Support Table 1 Parameter results of spline function terms in single-pollutant generalized additive mixed effects models

Variable	edf	Ref.df	*F*	*P*
PM_1	5.58829	5.58829	1.928018	0.07646
$PM_{2.5}$	5.65607	5.65607	2.778079	0.01304
PM_{10}	5.79233	5.79233	2.845904	0.00593
Black carbon	1.00005	1.00005	29.316220	<0.00001
Organic matter	1.00011	1.00011	10.463220	0.00122
Sulfate	1.00009	1.00009	10.646610	0.00110
Nitrate	1.00000	1.00000	2.322000	0.12757
Ammonium	1.00004	1.00004	6.204612	0.01275

Notes: When analyzing repeated measurement data, if Y and X are nonlinear, curve fitting (usually a spline function) needs to be used. The generalized additive mixed effects model is a combination of mixed effects and additive models. It can not only introduce random effects, but also use curve fitting for repeated measurements of X (independent variables) and other covariates, which can meet the above analysis requirements. The following parameters are used to describe the statistical information of a smooth term in the spline function model (in this example, `s(pol)`, pol is the pollutant). The following is a detailed explanation of these parameters:

1. edf (Effective Degrees of Freedom):

- This value represents the complexity of this smoothing term. It is a continuous value that represents the effective number of model parameters. For a perfectly linear relationship, edf is close to 1; for more complex smooth relationships, edf is larger.

2. Ref.df (Reference Degrees of Freedom):

- The reference degrees of freedom are used to calculate the distribution of the test statistic `F`. This is usually an integer, but in some complex models it can also be a decimal. This value is usually close to `edf`.

3. *F* (F-statistic):

- This is the F statistic used to test whether the smoothing term is significant. The larger the F statistic, the stronger the smoothing term's ability to explain the model.

4. *P* (p-value):

- This is the p-value corresponding to the F statistic that tests whether the smoothing term is significant. If the p-value is less than a certain threshold (usually 0.05), we consider the smoothing term to be significant in the model.

Support Table 2 Parameter results of spline function terms in multi-pollution generalized additive mixed effects model

Variable	edf	Ref.df	*F*	*P*
PM_1	1.000	1.000	5.063	0.02450
$PM_{2.5}$	5.898	5.898	5.155	<0.00001
PM_{10}	1.000	1.000	3.433	0.06390
Black carbon	7.313	7.313	3.763	<0.00001
Organic matter	5.271	5.271	3.140	0.01370
Sulfate	1.000	1.000	1.913	0.16659
Nitrate	1.000	1.000	0.169	0.68116
Ammonium	3.999	3.999	1.717	0.14043

Notes: When analyzing repeated measurement data, if Y and X are nonlinear, curve fitting (usually a spline function) needs to be used. The generalized additive mixed effects model is a combination of mixed effects and additive models. It can not only introduce random effects, but also use curve fitting for repeated measurements of X (independent variables) and other covariates, which can meet the above analysis requirements. The following parameters are used to describe the statistical information of a smooth term in the spline function model (in this example, `s(pol)`, pol is the pollutant). The following is a detailed explanation of these parameters:

1. edf (Effective Degrees of Freedom):

- This value represents the complexity of this smoothing term. It is a continuous value that represents the effective number of model parameters. For a perfectly linear relationship, edf is close to 1; for more complex smooth relationships, edf is larger.

2. Ref.df (Reference Degrees of Freedom):

- The reference degrees of freedom are used to calculate the distribution of the test statistic `F`. This is usually an integer, but in some complex models it can also be a decimal. This value is usually close to `edf`.

3. *F* (F-statistic):

- This is the F statistic used to test whether the smoothing term is significant. The larger the F statistic, the stronger the smoothing term's ability to explain the model.

4. *P* (p-value):

- This is the p-value corresponding to the F statistic that tests whether the smoothing term is significant. If the p-value is less than a certain threshold (usually 0.05), we consider the smoothing term to be significant in the model.

Support Table 3 Information of CMIP6 models used in this study.

(Names of CMIP6 models, the associated institutions and countries, their ensemble members used in this study (mostly r1i1p1f1 for CMIP6, with different ensembles labeled in bold), and unavailable scenarios)

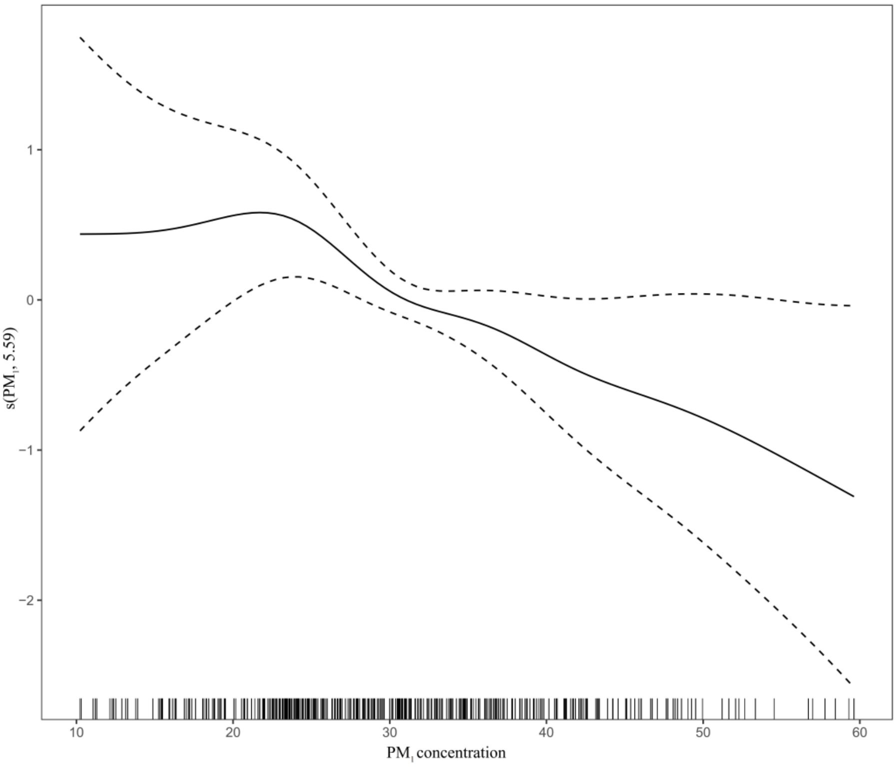
CMIP6 Model	Country &Institute	Resolution	Ensemble
BCC-ESM1[1]	China, Chinese Spirit Weather Bureau, Beijing Weather Waiting Center	2.81°×2.81°;month	r1i1p1f1
CESM2-WACCM[2]	America, Big Country Gas Research Center	0.90°×1.25°; month	r1i1p1f1
EC-Earth3-AerChem[3-5]	European Weather Suits Alliances, Research Institutional and High Performance Computing Center	3.00°×2.00°; month	r1i1p1f1
GFDL-ESM4[6,7]	United States, American Country Home Oceans and Atmosphere Authority Earth Objects Fluid Dynamics Laboratory	1.00°×1.25°; month	r1i1p1f1
IPSL-CM5A2-INCA[8,9]	France, Leatherel Simon Laplace Academy	3.75°×1.88°; month	r1i1p1f1
MIROC-ES2L[10-13]	Japan, Tokyo University Academic, National Environment Research Institute and Japan Ocean Earth Technology Graduate School	2.81°×2.81°;month	**r1i1p1f2**
MPI-ESM-1-2-HAM[14]	Germany, Max Planck Institute of Meteorology Institute	1.88°×1.88°;month	**r3i1p1f1(PM_{10})** & r1i1p1f1
MRI-ESM2-0[15,16]	Japan, Meteorological Research Institute	1.13°×1.13°;month	r1i1p1f1
NorESM2- LM[17,18]	Norway, Norwegian Gas Waiting Center	1.90°× 2.50°; month	r1i1p1f1
UKESM1- 0-LL[19,20]	UK, Natural Environment Environmental Research Committee and the Met Office	1.25°× 1.88°;month	**r1i1p1f2**

Notes: Not every model contains PM_1, $PM_{2.5}$, PM_{10}, black carbon, organic matter, sulfate, nitrate and ammonium. Data source: https://esgf-index1.ceda.ac.uk/search/cmip6-ceda/

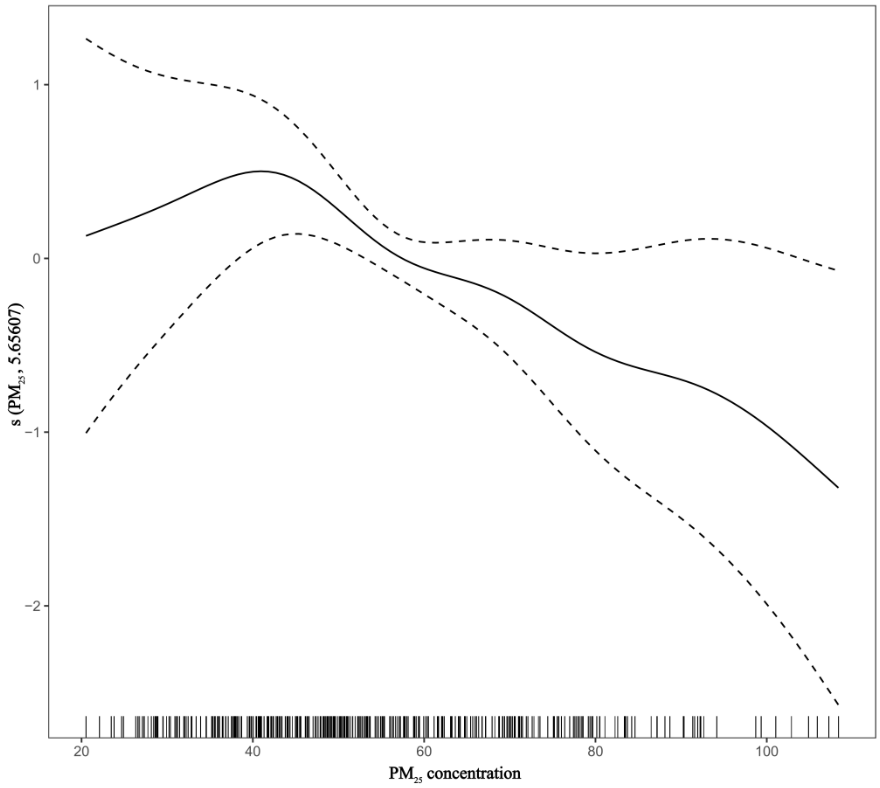
Support Table 4 China's population aged 45 and above under different scen arios in 2030 and 2050

Scenario	Year	Age	Population (thousands)
SSP1	2030	45--49	100261.6
SSP1	2030	50--54	93699.3
SSP1	2030	55--59	114295.2
SSP1	2030	60--64	116772
SSP1	2030	65--69	91351.8
SSP1	2030	70--74	65171.2
SSP1	2030	75--79	54879.3
SSP1	2030	80--84	27543.5
SSP1	2030	85--89	11879.6
SSP1	2030	90--94	4496.9
SSP1	2030	95--99	1101.8
SSP1	2030	100+	154.4
SSP2	2030	45--49	100104.4
SSP2	2030	50--54	93474.9
SSP2	2030	55--59	113827
SSP2	2030	60--64	115898
SSP2	2030	65--69	90071.9
SSP2	2030	70--74	63492.1
SSP2	2030	75--79	52432.9
SSP2	2030	80--84	25656
SSP2	2030	85--89	10741.8
SSP2	2030	90--94	3946.2
SSP2	2030	95--99	947.8
SSP2	2030	100+	133
SSP3	2030	45--49	100050.4
SSP3	2030	50--54	93295.4
SSP3	2030	55--59	113363.4
SSP3	2030	60--64	114994.1
SSP3	2030	65--69	88730.9
SSP3	2030	70--74	61755.9
SSP3	2030	75--79	49986
SSP3	2030	80--84	23858
SSP3	2030	85--89	9720.5
SSP3	2030	90--94	3480.2
SSP3	2030	95--99	824.7
SSP3	2030	100+	116.6
SSP1	2050	45--49	76597.3
SSP1	2050	50--54	78356.2
SSP1	2050	55--59	97086.4

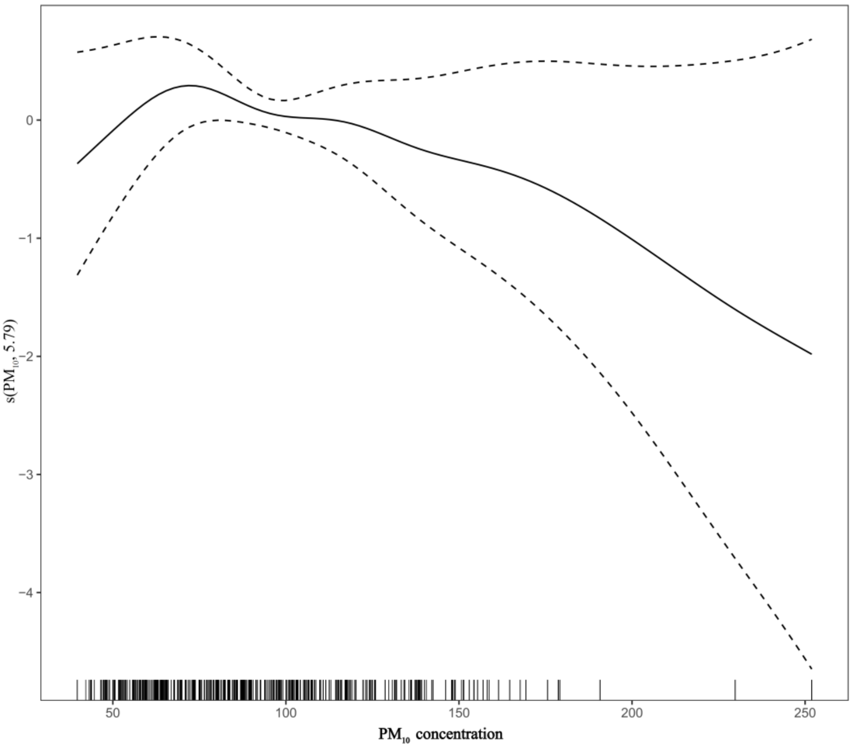
SSP1	2050	60--64	122998.5
SSP1	2050	65--69	93684.4
SSP1	2050	70--74	83077.7
SSP1	2050	75--79	91751
SSP1	2050	80--84	78475.1
SSP1	2050	85--89	44900
SSP1	2050	90--94	18995.9
SSP1	2050	95--99	7144.4
SSP1	2050	100+	1158.8
SSP2	2050	45--49	76525.7
SSP2	2050	50--54	77665.3
SSP2	2050	55--59	96239
SSP2	2050	60--64	120777.7
SSP2	2050	65--69	90874.7
SSP2	2050	70--74	78580.8
SSP2	2050	75--79	83092.4
SSP2	2050	80--84	66541
SSP2	2050	85--89	34622.7
SSP2	2050	90--94	12925.6
SSP2	2050	95--99	4222.5
SSP2	2050	100+	595.2
SSP3	2050	45--49	76663
SSP3	2050	50--54	77647.5
SSP3	2050	55--59	95567.5
SSP3	2050	60--64	118533.6
SSP3	2050	65--69	87576.9
SSP3	2050	70--74	73291.5
SSP3	2050	75--79	73377.1
SSP3	2050	80--84	54366.6
SSP3	2050	85--89	25516.2
SSP3	2050	90--94	8420.1
SSP3	2050	95--99	2439.9
SSP3	2050	100+	315.4



