. [53]; [c] He et al. [54]; [d] Huang et al. [55]; [e] U.S.EPA [56]; [f] MEE [57]; [g] Yin et al. [58]; [h] Zheng et al.

Table S3. Industry process emission factor (g/kg-product or raw material) [51].

Industry Process	Classification	SO_2	NO_x	CO	PM_{10}	$PM_{2.5}$	VOCs	NH_3
Non-metallic mineral products industry	Cement (pulverized)				8 [p]	2 [p]		
	Cement (new dry method)	4.8[c]	13.1[c]	40.2[p]	8.05[e]	3.40[e]	0.18[d]	
	Crick and tile	0.6 [p]	0.05 [p]	4.04 [p]	0.13 [p]	0.04[a]	0.13 [a]	
	Refractory				2.27[b]	1.63[b]		
	Ceramic	2.25 [p]	5 [p]		2.42 [p]	0.67 [p]	29.22 [p]	
	Glass				3.07[f]	2.94[f]		
Non-ferrous metal	Electrolytic aluminum				6.97[f]	5.2[f]		
	The combination method				56.4[f]	42.3[f]		
	Bayer method				12.4[f]	9.18[f]		
Chemical industry	Fertilizers				2.12 [f]	1.86[f]		2[n]
	Printing and dyeing						81.4[f]	
	Synthetic rubber						7.17[f]	
	Polypropylene						3 [p]	
	Viscose fiber						14.5[f]	
	Paint						15[f]	
	synthesis ammonia	3[g]	0.9[g]	142[n]			4.72[f]	2.1[m]
Black metal	Electric steelmaking				8.12[f]	6.02[f]		
	Converter steelmaking				14.68[f]	10.5[f]		
	Hot rolled steel						0.3[f]	
Paper industry							2.6[f]	
Ink printing							750[f]	
Textile							81.4f	

[a] U.S.EPA. [56]; [b] Zhou et al. [59]; [c] Lei et al. [60]; [d] Bo et al. [61]; [e] Lei et al. [62]; [f] MEE [57]; [g] Zhao et al. [63]; [m] Yin. [58]; [n] Zhao et al. [64]; [p] MEE. [65].

Table S4. Related parameters of PMx emission factors for coal-fired boilers [65].

Sector	Boiler Type	ar	$f_{2.5}$	f_{10}
Power Plant	Pulverized Coal Stove	0.25	0.06	0.23
	Circulating fluidized bed boiler	0.44	0.07	0.29
Industry Boiler	Stratum Burning Furnace	0.85	0.07	0.20
	Circulating fluidized bed furnace	0.40	0.07	0.20

Table S5. CO_2 emission factors and related parameters.

Energy type	NCV	CC	O	Emission Factor
Raw coal	20908 [a]	26.37 [b]	0.94 [b]	1.90
General bituminous coal	26620 [a]	26.1 [b]	0.93 [b]	1.97
Natural gas	35584 [a]	15.3 [b]	0.99 [b]	19.76
Liquefied natural gas	51434.72 [a]	17.2 [b]	0.98 [b]	3.10
Liquefied petroleum gas	50719 [a]	17.2 [b]	0.98 [b]	3.10
Gasoline	43070 [a]	18.9 [b]	0.98 [b]	2.93
Diesel oil	42652 [a]	20.2 [b]	0.98 [b]	3.10
Fuel oil	41816 [a]	21.1 [b]	0.98 [b]	3.17

Note: NCV, kJ/kg or kJ/m^3; CC, tones C/TJ; CO_2 emission factor, tCO_2/t or t $CO_2/10^4$ m^3.
a. NBS; b. NDRC [66].

Table S6. Energy saving of 11 energy efficiency technologies in coal-fired power plants [67].

