Supporting information for

**Air quality and health impacts from updated industrial emission standards in China**

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| Industry | Type | TSP | SO2 | NOx | Production Mt | Category |
|----------|------|-----|-----|-----|---------------|----------|
| sinter   | >180 m³ | 24.84  | 2.8  | 0.522 | 756.82 | Ferrous Metal |
|          | 50-180 m³ | 31.753  | 2.8  | 0.584 | 142.41 | |
|          | <50 m³ | 41.88  | 2.8  | 0.612 | 0.75  | |
| pellet   |       | 8.92  | 2.8  | 0.5  | 112.42 | |
| iron     | >2000 m³ | 37.63  | 0.109 | 0.15 | 536.27 | |
|          | 350-2000 m³ | 49  | 0.131 | 0.17 | 164.30 | |
|          | <350 m³ | 52.3  | 0.168 | 0.192 | 1.70  | |
| Steel-basic oxygen furnace | >150 t | 27.8  | 0 | 0 | 543.33 | |
|          | 50-150 t | 34.2  | 0 | 0 | 203.84 | |
|          | <50 t | 40.5  | 0 | 0 | 3.9  | |
| Electric arc furnace | ≥50 t | 17.72 | 0 | 0 | 1.17 | |
|          | <50 t | 22.75 | 0 | 0 | 55.36 | |
| Iron alloy |       | 55.59 | 0.125 | 0 | 35.55 | |
| Copper   |       | 349.4 | 2124 | 0 | 8.47 | Nonferrous Metal |
| Lead     |       | 383.1 | 502.4 | 0 | 4.24 | |
| Zinc     |       | 364.7 | 1147 | 0 | 6.27 | |
| Nickel   |       | 977.2 | 5706 | 0 | 2.18 | |
| Tin      |       | 353.7 | 36.1 | 0 | 1.83 | |
| Alumina  |       | 51 | 3.5 | 0 | 60.91 | |
| Aluminum |       | 100 | 7.5 | 0 | 32.65 | |
| magnesium |       | 45 | 187.5 | 0 | 0.91 | |
| Petroleum |       | 0 | 0.586 | 0 | 541.03 | Other |
| Coke     | ≥6 m | 9.8954 | 1.647 | 0.34 | 125.00 | Coke |
|          | 4.8-6 m | 10.6825 | 1.751 | 0.389 | 324.08 | Coke |
| Fertilizer |       | 2.36 | 0 | 0 | 66.30 | Chemical industry |
| Sulfuric |       | 0 | 2 | 0 | 91.33 | |
| Nitric   |       | 0 | 0 | 9 | 2.73 | |
| Calcium carbide |       | 42.1 | 0 | 0 | 25.64 | Nonmetal |
| Cement   | Clinker | 182.471 | 0.198 | 1.584 | 1446.18 | |
|          | Cement | 17.7 | 0 | 0 | 2410.31 | |
| Lime     |       | 15.611 | 0.341 | 0.124 | 240 | |
| Brick    |       | 11.618 | 14.834 | 6.874 | 56.77 | |
| Glass    |       | 3.243 | 5.613 | 4.37 | 40.20 | |
| Sanitary pottery |       | 32.233 | 33.206 | 81.313 | 0.22 | |
| Pottery  |       | 3751.933 | 919.413 | 513.108 | 1.23 | |
| Refractory |       | 0.36 | 2.21 | 1.88 | 79.45 | |
|                | Smoke | Dust | SO₂ | NOₓ | Standard          |
|----------------|-------|------|-----|-----|-------------------|
| Sinter/pellet  | 150   | 150  | 2860| 1430| GB 9078-1996     |
| Iron           | 150   | 150  | 2860| 1430| GB 9078-1996     |
| Steel-BOF     | 150   | 150  | 2860| 1430| GB 9078-1996     |
| Steel-EAF     | 150   | 150  | 2860| 1430| GB 9078-1996     |
| Iron alloy     | 200   | 1430|     |     | GB 9078-1996     |
| Copper         | 200   | 1430|     |     | GB 9078-1996     |
| Lead           | 200   | 1430|     |     | GB 9078-1996     |
| Zinc           | 200   | 1430|     |     | GB 9078-1996     |
| Nickel         | 200   | 1430|     |     | GB 9078-1996     |
| Tin            | 200   | 1430|     |     | GB 9078-1996     |
| Alumina        | 200   | 1430|     |     | GB 9078-1996     |
| Aluminum       | 200   | 1430|     |     | GB 9078-1996     |
| magnesium      | 200   | 1430|     |     | GB 9078-1996     |
| Petroleum      | 300   |     | 1200|     | GB 9078-1996     |
| Coke           | 250   | 850  |     |     | GB 16171-1996    |
| Fertilizer     | 300   | 1200 |     |     | GB 9078-1996     |
| Sulfuric       | 120   |     | 960 |     | GB 16297-1996    |
| Nitric         |       |     | 1400|     | GB 16297-1996    |
| Calcium carbide| 300   |     | 1200|     | GB 9078-1996     |
| Cement         | 100   | 200  | 800 |     | GB 4915-2004     |
| Lime           | 350   | 850  |     |     | GB 9078-1996     |