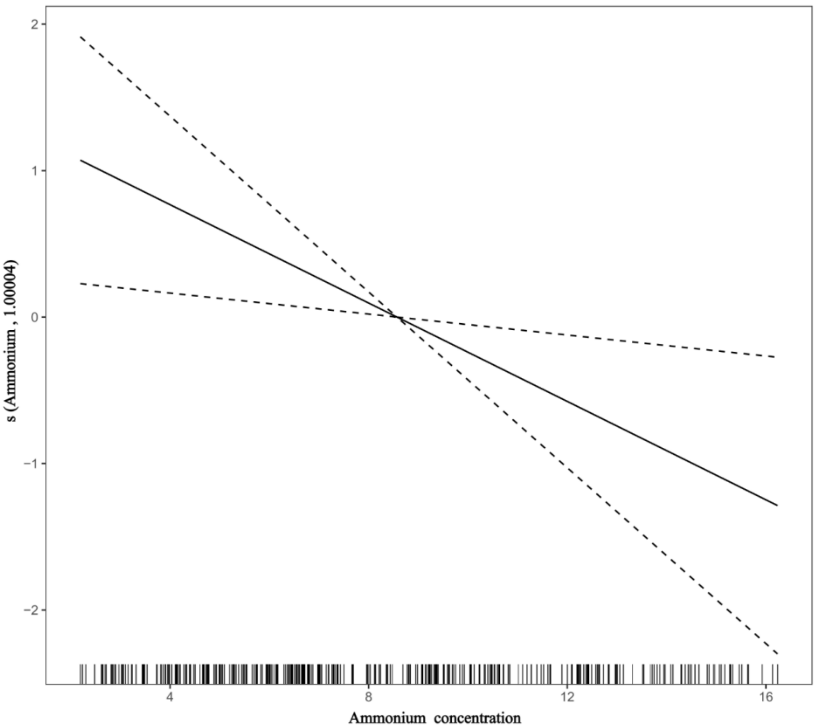
Support Figure 1 **PM_1 smoothing effect**



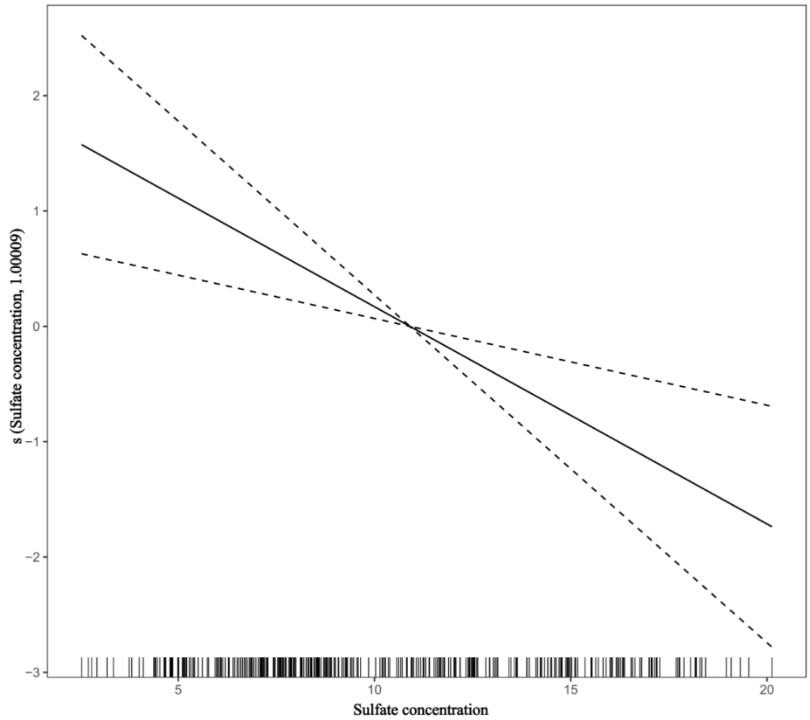
Support Figure 2 **$PM_{2.5}$ smoothing effect**



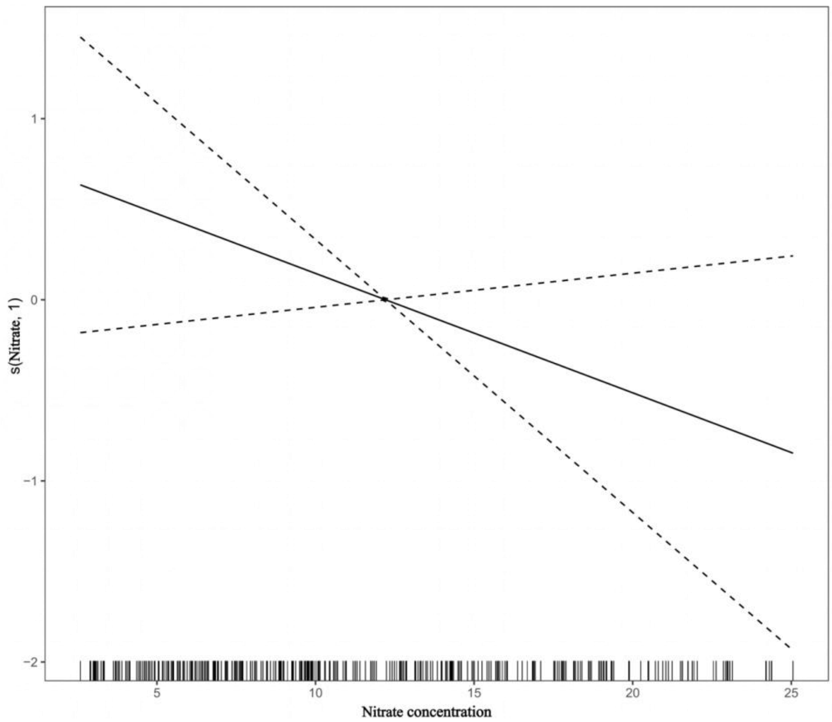
Support Figure 3 PM_{10} **smoothing effect**



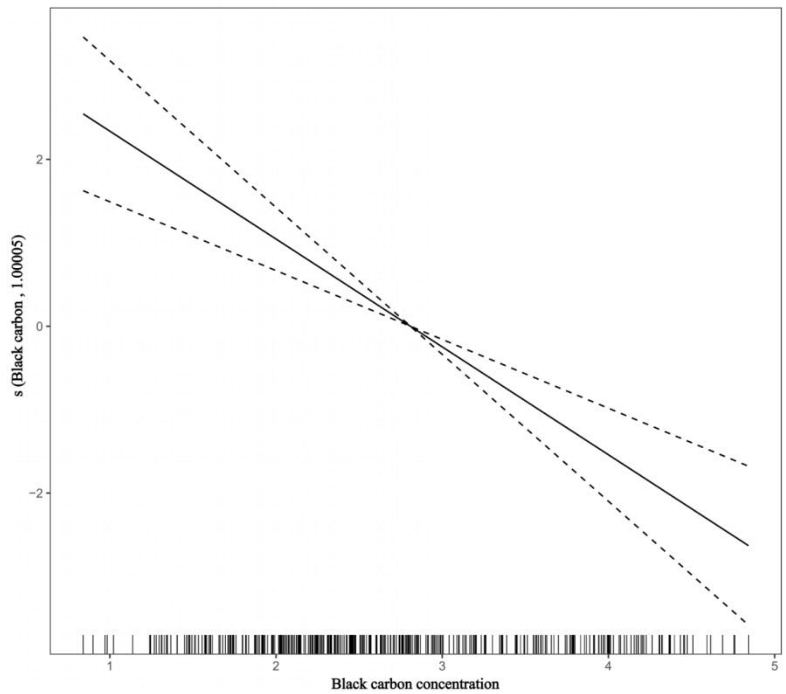
Support Figure 4 **Ammonium smoothing effect**



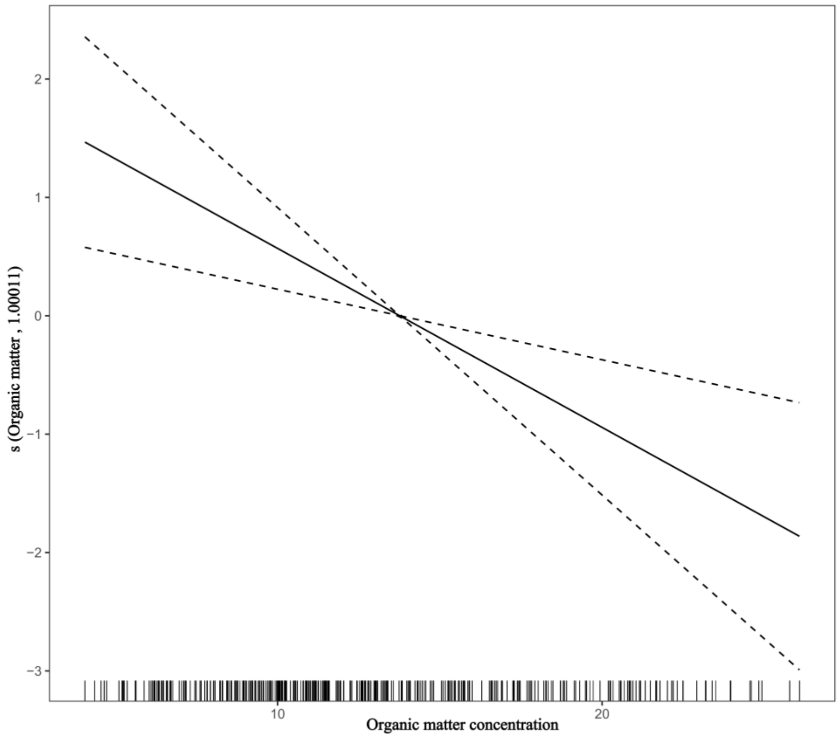
Support Figure 5 **Sulfate smoothing effect**



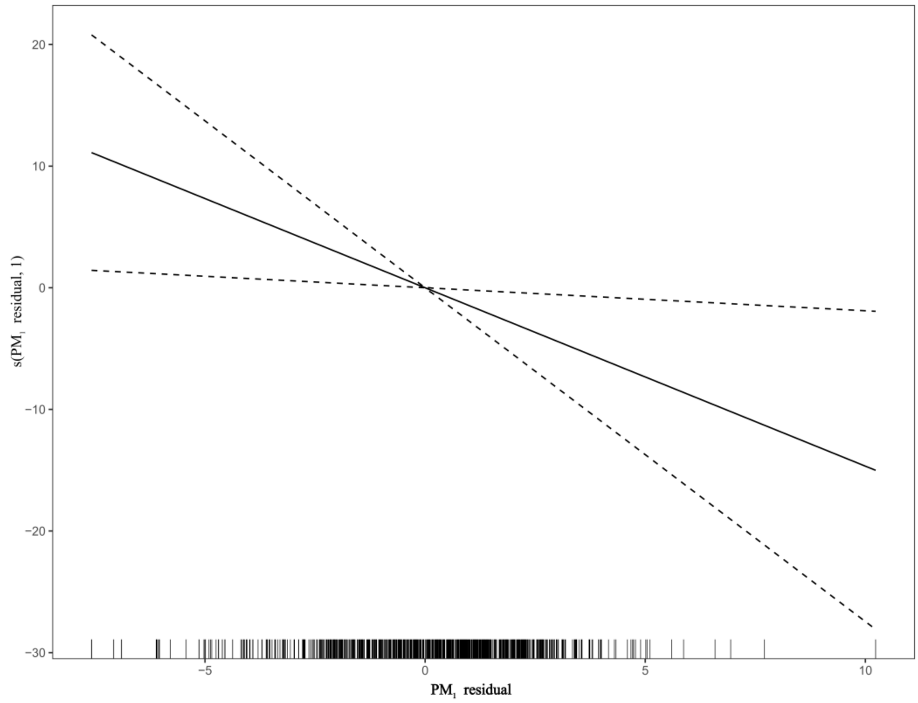
Support Figure 6 **Nitrate smoothing effect**



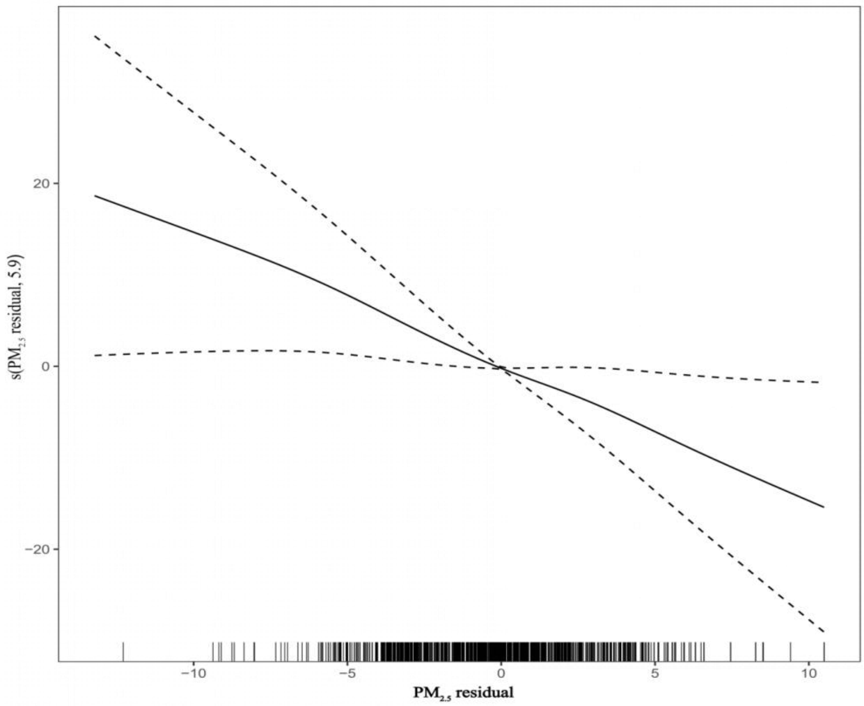
Support Figure 7 **Black carbon smoothing effect**



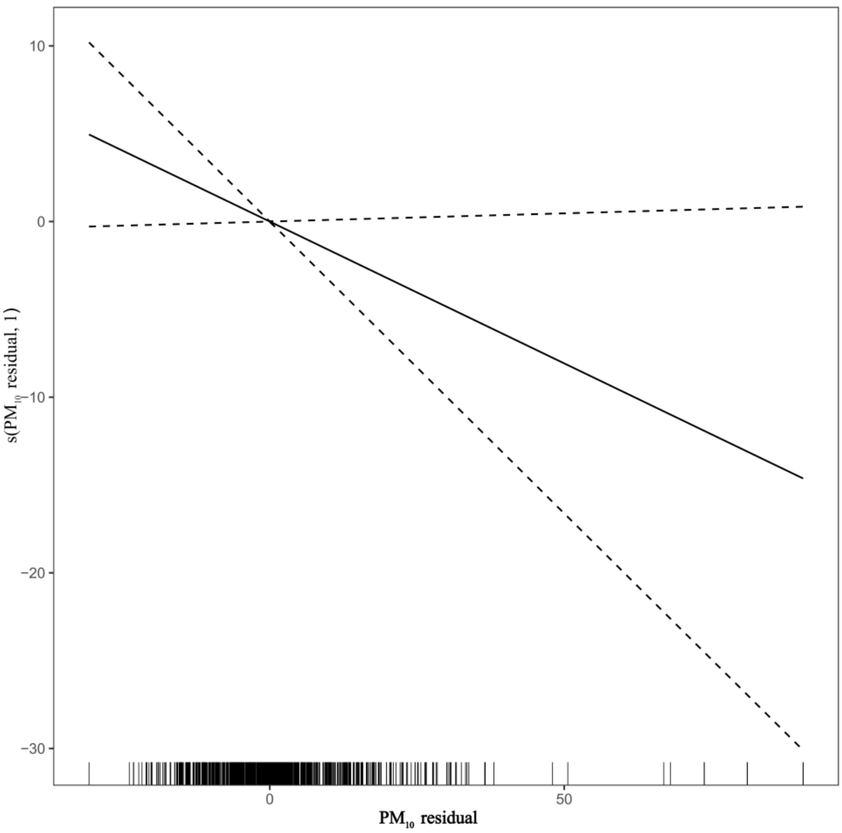
Support Figure 8 **Organic matter smoothing effect**



