

Supplementary Information

**Economic Trade and Atmospheric Transport in Shaping China's
Nitrogen Deposition Patterns**

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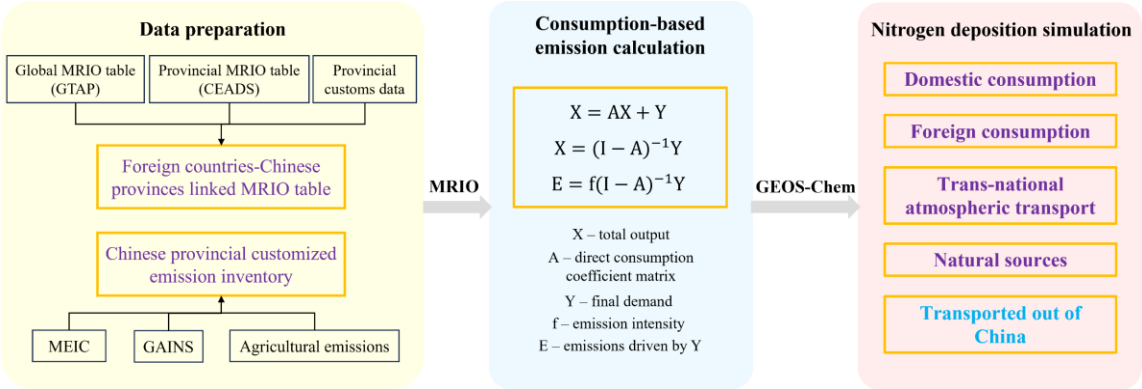
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The Supporting Information includes 27 pages, 14 figures, 9 tables and 3 text sections.

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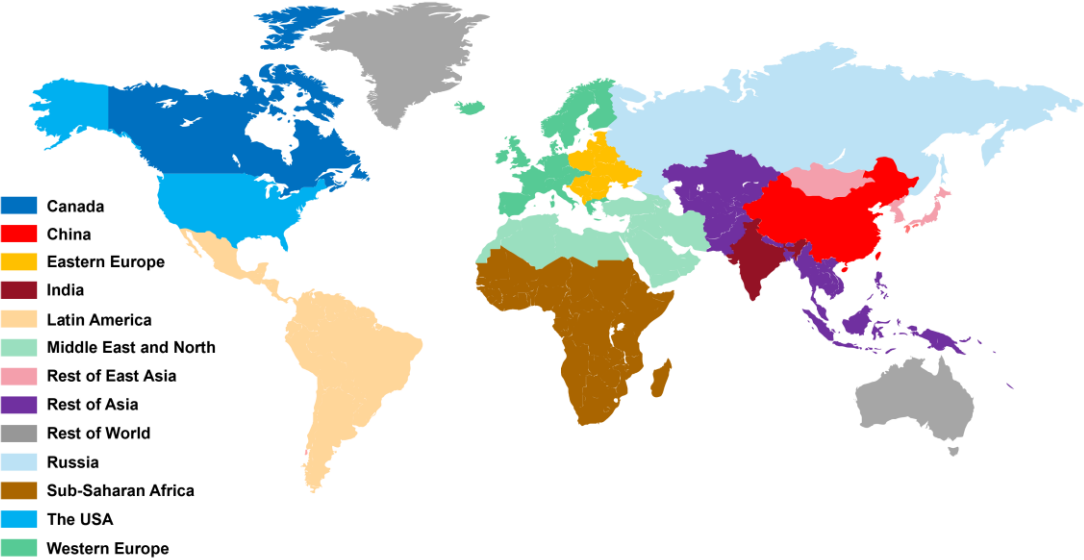
68 **Figures**

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70 **Figure S1.** The interdisciplinary framework.

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72 **Figure S2.** The 13 world regions defined in this study.



Figure S3. China's regional classification in this study.

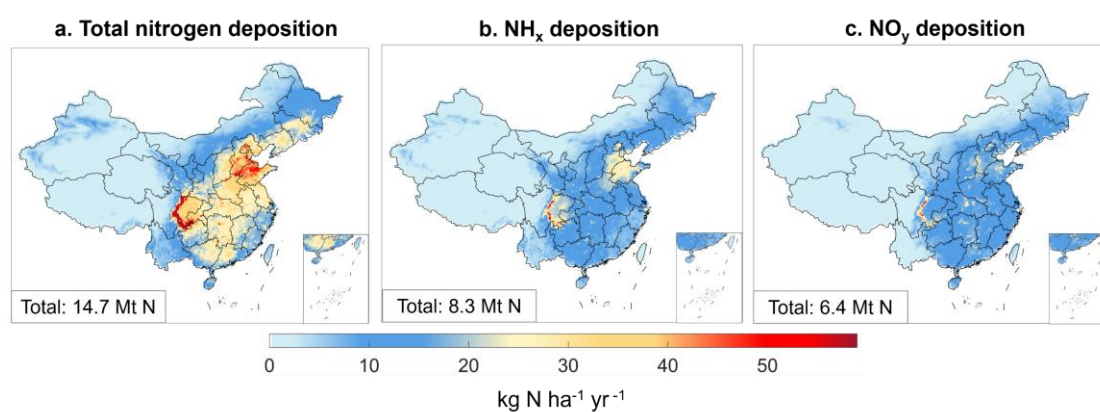


Figure S4. China's total nitrogen deposition in 2017.

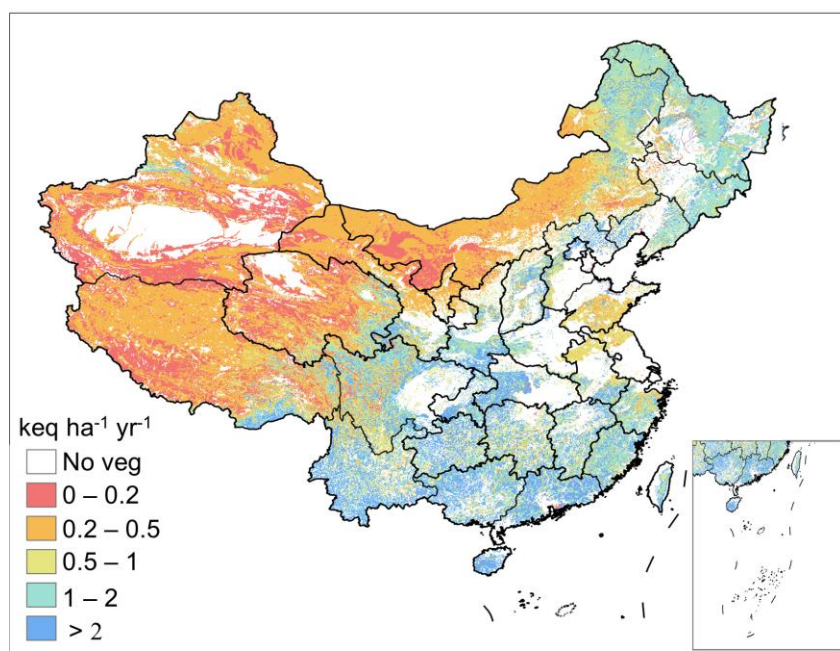


Figure S5. Critical loads of nitrogen in China. The white colour in the map represents croplands or area with no vegetation, where critical loads cannot be defined. This dataset is provided by the National Tibetan Plateau Data Center (<http://data.tpdc.ac.cn>), which is calculated based on the steady-state mass balance model (SMB), with high-resolution digital maps of soils, vegetation and other related data.

