Supplement of Atmos. Chem. Phys., 23, 1091–1101, 2023
https://doi.org/10.5194/acp-23-1091-2023-supplement


Atmospheric Chemistry and Physics
Open Access

*Supplement of*

# Temporal and spatial variations in atmospheric unintentional PCB emissions in Chinese mainland from 1960 to 2019

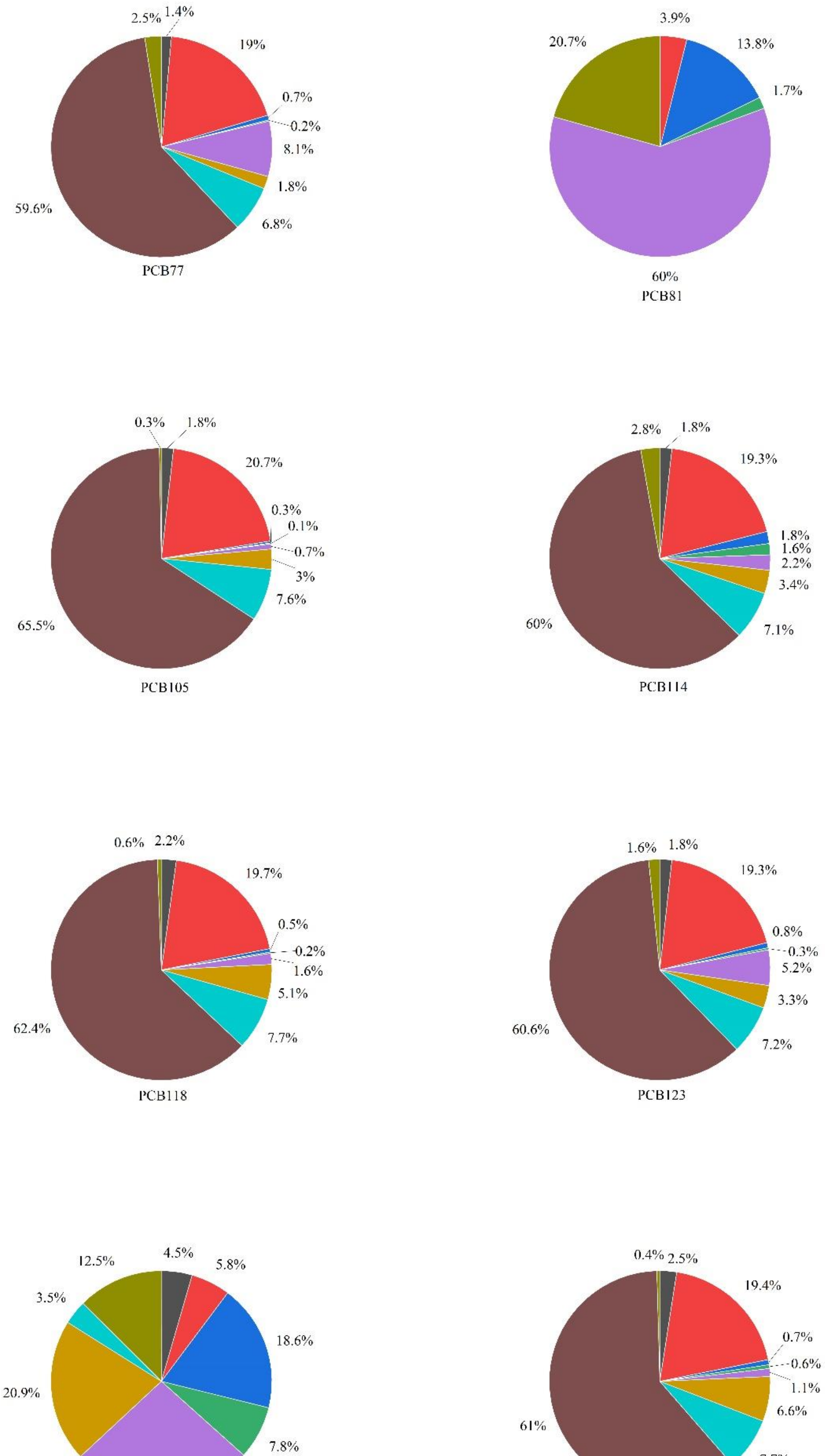
**Ye Li et al.**

*Correspondence to:* Ye Huang (huangye@geo.ecnu.edu.cn)

## List of Tables



## List of Figures


2.5%
1.4%
19%
0.7%
0.2%
8.1%
1.8%
6.8%
59.6%
PCB77
3.9%
13.8%
1.7%
20.7%
60%
PCB81
0.3%
1.8%
20.7%
0.3%
0.1%
0.7%
3%
7.6%
65.5%
PCB105
2.8%
1.8%
19.3%
1.8%
1.6%
2.2%
3.4%
7.1%
60%
PCB114
0.6%
2.2%
19.7%
0.5%
0.2%
1.6%
5.1%
7.7%
62.4%
PCB118
1.6%
1.8%
19.3%
0.8%
0.3%
5.2%
3.3%
7.2%
60.6%
PCB123
12.5%
4.5%
5.8%
3.5%
18.6%
20.9%
7.8%
26.4%
PCB126
0.4%
2.5%
19.4%
0.7%
0.6%
1.1%
6.6%
7.7%
61%
PCB156