Number	Technical name	Energy saving (gce/kWh)
1	Gasification micro-oil ignition technology	0.7
2	Plasma pulverized coal ignition technology	0.2
3	High temperature air ignition technology	1.4
4	Oxygen-enriched double-strength ignition stabilization and fuel-saving technology	1.5
5	Leading engine steam heating start technology	0.3
6	Weak blast wave soot blowing technology	1.4
7	Energy-saving technology of electric bag composite dust collector	0.9
8	Electric precipitator energy saving submission control technology	0.7
9	Boiler Intelligent Blowing Optimization and Online Coking Early Warning System Technology	1.1
10	Flue gas system optimization and waste heat recovery technology	1.1
11	Online information monitoring technology	0.8

Table S7. The removal efficiency under different end treatment and CCS technologies.

Sector	Second Sector	Pollutants	Technology	Removal efficiency (%)
Power Plant	Raw Coal	SO_2	Wet FGD	95.0[a]
		NO_x	SCR	90.0[b]
		CO	CFB	1.3 [a]
		PM_{10}	FBH	99.6[a]
		$PM_{2.5}$	FBH	99.4[a]
		CO_2	CCUS	34.0[d]
Industry boiler	Raw Coal	SO_2	Wet FGD	99.0[c]
		NO_x	SCR	90.0[c]
		PM_{10}	FBH	99.6[a]
		$PM_{2.5}$	FBH	99.4[a]
		CO_2	CCUS	34.0[d]
Industry process	Chemical industry	PM_{10}	FBH	99.6[a]
		$PM_{2.5}$	FBH	99.4[a]
		VOCs	UV	48.2[e]
	Rubber and Textile	VOCs	RTO	99.9[e]
	Cement	PM_{10}	FBH	99.6[a]
		$PM_{2.5}$	FBH	99.4[a]
	Others	PM_{10}	FBH	99.6[a]
		$PM_{2.5}$	FBH	99.4[a]
		SO_2	Wet FGD	99.0[c]
		CO_2	CCUS	34.0[d]

Note: FGD: flue gas desulfurization, SCR: selective catalytic reduction, CFB: selective catalytic reduction, FBH: Fabric baghouses, CCUS: Carbon Capture and Utilization and Storage. UV: activated carbon and photocatalytic degradation, RTO: regenerative thermal oxidation.
[a] Xu et al. [68]; [b] MEC; [c] MEC [69]; [d] CAEP [70]; [e] Zhang et al. [71].

Table S8. Specific parameter setting of WRF simulation.

Parameter	Set standards
Model version	WRF4.0
Vertical layering	43 floors
Horizontal resolution	4km, 12km, 36km
Microphysical solution	Thompson graupel scheme
Longwave radiation scheme	RRTM scheme
Shortwave radiation program	Goddard shortwave scheme Goddard shortwave scheme
Near-surface plan	Monin-Obukhov scheme
Land Surface Process Plan	unified Noah land-surface model
Boundary layer scheme	YSU scheme
Cumulus convection scheme	Grell-Devenyi ensemble scheme
Four-dimensional assimilation	Assimilation of the first layer of mesh

Table S9. Specific parameter setting of CMAQ simulation.

Parameter	Set standards
Model version	CMAQv5.0.2
Grid nesting	Three layers
Horizontal resolution	4km, 12km, 36km
Vertical layering	Fourteen floors
Gas phase chemical reaction mechanism	SAPRC99
Aerosol reaction mechanism	Aero6
Photochemical reaction rate	in-line
Sand dust	in-line
Initial conditions	Daily accumulation
Boundary conditions	Default

Table S10. Emission inventory of air pollutants (t).