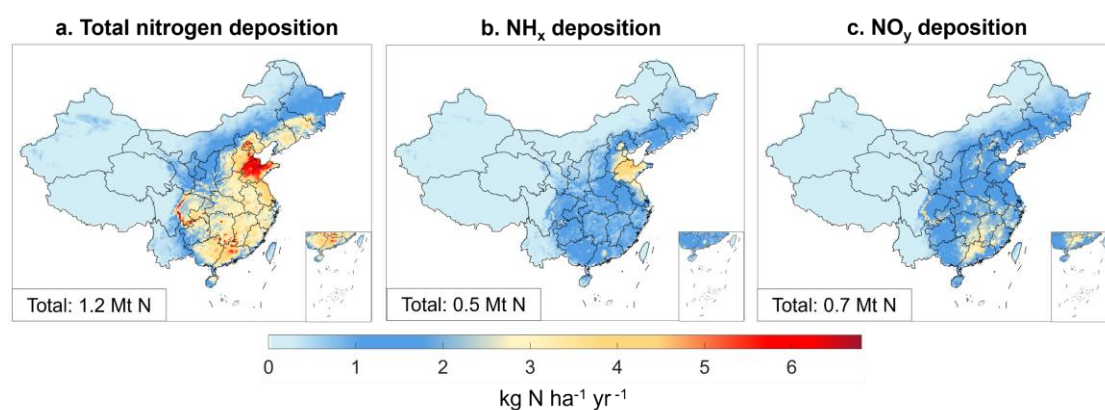
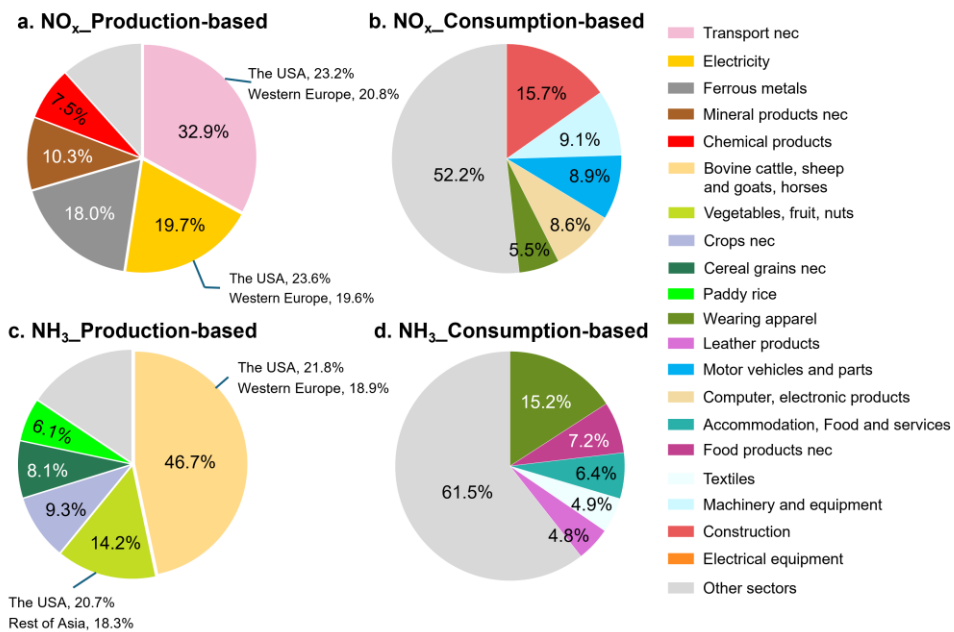


Figure S6. China's foreign consumption-related nitrogen deposition in 2017.



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88 **Figure S7.** Sectoral contributions. The production-based pie charts on the left illustrate the domestic
 89 sectors contributing most to China's export-related emissions, with annotated foreign regions indicating
 90 the top foreign contributors to these sectors' emissions. The consumption-based pie charts on the right
 91 highlight the main foreign consumption sectors driving China's export-related emissions.