Table S2. Emission limits (mg/m³) of the smoke in the Old Emission Standard.
| Material         | Smoke | Dust | SO₂ | NOₓ | Standard       |
|------------------|-------|------|-----|-----|----------------|
| Brick            | 300   | 300  | 1200|     | GB 9078-1996  |
| Glass            | 300   | 200  | 1200|     | GB 9078-1996  |
| Sanitary pottery | 300   |      | 1200|     | GB 9078-1996  |
| Pottery          | 300   |      | 1200|     | GB 9078-1996  |
| Refractory       | 300   |      | 1200|     | GB 9078-1996  |
| Carbon           | 300   | 300  | 1200|     | GB 9078-1996  |
| Casting          | 300   | 300  | 1200|     | GB 9078-1996  |
| Boiler-coal      | 350   |      | 1200|     | GB 13271-2001 |
| Boiler-oil       | 200   |      | 1200|     | GB 13271-2001 |
| Boiler-natural gas| 50    |      | 100 |     | GB 13271-2001 |
| Electricity-coal | 50    |      | 400 | 650 | GB 13223-2003 |
| Electricity-oil  | 50    |      | 400 | 400 | GB 13223-2003 |
| Electricity-natural gas | 50 |      | 400 |     | GB 13223-2003 |

Table S3. Emission limits (mg/m³) of the smoke in the Temporal Emission Standard
| Smoke                  | Dust | SO$_2$ | NO$_x$ | Standard          |
|------------------------|------|--------|--------|-------------------|
| **Carbon**             | 150  | 150    | 850    | GB 9078-1996      |
| **Casting**            | 150  | 850    | GB 9078-1996 |
| **Boiler-coal**        | 250  | 900    | GB 13271-2014 |
| **Boiler-oil**         | 150  | 900    | 400    | GB 13271-2014     |
| **Boiler-natural gas** | 50   | 100    | 400    | GB 13271-2014     |
| **Electricity-coal**   | 50   | 400    | 450    | GB 13223-2011     |
| **Electricity-oil**    | 50   | 400    | 200    | GB 13223-2011     |
| **Electricity-natural gas** | 50 | 400  | 200    | GB 13223-2011     |

Table S4. Emission limits (mg/m$^3$) of the smoke in the New Emission Standard
|                      | Smoke | Dust | SO₂ | NOₓ | Standard            |
|----------------------|-------|------|-----|-----|---------------------|
| Sinter/pellet        | 20    | 20   | 50  | 100 | GB 28662-2012      |
| Iron                 | 10    | 15   | 100 | 300 | GB 28663-2012      |
| Steel-BOF            | 50    |      |     |     | GB 28664-2012      |
| Steel-EAF            | 50    |      |     |     | GB 28664-2012      |
| Iron alloy           | 30    |      |     |     | GB 28666-2012      |
| Copper               | 10    | 100  |     |     | GB 25467-2010      |
| Lead                 | 10    | 100  |     |     | GB 25466-2010      |
| Zinc                 | 10    | 100  |     |     | GB 25466-2010      |
| Nickel               | 10    | 100  |     |     | GB 25467-2010      |
| Tin                  | 30    | 400  |     |     | GB 30770-2014      |
| Alumina              | 10    | 100  |     |     | GB 25467-2010      |
| Aluminum             |       | 100  |     |     | GB 25467-2010      |
| magnesium            |       | 100  |     |     | GB 25468-2010      |
| Petroleum            | 20    | 50   | 100 |     | GB 31570-2015      |
| Coke                 | 15    | 30   | 150 | 200 | GB 16171-2012      |
| Fertilizer           | 200   | 850  |     |     | GB 9078-1996       |
| Sulfuric             | 30    | 200  |     |     | GB 26132-2010      |
| Nitric               |       | 200  |     |     | GB 26131-2010      |
| Calcium carbide      | 200   | 850  |     |     | GB 9078-1996       |
| Cement               | 20    | 10   | 100 | 320 | GB 4915-2013       |
| Lime                 | 200   | 850  |     |     | GB 9078-1996       |
| Brick                | 20    | 20   | 100 | 150 | GB 29620-2013      |
| Glass                | 20    | 30   | 100 | 400 | GB 26453-2011      |
| Sanitary pottery     | 20    | 30   | 150 |     | GB 25464-2010      |
| Pottery              | 20    | 30   | 150 |     | GB 25464-2010      |
| Refractory           | 150   | 850  |     |     | GB 9078-1996       |
| Carbon               | 150   | 150  | 850 |     | GB 9078-1996       |
| Casting              | 150   | 150  | 850 |     | GB 9078-1996       |
| Boiler-coal          | 30    | 200  | 200 | 200 | GB 13271-2014      |
| Boiler-oil           | 30    | 100  | 200 | 200 | GB 13271-2014      |
| Boiler-natural gas   | 20    | 50   | 150 | 200 | GB 13271-2014      |
| Electricity-coal     | 20    | 50   | 100 | 200 | GB 13223-2011      |
| Electricity-oil      | 20    | 50   | 100 | 200 | GB 13223-2011      |
| Electricity-natural gas | 5    | 35   | 100 | 200 | GB 13223-2011      |
Table S6. Range for the volume of smoke.