		SO_2	NO_X	CO	PM_{10}	$PM_{2.5}$	VOCs	NH_3
Puyang Park								
Sector	The secondary sector							
Power plant		5395.40	3730.40	2408.70	554.00	144.50	180.60	24.09
Industry Boiler	Stratum Burning Furnace	7.42	2.59	27.75	0.06	0.03	0.33	0.04
	Circulating Fluidized bed furnace	2970.56	3887.19	1480.84	563.15	112.57	133.28	14.81
	Natural gas	0.00	41.30	25.69	4.74	3.36	3.56	0.99
Process	Non-metallic mineral products industry	72.30	6.00	487.00	633.43	409.54	16.99	0.00
	Chemical industry	0.00	0.00	0.00	38.97	96.66	144.01	956.00
Total		8445.68	7667.49	4429.98	1794.35	766.66	478.77	995.92
Zhengzhou ET Park								

Sector	The secondary sector							
Power plant		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industry Boiler	Circulating Fluidized bed furna	24.42	45.65	12.17	51.27	9.20	1.10	0.12
	Natural gas	0.00	87.71	54.56	10.07	7.13	7.55	2.10
Process	Non-metallic mineral products industry	283.40	23.62	1908.25	1386.96	456.45	233.40	0.00
Total		307.82	156.97	1974.98	1448.31	472.79	242.05	2.22
Kaifeng ET Park								
Sector	The secondary sector							
Power plant		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industry Boiler	Stratum Burning Furnace	4.26	3.32	15.95	2.87	0.41	0.19	0.02
	Circulating Fluidized bed furna	259.70	339.97	129.55	11.47	3.27	11.66	1.30
	Coke oven gas/blast furnace gas	0.00	28.74	17.84	3.29	2.33	2.47	0.69
	Stratum Burning Furnace	0.04	0.17	0.38	0.07	0.06	0.01	0.01
Process	Chemical industry	0.00	0.00	0.00	9.03	7.92	1463.93	8.52
	Non-metallic mineral products industry	833.29	87.15	5555.08	493.36	135.78	286.28	0.00
Total		1097.30	459.40	5718.80	520.10	149.80	1764.50	10.50
Hongqiqu Park								
Sector	The secondary sector							
Power plant		4392.28	5091.31	2481.96	371.25	169.61	191.21	33.14
Industry Boiler	Natural gas	0.00	1.21	0.75	0.14	0.10	0.10	0.03
Process	Chemical industry	0.00	0.00	0.00	1.19	1.04	5.02	1.12
	Non-metallic mineral products industry	2010.00	167.50	13534.00	32.30	12.83	424.80	0.00
Black metal		0.00	0.00	0.00	156.85	184.04	39.82	0.00
Non-ferrous metals		0.00	0.00	0.00	21.14	23.72	0.00	0.00
Total		6402.28	5260.02	16016.72	582.87	391.34	660.96	34.29
Hebi Park								
Sector	The secondary sector							

Power plant		3205.03	2474.47	1597.70	1102.43	671.04	119.83	15.98
Industry Boiler		0.00	9.60	5.97	1.10	0.78	0.83	0.23
Process	Chemical industry	0.00	0.00	0.00	0.00	0.00	436.19	0.00
Process	Non-metallic mineral products industry	0.00	0.00	0.00	26.01	10.35	0.00	0.00
Total		3205.03	2484.07	1603.67	1129.54	682.17	556.85	16.21
Xinxiang ET Park								
Sector	The secondary sector							
Power plant		1218.63	1122.41	486.02	424.53	110.75	36.45	4.86
Industry Boiler	Circulating Fluidized bed furna	24.07	34.22	13.53	1.29	0.40	1.27	0.15
	Natural gas	0.00	6.69	4.32	0.86	0.67	0.62	0.19
Process	Chemical industry						51.20	
	Non-metallic mineral products industry	0.18	0.08	12.12	0.22	0.12	0.30	0.00
Total		1242.88	1163.39	515.99	426.89	111.93	89.84	5.21
Zhengzhou HA Park								
Sector	The secondary sector							
Power plant		3038.42	8074.60	1891.52	289.05	140.16	148.39	29.64
Industry Boiler		308.94	111.24	1154.90	4.55	1.20	14.13	1.62
Process	Chemical industry	0.00	0.00	0.00	12.02	34.88	485.68	0.00
	Non-metallic mineral products industry	223.30	18.61	1503.53	485.44	162.48	632.13	0.00
	Non-ferrous metals	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		3570.66	8204.45	4549.96	791.06	338.73	1280.32	31.26
Anyang HA Park								
Sector	The secondary sector							
Power plant		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industry Boiler	Stratum Burning Furnace	60.83	60.65	227.43	0.52	0.29	2.73	0.30
	Pulverized coal stove	162.87	67.06	81.19	0.90	0.09	7.31	0.81
	Natural gas	0.00	2.21	1.38	0.25	0.18	0.19	0.05
		223.70	129.92	309.99	1.67	0.56	10.23	1.17
Process	Non-metallic mineral	32.92	2.74	221.63	3.65	1.45	7.13	0.00