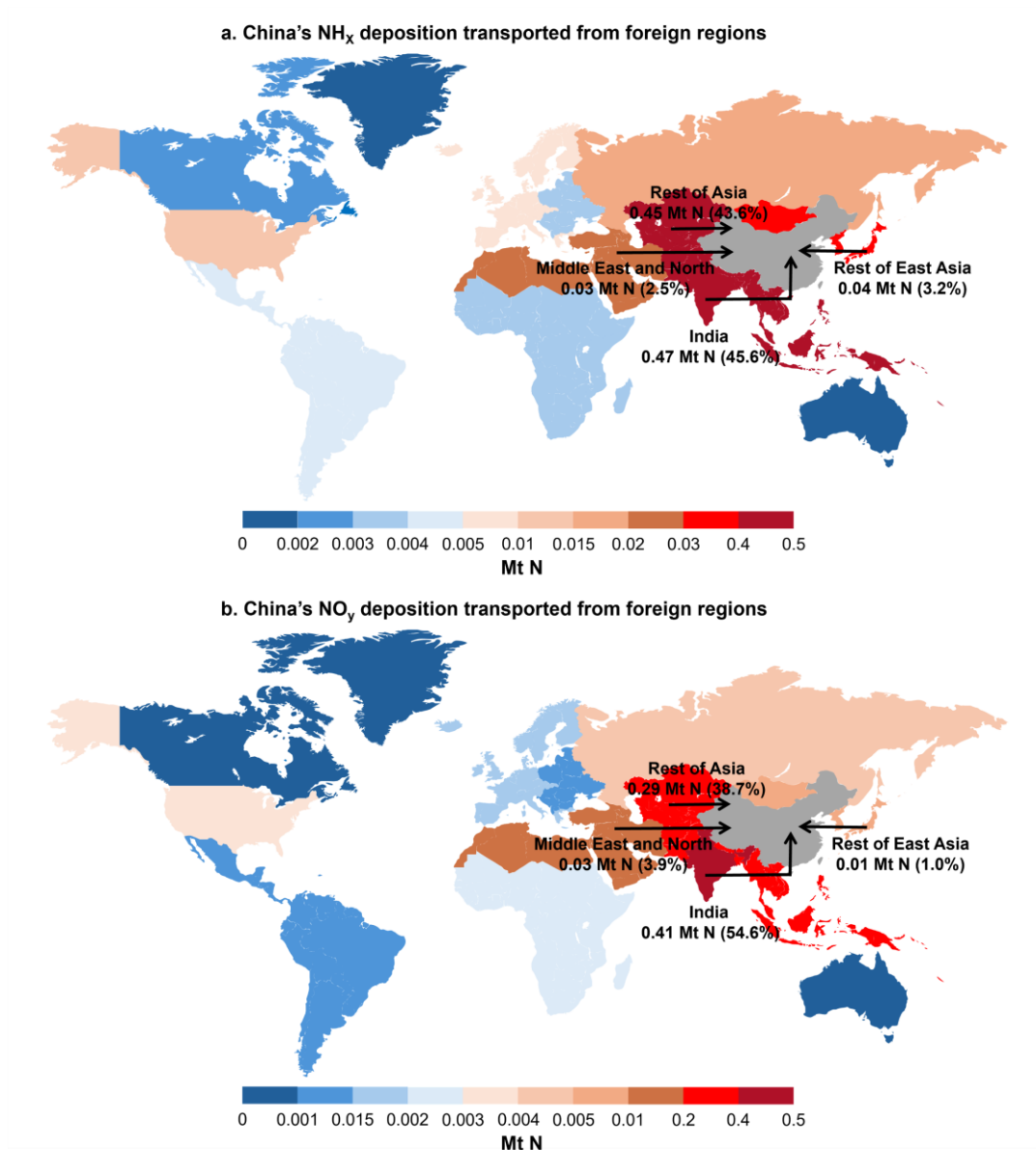


Figure S8. China's NH_x and NO_y deposition transported from foreign regions. The shading of each foreign region shows the amount of nitrogen deposition transported from this region.

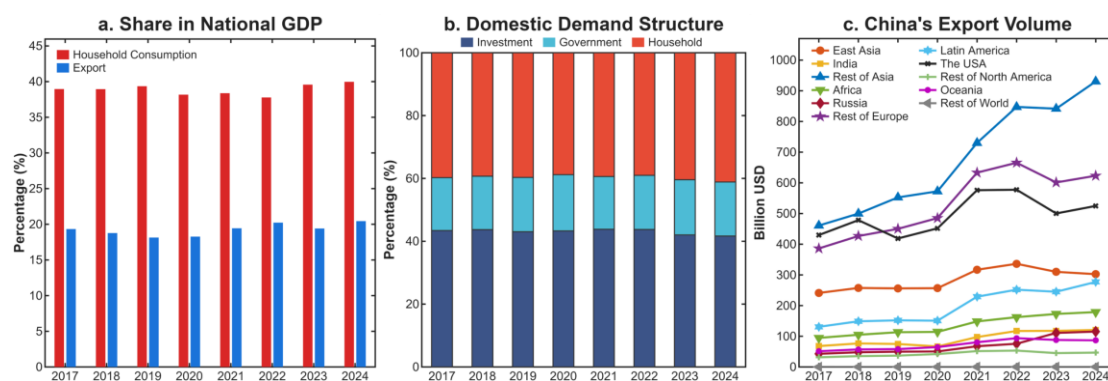


Figure S9. Chinese household consumption and exports during 2017–2024. (a) Share of household consumption and export in Chinese national GDP. (b) Structure of domestic demand in China. (c) China's export volume to each foreign region. Data is obtained from the World Bank (<https://data.worldbank.org/>) and National Bureau of Statistics of China (<https://www.stats.gov.cn/>).

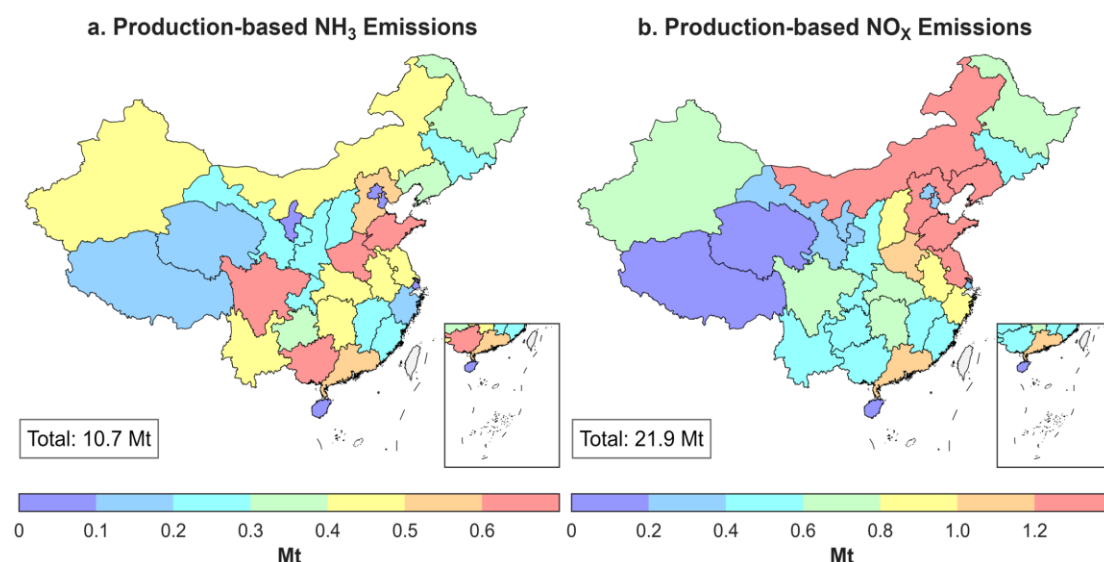


Figure S10. Provincial production-based emissions of NH₃ (a) and NO_x (b) in 2017.

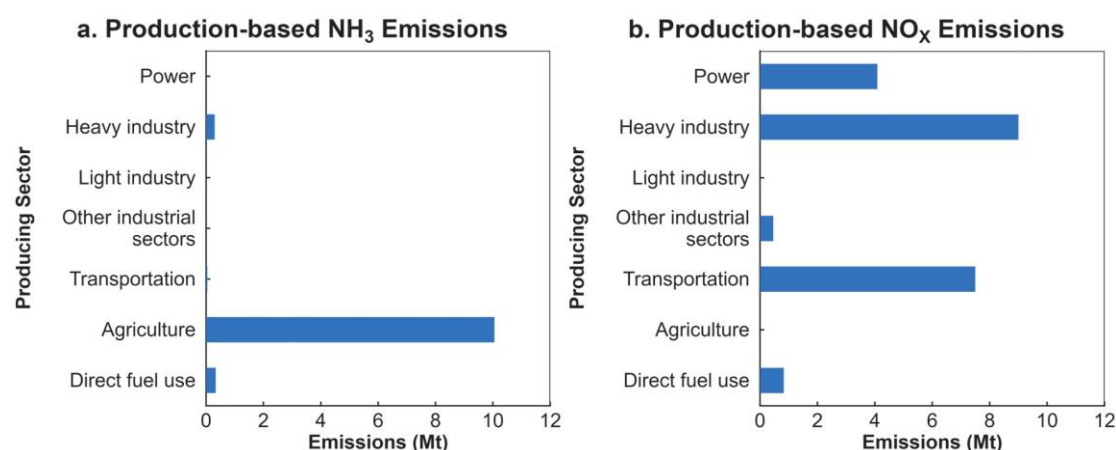


Figure S11. Sectoral production-based emissions of NH₃ (a) and NO_x (b) in 2017. The sector aggregation can be found in [Table S1](#).