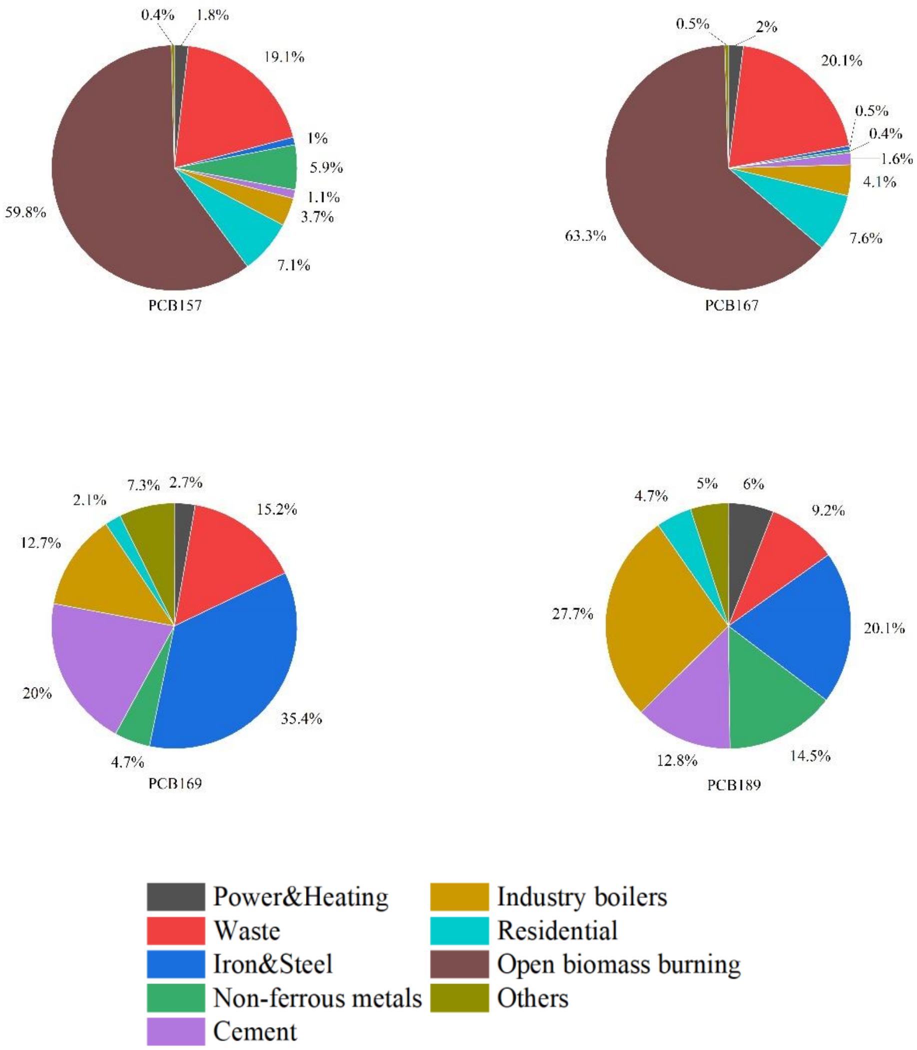



Fig. S1. Emission profiles for 9 source categories of 12 UP-PCBs.

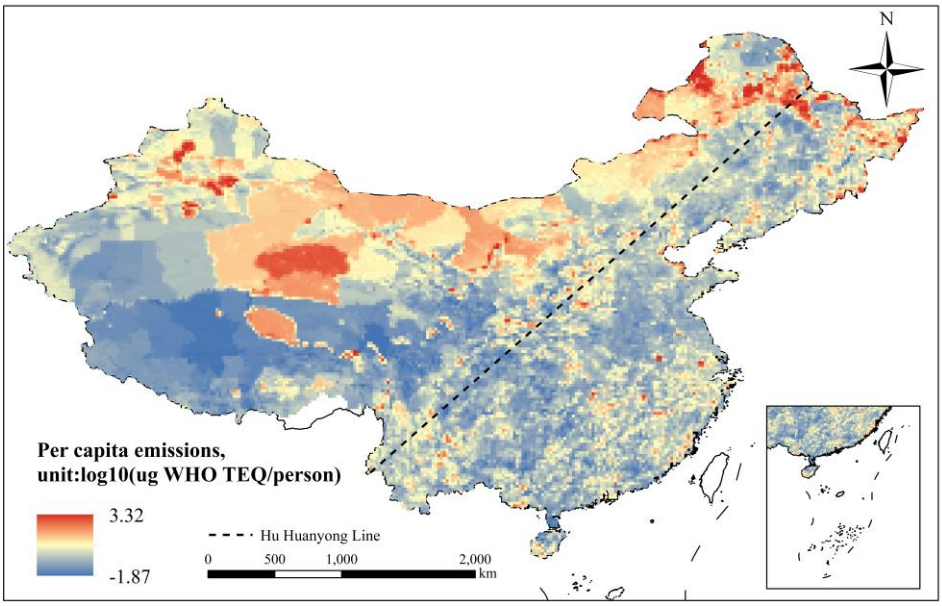



Fig. S2. Spatial distribution of per-capita UP-PCBs emissions

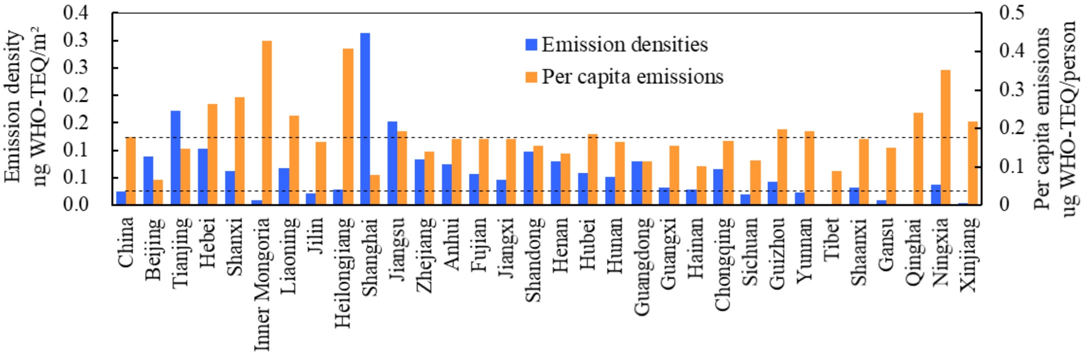



Fig. S3. Emission densities and per capita emissions of UP-PCBs for each province in China in 2019. The two dashed lines shows the national averages.

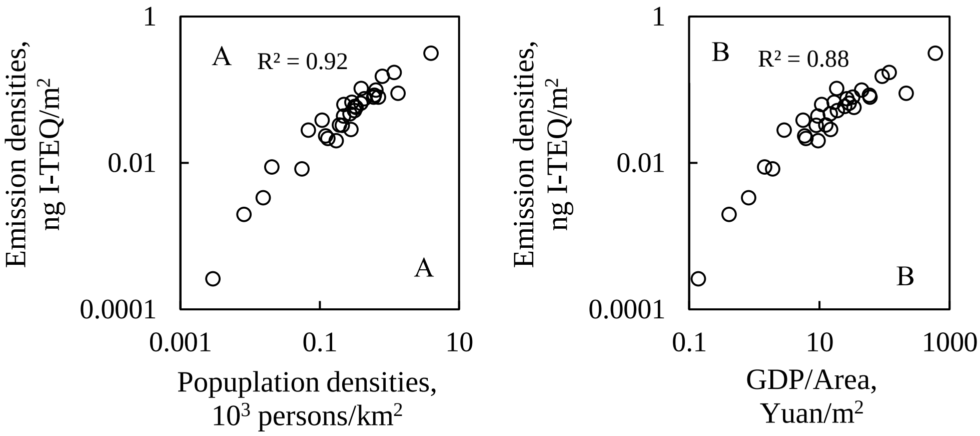



Fig. S4. Scatter plots of emission densities with population densities (A) and GDP/Area (B).

