Table List

Figure List

Table S1. Emission source categorization used in this study.

Category	Sector	Activity level data
Stationary combustion source	Power plant	Coal, diesel oil, fuel oil, natural gas dieses, liquefied petroleum gas
	Heating supply	Coal, diesel oil, fuel oil, natural gas dieses, liquefied petroleum gas
	Industrial combustion	Coal, diesel oil, fuel oil, natural gas dieses, kerosene, liquefied petroleum gas
	Commercial combustion	Coal
	Residential combustion	Raw coal, cleaned coal, other coal washing, coal briquette
Biomass burning	Interior straw burning	Wheat, rice, corn, soybean, cotton, peanut
	Open straw burning	Wheat, rice, corn, soybean, cotton, peanut
Road mobile source	Heavy truck	Diesel Oil, gasoline
	Light passenger Vehicles	Gasoline
	Light truck	Diesel Oi, gasoline
	Heavy passenger Vehicles	Diesel Oi, gasoline
	Motorbike	Gasoline
Non-road mobile source	Airport	Take-off cycles
	Railway	Freight turnover
	Waterway	Freight turnover
	Farm machinery	Agricultural machinery, fuel consumption
	Agricultural vehicle	Fuel consumption
	Building machinery	Fuel consumption

Table S2. Emission factors of stationary combustion source.

Source	Fuel type	Emission factors (kg/t-fuel)						
		SO_2	NOx	PM_{10}	$PM_{2.5}$	CO	VOCs	NH_3
Power plant	Coal	9.6[a]	9.95[a]	114.04[e]	29.43[f]	2.48[b]	0.15[b]	0.02[b]
	Diesel oil	11.2[a]	7.4[a]	0.5[e]	0.5 [f]	0.6[a]	0.12[g]	
	Fuel oil	11.2[a]	10.06[a]	0.85[e]	0.62 [f]	0.6[a]	0.13[g]	
	Natural gas	0.34[b]	4.096[a]	0.03[e]	0.03 [f]	1.3 [a]	0.045[g]	
	Liquefied petroleum gas		3.74[a]	0.03[e]	0.03 [f]	0.36 [a]	0.034[g]	
Heating supply	Coal	9.6[a]	3.75[a]	114.04[e]	29.43[f]	15 [a]	0.18[g]	0.05[b]
	Diesel oil		5.77[a]	0.5[e]	0.5 [f]	0.6 [a]	0.12[g]	0.11[b]
	Fuel oil		3.5[a]	0.85[e]	0.62 [f]	0.6 [a]	0.2[g]	0.04[b]
	Natural gas	0.18[a]	1.462[a]	0.03[e]	0.03 [f]	1.3 [a]	0.088[g]	
	Liquefied petroleum gas		1.58[a]	0.03[e]	0.03 [f]	0.36 [a]	0.5[g]	
Industrial combustion	Coal	9.6[a]	4.29[c]	53.4[e]	18.69 [f]	15[c]	0.39[g]	0.05[b]
	Diesel oil	2.24[a]	9.62[b]	0.5[b]	0.5[b]	0.6[b]	0.13[g]	0.11[b]
	Fuel oil	2.24[a]	5.84[b]	0.85[b]	0.67[b]	0.6[b]	0.35[g]	0.04[b]
	Kerosene	2.24[a]	7.46[a]	0.9[e]	0.9 [f]	0.6 [a]	0.093[g]	
	Natural gas	0.18[a]	2.085[a]	0.03[e]	0.03 [f]	1.3 [a]	0.088[g]	
	Liquefied petroleum gas	0.486[a]	7.10[a]	0.03[e]	0.03 [f]	0.972 [a]	0.48[g]	
	Coal gas	0.08[a]	0.8[a]	0.03[e]	0.03 [f]	1.3 [a]	0.00044[g]	
Commercial combustion Residential combustion	Coal	9.6[a]	3.75[a]	53.4[e]	18.69 [f]	15 [a]	0.45[g]	0.6
	Raw coal	9.6[a]	1.35[a]	9.52[e]	7.35 [f]	105 [a]	0.6[d]	0.9[c]
	Cleaned coal	9.6[a]	0.9[a]	3.71[e]	2.97 [f]	72.8 [a]	0.6[d]	0.32[c]
	Other coal washing	9.6[a]	0.9[a]	3.71[e]	2.97 [f]	72.8 [a]	0.6[d]	
	Coal briquette	9.6[a]	0.8[a]	3.71[e]	2.97 [f]	72.8 [a]	0.6[d]	
	Diesel oil		3.21[a]	0.5[e]	0.5 [f]	0.6 [a]	0.143[d]	
	Fuel oil		1.95[a]	0.85[e]	0.28 [f]	0.6 [a]	0.35[d]	
	Kerosene		2.49[a]	0.9[e]	0.9 [f]	0.6 [a]	0.15[d]	
	Natural gas	0.27[a]	1.462[a]	0.03[e]	0.03 [f]	1.3 [a]	0.13[d]	0.32[h]
	Liquefied petroleum gas	0.12[a]	4.141[a]	0.17[e]	0.17 [f]	0.7272 [a]	0.36[d]	
	Coal gas	0.16[a]	0.736[a]	0.03[e]	0.03 [f]	1.3 [a]	0.00044[d]	