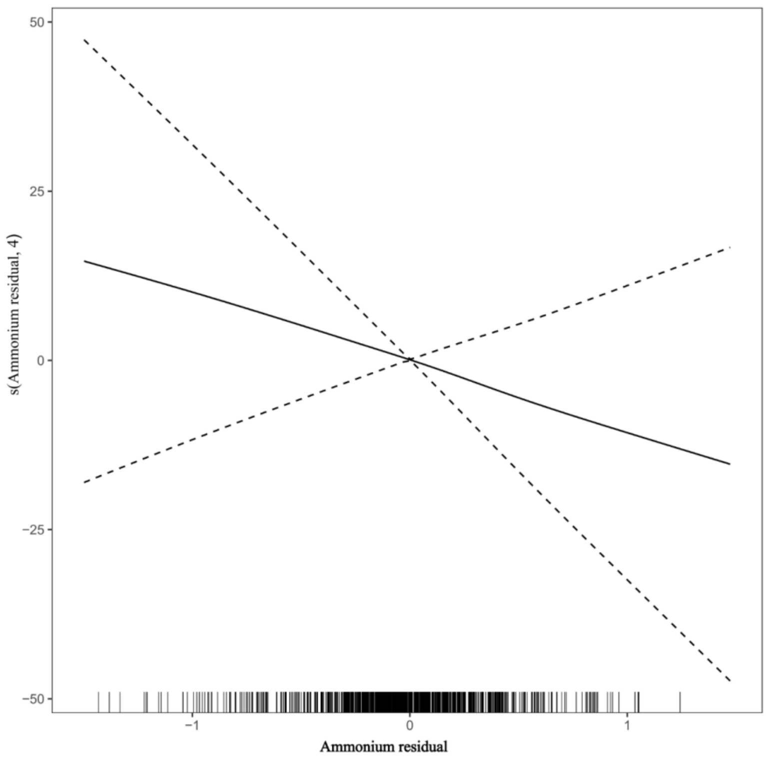
Support Figure 9 PM_1 residual smoothing effect in multi-pollution



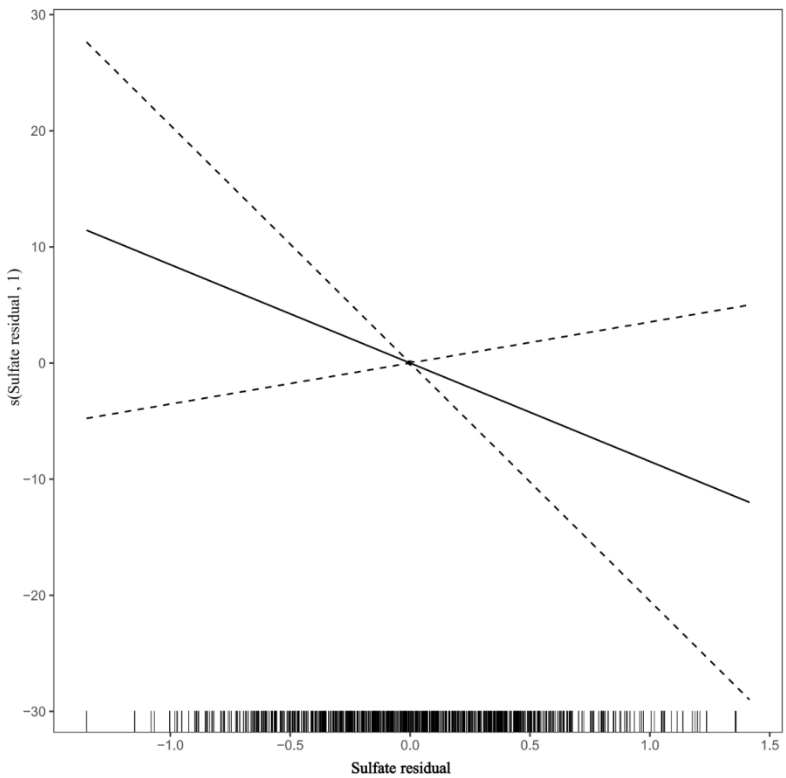
Support Figure 10 $PM_{2.5}$ residual smoothing effect in multi-pollution



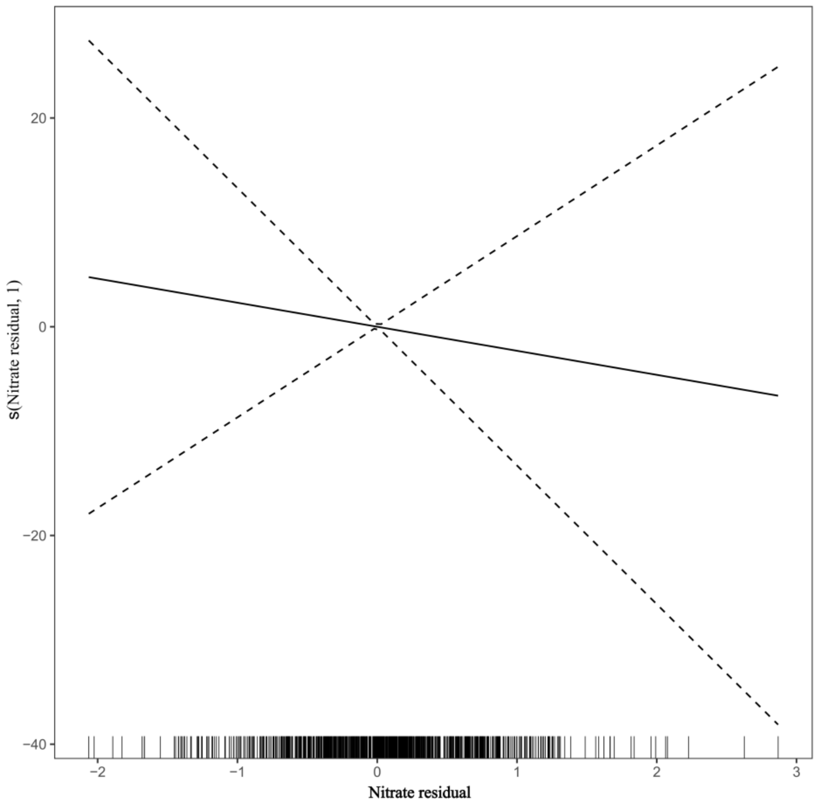
Support Figure 11 **PM_{10} residual smoothing effect in multi-pollution**



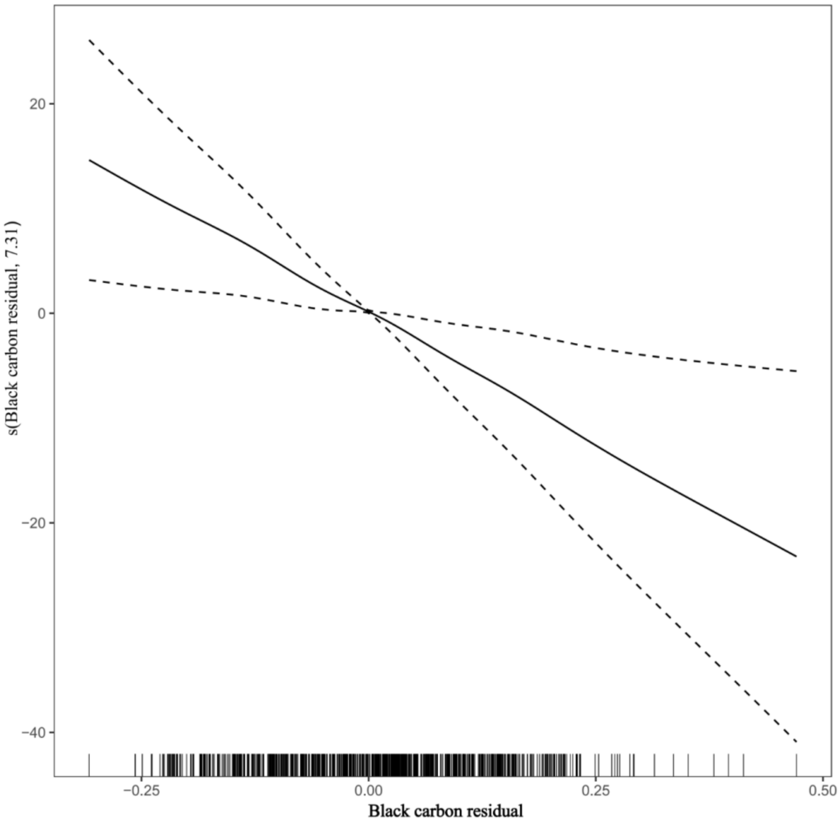
Support Figure 12 **Ammonium residual smoothing effect in multi-pollution**



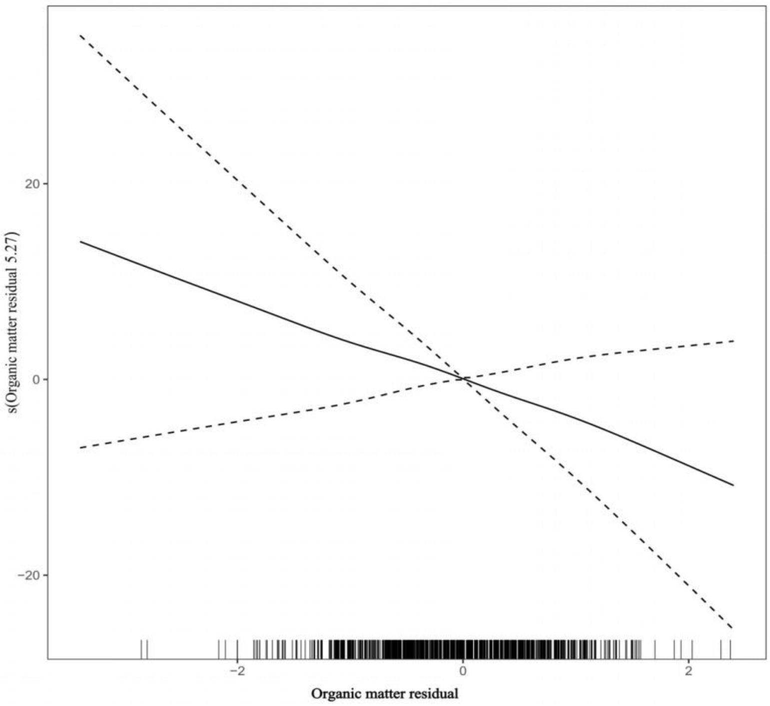
Support Figure 13 Sulfate residual smoothing effect in multi-pollution



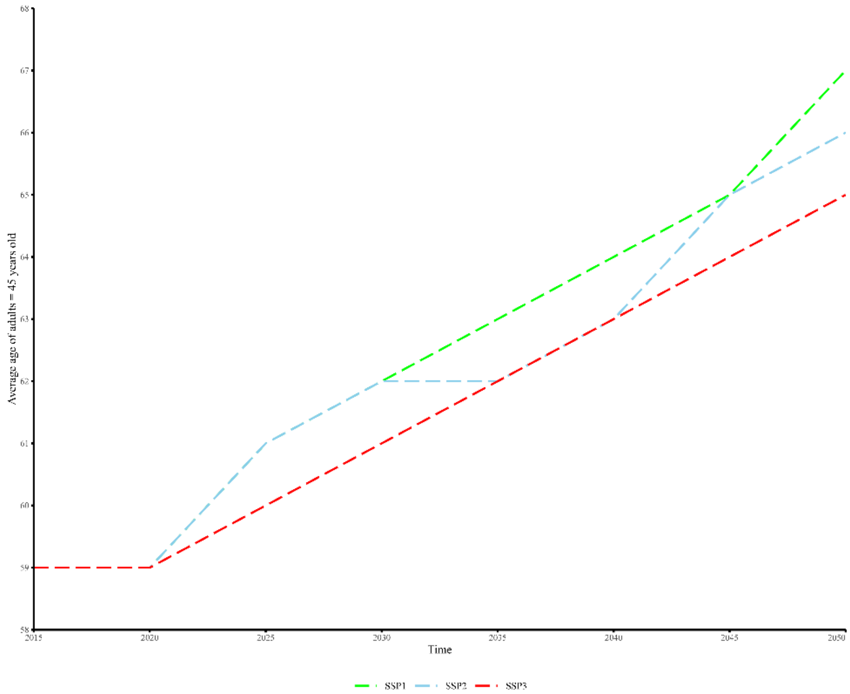
Support Figure 14 Nitrate residual smoothing effect in multi-pollution



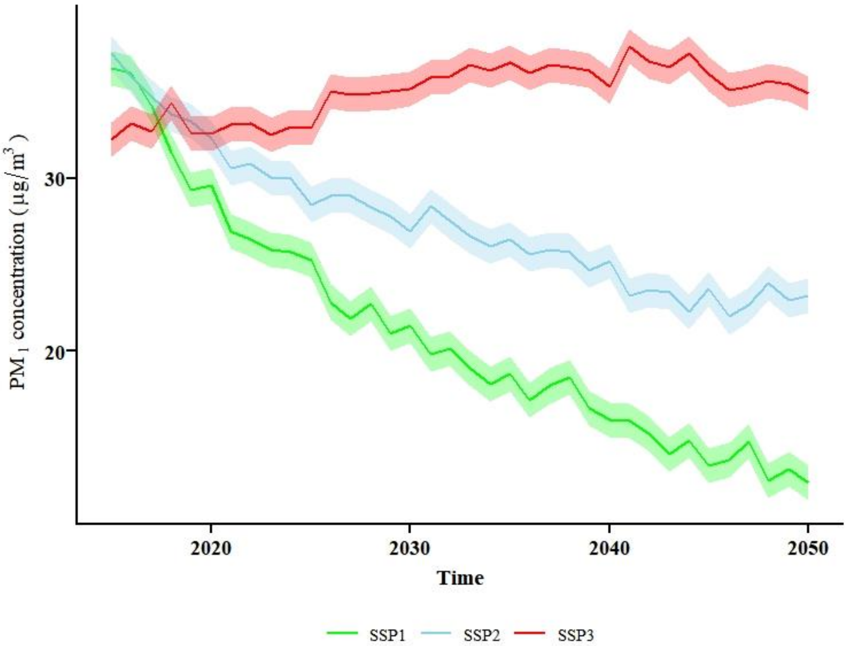
Support Figure 15 **Black carbon residual smoothing effect in multi-pollution**