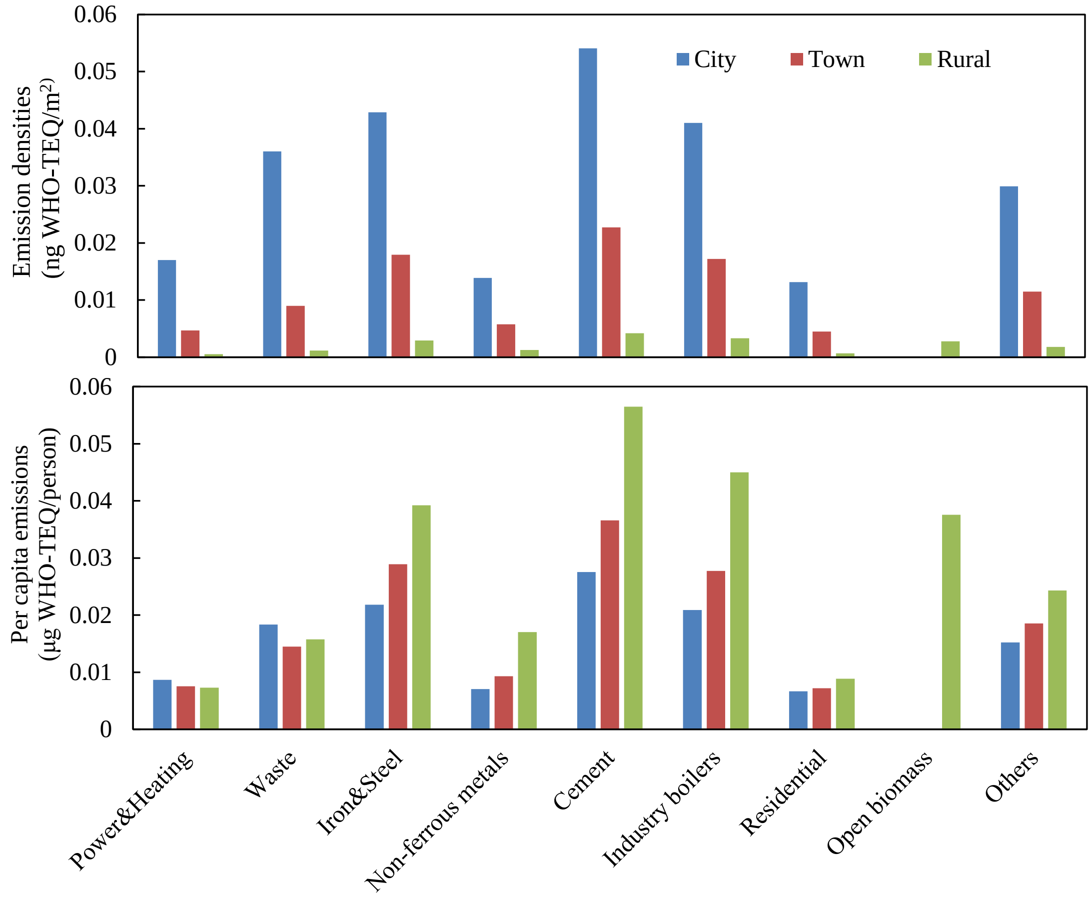



Fig. S5. Comparison of emission densities (A) and per capita emissions (B) among various source categories.