a. Jiang et al. (2020)

b. Liu et al. (2018)

c. Bai et al. (2020)

d. Technical guide for the compilation of the emission inventory of atmospheric volatile organic compounds

e. Technical Guidelines for the Compilation of Emission Inventories of Atmospheric Inhalable Particulate Matter from Primary Sources

f. Technical Guidelines for the Compilation of Emission Inventories of Atmospheric Fine Particulate Matter from Primary Sources

g. Technical Guidelines for the Compilation of Emission Inventories of Atmospheric Volatile Organic Compounds and Matter Sources

h. Qiu et al. (2014)

Table S3. Emission factors of biomass burning source.

Source type		Emission factor (kg/t)						
		SO_2	NOx	CO	PM_{10}	$PM_{2.5}$	VOCs	NH_3
Open straw burning	Wheat	0.74[a]	2.89[a]	60[b]	7.73[a]	7.13[a]	7.49[a]	0.37[b]
	Rice	0.64[d]	2.62[d]	53.2[b]	9.89[d]	9.39[d]	7.25[a]	0.53[b]
	Corn	0.45[d]	3.43[a]	53[b]	11.95[a]	11.3[a]	10.2[a]	0.68[b]
	Soyabean	0.48[b]	1.08[a]	32.3[b]	9.54[a]	7.58[a]	8.64[a]	0.53[b]
	Cotton	0.56[a]	2.68[a]	67.4[b]	9.54[a]	7.58[a]	8.17[a]	0.53[b]
	Peanut	0.48[b]	5.3[b]	102[b]	6.93[c]	6.3[b]	9.42[b]	0.53[b]
Interior straw burning	Wheat	1.2[c]	1.19[c]	139.46[c]	8.86[c]	8.24[c]	9.37[c]	0.37[c]
	Rice	0.48[c]	1.92[c]	79.7[c]	6.88[a]	6.4[a]	8.4[c]	0.52[c]
	Corn	1.33[c]	1.86[c]	82.37[c]	7.39[a]	6.87[c]	7.34[c]	0.68[c]
	Soyabean	0.53[c]	1.12[c]	80.7[c]	7.69[c]	7.15[c]	8.82[c]	1.3[c]
	Cotton	0.53[c]	2.49[c]	121.7[c]	7.69[c]	7.15[c]	8.82[c]	1.3[c]
	Peanut	0.53[c]	2.49[c]	121.7[c]	7.69[c]	7.15[c]	8.82[c]	1.3[c]

a. Zhou et al. (2021)
b. Gao et al. (2017)
c. Zhou et al. (2017)
d. Zhang et al. (2017a)

Table S4. Emission factors of road mobile source.