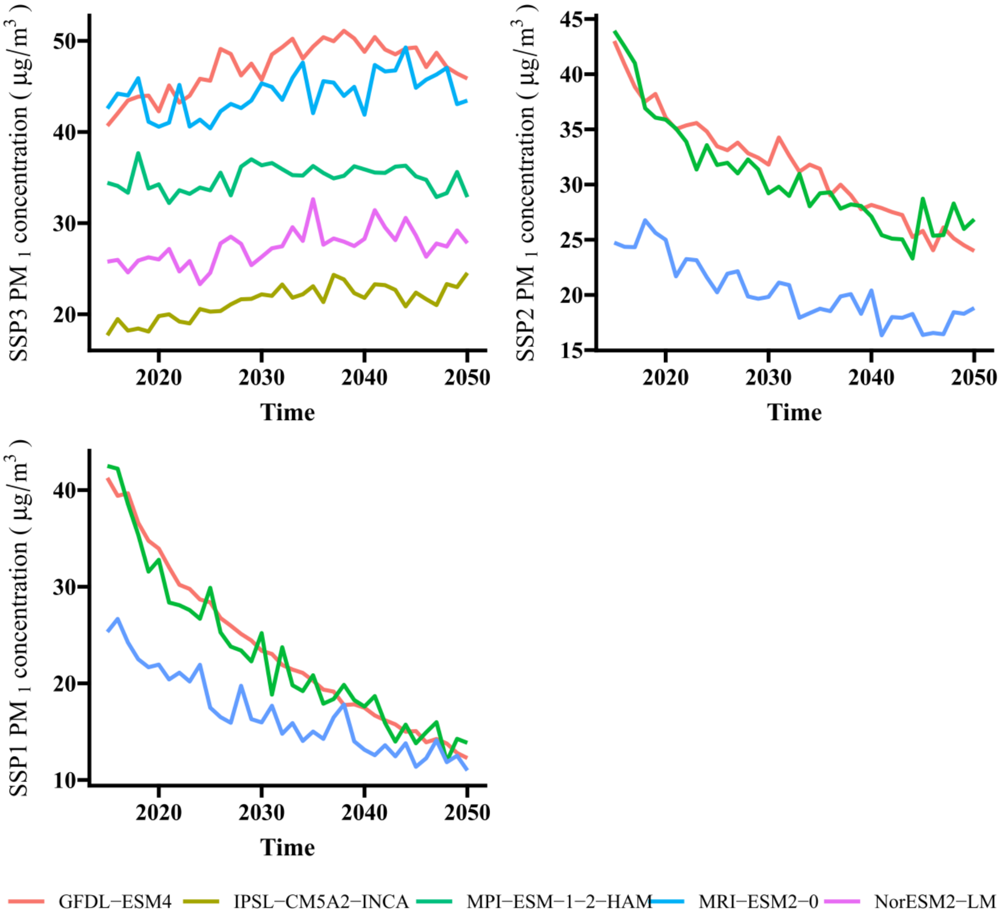
Support Figure 16 **Organic matter residual smoothing effect in multi-pollution**



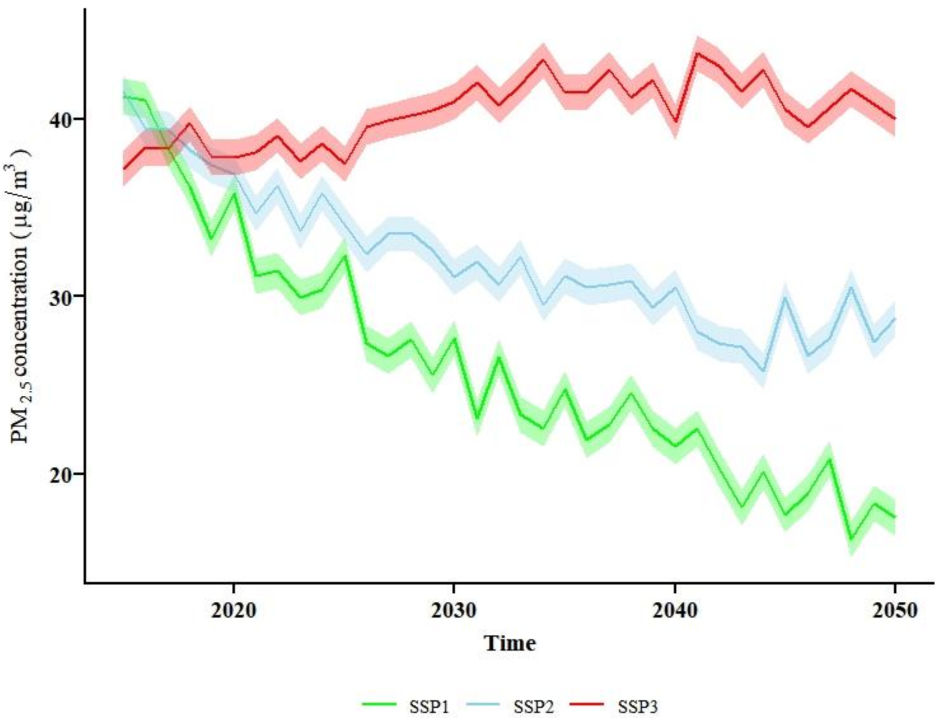
Support Figure 17 Average age of people over 45 years old in China under different SSPs



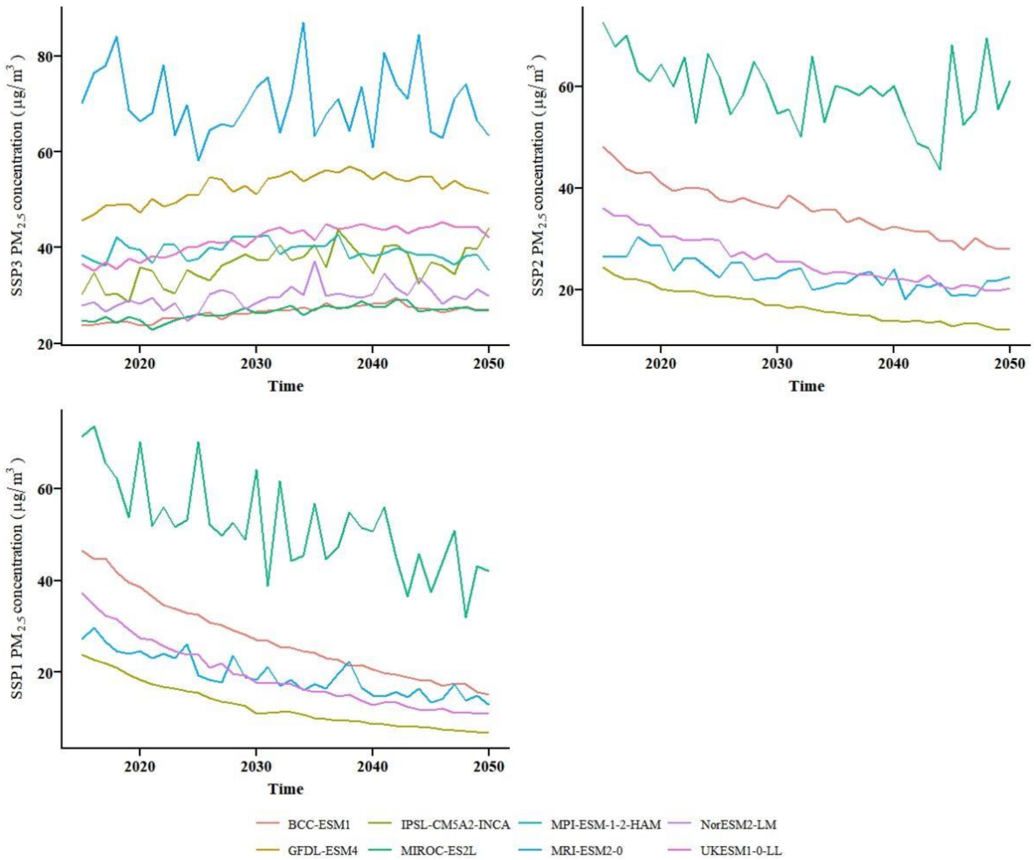
Support Figure 18 PM$_1$ predictions under different SSPs



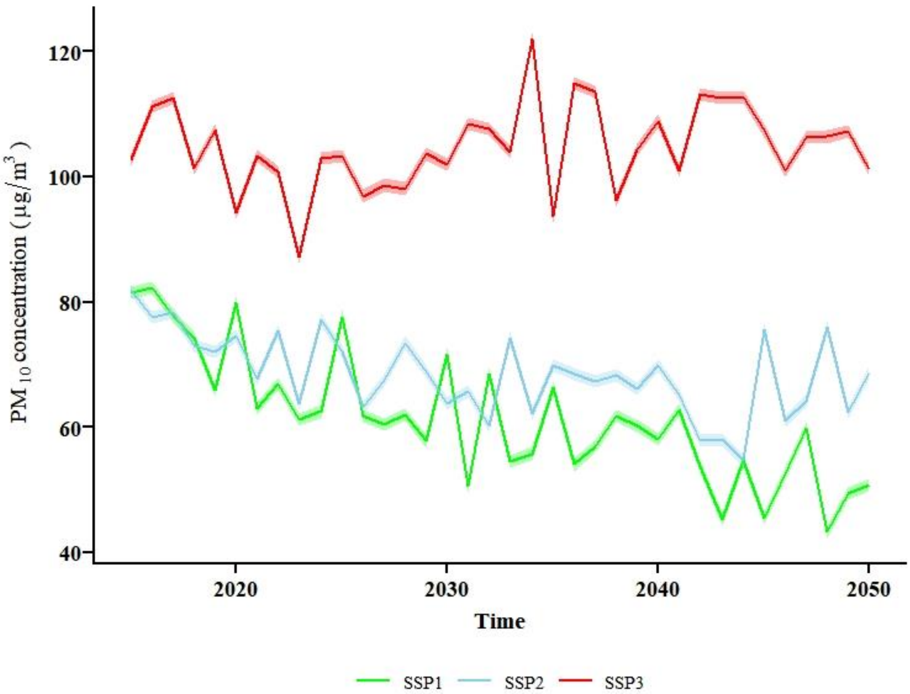
Support Figure 19 **PM_1 predictions under different SSPs and different development models**



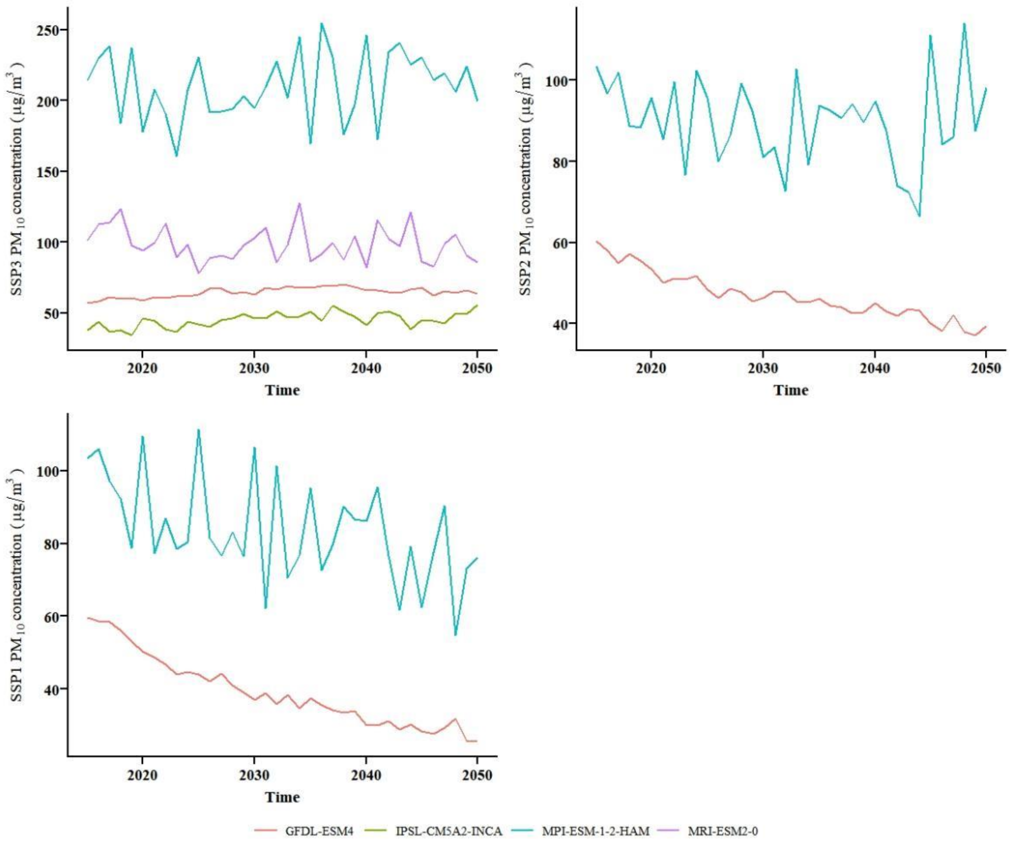
Support Figure 20 **$PM_{2.5}$ predictions under different SSPs**



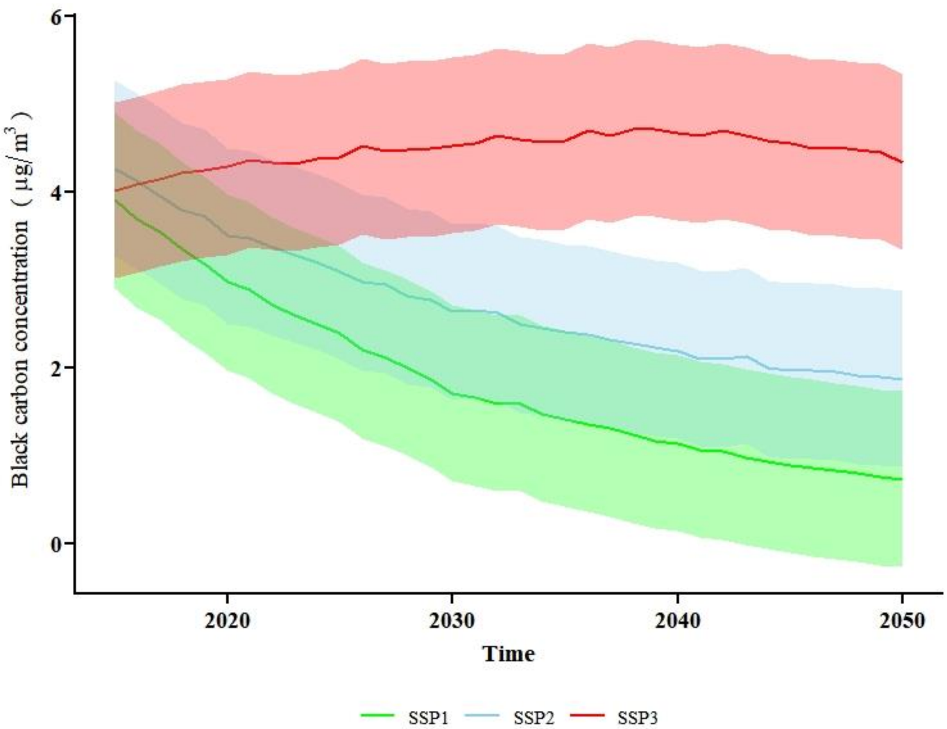
Support Figure 21 **$PM_{2.5}$ predictions under different SSPs and different development Models**



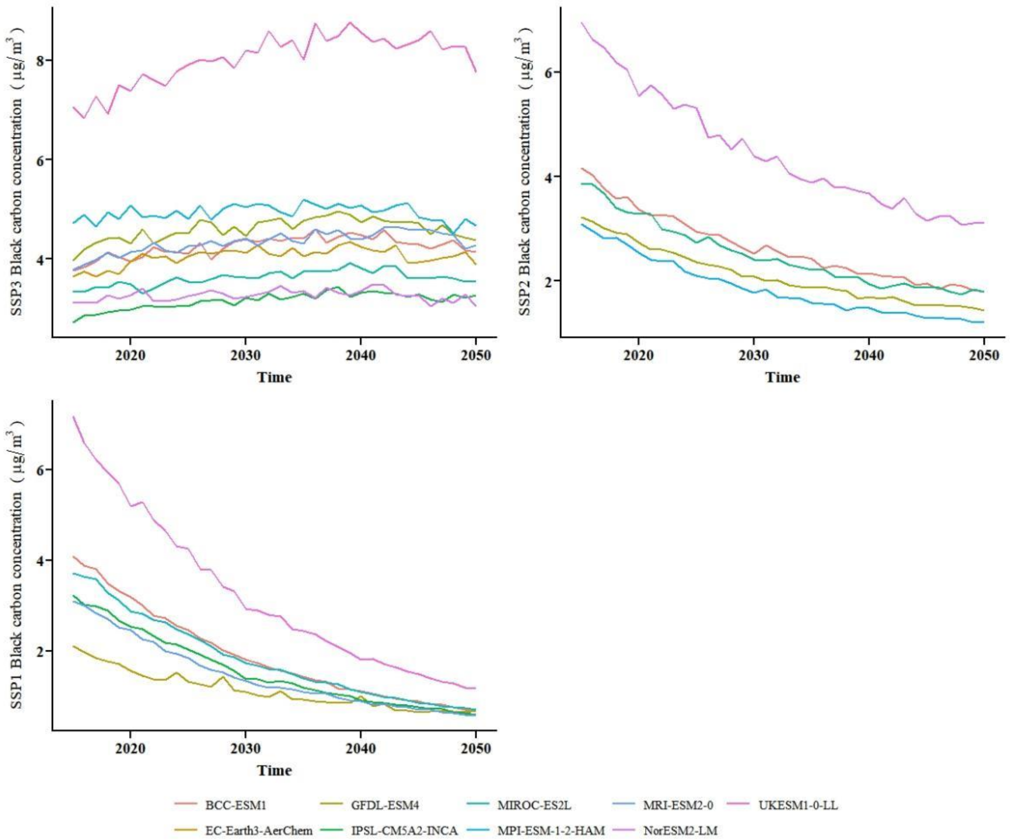
Support Figure 22 **PM_{10} predictions under different SSPs**