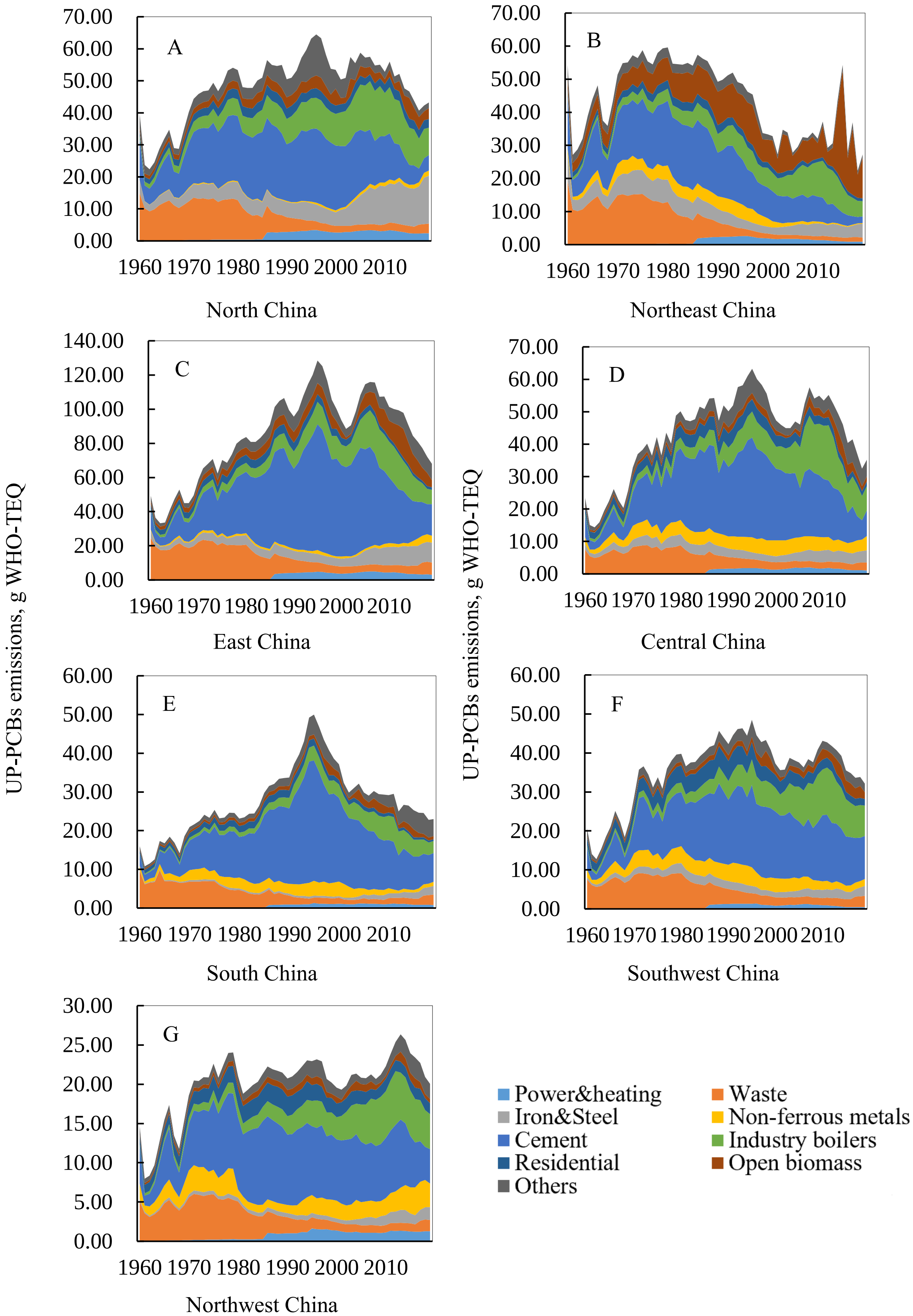



Fig. S6. Time trends of UP-PCBs emissions from various source categories from 1960 to 2019 in seven regions of China including North China (A), Northeast China (B), East China (C), Central China (D), South China (E), Southwest China (F), and Northwest China (G).

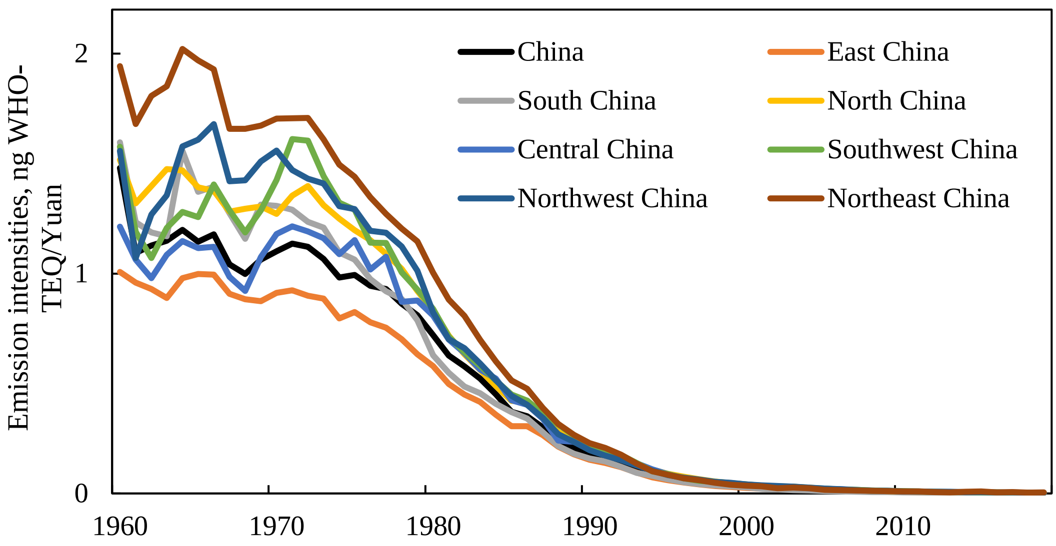



Fig. S7. Time trends of emission intensities for China and seven regions.

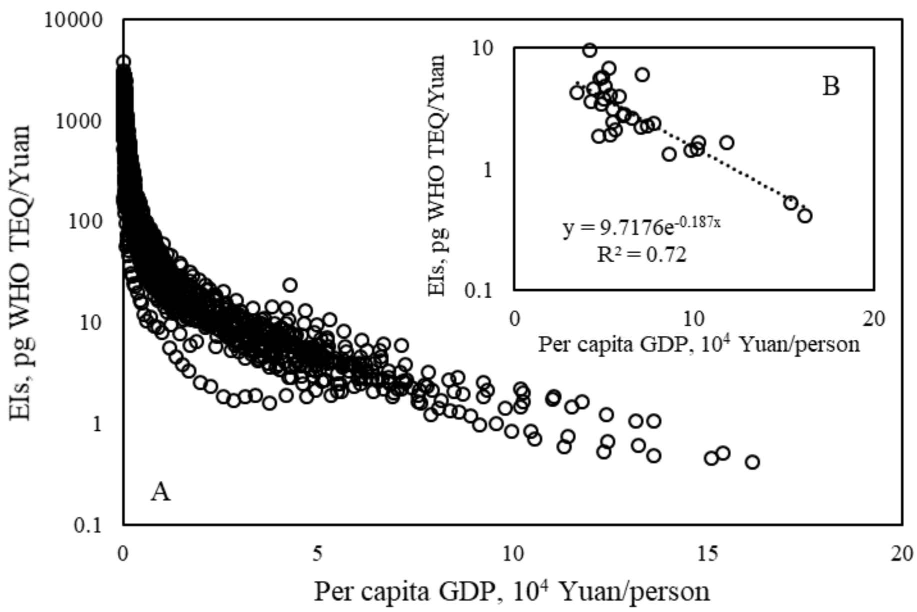



Fig. S8. Relationship between per capita GDP and emission intensities (EIs) with all provincial data from 1960 to 2019 (A) and only provincial data in 2019 (B).