Source	Emission factors (g/km)					
	SO_2	NOx	CO	PM_{10}	$PM_{2.5}$	VOCs
Heavy truck	0.067[a]	10[b]	2.8[b]	0.3[b]	0.381[a]	0.5[b]
Light passenger Vehicles	0.051[a]	0.2[b]	3.2[b]	0.1[b]	0.026[a]	0.5[b]
Light truck	0.056[a]	6[b]	2.3[b]	0.3[b]	0.282[a]	0.7[b]
Heavy passenger Vehicles	0.054[a]	0.1[b]	9[b]	0.1[b]	0.007[a]	0.1[b]
Motorbike	0.027[a]	0.2[b]	3.2[b]	0.1[b]	0.36[a]	1.1[b]

a. Technical Guidelines for Compiling Atmospheric Pollutant Emission Inventory of Road Vehicles
b. Sun et al. (2016)

Table S5. Emission factors of non-road mobile source.

Source	Emission factors (kg/t)					
	SO_2	NOx	PM_{10}	$PM_{2.5}$	CO	VOCs
Airport	1[a]	28.63[a]	14.56[a]	0.53[a]	0.23[a]	0.1[a]
Ship	30[e]	55[e]	1.1[f]	0.98[f]	8.94[e]	4.76[e]
Railroad	10[e]	54.1[b]	2.07[b]	1.97[b]	8.29[b]	6.14[c]
Agricultural machinery	13.5[d]	68.16[d]	4.2[d]	3.97[d]	28.9[d]	91.5[c]
Construction machinery	126.8[d]	31.09[d]	1.44[d]	1.36[d]	1.29[d]	11.66[c]

a. WANG Rui-peng (2020)
b. Zhou et al. (2019)
c. Zhang et al. (2017b)
d. Hua et al. (2019)
e. Zhou et al. (2018)
f. Yi et al. (2021)

Table S6 Spatial allocation profile and Spatial type for different sources

Category	Subcategory	Spatial allocation	Spatial type
Stationary combustion	Power plant	Longitude and latitude	Point source
	Heating plant	Longitude and latitude	Point source
	Industry	Spatial distribution of GDP	Surface source
	Commerce or Commercial	Spatial distribution of GDP	Surface source
	Resident	Population density	Surface source
Biomass combustion	Outdoor biomass combustion	Cultivated land distribution	Surface source
	Indoor combustion	Rural residential area	Surface source
Road mobile source	Heavy-duty passenger vehicle Light-duty passenger vehicle Heavy-duty cargo truck Light-duty cargo truck Motorcycle	Road network	Line source
Non-road mobile source	Airplane	Latitude and longitude	Point source
	Train	Railway network	Line source
	Ship	Latitude and longitude	Point source
	Agricultural machinery	Cultivated land distribution	Surface source
	Construction machinery	Spatial distribution of GDP	Surface source

Table S7. Temporal allocation profile for different source

Category	Subcategory	Temporal allocation	profile reference
Stationary combustion	Power plant	Thermal power generation	National Bureau of Statistics of China
	Heating plant	Heating time	Shandong Provincial People's Government
	Industry	Industrial Boiler Output	
	Commerce or Commercial	Average	National Bureau of Statistics of China
	Resident	Natural gas variation	
Mobile source	On-road mobile sources	Traffic flow	Shandong Provincial Department of transportation
	Diurnal variation of on-road mobile source	Congestion delay index	https://report.amap.com/index.do
Biomass combustion	Indoor combustion	Average	http://nync.shandong.gov.cn/
	Outdoor biomass combustion	Monthly fire points	https://firms.modaps.eosdis.nasa.gov
Non-road mobile source	Airplane	Airports' passenger flow	Shandong Provincial Department of transportation
	Train	Railway transport data	
	Ship	Waterways transport data	
	Agricultural machinery	Agricultural busy production and operation	
	Construction machinery	Average	

Table S8. Uncertainty of the emission inventory

Type	CO_2	SO_2	NOx	PM_{10}	$PM_{2.5}$	CO	VOCs	NH_3
Stationary combustion	-26%-26%	-15%-13%	-21%-23%	-17%-25%	-17%-25%	-32%-35	-43%-55%	-63%-57%
Biomass combustion	/	-35%-35%	-37%-36%	-42%-42%	-42%-42%	-45%-60%	-29%-31%	-74%-73%
Non-road mobile	-32%-32%	-32%-32%	-32%-32%	-37%-42%	-37%-42%	-32%-35%	-44%-54%	/
Road mobile	-35%-35%	-7%-8%	-23%-23%	-19%-17%	-19%-17%	-25%-27%	-33%-50%	/
Total	-26%-26%	-16%-14%	-23%-23%	-18%-14%	-18%-23%	33%-38%	-34%-48%	-65%-61%