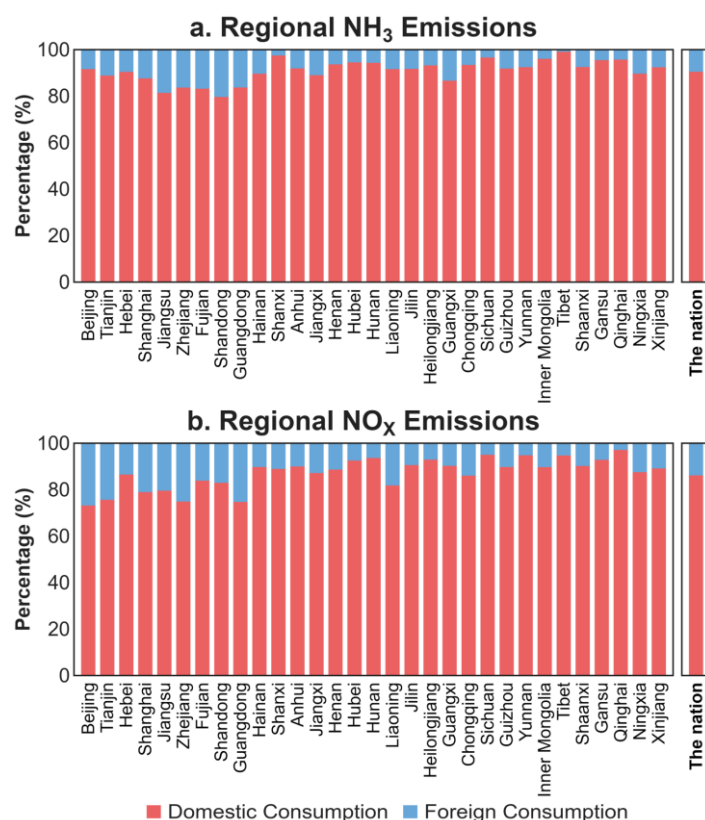


Figure S12. Share of the emission contribution from domestic and foreign consumption in regional NH₃ (a) and NO_x emissions (b).

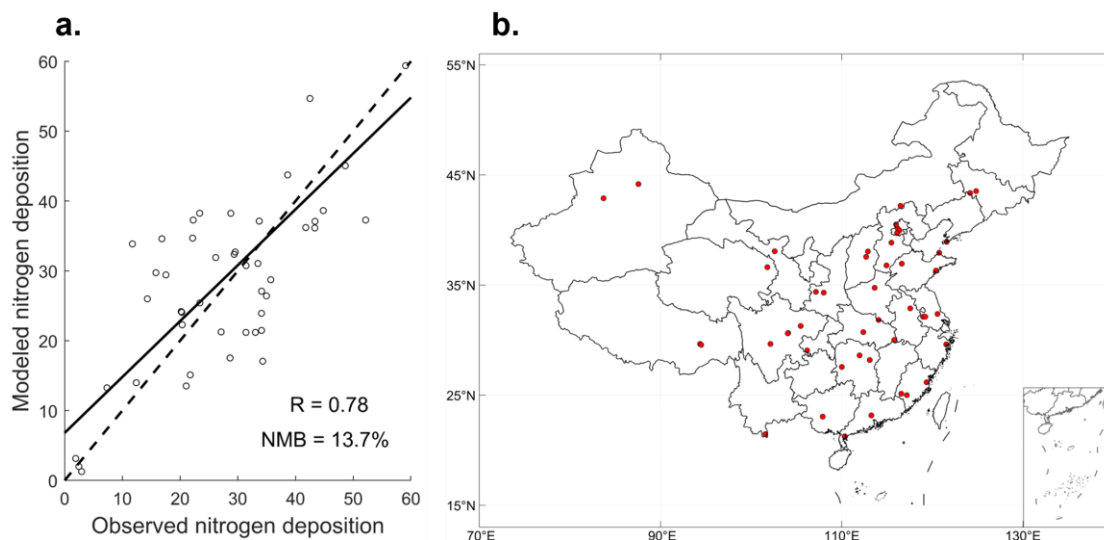


Figure S13. Comparison between the simulated and observed nitrogen deposition flux ($\text{kg N ha}^{-1} \text{ yr}^{-1}$) in China (a), and the spatial distribution of monitoring stations (b). The observation data is obtained from Nationwide Nitrogen Deposition Monitoring Network (NNDMN).

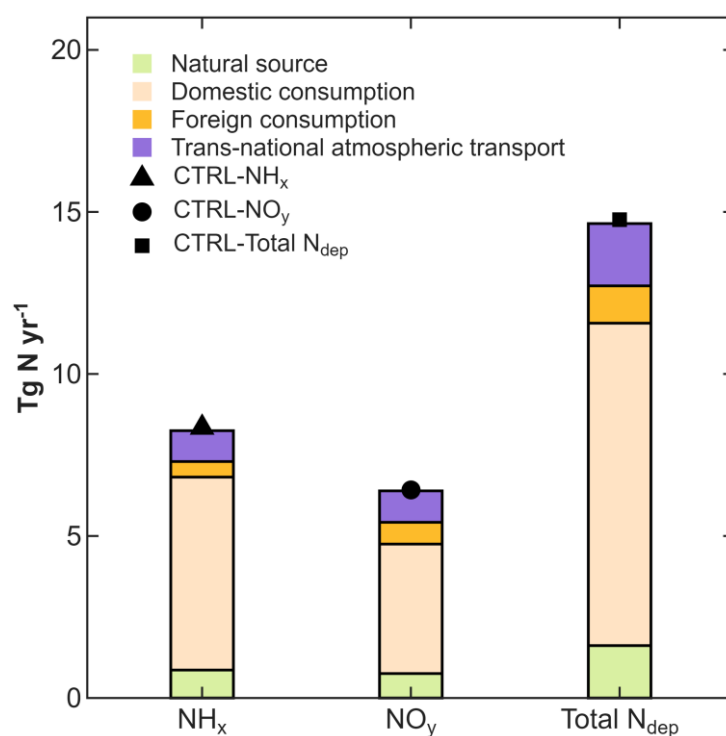


Figure S14. National deposition budgets of NH_x , NO_y , and total nitrogen in China under the CTRL simulation and four independent component simulations. Here, bars represent deposition from each of the four independently simulated components (natural source, domestic consumption, foreign consumption, and trans-national atmospheric transport), while symbols indicate the corresponding CTRL simulation (i.e., with all emissions included).

Tables

Table S1. MEIC 22 sectors and aggregated sectors.