Table S1. List of PCBs emission sources with best estimates (BE) and geometric standard deviations (SD) of EFs. The units of EF are ng WHO-TEQ/cigarette for cigarette smoking, ng WHO-TEQ/body for cremation of corpses, and ng WHO-TEQ/kg fuel consumed or product produced for all other sources.

| Categories | Fuel/Product | No. | Sub-source | BE | SD | Ref[a] |
|---|---|---|---|---|---|---|
| Power & Heating | Anthracite/ Coke/ Bituminous coal/ Lignite/ Peat | 1-5 | Uncontrolled/ Controlled | 0.105/0.0018 | 0.07/0.38 | 1 |
| | Gas/Diesel | 6 | | 0.000823 | 0.1 | 2 |
| | Residue fuel oil | 7 | | 0.000823 | 0.1 | 2 |
| | Solid biomass | 8 | Uncontrolled/ Controlled | 0.662/0.066 | 0.1 | 2 |
| | Natural gas liquids | 9 | | 0.000823 | 0.1 | 2 |
| Waste | Municipal waste | 10 | Uncontrolled/ Controlled | 15.31/0.036 | 1.32 | 3,4,5,6 |
| | Industry waste | 11 | Uncontrolled/ Controlled | 15.31/0.036 | 1.32 | 3,4,5 |
| | Non-organized waste burning | 12 | | 15.31 | 1.32 | 3,4,5 |
| | Medical waste | 13 | Uncontrolled/ Controlled | 13.29/1.77 | 0.09/1.04 | 1,3,5 |
| Iron & Steel | Sintering iron | 14 | Uncontrolled/ Controlled | 0.379/0.016 | 0.60 | 2,3,5,7,8 |
| | Electric arc furnace | 15 | Uncontrolled/ Controlled | 0.628/0.084 | 0.59 | 2,3,7,8,9 |
| | Open Hearth Furnace | 16 | Uncontrolled/ Controlled | 0.01/0.001 | 0.59 | 6 |
| | Oxygen Blown Converter | 17 | Uncontrolled/ Controlled | 0.01/0.001 | 0.59 | 6 |
| | Hot rolling | 18 | Uncontrolled/ Controlled | 0.62/0.025 | 1.01 | 1,2,3,10 |
| Non-ferrous metals | Aluminum | 19 | Uncontrolled/ Controlled | 1.37/0.14 | 0.48 | 2,6,7,8,9,11 |
| | Lead | 20 | Uncontrolled/ Controlled | 40/0.36 | 1.39 | 2,3,8 |
| | Magnesium | 21 | Uncontrolled/ Controlled | 2.462/0.2462 | 0.74 | 6,12 |
| | Zinc | 22 | Uncontrolled/ Controlled | 100/0.324 | 1.47 | 1,2,6,7,9 |
| | Copper | 23 | Uncontrolled/ Controlled | 0.92/0.092 | 0.88 | 1,2,6,7,8,13,14 |
| | Secondary lead | 24 | Uncontrolled/ Controlled | 1.1/0.002 | 1.67 | 2,3,8 |
| | Secondary zinc | 25 | Uncontrolled/ Controlled | 100/1.33 | 1.25 | 1,6,15 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Secondary copper | 26 | Uncontrolled/ Controlled | 9.77/0.83 | 1.55 | 1,6,9,11,13 |
| | Secondary aluminum | 27 | Uncontrolled/ Controlled | 1.616/0.162 | 0.19 | 2 |
| Cement | Cement | 28 | Uncontrolled/ Controlled | 3.844/0.216 | 0.58 | 2,3,7 |
| Industry boilers | Machine diesel | 29 | | 0.000823 | 0.1 | 2 |
| | Anthracite/ Coke/ Bituminous coal/ Lignite/ Peat | 30-34 | Uncontrolled/ Controlled | 0.105/0.0018 | 0.07/0.38 | 1 |
| | Natural gas liquid | 35 | | 0.000823 | 0.1 | 2 |
| | Residue fuel | 36 | | 0.000823 | 0.1 | 2 |
| | Solid biomass | 37 | | 0.066 | 0.1 | 2 |
| Residential | Anthracite | 38 | | 0.084 | 0.65 | 16,17,18 |
| | Coke/ Bituminous coal/ Lignite/ Peat | 39-42 | | 0.084 | 0.65 | 16,17,18 |
| | Natural gas liquids/Kerosene | 43-44 | | 0.000823 | 0.1 | 2 |
| | Firewood | 45 | | 0.016 | 0.17 | 16 |
| | Straw/Dung cake | 46-47 | | 0.016 | 0.17 | 16 |
| Open biomass | Agricultural waste | 48 | | 1.525 | 0.89 | 6 |
| | Savanna | 49 | | 0.03 | 0.89 | 16,9 |
| | Forest fire/Deforestation/Peat/Woodland | 50-53 | | 0.1 | 0.89 | 16,19 |
| Others | Coke production | 54 | Beehive coke/Uncontrolled/ Controlled | 0.2/0.2/0.002 | 0.96 | 2,7 |
| | Brick production | 55 | Uncontrolled/ Controlled | 0.20/0.02 | 0.50 | 2 |
| | Gas Flaring/ Machine diesel in agriculture | 56-57 | | 0.000823 | 0.1 | 2 |
| | Pulp and paper mill | 58 | Uncontrolled/ Controlled | 0.696/0.070 | 0.5 | 2 |
| | Cremation of corpses | 59 | Uncontrolled/ Controlled | 0.006/0.0006 | 0.5 | 2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Vinyl chloride monomer manufacturing facilities | 60 | Uncontrolled/ Controlled | 0.122/0.012 | 0.5 | 2 |
| | Motor gasoline/ Aviation gasoline/ Biodiesel/ Jet Kerosene/ Gas& Diesel | 61-65 | | 0.000823 | 0.1 | 2 |
| | Lime | 66 | Uncontrolled/ Controlled | 0.108/0.011 | 0.1 | 2 |

Notes: [a]1.Pham et al., 2019; 2.Cui et al., 2013; 3.Liu et al., 2013b; 4.Zhang et al., 2011; 5.Li et al., 2017; 6. UNEP; 7.Cui et al., 2015; 8.Yu et al., 2006; 9.Antunes et al., 2012; 10.Lv et al., 2011; 11.Ba et al., 2009b; 12.Nie et al., 2011; 13.Nie et al., 2012a; 14.Hu et al., 2013; 15.Ba et al., 2009a; 16.Lee et al., 2005; 17.Hopan et al., 2009; 18. Šyc et al., 2010; 19.Lohmann et al., 2006

Table S2. Emission profiles (percentage of mass) of 12 dioxin-like UP-PCBs used to derived congener specific EFs.