Table S9. Results of multicollinearity test for factors influencing GHG and air pollutant emissions in Shandong Province, 2010-2021.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig	Collinearity Statistics	
	B	SE(B)	Beta			Tolerance	VIF
Constant	-12.646	26.435		-0.478	0.653		
lnP1	2.322	2.923	1.047	0.794	0.463	0.007	138.055
lnA1	-0.059	0.623	-0.255	-0.095	0.928	0.002	572.175
lnA2	0.503	0.446	1.092	1.128	0.311	0.013	74.566
lnT1	0.413	0.747	1.128	0.552	0.604	0.003	331.720
lnT2	-0.378	0.446	-1.210	-0.849	0.435	0.006	161.330
lnT3	-0.076	0.059	-1.087	-1.286	0.255	0.018	56.858

Table S10. Ridge regression coefficients and variance test results of the factors influencing GHGs when k=0.62

	B	SE(B)	Beta.std	t	sig
lnP1	0.346012	0.083911	0.155996	4.123568	0.009142
lnA1	0.034484	0.007074	0.148418	4.87511	0.004572
lnA2	-0.06179	0.019327	-0.1343	-3.1973	0.024068
lnT1	0.050482	0.013475	0.138036	3.746437	0.013343
lnT2	-0.05342	0.014996	-0.17079	-3.56237	0.016174
lnT3	0.007744	0.002978	0.110606	2.600611	0.048214
Constant	9.804389	0.822163	0	11.92512	0.000073

Table S11. Ridge regression coefficients and variance test results of the factors influencing air pollutants when k=0.3

	B	SE(B)	Beta.std	t	sig
lnP1	-4.83341835	0.72254976	-0.17746468	-6.68939168	0.00112883
lnA1	-0.49136298	0.07265641	-0.17222693	-6.76283061	0.00107386
lnA2	0.90852181	0.18701886	0.16081302	4.85791546	0.0046416
lnT1	1.05972771	0.40771272	0.16153224	2.59920199	0.04829604
lnT2	0.57053609	0.14925013	0.1485489	3.82268392	0.01233932
lnT3	-0.12705376	0.03226139	-0.14778961	-3.93826104	0.010979
Constant	49.59168683	6.71754001	0	7.38241778	0.00071698

Table S12. Scenario setting of annual change rate of carbon emission drivers in Shandong Province

Scenarios	Year	P1	A1	A2	T1	T2	T3
L	2022-2025	-0.003	0.045	-0.013	-0.013	-0.039	0.05
	2026-2030	-0.005	0.04	-0.011	-0.023	-0.027	0.04
	2031-2035	-0.006	0.035	-0.009	-0.033	-0.015	0.03
M	2022-2025	-0.002	0.055	-0.011	-0.008	-0.034	0.06
	2026-2030	-0.003	0.05	-0.009	-0.018	-0.022	0.05
	2031-2035	-0.004	0.04	-0.007	-0.028	-0.001	0.04
H	2022-2025	-0.001	0.075	-0.009	-0.003	-0.029	0.07
	2026-2030	-0.0015	0.055	-0.007	-0.013	-0.017	0.06
	2031-2035	-0.002	0.05	-0.005	-0.023	-0.005	0.05