Code	Sector name	Aggregated sector
S1	Electricity	Power
S2	Heating	Heavy industry
S3	Industrial boilers	
S4	Cement	
S5	Coking	
S6	Steel	
S7	Petrochemical industry	
S8	Oil and gas storage and transportation	
S9	Industrial coating	Light industry
S10	Printing and dyeing	
S11	Architectural coatings	
S12	Other industrial sectors	Other industrial sectors
S13	Civilian coal	Direct fuel use
S14	Civilian biomass burning	
S15	Use of chemicals for civil use	
S16	Other civilian sources	
S17	Gasoline cars	Transportation
S18	Diesel vehicles	
S19	Motorcycle	
S20	Non-road mobile sources	
S21	Fertilizer application	Agriculture
S22	Animal husbandry	

130 **Table S2.** GTAP 65 sectors.

Sector name	Code	Sector name	Code
Paddy rice	S1	Basic pharmaceutical products	S34
Wheat	S2	Rubber and plastic products	S35
Cereal grains, not elsewhere classified (n.e.c.)	S3	Mineral products nec	S36
Vegetables, fruit, nuts	S4	Ferrous metals	S37
Oil seeds	S5	Metals n.e.c.	S38
Sugar cane, sugar beet	S6	Metal products	S39
Plant-based fibers	S7	Computer, electronic and optical products	S40
Crops n.e.c.	S8	Electrical equipment	S41
Bovine cattle, sheep and goats, horses	S9	Machinery and equipment n.e.c.	S42
Animal products n.e.c.	S10	Motor vehicles and parts	S43
Raw milk	S11	Transport equipment n.e.c.	S44
Wool, silk-worm cocoons	S12	Manufactures nec	S45
Forestry	S13	Electricity	S46
Fishing	S14	Gas manufacture, distribution	S47
Coal	S15	Water	S48
Oil	S16	Construction	S49
Gas	S17	Trade	S50
Other extraction (formerly omn Minerals n.e.c.)	S18	Accommodation, Food and service activities	S51
Meat: cattle, sheep, goats, horse	S19	Transport n.e.c.	S52
Meat products n.e.c.	S20	Sea transport	S53
Vegetable oils and fats	S21	Air transport	S54
Dairy products	S22	Warehousing and support activities	S55
Processed rice	S23	Communication	S56
Sugar	S24	Financial services n.e.c.	S57
Food products n.e.c.	S25	Insurance (formerly isr)	S58
Beverages and tobacco products	S26	Real estate activities	S59
Textiles	S27	Business services n.e.c.	S60
Wearing apparel	S28	Recreational and other services	S61
Leather products	S29	Public Administration and defense	S62
Wood products	S30	Education	S63
Paper products, publishing	S31	Human health and social work activities	S64
Petroleum, coal products	S32	Dwellings	S65
Chemical products	S33		

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133 **Table S3.** Sectoral mapping between MEIC, GAINS and GTAP. “NaN” means that the sector does not
134 include in MEIC, or does not participate in economic production and is excluded in this study. Sector
135 code of MEIC and GTAP can be found in [Table S1](#) and [S2](#).

No.	GAINS	MEIC	GTAP
1	Public electricity and heat production	S1, S2	S46
2	Petroleum refining	S7	S32
3	Manufacture of solid fuels and other energy industries	S5	S15-S17, S32
4	Stationary combustion in industry: Iron and steel	S3	S37
5	Stationary combustion in industry: Non-ferrous metals	S3	S38
6	Stationary combustion in industry: Chemicals	S3	S33, S34
7	Stationary combustion in industry: Pulp, Paper and Print	S3	S31
8	Stationary combustion in industry: Food processing, beverages and tobacco and Other	S3	S26
9	Stationary combustion in industry: Non metallic minerals	S4	S36
10	Mobile Combustion in industry	S20	S15-S45, S49, S59
11	Civil aviation	S20	S54
12	Road transport: Passenger cars	S17	S52
13	Road transport: Light duty vehicles	S17	S52
14	Road transport: Heavy duty vehicles and buses	S18	S52
15	Road transport: Mopeds and motorcycles	S19	S52
16	Road transport: Automobile tyre and brake wear	S17, S18	S52
17	Road transport: Automobile road abrasion	S17, S18	S52
18	Railways	S20	S52
19	National navigation incl. Int. inland waterways; Fishing	S20	S53
20	Commercial / institutional: stationary	NaN	S50, S51, S55-S64
21	Residential stationary	S13-S16	NaN
22	Agriculture/Forestry/Fishing: Stationary	S22	S1-S14
23	Agriculture/Forestry/Fishing: Off_road vehicles and other machinery	S20	S52
24	Other / mobile (including military / land based and recreational boats)	S20	S52, S53
25	Solid fuel transformation	S5	S32
26	Oil: Refining / storage	S8	S32
27	Fugitive emissions from natural gas	S8	S17, S47
28	Chemical industry: Other	S12	S33, S34
29	Nitric acid production	S7	S33, S34
30	Iron and steel production	S6	S37
31	Aluminium production	S12	S38

32	Other metal production	S12	S38, S39
33	Non_dairy cattle_ Manure management	S22	S9
34	Dairy cattle_ Manure management	S22	S9
35	Other solvent use	S9, S11	S33, S34
36	Pulp and paper industry	S10	S31
37	Field burning of agricultural residues	NaN	NaN
38	Open burning of waste	NaN	NaN
39	Sheep_ Manure management	S22	S9
40	Swine_ Manure management	S22	S9
41	Horses_ Manure management	S22	S9
42	Laying hens_ Manure management	S22	S9
43	Buffalo_ Manure management	S22	S9
44	Other poultry_ Manure management	S22	S9
45	Other animals_ Manure management	S22	S9
46	N-fertilizer	S21	S1-S8
47	Coal mining and handling	S12	S15
48	Quarrying and mining of minerals other than coal	S12	S18
49	Construction and demolition	S12	S49
50	Storage, handling and transport of mineral products	S18	S52-S55
51	Storage, handling and transport of chemical products	S18	S52-S55
52	Storage, handling and transport of agricultural products	S18	S52-S55
53	Wood processing	S12	S30
54	Venting and flaring	S12	S16, S17, S32, S48
55	Household and gardening (mobile)	S16	NaN
56	Other (included in national total)	S12	S1-S65

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Table S4. Sectoral mapping between agricultural NH₃ inventory developed by Chen et al.¹ and GTAP.
Sector code of GTAP can be found in [Table S2](#).

No.	Sectors from agricultural NH ₃ inventory	Sector code of GTAP
1	Wheat	S1
2	Rice	S2
3	Maize	S3
4	Veg & fruit	S4
5	Oil seeds	S5
6	Potato	S8
7	Cotton	S7
8	Beef	S9
9	Dairy	S10
10	Goat	S9
11	Sheep	S9
12	Pig	S10
13	Laying poultry	S10
14	Meat poultry	S10
15	Other	S1-S12

171 **Table S5.** Simulation configurations.