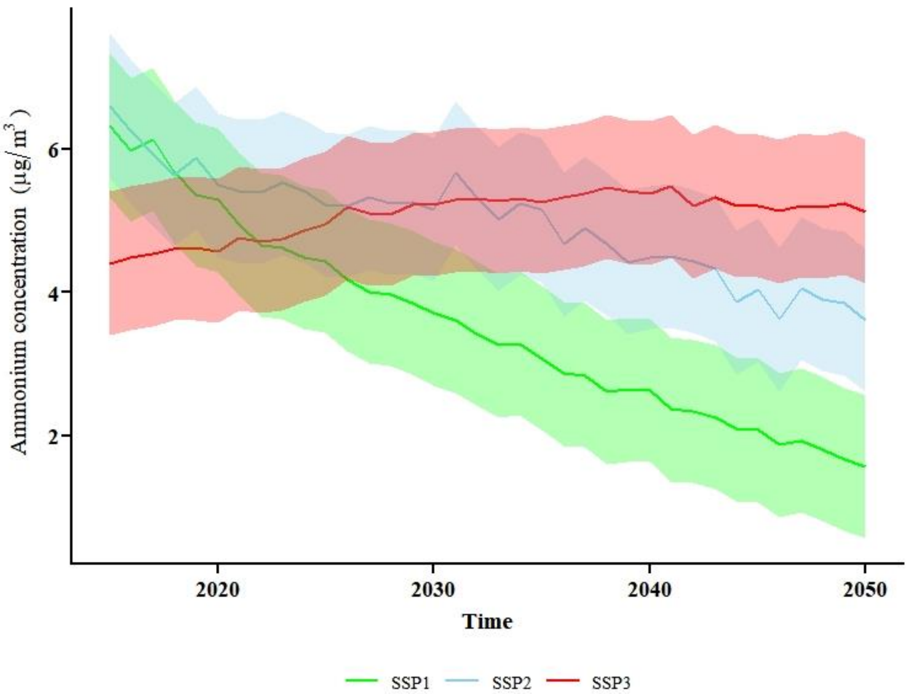
Support Figure 23 **PM$_{10}$ predictions under different SSPs and different development models**



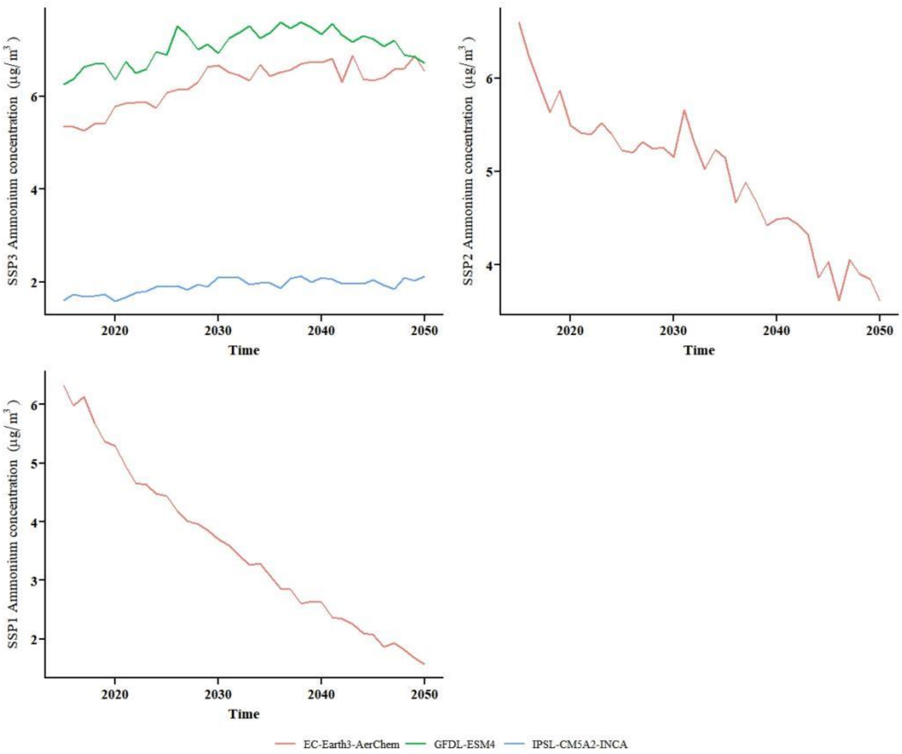
Support Figure 24 **Black carbon predictions under different SSPs**



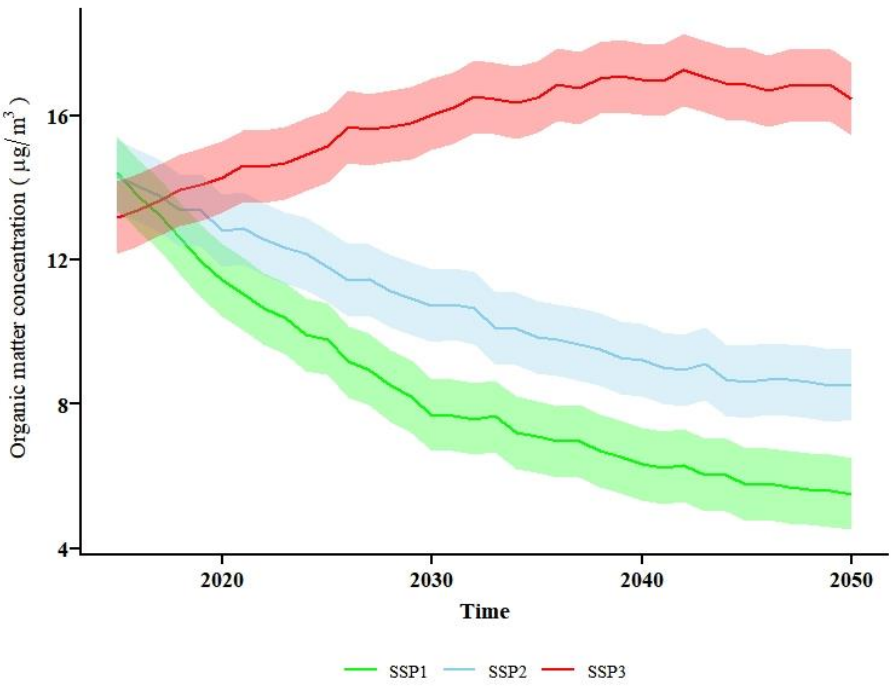
Support Figure 25 Black carbon predictions under different SSPs and different development models



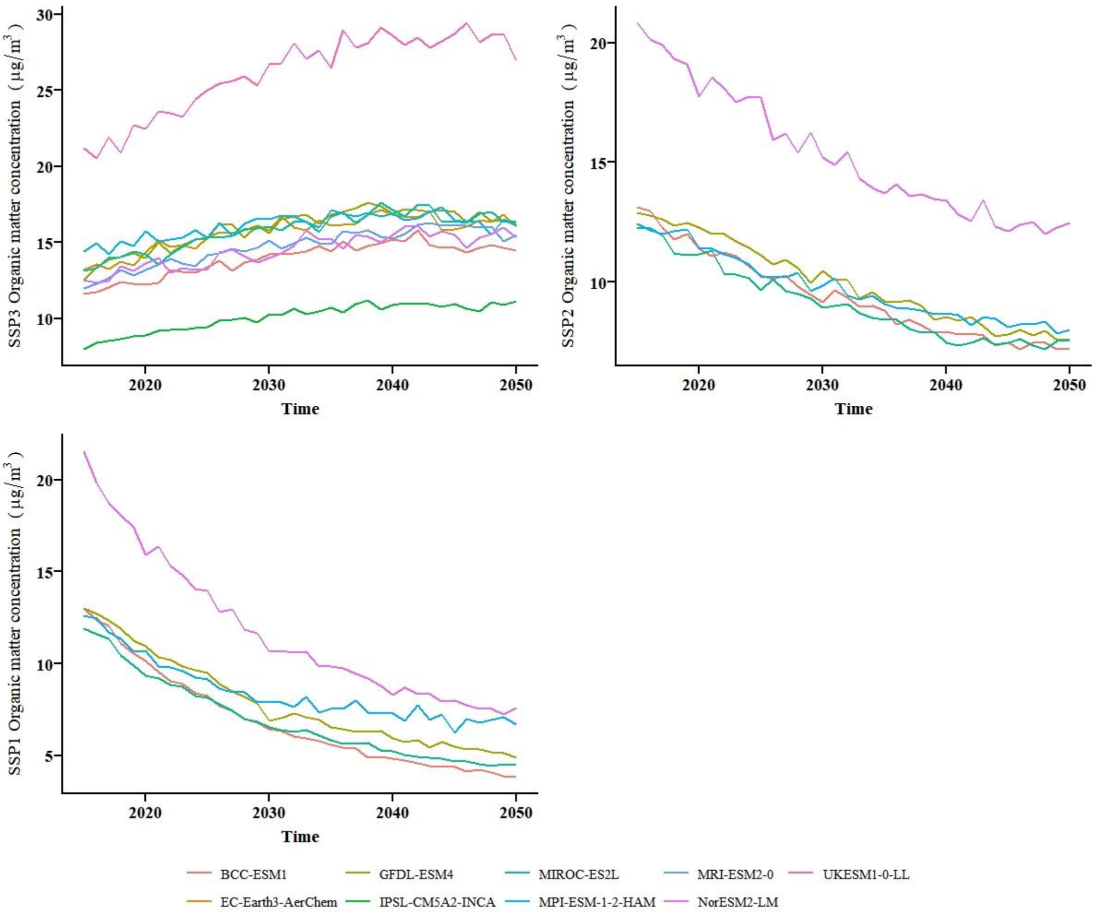
Support Figure 26 Ammonium predictions under different SSPs



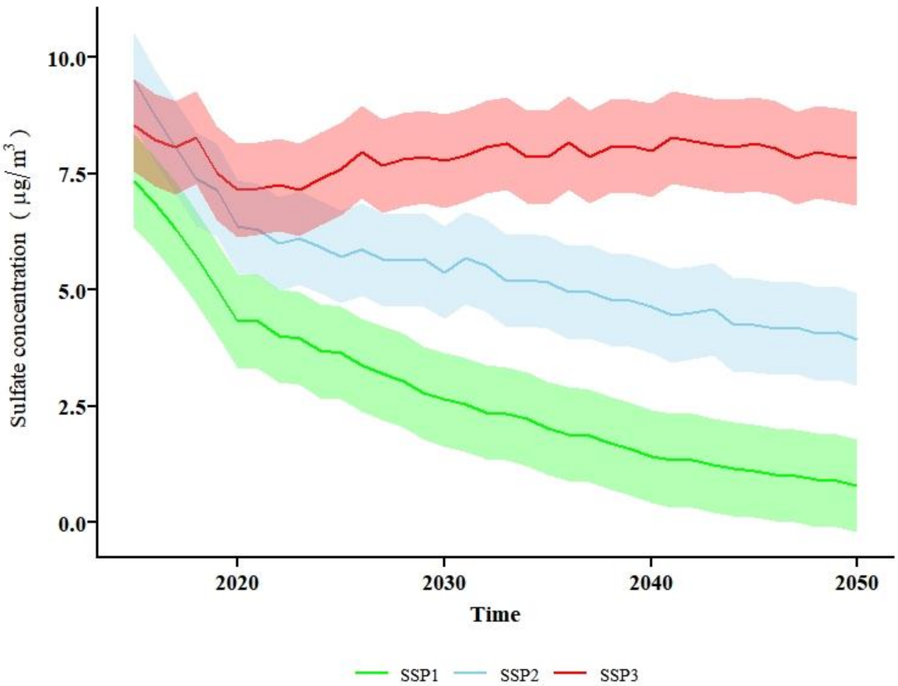
Support Figure 27 **Ammonium predictions under different SSPs and different development models**



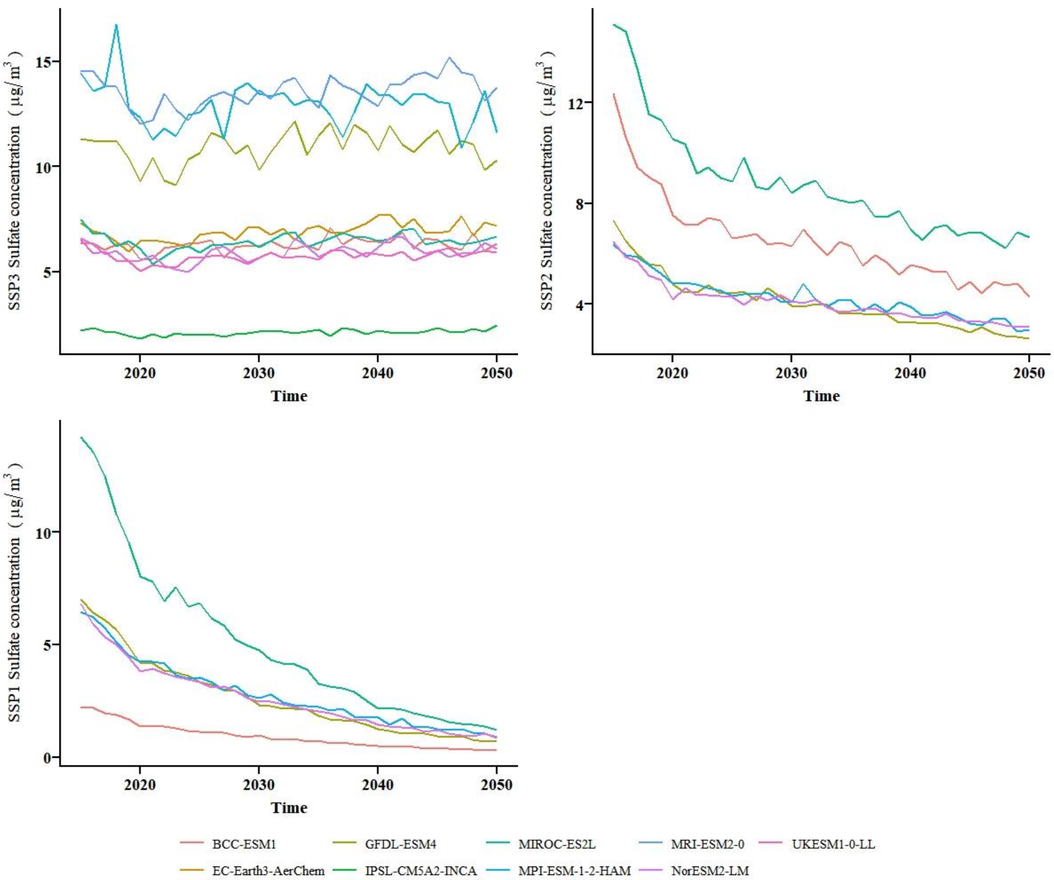
Support Figure 28 **Organic matter predictions under different SSPs**