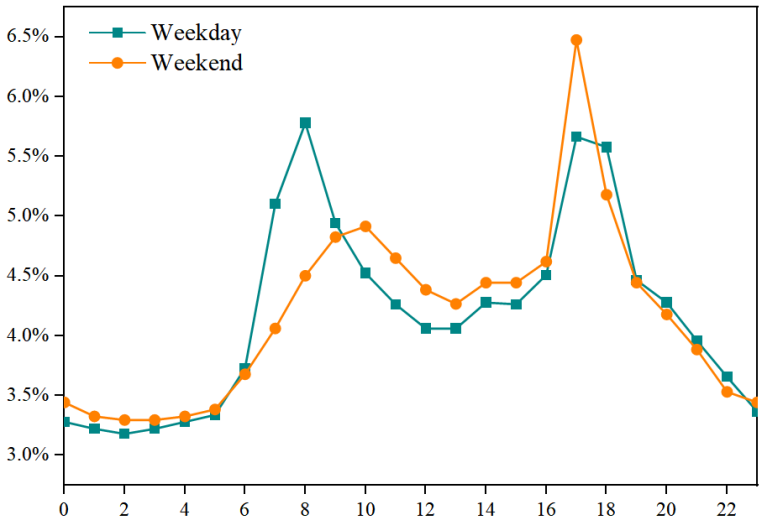

Figure S1. Hourly variation profiles for on-road mobile sources. Note: Data are weekend and weekday averages for 2021.