Simulation type	Number of experiment sets	Area	Emission setting	Resolution (lon × lat)	Met fields
Ctrl	1	Global	Including all the emissions	2.5° × 2°	MERRA-2
		China	Including all the emissions	0.3125° × 0.25°	GEOS-FP
Xdomestic_con	6	Global	Excluding emissions driven by 6 categories of domestic final demand in China	2.5° × 2°	MERRA-2
		China	Excluding emissions driven by 6 categories of domestic final demand in China	0.3125° × 0.25°	GEOS-FP
Xforeign_con	12	Global	Excluding emissions driven by the consumption of 12 foreign regions	2.5° × 2°	MERRA-2
		China	Excluding emissions driven by the consumption of 12 foreign regions	0.3125° × 0.25°	GEOS-FP
Xch_pro	1	Global	Excluding China's production-based emissions	2.5° × 2°	MERRA-2
Xch_ex	1	Global	Excluding China's export-related emissions	2.5° × 2°	MERRA-2
Xforeign_pro	12	Global	Excluding production-based emissions in 12 foreign regions	2.5° × 2°	MERRA-2

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174 **Table S6.** Contributions of domestic demands to NH_x deposition (kg N ha⁻¹ yr⁻¹).

Provinces	Investment	Government	Urban direct fuel use	Rural direct fuel use	Urban economic consumption	Rural economic consumption	Total
Beijing	13.13	1.49	0.42	0.41	3.51	1.18	20.14
Tianjin	13.73	1.61	0.11	0.44	3.68	1.18	20.75
Hebei	11.50	1.27	0.05	0.33	3.14	1.13	17.42
Shanxi	7.91	0.68	0.03	0.18	2.27	0.82	11.89
Inner Mongolia	2.11	0.22	0.01	0.06	0.69	0.25	3.34
Liaoning	7.13	0.77	0.07	0.29	2.23	0.69	11.18
Jilin	6.25	0.74	0.06	0.28	1.88	0.63	9.84
Heilongjiang	4.33	0.52	0.01	0.18	1.17	0.39	6.60
Shanghai	5.64	0.80	0.37	0.27	1.64	0.42	9.14
Jiangsu	10.02	1.16	0.13	0.33	2.85	0.86	13.48
Zhejiang	3.41	0.46	0.13	0.20	1.51	0.46	6.17
Anhui	8.16	0.84	0.05	0.30	2.70	0.93	12.98
Fujian	3.76	0.52	0.17	0.25	1.64	0.52	6.86
Jiangxi	4.89	0.54	0.08	0.23	1.85	0.65	8.24
Shandong	15.36	1.72	0.05	0.45	4.41	1.52	23.51
Henan	12.51	1.29	0.01	0.17	3.39	1.23	18.60
Hubei	9.08	0.88	0.04	0.24	2.67	0.91	13.82
Hunan	7.68	0.72	0.06	0.27	2.20	0.77	11.70
Guangdong	5.70	0.62	0.16	0.30	1.78	0.43	8.99
Guangxi	7.48	0.62	0.08	0.36	1.84	0.69	11.07
Hainan	4.20	0.42	0.09	0.19	1.04	0.32	6.26
Chongqing	12.02	1.29	0.09	0.53	3.42	1.21	18.56
Sichuan	8.38	0.83	0.08	0.39	2.22	1.03	12.93
Guizhou	9.33	0.85	0.05	0.32	2.29	0.95	13.79
Yunnan	3.70	0.31	0.01	0.09	0.92	0.41	5.44
Tibet	0.44	0.02	0.01	0.01	0.08	0.05	0.61
Shaanxi	7.03	0.69	0.04	0.23	1.90	0.70	10.59
Gansu	3.89	0.36	0.02	0.14	0.85	0.37	5.63
Qinghai	1.02	0.10	0.01	0.02	0.24	0.11	1.50
Ningxia	4.21	0.36	0.02	0.14	1.09	0.44	6.26
Xinjiang	0.97	0.10	0.01	0.01	0.22	0.09	1.40

Provinces	Investment	Government	Urban direct fuel use	Rural direct fuel use	Urban economic consumption	Rural economic consumption	Total
Beijing	8.70	0.91	0.42	0.35	2.74	0.89	14.01
Tianjin	7.84	0.73	0.37	0.52	2.38	0.77	12.61
Hebei	7.21	0.71	0.34	0.48	2.16	0.71	11.61
Shanxi	6.90	0.78	0.31	0.48	2.18	0.76	11.41
Inner Mongolia	1.35	0.17	0.05	0.08	0.46	0.16	2.27
Liaoning	7.13	0.77	0.07	0.29	2.23	0.69	11.18
Jilin	6.26	0.60	0.32	0.39	1.98	0.61	10.16
Heilongjiang	1.95	0.24	0.14	0.16	0.72	0.23	3.44
Shanghai	3.98	0.41	0.07	0.07	1.39	0.39	6.31
Jiangsu	5.86	0.57	0.19	0.25	1.90	0.57	9.34
Zhejiang	5.48	0.57	0.12	0.15	1.62	0.46	8.40
Anhui	6.80	0.67	0.26	0.34	2.09	0.64	10.80
Fujian	5.27	0.52	0.08	0.09	1.61	0.48	8.05
Jiangxi	6.72	0.63	0.20	0.25	1.95	0.54	10.29
Shandong	8.05	0.75	0.36	0.49	2.50	0.79	12.94
Henan	7.18	0.75	0.36	0.56	2.22	0.72	11.79
Hubei	7.44	0.76	0.34	0.49	2.27	0.75	12.05
Hunan	7.20	0.72	0.31	0.39	2.21	0.69	11.52
Guangdong	5.47	0.55	0.10	0.11	1.97	0.52	8.72
Guangxi	4.45	0.49	0.09	0.10	1.58	0.50	7.21
Hainan	3.18	0.38	0.07	0.08	1.24	0.35	5.30
Chongqing	7.13	0.82	0.19	0.40	2.29	0.82	11.65
Sichuan	4.15	0.46	0.11	0.24	1.28	0.53	6.77
Guizhou	5.20	0.58	0.18	0.36	1.64	0.62	8.58
Yunnan	1.21	0.12	0.03	0.07	0.30	0.13	1.86
Tibet	0.01	0.01	0.01	0.01	0.01	0.01	0.06
Shaanxi	4.94	0.60	0.17	0.32	1.63	0.58	8.24
Gansu	1.50	0.21	0.03	0.08	0.53	0.22	2.57
Qinghai	0.21	0.03	0.01	0.01	0.07	0.03	0.36
Ningxia	2.43	0.33	0.05	0.13	0.83	0.33	4.10

Xinjiang	0.39	0.05	0.01	0.01	0.09	0.04	0.59
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178 **Table S8.** The top 10 interprovincial transfer pathways for NH₃ and NO_x emissions along with their
179 leading emitting sectors. The percentage represents the contribution of the sector to the emission flow.
180 The detailed information for sector codes can be found in [Table S1](#).