|                          | Volume of smoke | Unit   |
|--------------------------|-----------------|--------|
| Sinter                   | 2900-3400       | m³/ton |
| Pellet                   | 1900            | m³/ton |
| Iron                     | 1520-1850       | m³/ton |
| Steel-BOF                | 4123-5800       | m³/ton |
| Steel-EAF                | 12000-2000      | m³/ton |
| Iron alloy               | 27053           | m³/ton |
| Copper                   | 20450-25930     | m³/ton |
| Lead                     | 50080-51910     | m³/ton |
| Zinc                     | 12700           | m³/ton |
| Nickel                   | 92570           | m³/ton |
| Tin                      | 28740           | m³/ton |
| Alumina                  | 2200            | m³/ton |
| Aluminum                 | 10000-130000    | m³/ton |
| magnesium                | 75000           | m³/ton |
| Petroleum                | 916.32-1092.25  | m³/ton |
| Coke                     | 1275-4096       | m³/ton |
| Fertilizer               | 10000           | m³/ton |
| Sulfuric                 | 2000            | m³/ton |
| Nitric                   | 3400            | m³/ton |
| Calcium carbide          | 14000           | m³/ton |
| Cement                   | 3964-2069       | m³/ton |
| Lime                     | 3344-11737      | m³/ton |
| Brick                    | 42970-51040     | m³/piece|
| Glass                    | 3990-5629       | m³/ton |
| Sanitary pottery         | 1260670-2814370 | m³/piece|
| Pottery                  | 1072830-1590550 | m³/m²  |
| Refractory               | 5134            | m³/ton |
| Carbon                   | 5500            | m³/ton |
| Casting                  | 1400-2200       | m³/ton |
| Boiler-coal              | 10290           | m³/ton |
| Boiler-oil               | 15366.93        | m³/ton |
| Boiler-natural gas       | 136259.17       | m³/m³  |
| Electricity-coal         | 8178-10150      | m³/ton |
| Electricity-oil          | 11152           | m³/ton |
| Electricity-natural gas  | 245500          | m³/m³  |
Table S7. Comparison of the estimated emissions with MEIC 2016 (Zheng et al., 2018), and the uncertainty level of the estimated emissions.

|          | SO2   | NOx   | TSP   | PM2.5 | BC    | OC    |
|----------|-------|-------|-------|-------|-------|-------|
| Old      | (18.4-21.5) | (15.6-19.2) | (8.0-11.5) | (3.3-4.4) | (0.18-0.23) | (0.21-0.28) |
| Standard | Temporal | 15.4   | 13.1  | 4.5   | 2.1   | 0.14  | 0.10  |
|          | (14.6-17.0) | (12.3-15.0) | (4.3-6.0) | (2.0-2.2) | (0.13-0.16) | (0.09-0.13) |
| New      | 7.9    | 7.3    | 2.5   | 1.0   | 0.039 | 0.039 |
| Standard | (7.5-8.6) | (6.8-7.7) | (2.3-3.1) | (0.9-1.2) | (0.28-0.63) | (0.28-0.071) |
| Special  | 3.3    | 5.9    | 1.7   | 0.55  | 0.027 | 0.031 |
| Standard | (3.1-3.5) | (5.5-6.3) | (1.5-2.3) | (0.53-0.63) | (0.021-0.30) | (0.025-0.035) |
| MEP,2015 | 15.6   | 11.8   | 12.3  | 5.0   | 0.4   | 0.4   |
| MEIC,2016 | 10.4  | 13.9   | 13.4  | 4.3   | 0.3   | 0.3   |