| No. | PCB77 | PCB81 | PCB105 | PCB114 | PCB118 | PCB123 | PCB126 | PCB156 | PCB157 | PCB167 | PCB169 | PCB189 | Refs |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1-5 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 6 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 7 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 8 | 11.6 | 0.0 | 31.9 | 1.4 | 42.0 | 4.3 | 0.0 | 4.3 | 1.4 | 2.9 | 0.0 | 0.0 | Lee et al., 2005 |
| 9 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 10 | 25.2 | 6.7 | 10.0 | 3.7 | 15.9 | 4.8 | 10.6 | 5.6 | 3.7 | 3.8 | 5.0 | 5.1 | Wang et al., 2010a; Wang et al., 2010b; Liu et al., 2013 |
| 11 | 25.2 | 6.7 | 10.0 | 3.7 | 15.9 | 4.8 | 10.6 | 5.6 | 3.7 | 3.8 | 5.0 | 5.1 | Wang et al., 2010a; Wang et al., 2010b; Liu et al., 2013a |
| 12 | 11.6 | 0.0 | 31.9 | 1.4 | 42.0 | 4.3 | 0.0 | 4.3 | 1.4 | 2.9 | 0.0 | 0.0 | Lee et al., 2005 |
| 13 | 13.3 | 8.4 | 21.1 | 6.2 | 11.5 | 6.2 | 8.4 | 5.9 | 3.5 | 4.6 | 4.3 | 6.5 | Liu et al., 2013a |
| 14 | 18.1 | 4.4 | 11.6 | 2.8 | 33.3 | 4.5 | 11.9 | 4.7 | 2.0 | 2.3 | 1.8 | 2.6 | Aries et al., 2006; Lv et al., 2011; Liu et al., 2013a |
| 15 | 18.5 | 3.1 | 18.1 | 2.3 | 37.4 | 5.7 | 5.9 | 4.0 | 1.4 | 1.2 | 1.1 | 1.4 | Liu et al., 2013a |
| 16 | 18.5 | 3.1 | 18.1 | 2.3 | 37.4 | 5.7 | 5.9 | 4.0 | 1.4 | 1.2 | 1.1 | 1.4 | Liu et al., 2013a |
| 17 | 10.8 | 1.9 | 17.5 | 2.3 | 42.8 | 4.6 | 3.2 | 9.6 | 2.8 | 1.2 | 2.2 | 1.1 | Li et al., 2014 |
| 18 | 11.9 | 6.3 | 13.7 | 5.6 | 34.5 | 6.1 | 4.6 | 6.0 | 3.0 | 3.0 | 2.5 | 2.8 | Nie et al., 2012b |
| 19 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 90.7 | 0.0 | 0.0 | 0.0 | 9.3 | 0.0 | Yu et al., 2006 |
| 20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 96.7 | 0.0 | 0.0 | 0.0 | 3.3 | 0.0 | Yu et al., 2006 |
| 21 | 7.0 | 0.4 | 19.1 | 14.0 | 33.1 | 5.6 | 0.2 | 12.3 | 4.4 | 2.0 | 0.0 | 2.0 | Nie et al., 2011 |
| 22 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 93.6 | 0.0 | 0.0 | 0.0 | 6.4 | 0.0 | Yu et al., 2006 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 23 | 10.4 | 1.6 | 13.4 | 7.5 | 20.2 | 7.3 | 1.3 | 9.7 | 9.7 | 9.7 | 0.3 | 9.0 | Nie et al., 2012a; Yu et al., 2006 |
| 24 | 89.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 9.5 | 0.0 | 0.0 | 0.0 | 0.9 | 0.0 | Ba et al., 2009a; Yu et al., 2006 |
| 25 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 2.8 | 0.0 | 96.9 | 0.0 | 0.3 | 0.0 | Ba et al., 2009a; Yu et al., 2006 |
| 26 | 5.0 | 1.7 | 9.8 | 9.8 | 12.2 | 8.6 | 1.9 | 14.7 | 12.3 | 12.3 | 0.7 | 11.0 | Ba et al., 2009b; Nie et al., 2012a; Yu et al., 2006 |
| 27 | 7.6 | 5.8 | 16.5 | 0.0 | 66.4 | 0.0 | 3.0 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | Ba et al., 2009b; Yu et al., 2006 |
| 28 | 39.9 | 5.5 | 9.2 | 1.4 | 27.3 | 9.4 | 2.1 | 2.1 | 0.7 | 1.8 | 0.3 | 0.4 | Juan et al., 2016; Liu et al., 2013a |
| 29 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 30-34 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 35 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 36 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 37 | 11.6 | 0.0 | 31.9 | 1.4 | 42.0 | 4.3 | 0.0 | 4.3 | 1.4 | 2.9 | 0.0 | 0.0 | Lee et al., 2005 |
| 38 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 39-42 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 43-44 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 45 | 11.6 | 0.0 | 31.9 | 1.4 | 42.0 | 4.3 | 0.0 | 4.3 | 1.4 | 2.9 | 0.0 | 0.0 | Lee et al., 2005 |
| 46-47 | 11.6 | 0.0 | 31.9 | 1.4 | 42.0 | 4.3 | 0.0 | 4.3 | 1.4 | 2.9 | 0.0 | 0.0 | Lee et al., 2005 |
| 48 | 11.6 | 0.0 | 31.9 | 1.4 | 42.0 | 4.3 | 0.0 | 4.3 | 1.4 | 2.9 | 0.0 | 0.0 | Lee et al., 2005 |
| 49 | 11.6 | 0.0 | 31.9 | 1.4 | 42.0 | 4.3 | 0.0 | 4.3 | 1.4 | 2.9 | 0.0 | 0.0 | Lee et al., 2005 |
| 50-53 | 11.6 | 0.0 | 31.9 | 1.4 | 42.0 | 4.3 | 0.0 | 4.3 | 1.4 | 2.9 | 0.0 | 0.0 | Lee et al., 2005 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 54 | 20.5 | 3.8 | 21.0 | 3.2 | 41.2 | 4.3 | 1.3 | 2.1 | 0.6 | 0.8 | 0.4 | 0.7 | Liu et al., 2009 |
| 55 | 39.9 | 5.5 | 9.2 | 1.4 | 27.3 | 9.4 | 2.1 | 2.1 | 0.7 | 1.8 | 0.3 | 0.4 | Juan et al., 2016; Liu et al., 2013a |
| 56-57 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 58 | 0.0 | 7.1 | 0.0 | 71.1 | 0.0 | 0.0 | 21.1 | 0.0 | 0.0 | 0.0 | 0.7 | 0.0 | Yu et al., 2006 |
| 59 | 11.6 | 0.0 | 31.9 | 1.4 | 42.0 | 4.3 | 0.0 | 4.3 | 1.4 | 2.9 | 0.0 | 0.0 | Lee et al., 2005 |
| 60 | 7.5 | 8.9 | 18.6 | 6.1 | 40.4 | 9.0 | 0.9 | 5.1 | 1.1 | 0.7 | 0.1 | 1.5 | Liu et al., 2012 |
| 61-65 | 5.6 | 0.0 | 22.4 | 1.3 | 53.8 | 3.7 | 1.0 | 7.3 | 1.4 | 2.9 | 0.1 | 0.5 | Lee et al., 2005 |
| 66 | 39.9 | 5.5 | 9.2 | 1.4 | 27.3 | 9.4 | 2.1 | 2.1 | 0.7 | 1.8 | 0.3 | 0.4 | Juan et al., 2016; Liu et al., 2013a |