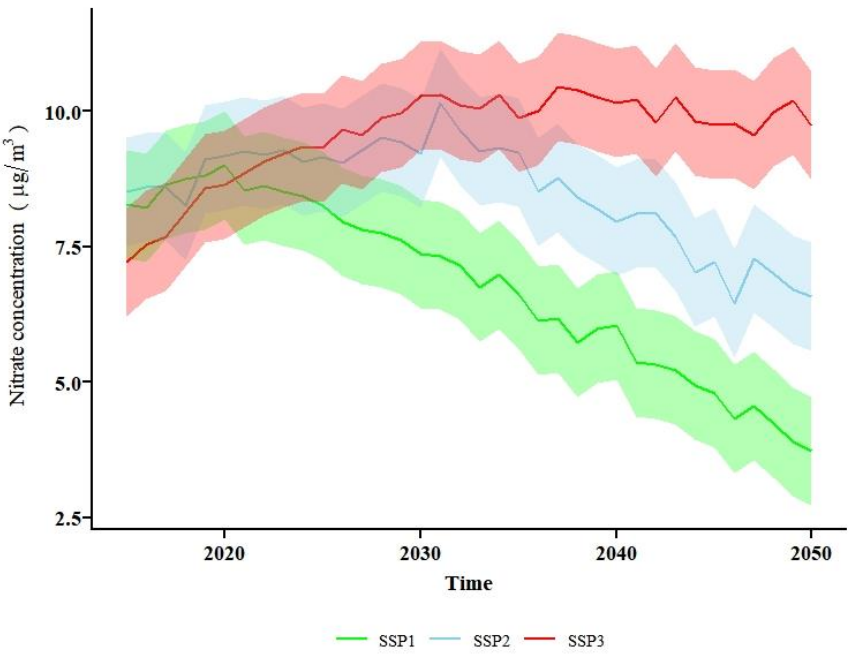
Support Figure 29 **Organic matter predictions under different SSPs and different development models**



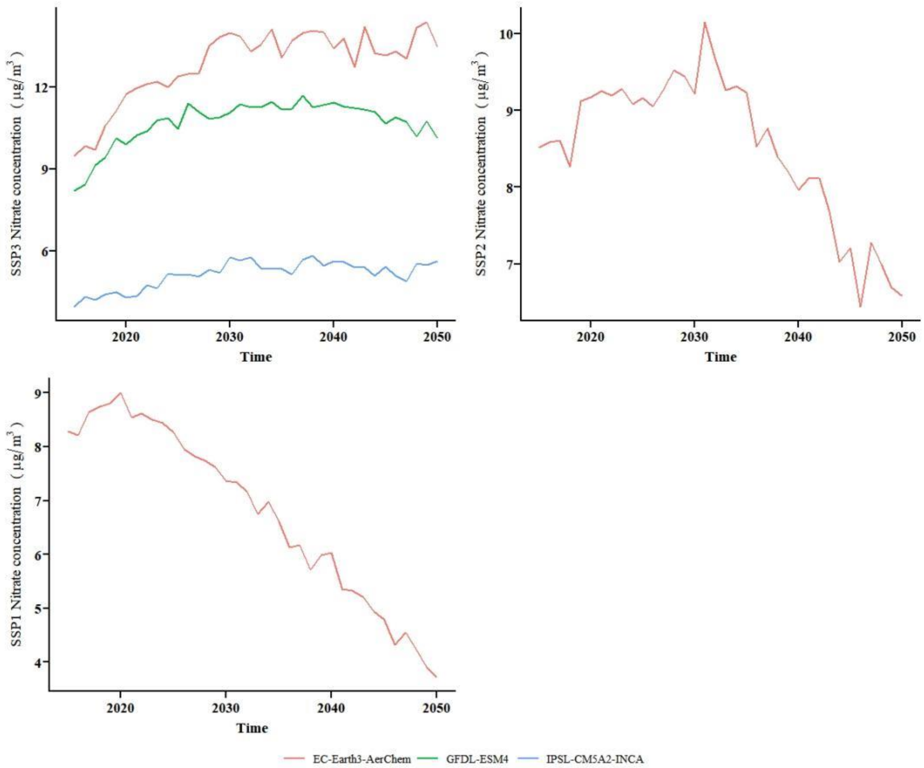
Support Figure 30 **Sulfate predictions under different SSPs**



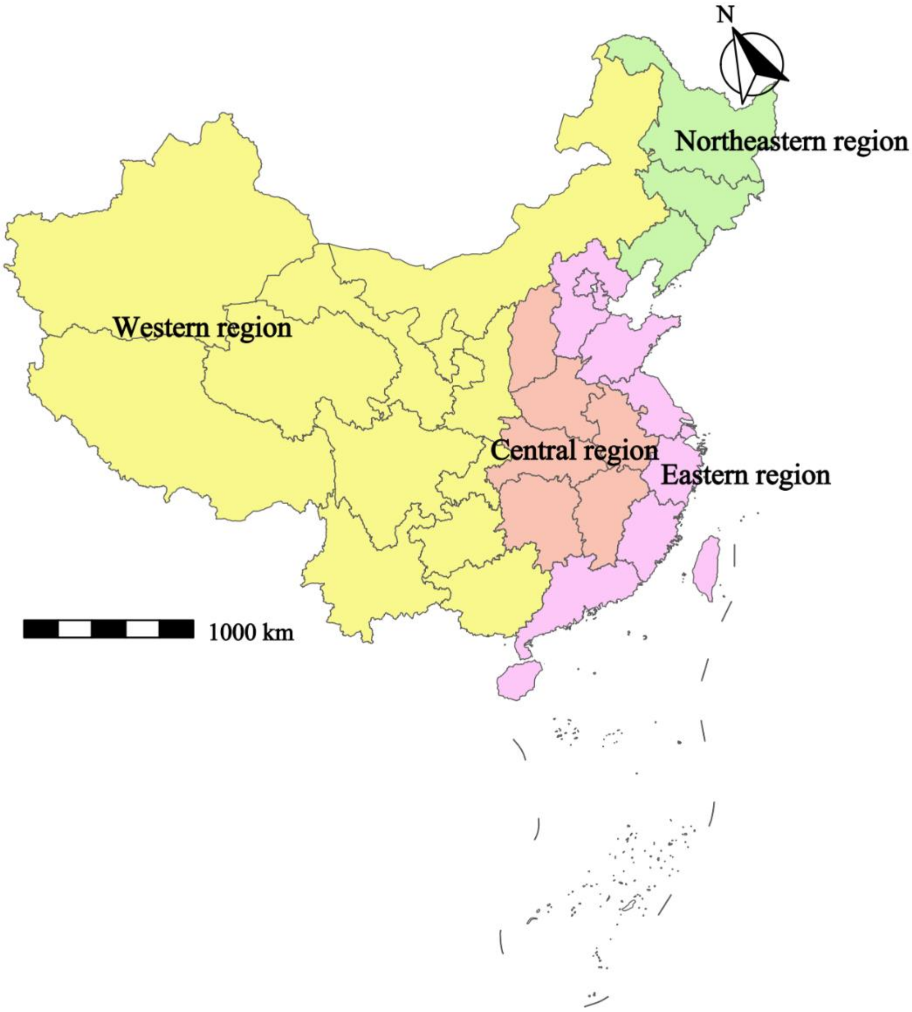
Support Figure 31 **Sulfate predictions under different SSPs and different development models**



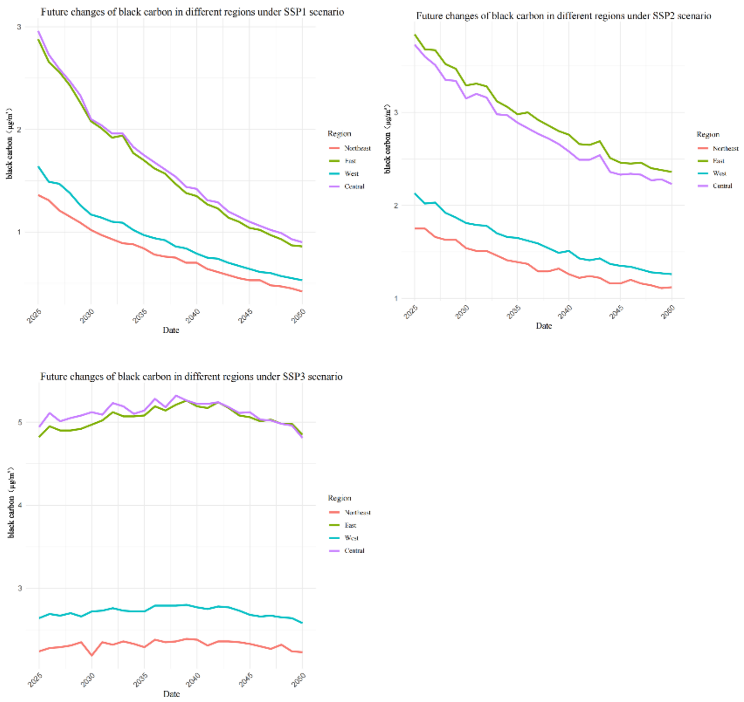
Support Figure 32 **Nitrate predictions under different SSPs**



Support Figure 33 Nitrate predictions under different SSPs and different development models

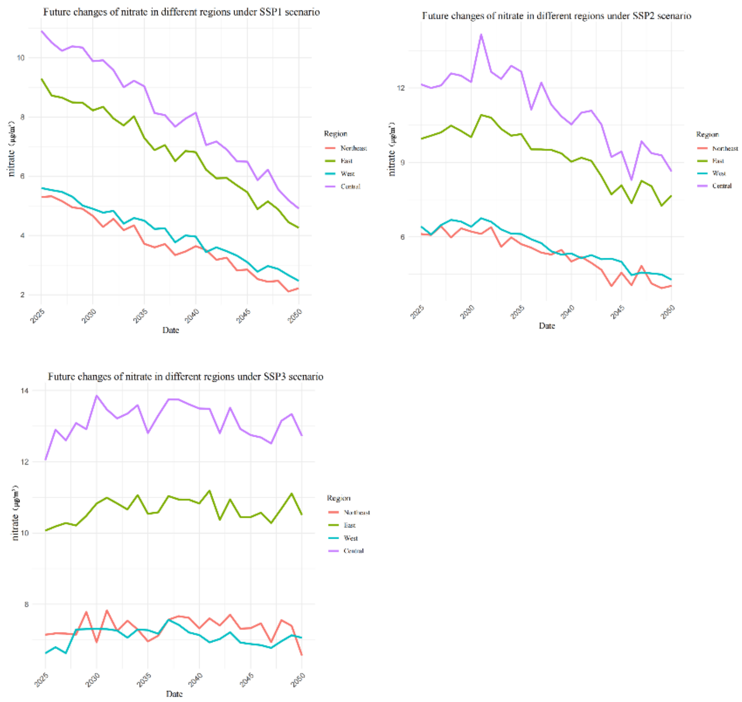


Support Figure 34 China's four major geographical regions (To scientifically reflect the socio-economic development status of different regions in China and provide a basis for formulating regional development policies, the Chinese government has divided the country's economic regions into four major areas: the eastern, central, western, and northeastern regions.)

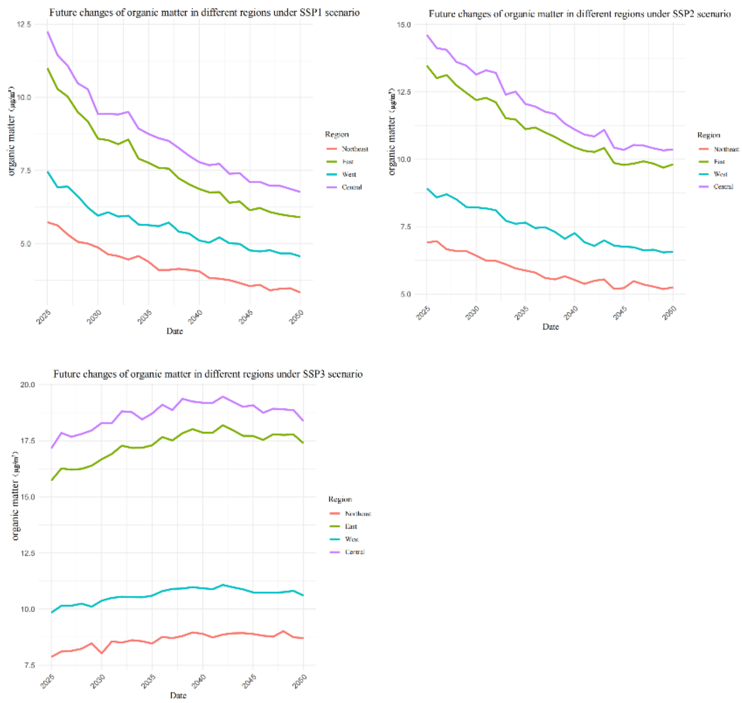


Support Figure 35 Changes in black carbon concentrations in four major geographical regions of China under SSP1, SSP2 and SSP3 scenarios

Support Figure 36 Changes in ammonium concentrations in four major geographical regions of China under SSP1, SSP2 and SSP3 scenarios

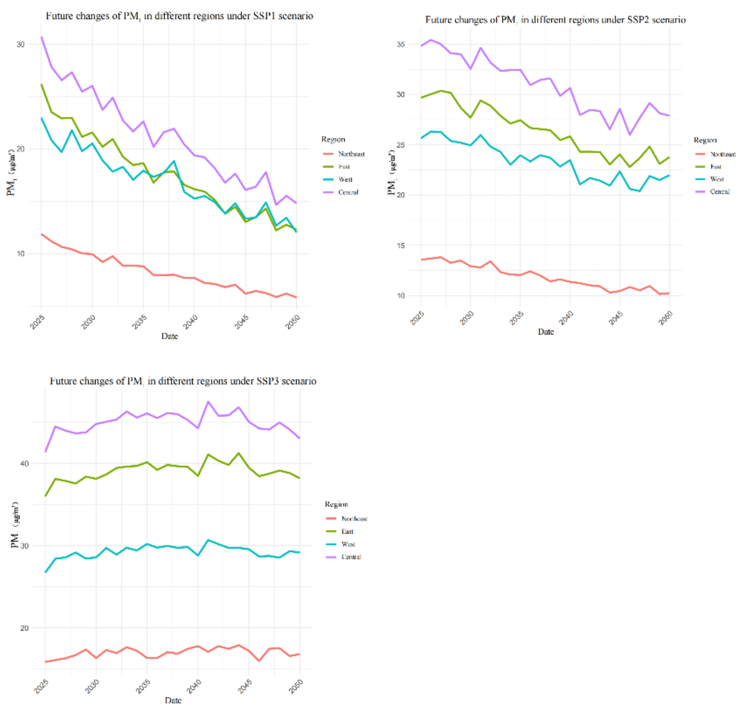


Support Figure 37 Changes in nitrate concentrations in four major geographical regions of China under SSP1, SSP2 and SSP3 scenarios