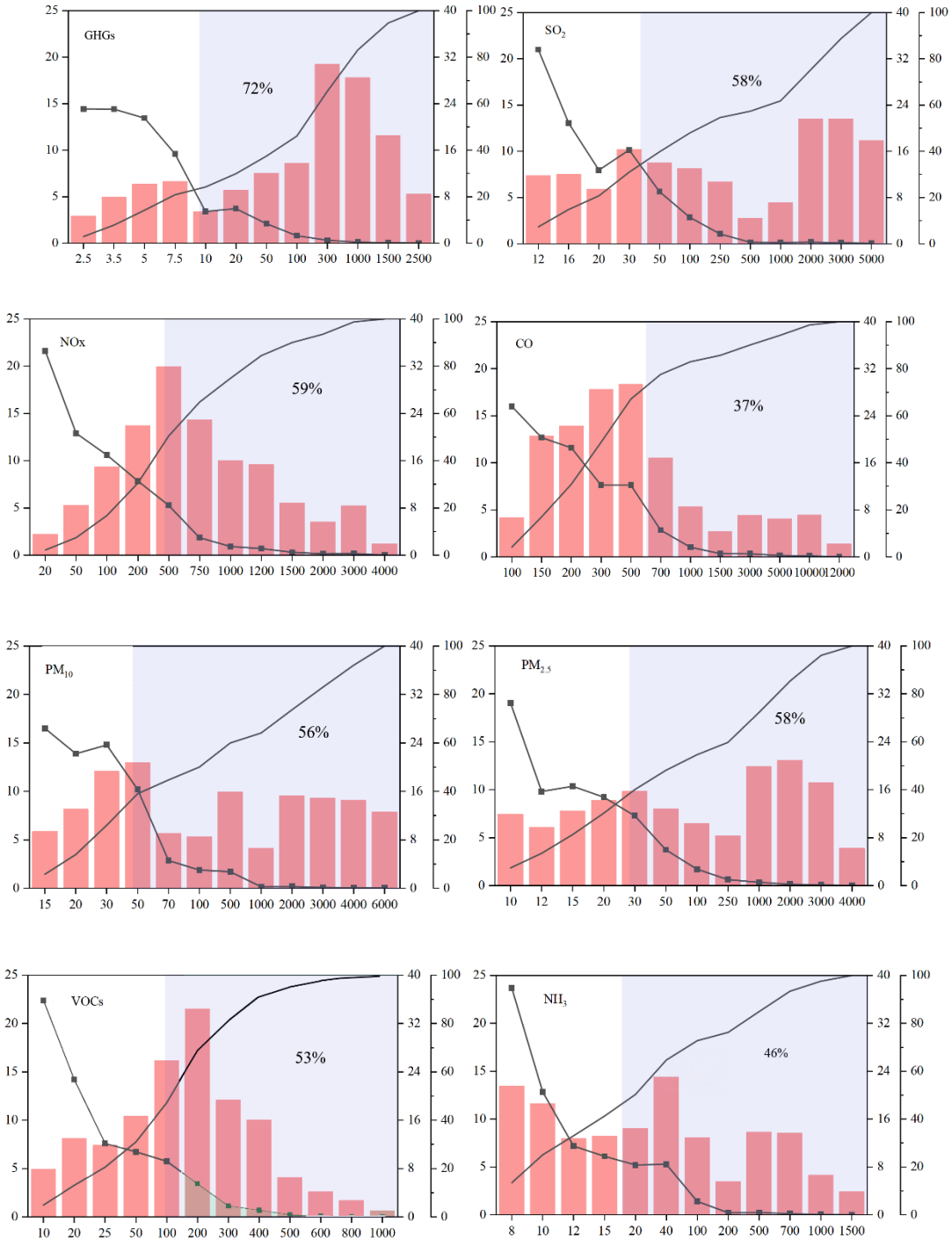

Figure S2. The probability of emission amount and cumulative probability in 2021 over all grids (at 5 km by 5 km) for each species, including GHGs, SO_2, NOx, CO, PM_{10}, $PM_{2.5}$, VOCs, and NH_3. Shown are the probability of emissions (left Y axis), the corresponding sample size (right Y1 axis), and cumulative probability (right Y2 axis) for each bin of emission amount (X axis).