Table S3. List of 12 PCBs congeners included in this study and their TEF values.

| Congeners | Abbreviation | WHO 1998 TEF[1] | WHO 2005 TEF[2] |
|---|---|---|---|
| 3,3‘,4,4’-tetraCB | PCB77 | 0.0001 | 0.0001 |
| 3,4,4',5-tetraCB | PCB81 | 0.0001 | 0.0003 |
| 2,3,3',4,4'-pentaCB | PCB105 | 0.0001 | 0.00003 |
| 2,3,4,4',5-pentaCB | PCB114 | 0.0005 | 0.00003 |
| 2,3',4,4',5-pentaCB | PCB118 | 0.0001 | 0.00003 |
| 2',3,4,4',5-pentaCB | PCB123 | 0.0001 | 0.00003 |
| 3,3',4,4',5-pentaCB | PCB126 | 0.1 | 0.1 |
| 2,3,3',4,4',5-hexaCB | PCB156 | 0.0005 | 0.00003 |
| 2,3,3',4,4',5'-hexaCB | PCB157 | 0.0005 | 0.00003 |
| 2,3',4,4',5,5'-hexaCB | PCB167 | 0.00001 | 0.00003 |
| 3,3',4,4',5,5'-hexaCB | PCB169 | 0.01 | 0.03 |
| 2,3,3',4,4',5,5'-hexaCB | PCB189 | 0.0001 | 0.00003 |

Notes:[1]Van den Berg et al., 1998; [2]Van den Berg et al., 2006.

Table S4. Definitions of the seven regions in China.

| Regions | Provinces |
|---|---|
| North China | Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia |
| Northeast China | Liaoning, Jilin, Heilongjiang |
| East China | Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong |
| Central China | Henan, Hubei, Hunan |
| South China | Guangdong, Guangxi, Hainan |
| Southwest China | Chongqing, Sichuan, Guizhou, Yunnan, Tibet |
| Northwest China | Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang |

Table S5. TEQ/u (g WHO-TEQ per unit of mass of UP-PCBs emissions) for nine source categories.

| Sources | Values, g WHO-TEQ/g. |
|---|---|
| Power & heating | $5 \times 10^{-4}$ |
| Waste burning | $1 \times 10^{-4}$ |
| Iron & Steel production | $6.8 \times 10^{-3}$ |
| Non-ferrous metals | $4.6 \times 10^{-3}$ |
| Cement production | $2.2 \times 10^{-3}$ |
| Industry boilers | $1.1 \times 10^{-3}$ |
| Residential | $1 \times 10^{-4}$ |
| Open biomass | $4 \times 10^{-5}$ |
| Others | $3 \times 10^{-3}$ |

**References:**


Antunes, P., Viana, P., Vinhas, T., Rivera, J., Gaspar, E. Emission profiles of polychlorinated dibenzodioxins, polychlorinated dibenzofurans (PCDD/Fs), dioxin-like PCBs and hexachlorobenzene (HCB) from secondary metallurgy industries in Portugal[J]. Chemosphere, 2012, 88, 1332-1339.

Aries, E., Anderson, DR., Fisher, R., Fray, TAT., Hemfrey, D. PCDD/F and "Dioxin-like" PCB emissions from iron ore sintering plants in the UK[J]. Chemosphere, 2006, 1470-1480.

Ba, T., Zheng, M., Zhang, B., Liu, W., Su, G., Xiao, K. Estimation and characterization of PCDD/Fs and dioxin-like PCB emission from secondary zinc and lead metallurgies in China[J]. Journal of Environmental Monitoring, 2009a, 11, 867-872.

Ba, T., Zheng, M., Zhang, B., Liu, W., Xiao, K., Zhang, L. Estimation and characterization of PCDD/Fs and dioxin-like PCBs from secondary copper and aluminum metallurgies in China[J]. Chemosphere, 2009b, 75, 1173-1178.

Cui, S., Fu, Q., Ma, W., Song, W., Liu, L., Li, Y. A preliminary compilation and evaluation of a comprehensive emission inventory for polychlorinated biphenyls in China[J]. Science of the Total Environment, 2015, 533, 247-255.

Cui, S., Qi, H., Liu, L., Song, W., Ma, W.L., Jia, H.L., Ding, Y., Li, Y. Emission of unintentionally produced polychlorinated biphenyls (UP-PCBs) in China: Has this become the major source of PCBs in Chinese air? [J]. Atmospheric Environment, 2013, 67, 73-79.

Hopan, F., Šyc, M., Horák, J., Dej, M., Krpec, K., Ocelka, T., Tomšej, T., Pekárek, V. Emission factors of selected organic compounds from domestic hardwood combustion[J]. Transactions of the VŠB – Technical University of Ostrava, Mechanical Series, 2009, 1723, 81-85.

Hu, J., Zheng, M., Liu, W., Li, C., Nie, Z., Liu, G., Xiao, K., Dong, S. Occupational exposure to polychlorinated dibenzo-p-dioxins and dibenzofurans, dioxin-like polychlorinated biphenyls, and polychlorinated naphthalenes in workplaces of secondary nonferrous metallurgical facilities in China[J]. Environmental Science & Technology, 2013, 47, 7773-7779.

Juan, A., Nuria, O., Esteban, A., Joan, R. Emissions of PCDD/Fs, PBDD/Fs, dioxin like-PCBs and PAHs from a cement plant using a long-term monitoring system[J]. Science of The Total Environment, 2016, 435-443.

Lee, R., Coleman, P., Jones, J., Jones, K., Lohmann, R. Emission factors and importance of PCDD/Fs, PCBs, PCNs, PAHs and PM10 from the domestic burning of coal and wood in the UK[J]. Environmental Science & Technology, 2005, 39, 1436-1447.

Li, S., Liu, G., Zheng, M., Liu, W., Li, J., Wang, M., Li, C., Chen, Y. Unintentional production of persistent chlorinated and brominated organic pollutants during iron ore sintering processes[J]. Journal of Hazardous Materials, 2017, 331, 63-70.