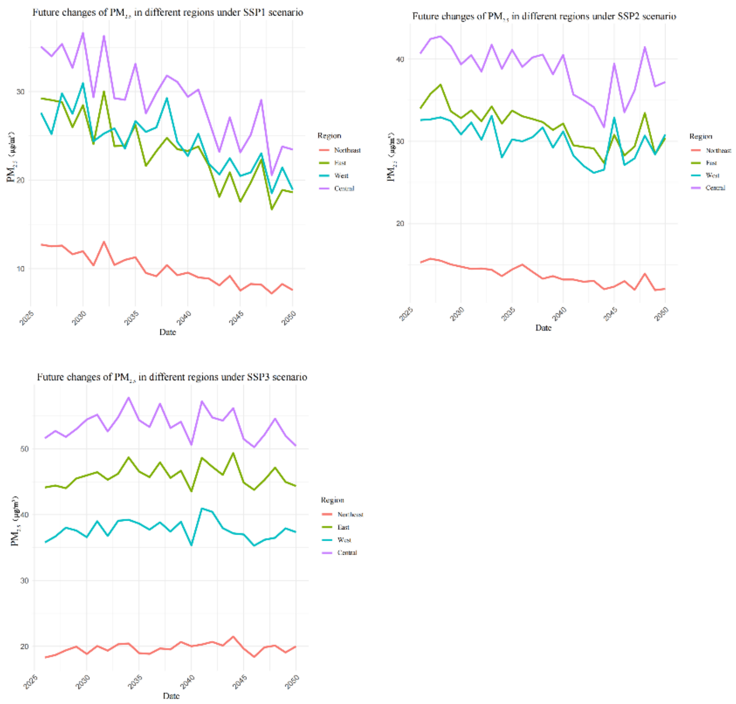


Support Figure 38 Changes in organic matter in four major geographical regions of China under SSP1, SSP2 and SSP3 scenarios

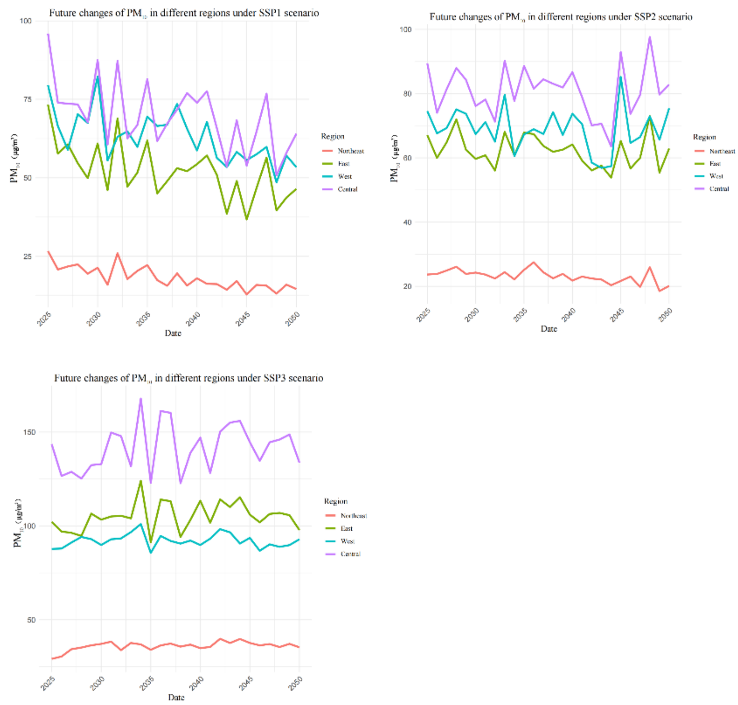
Support Figure 39 Changes in sulfate in four major geographical regions of China under SSP1, SSP2 and SSP3 scenarios



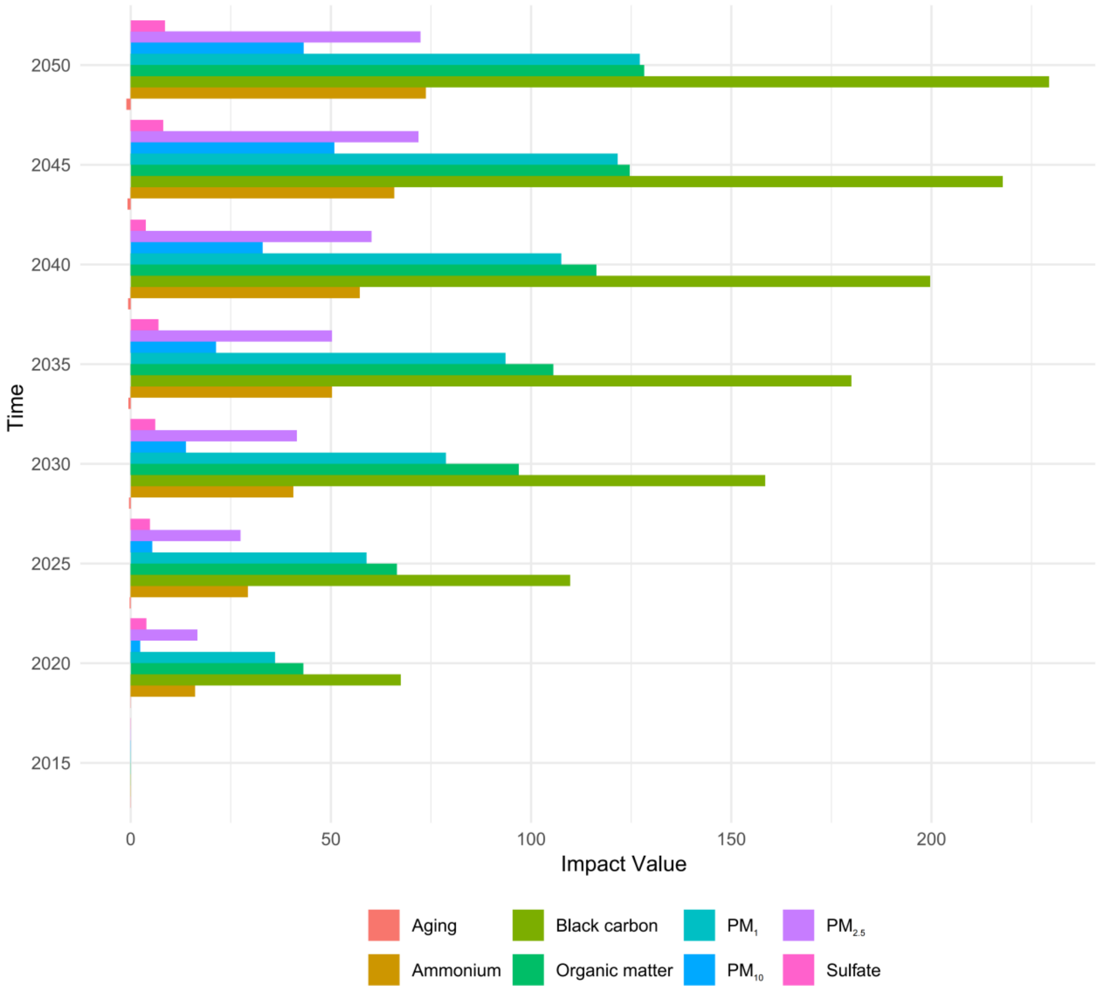
Support Figure 40 Changes in PM_1 in four major geographical regions of China under SSP1, SSP2 and SSP3 scenarios



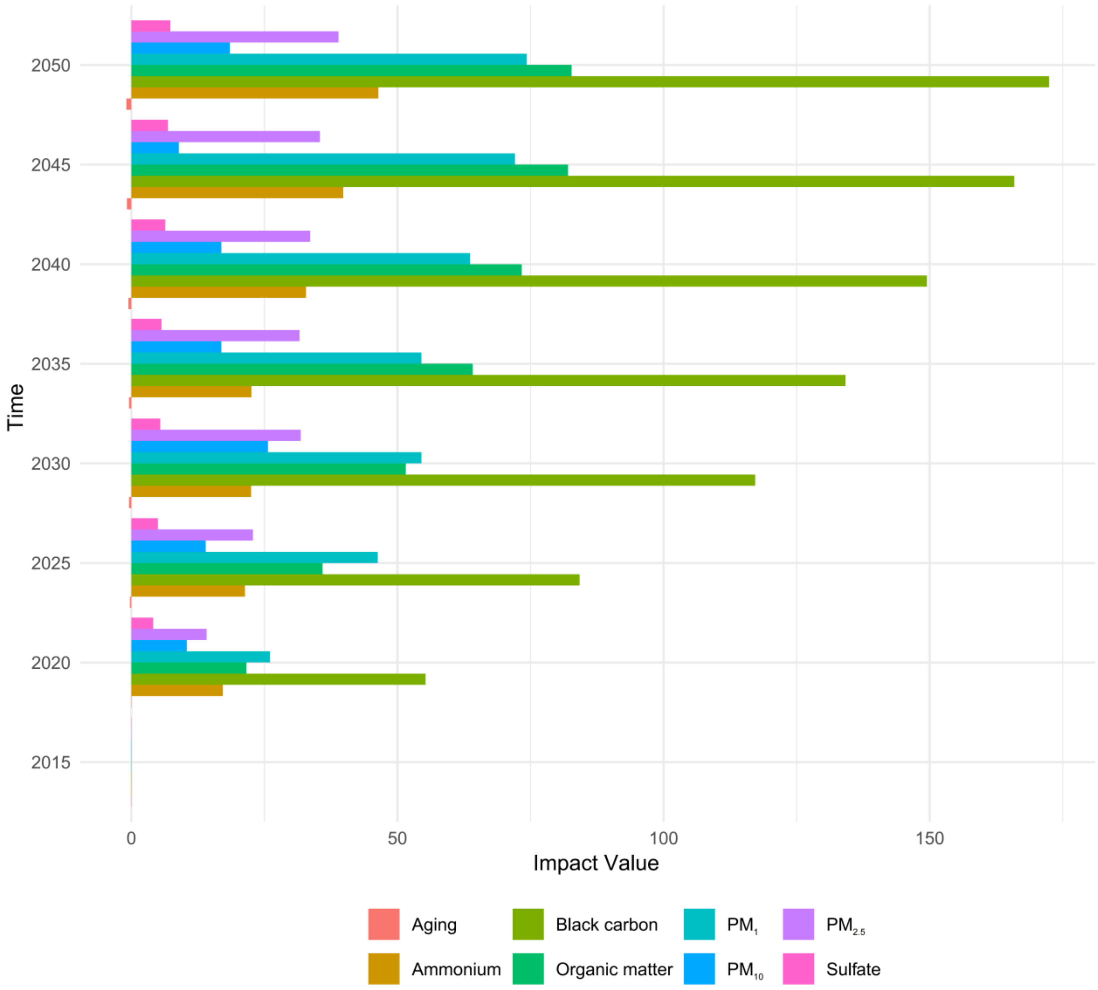
Support Figure 41 **Changes in $PM_{2.5}$ in four major geographical regions of China under SSP1, SSP2 and SSP3 scenarios**



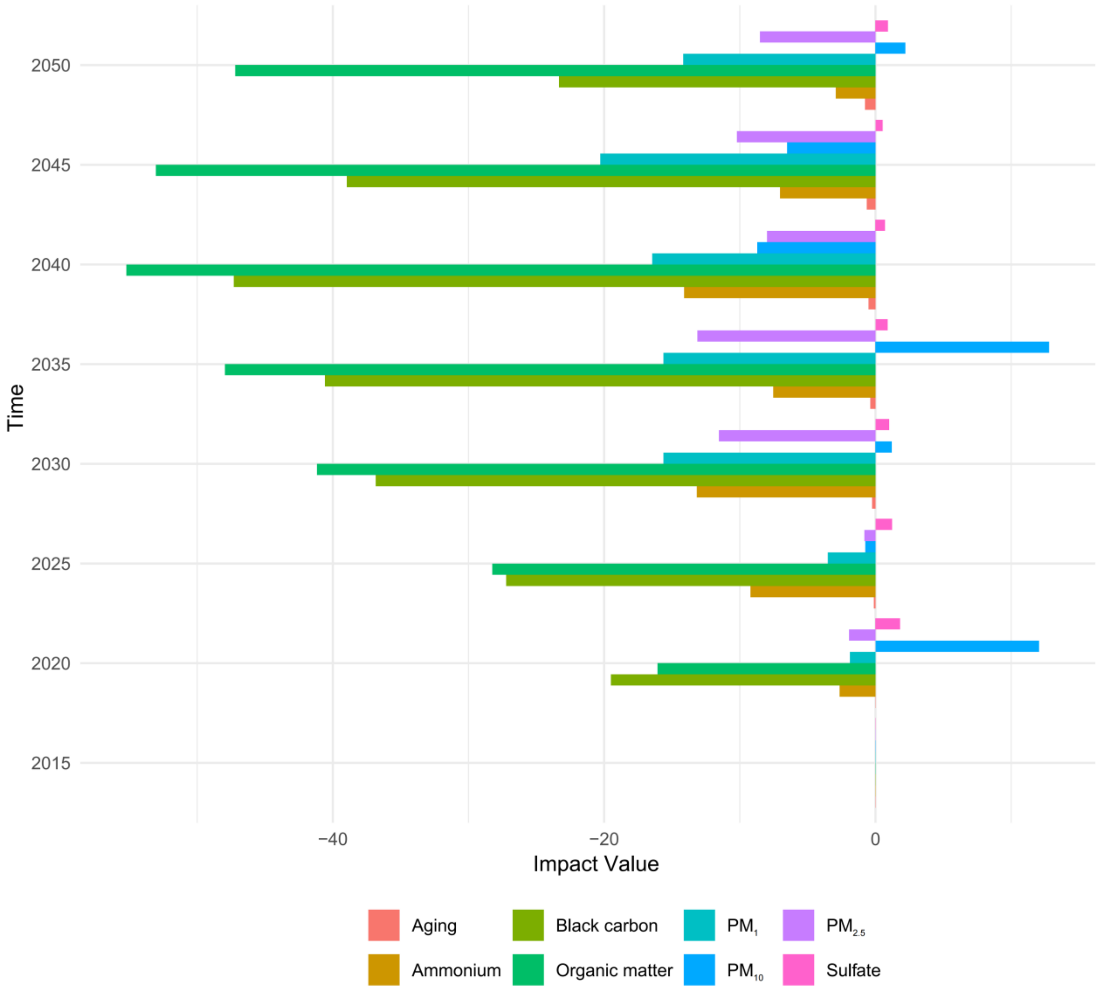
Support Figure 42 **Changes in PM_{10} in four major geographical regions of China under SSP1, SSP2 and SSP3 scenarios**