Table S8. WRF-CHEM model configurations.

| Parameter                                    | Details                                                                 |
|----------------------------------------------|-------------------------------------------------------------------------|
| Grid size                                    | 180×150                                                                 |
| Domain center                                | 35°N, 105°E                                                             |
| Horizontal resolution                        | 30 km × 30 km                                                           |
| Vertical layer                               | 36                                                                      |
| Microphysics                                 | Lin et al. scheme (Lin et al., 1983)                                    |
| Longwave radiation                           | RRTM scheme (Mlawer et al., 1997)                                      |
| Shortwave radiation                          | Goddard shortwave (Kim and Wang, 2011)                                  |
| Surface layer                                | Eta similarity (Janjić, 2002)                                           |
| Land layer                                   | Noah Land Surface Model (Chen, 2001)                                    |
| Boundary layer                               | Mellor-Yamada-Janjić scheme (Janjić, 2002)                              |
| Meteorology initial and boundary conditions   | GFS analysis and forecast every 6 h                                     |
| Biogenic emission inventory                  | MEGAN model developed by Guenther et al. (2006)                         |
| Photolysis scheme                            | Madronich F-TUV(Guenther et al., 2006)                                  |
| Spin-up period                               | 7 days                                                                  |
Table S9. Geographical classification of the provinces in China.

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

Table S9. Change in PM$_{2.5}$-related premature deaths.

| Province | Old→Temporal | Temporal→New | New→Special | Old→Special |
|----------|--------------|--------------|-------------|-------------|
|          | Mean         | 95% lower    | 95% upper   |
| Beijing  | -0.83        | -1.19        | -0.55       | -2.56       | -2.89       | -2.25       |
| Tianjin  | -0.59        | -0.77        | -0.35       | -1.72       | -1.93       | -1.52       |
| Hebei    | -3.64        | -4.28        | -2.04       | -9.96       | -11.18      | -8.86       |
| Province     | Old→Temporal | Temporal→New | New→Special | Old→Special |
|--------------|--------------|--------------|-------------|-------------|
|              | Mean  | 95% lower | 95% upper  | Mean  | 95% lower | 95% upper  |
| Beijing      | 0.26  | 0.16       | 0.04        | 0.46  | 0.20       | 0.60        |
| Tianjin      | 0.16  | 0.11       | 0.04        | 0.30  | 0.13       | 0.40        |
| Hebei        | 0.53  | 0.47       | 0.09        | 1.10  | 0.45       | 1.48        |
| Shanxi       | 0.23  | 0.17       | 0.01        | 0.41  | 0.15       | 0.59        |
| Inner        | 0.08  | 0.02       | -0.03       | 0.07  | 0.02       | 0.11        |
| Mongolia     | 0.12  | 0.01       | -0.02       | 0.11  | 0.04       | 0.16        |