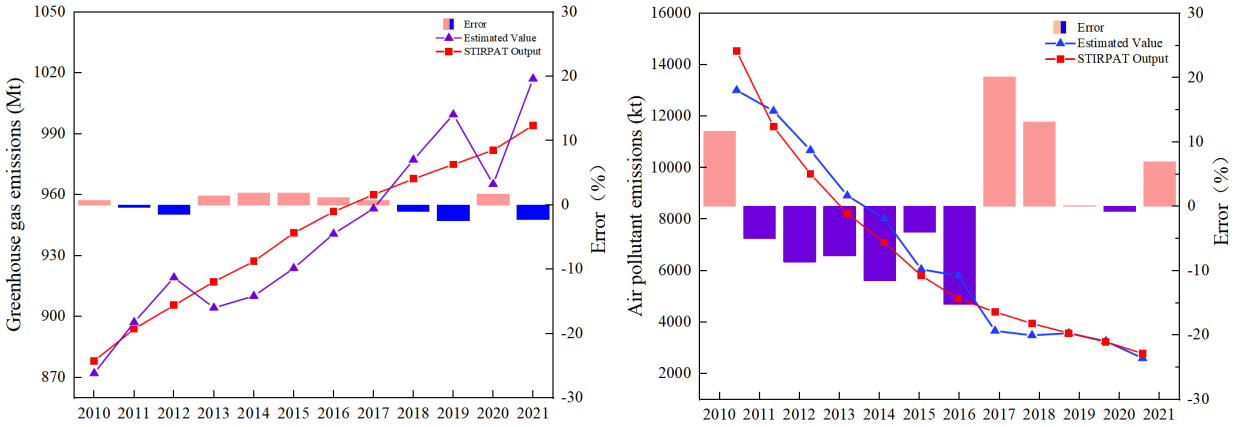

Figure S3. Simulation values and errors of GHGs and air pollutants

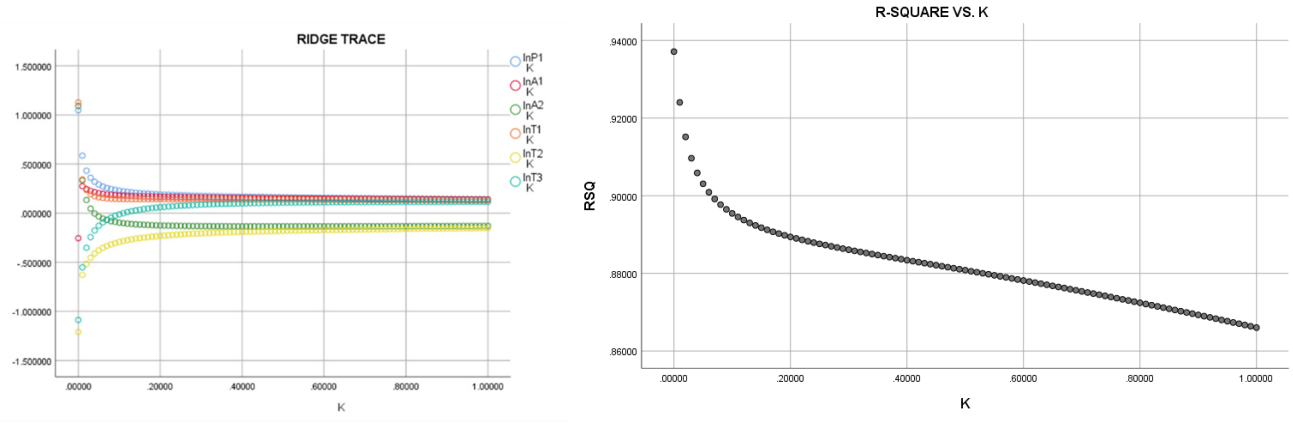

Figure S4. Relationship between the GHG ridge regression coefficient and K value and scatter diagram of determinable coefficient R^2 and K value

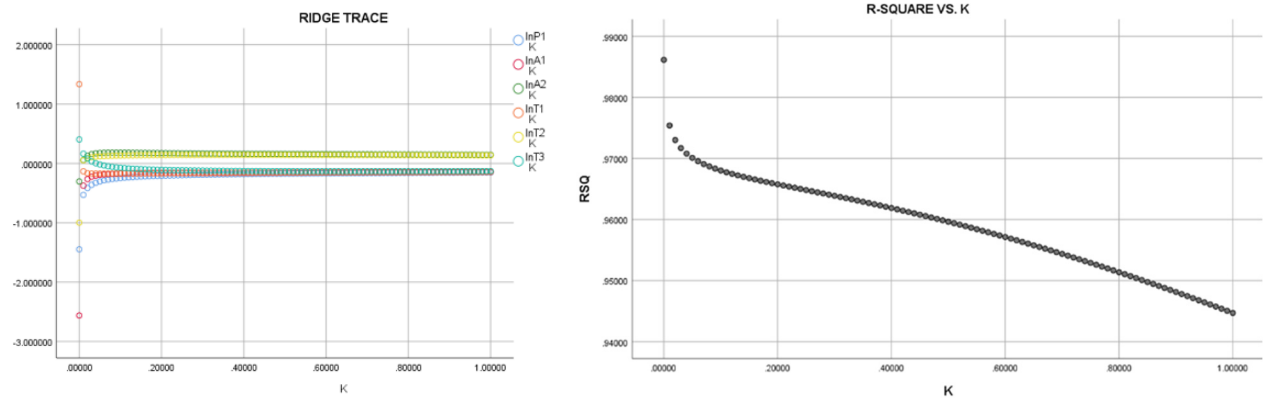

Figure S5. Relationship between the air pollutant ridge regression coefficient and K value and scatter diagram of determinable coefficient R^2 and K value

References

Bai, L., Lu, X., Yin, S., Zhang, H., Ma, S., Wang, C., Li, Y., Zhang, R., 2020. A recent emission inventory of multiple air pollutant, PM2.5 chemical species and its spatial-temporal characteristics in central China. Journal of Cleaner Production 269.

Gao, R., Jiang, W., Gao, W., Sun, S., 2017. Emission inventory of crop residue open burning and its high-resolution spatial distribution in 2014 for Shandong province, China. Atmospheric Pollution Research 8, 545-554.

Hasanbeigi, A., Lobscheid, A., Lu, H., Price, L., Dai, Y., 2013. Quantifying the co-benefits of energy-efficiency policies: a case study of the cement industry in Shandong Province, China. Sci Total Environ 458-460, 624-636.

Hua, H., Jiang, S., Sheng, H., Zhang, Y., Liu, X., Zhang, L., Yuan, Z., Chen, T., 2019. A high spatial-temporal resolution emission inventory of multi-type air pollutants for Wuxi city. Journal of Cleaner Production 229, 278-288.

Jiang, P., Chen, X., Li, Q., Mo, H., Li, L., 2020. High-resolution emission inventory of gaseous and particulate pollutants in Shandong Province, eastern China. Journal of Cleaner Production 259.