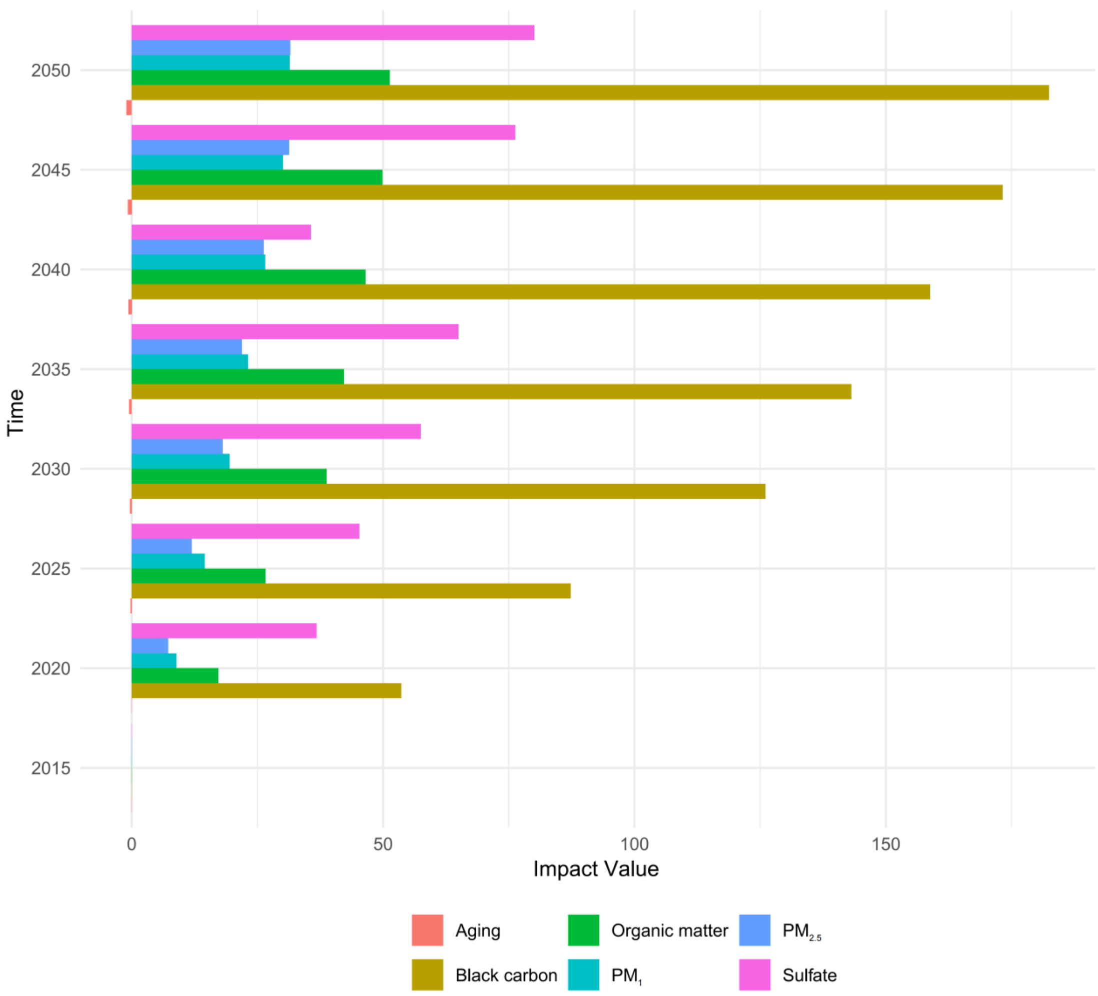
Support Figure 43 Comparison of the impact of aging and pollutant changes on cognition under SSP1



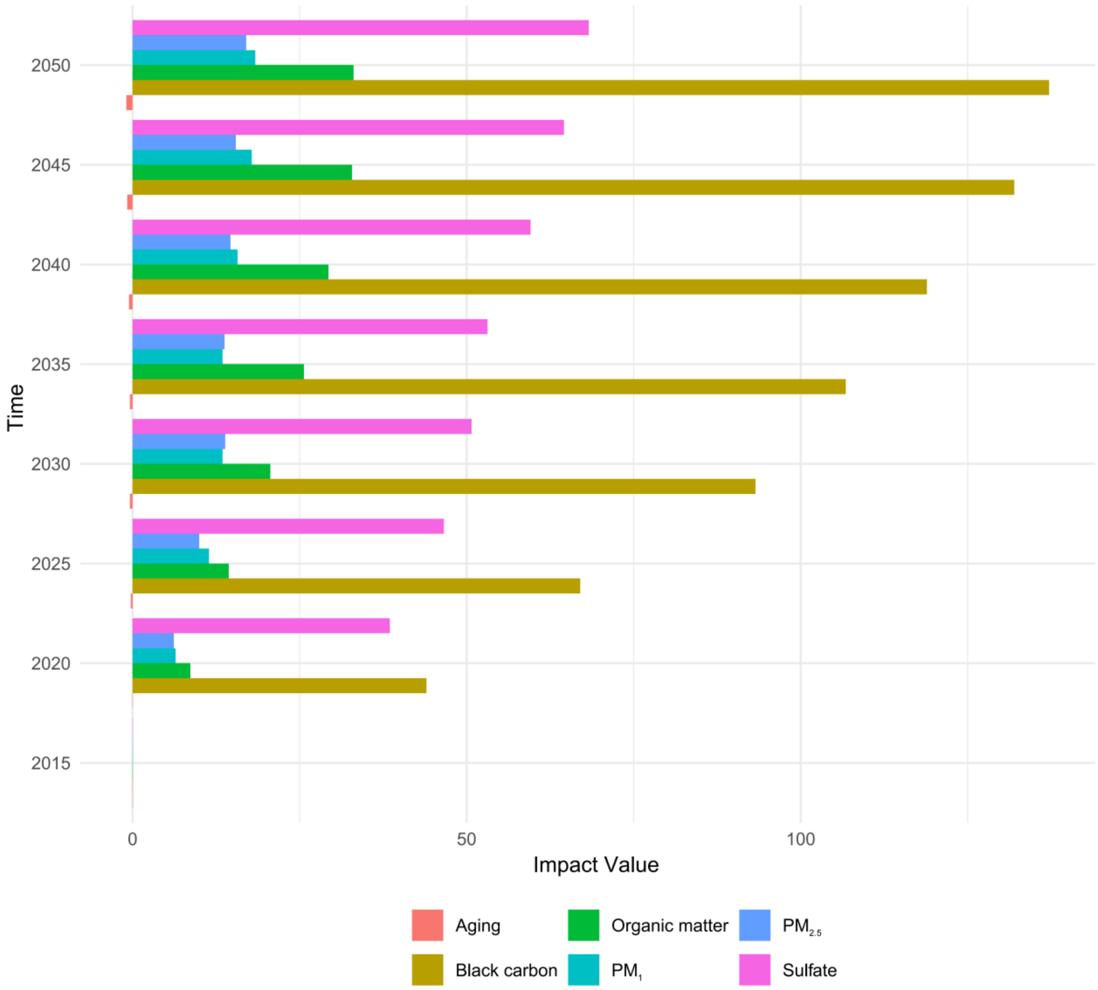
Support Figure 44 Comparison of the impact of aging and pollutant changes on cognition under SSP2



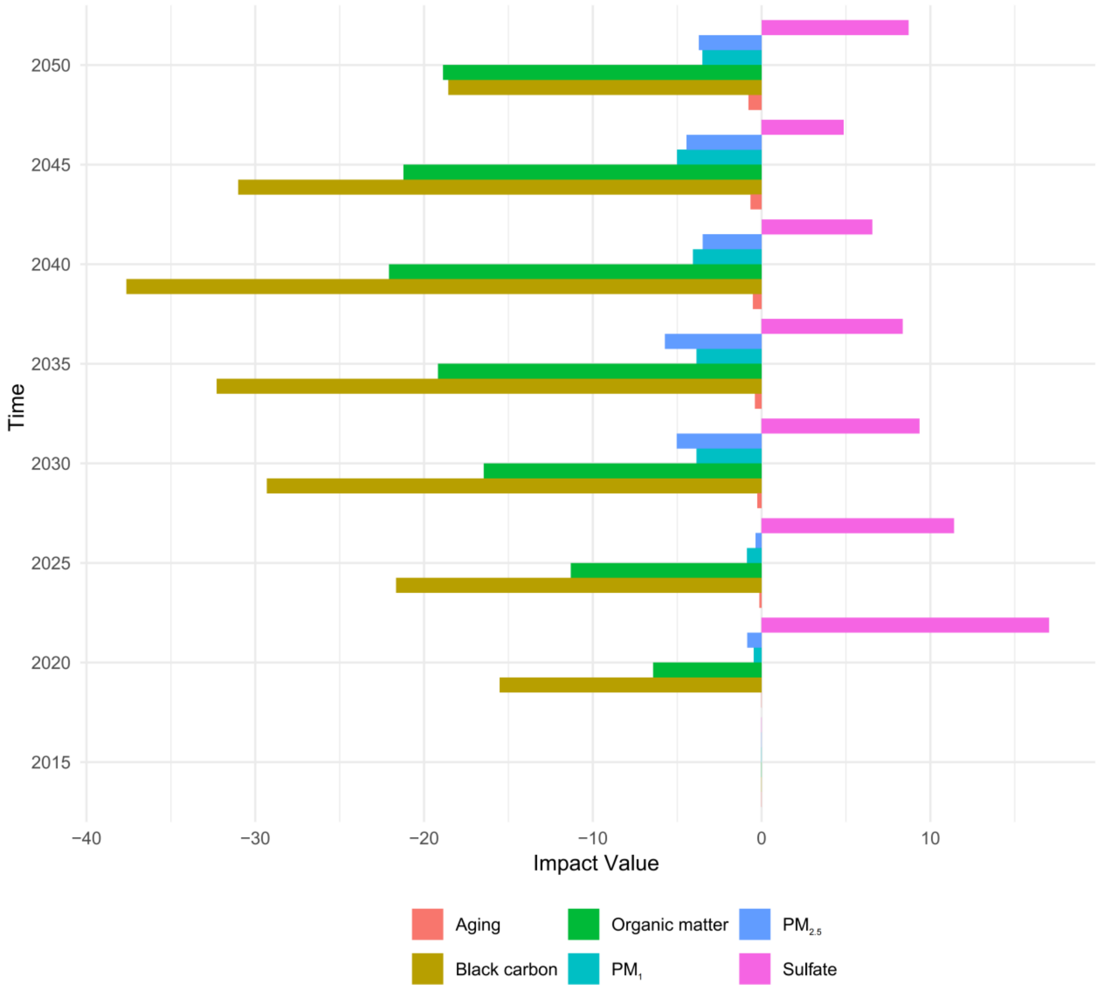
Support Figure 45 **Comparison of the impact of aging and pollutant changes on cognition under SSP3**



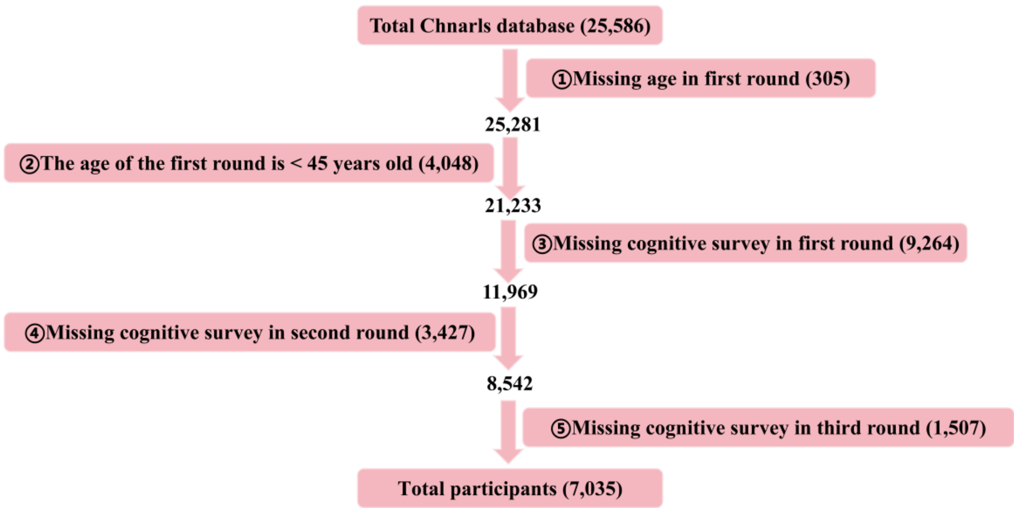
Support Figure 46 **Comparison of the impact of aging and pollutant changes on cognition under SSP1 in multi-pollutant model**



Support Figure 47 Comparison of the impact of aging and pollutant changes on cognition under SSP2 in multi-pollutant model



Support Figure 48 **Comparison of the impact of aging and pollutant changes on cognition under SSP3 in multi-pollutant model**



Support Figure 49 **Inclusion and exclusion flow chart**

Reference:

1 Wu, T. *et al.* Beijing Climate Center Earth System Model version 1 (BCC-ESM1): model description and evaluation of aerosol simulations. *Geoscientific Model Development* **13**, 977-1005 (2020).

2 Danabasoglu, G. *et al.* The community earth system model version 2 (CESM2). *Journal of Advances in Modeling Earth Systems* **12**, e2019MS001916 (2020).

3 Van Noije, T. *et al.* EC-Earth3-AerChem, a global climate model with interactive aerosols and atmospheric chemistry participating in CMIP6. *Geoscientific Model Development Discussions* **2020**, 1-46 (2020).

4 Huijnen, V. *et al.* The global chemistry transport model TM5: description and evaluation of the tropospheric chemistry version 3.0. *Geoscientific Model Development* **3**, 445-473 (2010).

5 Krol, M. *et al.* The two-way nested global chemistry-transport zoom model TM5: algorithm and applications. *Atmospheric Chemistry and Physics Discussions* **4**, 3975-4018 (2004).

6 Dunne, J. P. *et al.* The GFDL Earth System Model version 4.1 (GFDL-ESM 4.1): Overall coupled model description and simulation characteristics. *Journal of Advances in Modeling Earth Systems* **12**, e2019MS002015 (2020).

7 Horowitz, L. W. *et al.* The GFDL global atmospheric chemistry-climate model AM4. 1: Model description and simulation characteristics. *Journal of Advances in Modeling Earth Systems* **12**, e2019MS002032 (2020).

8 Sepulchre, P. *et al.* IPSL-CM5A2–an Earth system model designed for multi-millennial climate simulations. *Geoscientific Model Development* **13**, 3011-3053 (2020).

9 Szopa, S. *et al.* Aerosol and ozone changes as forcing for climate evolution between 1850 and 2100. *Climate dynamics* **40**, 2223-2250 (2013).

10 Hajima, T. *et al.* Development of the MIROC-ES2L Earth system model and the evaluation of biogeochemical processes and feedbacks. *Geoscientific Model Development* **13**, 2197-2244 (2020).

11 Takemura, T. *et al.* A simulation of the global distribution and radiative forcing of soil dust aerosols at the Last Glacial Maximum. *Atmospheric Chemistry and Physics* **9**, 3061-3073 (2009).

12 Takemura, T., Nozawa, T., Emori, S., Nakajima, T. Y. & Nakajima, T. Simulation of climate response to aerosol direct and indirect effects with aerosol transport-radiation model. *Journal of Geophysical Research: Atmospheres* **110** (2005).

13 Takemura, T. *et al.* Global three-dimensional simulation of aerosol optical thickness distribution of various origins. *Journal of Geophysical Research: Atmospheres* **105**, 17853-17873 (2000).

14 Tegen, I. *et al.* The global aerosol–climate model ECHAM6. 3–HAM2. 3–Part 1: Aerosol evaluation. *Geoscientific Model Development* **12**, 1643-1677 (2019).

15 Yukimoto, S. *et al.* The Meteorological Research Institute Earth System Model version 2.0, MRI-ESM2. 0: Description and basic evaluation of the physical component. *Journal of the Meteorological Society of Japan. Ser. II* **97**, 931-965 (2019).

16 Oshima, N. *et al.* Global and Arctic effective radiative forcing of anthropogenic gases and aerosols in MRI-ESM2. 0. *Progress in Earth and Planetary Science* **7**, 1-21 (2020).

17 Kirkevåg, A. *et al.* A production-tagged aerosol module for Earth system models, OsloAero5. 3–extensions and updates for CAM5. 3-Oslo. *Geoscientific Model Development* **11**, 3945-3982 (2018).

18 Seland, Ø. *et al.* Overview of the Norwegian Earth System Model (NorESM2) and key climate response of CMIP6 DECK, historical, and scenario simulations. *Geoscientific Model Development* **13**, 6165-6200 (2020).

19 Sellar, A. A. *et al.* UKESM1: Description and evaluation of the UK Earth System Model. *Journal of Advances in Modeling Earth Systems* **11**, 4513-4558 (2019).

20 Mulcahy, J. Description and evaluation of aerosol in UKESM1 and HadGEM3-GC3. 1 CMIP6 historical simulations Geosci. *Model Dev. Discuss*, 1-59 (2020).