Li, S., Zheng, M., Liu, W., Liu, G., Xiao, K., Li, C. Estimation and characterization of unintentionally produced persistent organic pollutant emission from converter steelmaking processes[J]. Environmental Science Pollution Research, 2014, 21, 7361-7368.

Liu, G., Liu, W., Cai, Z., Zheng, M. Concentrations, profiles, and emission factors of unintentionally produced persistent organic pollutants in fly ash from coking processes[J]. Journal of Hazardous Materials, 2013a, 261, 421-426.

Liu, G., Zheng, M., Ba, T., Liu, W., Guo, L. A preliminary investigation on emission of polychlorinated dibenzo-p-dioxins/dibenzofurans and dioxin-like polychlorinated biphenyls from coke plants in China[J]. Chemosphere, 2009, 75, 692-695.

Liu, G., Zheng, M., Cai, M., Nie, Z., Zhang, B., Liu, W., Du, B., Dong, S., Hu, J., Xiao, K. Atmospheric emission of polychlorinated biphenyls from multiple industrial thermal processes[J]. Chemosphere, 2013b, 90, 2453-2460.

Liu, G., Zheng, M., Du, B., Nie, Z., Zhang, B., Hu, J., Xiao, K. Identification and characterization of the atmospheric emission of polychlorinated naphthalenes from electric arc furnaces[J]. Environmental Science Pollution Research, 2012a, 19, 3645-3650.

Liu, W., Zhang, W., Li, S., Meng, C., Tao, F., Li, H., Zhang, B. Concentrations and profiles of polychlorinated dibenzo-p-dioxins and dibenzofurans in air and soil samples in the proximity of a municipal solid waste incinerator plant[J]. Environmental Engineering Science, 2012b, 29, 693-699.

Lohmann, R., Lee, R., Abbott, J., Coleman, P., Jones, K. Verifying emission factors and national POPs emission inventories for the UK using measurements and modelling at two rural locations[J]. Journal of Environmental Monitoring, 2006, 8, 79-88.

Lv, P., Zheng, M., Liu, G., Liu, W., Xiao, K. Estimation and characterization of PCDD/Fs and dioxin-like PCBs from Chinese iron foundries[J]. Chemosphere, 2011, 82, 759-763.

Nie, Z., Liu, G., Liu, W., Zhang, B., Zheng, M. Characterization and quantification of unintentional POP emissions from primary and secondary copper metallurgical processes in China[J]. Atmospheric Environment, 2012a, 57, 109-115.

Nie, Z., Zheng, M., Liu, G., Liu, W., Lv, P., Zhang, B., Su, G., Gao, L., Xiao, K. A preliminary investigation of unintentional POP emissions from thermal wire reclamation at industrial scrap metal recycling parks in China[J]. Journal of Hazardous Materials, 2012b, 215, 259-265.

Nie, Z., Zheng, M., Liu, W., Zhang, B., Liu, G., Su, G., Lv, P., Xiao, K. Estimation and characterization of PCDD/Fs, dl-PCBs, PCNs, HxCBz and PeCBz emissions from magnesium metallurgy facilities in China[J]. Chemosphere, 2011, 85, 1707-1712.

Pham, M., Anh, H., Nghiem, X., Tu, B., Dao, T., Nguyen, M. Characterization of PCDD/Fs and dioxin-like PCBs in flue gas from thermal industrial processes in Vietnam: A comprehensive investigation on emission profiles and levels[J]. Chemosphere, 2019, 225, 238-246.

Šyc, M., Keppert, M., Pohořelý, M., Novák, P., Punčochář, M., Fišerová, E., Pekárek, V. Fly ash treatment technology in modern waste incineration plant, Proceedings of the Second International Conference on Sustainable Construction Materials and Technologies[M]. June 28-June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.

United Nations Environment Program (UNEP), Toolkit for Identification and Quantification of Releases of Dioxins, Furans and Other Unintentional POPs. 2013, http://toolkit.pops.int/Publish/Downloads/UNEP-POPS-TOOLKIT-2012-En.pdf.

Van den Berg, M., Birnbaum, L., Bosveld, A.T., Brunström, B., Cook, P., Feeley, M., Giesy, J.P., Hanberg, A., Hasegawa, R., Kennedy, S.W., Kubiak, T., Larsen, J.C., van Leeuwen, F.X., Liem, A.K., Nolt, C., Peterson, R.E., Poellinger, L., Safe, S., Schrenk, D., Tillitt, D., Tysklind, M., Younes, M., Waern, F., Zacharewski, T., 1998. Toxic equivalency factors (TEFs) for PCBs, PCDDs, PCDFs for humans and wildlife. Environ. Health Perspect. 106, 775–792.

Van den Berg, M., Birnbaum, L.S., Denison, M., De Vito, M., Farland, W., Feeley, M., Fiedler, H., Hakansson, H., Hanberg, A., Haws, L., Rose, M., Safe, S., Schrenk, D., Tohyama, C., Tritscher, A., Tuomisto, J., Tysklind, M., Walker, N., Peterson, R.E., 2006. The 2005 World Health Organization reevaluation of human and Mammalian toxic equivalency factors for dioxins and

dioxin-like compounds. Toxicol. Sci. 93, 223–241.
Wang, M., Chen, S., Huang, K., Lai, Y., Chang-Chien, G., Tsai, J. Characterization of Persistent Organic Pollutants Emitted from a Municipal Solid Waste Incinerator in Taiwan[J]. Environmental Engineering Science, 2010a, 27:11, 955-965.
Wang, M., Chen, S., Lai, Y., Huang, K., Chang-Chien, G. Characterization of Persistent Organic Pollutants in Ash Collected from Different Facilities of a Municipal Solid Waste Incinerator[J]. Aerosol and Air Quality Research, 2010b, 10: 391–402.
Yu, B., Jin, G., Moon, Y., Kim, M., Kyoung, J., Chang, Y. Emission of PCDD/Fs and dioxin-like PCBs from metallurgy industries in S. Korea[J]. Chemosphere, 2006, 62, 494-501.
Zhang, T., Fiedler, H., Yu, G., Ochoa, G., Carroll Jr, W., Gullett, B., Marklund, S., Touati, A. Emissions of unintentional persistent organic pollutants from open burning of municipal solid waste from developing countries[J]. Chemosphere, 2011, 84, 994-1001.