Jiang, Q.Z., Ma, J.K., Chen, G.S., Li, Z.W., 2013. Estimation and analysis of carbon dioxide emissions in refineries. Xiandai Huagong/Modern Chemical Industry 33, 1-4+6.

Liu, S., Hua, S., Wang, K., Qiu, P., Liu, H., Wu, B., Shao, P., Liu, X., Wu, Y., Xue, Y., Hao, Y., Tian, H., 2018. Spatial-temporal variation characteristics of air pollution in Henan of China: Localized emission inventory, WRF/Chem simulations and potential source contribution analysis. Sci Total Environ 624, 396-406.

Qiu, P., Tian, H., Zhu, C., Liu, K., Gao, J., Zhou, J., 2014. An elaborate high resolution emission inventory of primary air pollutants for the Central Plain Urban Agglomeration of China. Atmospheric Environment 86, 93-101.

Sun, S., Jiang, W., Gao, W., 2016. Vehicle emission trends and spatial distribution in Shandong province, China, from 2000 to 2014. Atmospheric Environment 147, 190-199.

WANG Rui-peng, Z.Y., CHENG Shui-yuan, DUAN Wen-jiao, Lü Zhe, SHEN Ze-ya, 2020. The establishment of airports emission inventory and the air quality impactsfor typical airports in North China. CHINA ENVIRONMENTAL SCIENCECE 40, 1468-1476.

Yi, X., Yin, S., Huang, L., Li, H., Wang, Y., Wang, Q., Chan, A., Traoré, D., Ooi, M.C.G., Chen, Y., Allen, D.T., Li, L., 2021. Anthropogenic emissions of atomic chlorine precursors in the Yangtze River Delta region, China. Science of The Total Environment 771, 144644.

Zhang, B., Yin, S., Lu, X., Wang, S., Xu, Y., 2023. Development of city-scale air pollutants and greenhouse gases emission inventory and mitigation strategies assessment: A case in Zhengzhou, Central China. Urban Climate 48.

Zhang, H., Hu, J., Qi, Y., Li, C., Chen, J., Wang, X., He, J., Wang, S., Hao, J., Zhang, L., Zhang, L., Zhang, Y., Li, R., Wang, S., Chai, F., 2017a. Emission characterization, environmental impact, and control measure of PM2.5 emitted from agricultural crop residue burning in China. Journal of Cleaner Production 149, 629-635.

Zhang, K., Yu, Z., Gao, H., Huang, T., Ma, J., Zhang, X., Wang, Y., 2017b. Gridded emission inventories and spatial distribution characteristics of anthropogenic atmospheric pollutants in Lanzhou valley. Huanjing Kexue Xuebao/Acta Scientiae Circumstantiae 37, 1227-1242.
Zhong, Z., Zheng, J., Zhu, M., Huang, Z., Zhang, Z., Jia, G., Wang, X., Bian, Y., Wang, Y., Li, N., 2018. Recent developments of anthropogenic air pollutant emission inventories in Guangdong province, China. Sci Total Environ 627, 1080-1092.
Zhou, M., Jiang, W., Gao, W., Gao, X., Ma, M., Ma, X., 2021. Anthropogenic emission inventory of multiple air pollutants and their spatiotemporal variations in 2017 for the Shandong Province, China. Environ Pollut 288, 117666.
Zhou, Y., Xing, X., Lang, J., Chen, D., Cheng, S., Wei, L., Wei, X., Liu, C., 2017. A comprehensive biomass burning emission inventory with high spatial and temporal resolution in China. Atmos. Chem. Phys. 17, 2839-2864.
Zhou, Z., Tan, Q., Deng, Y., Wu, K., Yang, X., Zhou, X., 2019. Emission inventory of anthropogenic air pollutant sources and characteristics of VOCs species in Sichuan Province, China. Journal of Atmospheric Chemistry 76, 21-58.
Zhou, Z.H., Deng, Y., Tan, Q.W., Wu, K.Y., Yang, X.Y., Zhou, X.L., 2018. [Emission Inventory and Characteristics of Anthropogenic Air Pollutant Sources in the Sichuan Province]. Huan Jing Ke Xue 39, 5344-5358.