	products industry							
Total		256.62	132.67	531.63	5.31	2.01	17.36	1.17
Xinxiang HA Park								
Sector	The secondary sector							
Power plant		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industry Boiler	Natural gas	0.00	13.97	8.69	1.60	1.14	1.20	0.33
Process	Chemical industry	0.00	0.00	0.00	0.00	0.00	28.32	0.00
Total		0.00	13.97	8.69	1.60	1.14	29.52	0.33
Jiaozuo Park								
Sector	The secondary sector							
Power plant	Circulating Fluidized bed furna	262.73	49.11	137.52	0.95	0.44	9.82	1.31
Industry Boiler	Natural gas	1.18	6.19	3.85	0.71	0.50	0.53	0.15
Process	Chemical industry				0.00	0.00	92.30	
	Non-metallic mineral products industry	92.07	24.18	643.36	74.62	25.46	21.22	
Jiaozuo Park								
Total		355.98	79.48	784.73	76.29	26.40	123.87	91.46
Zhengzhou AP Park								
Sector	The secondary sector							
Power plant		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industry Boiler	Stratum Burning Furnace	6.31	25.14	56.04	10.09	8.56	10.18	2.16
	Other gases	1.53	0.74	0.31	0.55	0.03	0.03	0.00
	Natural gas	0.00	48.32	30.06	5.55	3.93	4.16	1.16
Process	Non-metallic mineral products industry	221.67	18.47	1492.57	1230.40	442.70	48.03	0.00
	Chemical industry	0.00	0.00	0.00	2.33	2.05	0.00	2.45
Total		229.50	92.67	1578.98	1248.92	457.27	62.40	5.77
Huanglong Park								
Sector	The secondary sector							
Power plant	Stratum Burning Furnace	7.00	125.00	1283.00	4.00	2.00	0.00	14.00
Industry Boiler	Circulating Fluidized bed furna	243.00	373.00	4866.00	7829.00	1405.00	11.00	49.00

	Chemical industry	193.00	294.00	1912.00	206.00	151.00	2471.00	1187.00
Total		443.00	792.00	8061.00	8039.00	1558.00	2482.00	1250.00
Anyang Steel Park								
Sector	The secondary sector							
Power plant		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industry Boiler		925.00	1138.00	5844.00	135.00	135.00	205.00	0.00
	Black metal	16369.00	11635.00	299833.00	3003.00	1984.00	10085.00	0.00
Anyang Steel Park Total		17294.00	12773.00	305677.00	3138.00	2119.00	10290.00	0.00
Total of all industry park		42850.74	39279.57	351452.12	19202.25	7077.23	18078.44	2444.34

Table S11. Emission inventory of CO_2 (10^4 t).

Industry Park	Power Plant	Terminal Energy use
Puyang Park	229	435
Zhengzhou ET Park	0	98
Kaifeng ET Park	0	27
Hongqiqu Park	252	291
Hebi Park	152	3
Xinxiang ET Park	53	37
Zhengzhou HA Park	201	80
Anyang HA Park	0	18
Xinxiang HA Park	0	18
Jiaozuo Park	20	3
Zhengzhou AP Park	0	14
Huanglong Park	0	493
Anyang Steel Park	0	1132
Total	908	2647

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