Pollutant	Emission transfer (Mt)	Driver	Receptor	Leading emitter
NH ₃	0.101	Shanxi	Inner Mongolia	S9 (57.7%)
	0.099	Guangdong	Guangxi	S8 (38.3%)
	0.067	Zhejiang	Guangdong	S9 (41.9%)
	0.049	Henan	Shaanxi	S9 (39.6%)
	0.044	Guangdong	Guizhou	S9 (47.2%)
	0.043	Guangdong	Yunnan	S9 (58.6%)
	0.042	Shandong	Hebei	S9 (48.9%)
	0.041	Henan	Inner Mongolia	S9 (55.6%)
	0.039	Shaanxi	Gansu	S9 (56.1%)
	0.035	Zhejiang	Henan	S9 (49.9%)
NO _x	0.081	Guangdong	Henan	S52 (43.9%)
	0.067	Guangdong	Shandong	S46 (32.3%)
	0.063	Zhejiang	Hebei	S37 (43.5%)
	0.062	Zhejiang	Henan	S52 (44.8%)
	0.061	Henan	Inner Mongolia	S46 (54.4%)
	0.060	Jiangsu	Anhui	S36 (43.3%)
	0.060	Guangdong	Inner Mongolia	S46 (48.5%)
	0.059	Guangdong	Liaoning	S52 (29.4%)
	0.057	Beijing	Hebei	S36 (35.6%)
	0.056	Guangdong	Hebei	S52 (43.5%)

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187 **Table S9.** Top contributors of provincial export-related nitrogen deposition. The percentages represent
188 the foreign region's contribution to the provincial export-related nitrogen deposition.

Province	Export-related deposition (kg N ha ⁻¹ yr ⁻¹)		Major foreign contributors	
	NH _x	NO _y	NH _x	NO _y
Beijing	2.42	2.24	REA (20.4%), WE (18.7%)	USA (20.1%), WE (16.7%)
Tianjin	2.33	1.76	REA (18.7%), WE (18.6%)	USA (20.0%), WE (16.4%)
Hebei	1.65	1.69	USA (18.5%), WE (18.3%)	USA (19.9%), WE (16.9%)
Shanxi	0.70	1.64	USA (19.6%), WE (17.9%)	USA (20.7%), WE (18.1%)
Inner Mongolia	0.19	0.38	USA (18.7%), WE (18.0%)	USA (19.7%), WE (17.4%)
Liaoning	1.08	1.64	USA (19.6%), REA (19.4%)	USA (18.9%), REA (16.2%)
Jilin	0.91	1.33	USA (19.1%), WE (17.7%)	USA (18.8%), WE (16.5%)
Heilongjiang	0.46	0.55	USA (18.5%), WE (17.8%)	USA (18.3%), WE (16.5%)
Shanghai	1.18	1.52	USA (22.6%), WE (19.8%)	USA (19.3%), WE (17.1%)
Jiangsu	2.23	1.60	USA (25.1%), WE (19.3%)	USA (19.3%), WE (16.5%)
Zhejiang	0.87	2.07	USA (21.8%), WE (19.0%)	USA (20.1%), WE (17.7%)
Anhui	1.17	1.87	USA (22.2%), WE (18.4%)	USA (20.3%), WE (17.3%)
Fujian	0.92	2.16	USA (24.3%), WE (17.9%)	USA (22.2%), WE (18.7%)
Jiangxi	0.85	2.37	USA (22.4%), WE (17.6%)	USA (21.4%), WE (18.6%)
Shandong	3.41	1.77	USA (20.4%), WE (20.1%)	USA (20.8%), WE (16.9%)
Henan	1.30	1.62	USA (20.8%), WE (18.3%)	USA (20.1%), WE (17.0%)
Hubei	0.99	1.88	USA (19.7%), WE (17.5%)	USA (20.5%), WE (17.4%)
Hunan	0.95	2.11	USA (21.1%), WE (17.2%)	USA (21.2%), WE (18.2%)
Guangdong	1.19	2.25	USA (24.7%),	USA (21.4%),

			WE (18.6%)	WE (19.1%)
Guangxi	1.24	1.71	USA (22.5%), RA (17.6%)	USA (22.2%), WE (19.5%)
Hainan	0.62	1.52	USA (24.2%), WE (18.4%)	USA (21.4%), WE (19.2%)
Chongqing	1.17	1.79	USA (19.3%), WE (18.1%)	USA (21.0%), WE (17.9%)
Sichuan	0.58	0.77	USA (20.0%), WE (17.9%)	USA (21.5%), WE (17.9%)
Guizhou	1.11	1.39	USA (20.0%), WE (17.5%)	USA (21.2%), WE (17.9%)
Yunnan	0.38	0.23	RA (23.1%), USA (17.2%)	USA (19.7%), RA (18.2%)
Tibet	0.01	0.01	RA (25.8%), WE (16.8%)	RA (20.4%), USA (19.2%)
Shaanxi	0.65	1.19	USA (19.5%), WE (17.6%)	USA (20.4%), WE (17.8%)
Gansu	0.27	0.31	USA (20.4%), WE (19.2%)	USA (20.6%), WE (17.6%)
Qinghai	0.06	0.04	USA (20.2%), WE (19.3%)	USA (20.6%), RA (16.8%)
Ningxia	0.41	0.51	WE (22.2%), USA (21.1%)	USA (20.3%), WE (17.4%)
Xinjiang	0.08	0.08	RA (31.8%), WE (14.9%)	RA (37.4%), USA (13.3%)

Note:

a. The regional abbreviations are: WE=Western Europe; RA=Rest of Asia; REA=Rest of East Asia.

1. Consumption-based emission accounting

The basic MRIO model could be expressed as:

$$\mathbf{X} = \mathbf{A}\mathbf{X} + \mathbf{Y}. \quad (1)$$

Here, $\mathbf{X}$ refers to the total output matrix. $\mathbf{A}$ is the matrix of direct requirement coefficients reflecting the requirement to produce per unit output. $\mathbf{Y}$ is the matrix of final demand.

Eq. (1) could be transformed as:

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}. \quad (2)$$

Here, $\mathbf{I}$ represents the identity matrix. $(\mathbf{I} - \mathbf{A})^{-1}$ is the Leontief matrix (or written as $\mathbf{L}$), whose element a_{ij} tracks the overall direct and indirect inputs along the domestic supply chains from sector i for meeting unit final demand in sector j .

Thus, air pollutant emissions driven by a certain consumption demand can be calculated as:

$$\mathbf{E}_{ns}^k = \mathbf{F}_{ns}^k(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}^d, \quad (3)$$

where $\mathbf{E}_{ns}^k$ refers to the emission of air pollutant k in sector s of province n driven by final demand $\mathbf{Y}^d$. Here, $\mathbf{Y}^d$ refers to the final demand type d , including investment, government consumption, household consumption and foreign consumption in this study. $\mathbf{F}_{ns}^k$ refers to the emission intensity (i.e., emission per unit of output) of air pollutant k in sector s of province n . In our study, emissions contributed from household consumption and foreign consumption were traced with Eq. (3). Here, foreign consumption-related emissions refer to emissions generated in China via international trade supply chains driven by foreign consumption of goods and services.