Table S10. Change in \(O_3\)-related premature deaths.
| Province     | 0.00 | -0.08 | -0.04 | -0.12 | -0.19 | -0.04 |
|--------------|------|-------|-------|-------|-------|-------|
| Jilin        | 0.00 | -0.09 | -0.03 | -0.12 | -0.20 | -0.04 |
| Heilongjiang | 0.00 | -0.09 | -0.03 | -0.12 | -0.20 | -0.04 |
| Shanghai     | 0.28 | -0.07 | -0.07 | 0.14  | 0.07  | 0.16  |
| Jiangsu      | 0.79 | 0.15  | -0.17 | 0.76  | 0.38  | 0.91  |
| Zhejiang     | 0.04 | -0.44 | -0.26 | -0.66 | -0.80 | -0.32 |
| Anhui        | 0.32 | 0.05  | -0.11 | 0.27  | 0.11  | 0.35  |
| Fujian       | 0.03 | -0.12 | -0.12 | -0.21 | -0.30 | -0.08 |
| Jiangxi      | -0.18| -0.55 | -0.26 | -0.99 | -1.32 | -0.41 |
| Shandong     | 0.82 | 0.30  | -0.11 | 1.01  | 0.42  | 1.35  |
| Henan        | 0.54 | 0.25  | -0.05 | 0.74  | 0.31  | 1.00  |
| Hubei        | -0.09| -0.15 | -0.05 | -0.29 | -0.41 | -0.12 |
| Hunan        | -0.19| -0.48 | -0.27 | -0.93 | -1.28 | -0.38 |
| Guangdong    | 0.15 | -0.59 | -0.39 | -0.84 | -1.20 | -0.31 |
| Guangxi      | -0.23| -0.41 | -0.20 | -0.84 | -1.21 | -0.32 |
| Hainan       | -0.03| -0.06 | -0.03 | -0.12 | -0.17 | -0.05 |
| Chongqing    | -0.07| -0.15 | -0.07 | -0.29 | -0.40 | -0.12 |
| Sichuan      | -0.26| -0.48 | -0.28 | -1.02 | -1.41 | -0.40 |
| Guizhou      | -0.06| -0.24 | -0.10 | -0.40 | -0.59 | -0.15 |
| Yunnan       | -0.09| -0.18 | -0.12 | -0.38 | -0.58 | -0.13 |
| Tibet        | 0.00 | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| Shaanxi      | 0.11 | 0.00  | -0.03 | 0.09  | 0.04  | 0.10  |
| Gansu        | -0.02| -0.08 | -0.04 | -0.15 | -0.22 | -0.05 |
| Qinghai      | 0.01 | 0.01  | 0.00  | 0.02  | 0.01  | 0.03  |
| Ningxia      | 0.02 | 0.02  | -0.01 | 0.03  | 0.01  | 0.05  |
| Xinjiang     | 0.00 | 0.02  | 0.00  | 0.03  | 0.01  | 0.04  |
Figure S1. Air quality measurement stations in China. The red points represent the location of the stations.

Figure S2. Validation of the simulated monthly average (a) PM$_{2.5}$ ($\mu$g/m$^3$) and daily maximum 1-hour (b) O$_3$ ($\mu$g/m$^3$) in January, April, July and October. We calculated the average value of
air pollutants in cities with more than 5 measurement stations. The observed value is the average value of the measurement stations in a city. The simulated value is the average value of the grids in a city. The blue lines represent that the ratio of the simulation and the observation value is 1:2 and 2:1, and the red lines represent that the ratio of the simulation and the observation value is 1:4, 1:1 and 4:1.

Figure S3. The geographical distribution of the provinces in China. This figure helps to identify the geographical location of the provinces in China.
Figure S4. (a) SO$_2$, NO$_x$ and PM$_{2.5}$ emissions (Tg) in the Old Emission Standard. (b) Relative reduction of SO$_2$, NO$_x$ and PM$_{2.5}$ emissions when shifting from the Old Emission Standard to the Temporal Emission Standard, the Temporal Emission Standard to the New Emission Standard and the New Emission Standard to the Special Emission Standard.
Figure S5. Comparison of the monthly average PM$_{2.5}$ concentrations in the (a) present-day simulations with that in the (b) Temporal Emission Standard and (c) New Emission Standard.

Figure S6. Comparison of the monthly average daily maximum 1-hour O$_3$ concentrations in the (a) present-day simulation with that in the (b) Temporal Emission Standard and (c) New Emission Standard.
Figure S7. Change in monthly average PM$_{2.5}$ concentrations in the (a) Old→Temporal scenario, (b) Temporal→New scenario and (c) New→Special scenario.

Figure S8. Change in monthly average of daily maximum 1-hour O$_3$ concentrations in the (a) Old→Temporal scenario, (b) Temporal→New scenario and (c) New→Special scenario.
Figure S9. (a) The changes in annual premature deaths per capita due to PM$_{2.5}$ and O$_3$ in the 30 provinces of China (except Tibet and Taiwan) after shifting from the Old emission standards to the Special Emission Standards and (b) the initial air pollution-related premature deaths per capita in 30 provinces following the Old Emission Standard and the provincial reduction of annual air pollution-related premature deaths per capita if the Special Emission Standard should be fully implemented.
Figure S10. Change in the number of annual PM$_{2.5}$-related premature deaths (thousands). The error bar shows the 95% confidence level of our estimation.
Figure S11. Change in annual PM$_{2.5}$-related premature deaths in (a) Old→Temporal scenario, (b) Temporal→New scenario and (c) New→Special scenario.
Figure S12. Change in the number of annual O$_3$-related premature deaths (thousands). The error bar shows the 95% confidence level of our estimation.
Figure S13. Change in annual O₃-related premature deaths in (a) Old→Temporal scenario, (b) Temporal→New scenario and (c) New→Special scenario.
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