Household consumption could also drive emission transfers among different provinces. To recognize the role of a province in emission transfers, we further calculated net emissions of a province as:

$$\mathbf{E}_{n_net}^k = \mathbf{E}_{n_c}^k - \mathbf{E}_{n_p}^k = \mathbf{F}_{all}^k(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}_n^d - \mathbf{F}_n^k(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}_{all}^d, \quad (4)$$

where $\mathbf{E}_{n_net}^k$ refers to net emission of air pollutant k in province n , i.e., the differences in consumption- and production-based emission. $\mathbf{E}_{n_c}^k$ is the consumption-based emission of air pollutant k in province n , i.e., the emissions due to the consumption activities of province n . $\mathbf{E}_{n_c}^k$ is calculated as $\mathbf{F}_{all}^k(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}_n^d$, where $\mathbf{F}_{all}^k$ means the emission intensities of all provinces and $\mathbf{Y}_n^d$ means the final demand of province n . $\mathbf{E}_{n_p}^k$ is the production-based emission of air pollutant k in province n ,

i.e., the emissions due to the production activities of province n . $\mathbf{E}_{n,p}^k$ is calculated as $\mathbf{F}_n^k(\mathbf{I} - \mathbf{A})^{-1}\mathbf{Y}_{all}^d$, where $\mathbf{F}_n^k$ means the emission intensity of province n and $\mathbf{Y}_{all}^d$ means the final demand of all provinces. A positive $\mathbf{E}_{n,net}^k$ means that in net the province n has outsourced its pollution to other provinces, and a negative $\mathbf{E}_{n,net}^k$ means the opposite.

2. Production- and consumption-based Nr emissions

From a production-based perspective, China emits 10.7 Mt of NH₃ and 21.9 Mt of NO_x in 2017 (Figure S10). NH₃ emissions concentrate in provinces characterized by substantial agricultural activities such as Shandong, Henan, Sichuan and Guangxi, each exceeding 0.6 Mt (Figure S10a). This spatial pattern arises because NH₃ emissions are predominantly associated with fertilizer application and livestock production, which are intensive in these major agricultural provinces. NO_x emissions are more concentrated in provinces with large populations or heavy industries such as Hebei, Shandong, Jiangsu, Liaoning, and Inner Mongolia, each exceeding 1.2 Mt (Figure S10b). This is because NO_x is primarily generated from high-temperature combustion processes in industrial facilities and vehicle fleets, which are dense in these economically active and urbanized regions. Figure S11a shows that agriculture contributes 10.1 Mt of NH₃ and accounts for 94.4% of the national total. In contrast, Heavy industry, Transportation and Power contribute approximately 9.0, 7.5 and 4.1 Mt of NO_x, respectively, together accounting for 94.1% of national NO_x emissions (Figure S11b).

From a consumption-based perspective, domestic consumption serves as the primary driver of emissions generated in China (Figure S12). Domestic consumption accounts for 90.5% of NH₃ and 86.2% of NO_x emissions, while foreign consumption contributes the remaining 9.5% and 13.8%, respectively. Their contributions vary among different regions and sectors. Regionally, Figure S12a shows that foreign consumption exhibits relatively large contributions in provinces Shandong, Jiangsu, Zhejiang, and Fujian in NH₃ emissions, even reaching 20.4% in Shandong. For NO_x emissions, the contribution share of foreign consumption reaches 26.8% in Beijing and 25.4% in Guangdong (Figure S12b).

3. Uncertainty analysis

Despite efforts to enhance the precision of our findings, this study is still subject to several uncertainties in the following steps.

First, the process of constructing the Foreign countries-Chinese provinces linked MRIO table introduces certain uncertainties, which have been addressed in our previous work². During the linking process, we used the economic linkages between Chinese provinces and foreign countries from provincial customs export data to replace the sectoral trade flows between China and foreign countries in the global MRIO table. The export structure was obtained from customs data, but the export volume followed that in Chinese provincial MRIO table. Discrepancies between provincial export volume in customs data and Chinese provincial MRIO table are within 20.0% for most provinces, narrowing to approximately 15.0% for eastern coastal provinces with high export volumes.

Second, the uncertainty in consumption-based emissions is higher compared with the territorial emission³, resulting from multi-factors such as emission inventories (MEIC, GAINS and agricultural NH₃ emissions), MRIO tables and sectoral mapping across different datasets. For example, the uncertainties of MEIC have been estimated to be 12% for SO₂, 31% for NO_x and 68% for NMVOC^{4, 5}. The uncertainty inherent in the GTAP MRIO table arises from processes such as international trade linkage, sector classification, and table balancing, which is rarely quantified, but tends to be relatively small for large economies such as the USA and China^{6, 7}. In the Chinese provincial MRIO tables, most sectors exhibit only a $\pm 5\%$ discrepancy when benchmarked against the official national single-region IO table⁸. Beyond statistical uncertainties, sectoral mapping across different datasets introduces additional uncertainties into our estimates. Based on our detailed mapping tables ([Table S3 and S4](#)), we quantified the mismatches in some critical cases. Specifically, the cases for multiple MEIC sectors mapped with one GAINS sector (except the sector Public electricity and heat production) represent less than 1% of the total NH₃ and NO_x emissions, and the cases for sectors present in GAINS but absent in MEIC contribute approximately 2% and 0.5% of total NH₃ and NO_x emissions, respectively. Meanwhile, the cases for multiple GTAP sectors mapped with one GAINS sector account for about 10% of supply-chain embodied emissions. Their potential impacts on sectoral emission intensities, consumption-based attribution, and deposition estimates are further largely diluted after sectoral aggregation. More importantly, our simulation framework does not rely on sector-level atmospheric modeling, largely avoiding the propagation of sectoral mapping uncertainties into the deposition simulation.

Third, GEOS-Chem simulations are unavoidably affected by errors in the representation of atmospheric chemical and deposition formation mechanisms⁹. A full evaluation of model uncertainties is computationally prohibitive. In particular, the

combination of global CEDS and our customized Chinese emission inventories may introduce potential inconsistencies near the transition boundaries. However, our study focuses on the interior of China rather than the border regions, and the replacement with spatial pattern of MEIC ($0.1^{\circ} \times 0.1^{\circ}$) substantially improves the accuracy and spatial representativeness of local emissions over the original CEDS data ($0.5^{\circ} \times 0.5^{\circ}$). So these boundary effects have little influence on our main results. We evaluate our all-emissions simulation results against the nationwide nitrogen deposition monitoring network (NNDMN) data¹⁰ in [Figure S13](#). It shows that R is close to 0.8 and NMB is less than 15.0%, indicating that GEOS-Chem performs well on the magnitude and spatial distribution of nitrogen deposition over China. Furthermore, to address the potential nonlinearity in nitrogen deposition simulation, we include only natural emissions, allowing for a direct calculation of natural deposition, rather than deriving it as a residual. [Figure S14](#) shows that the sum of the four independently simulated components (natural source, domestic consumption, foreign consumption, and transnational atmospheric transport) reproduces the CTRL simulation with closure errors of only 1.1%, 0.4%, and 0.8% for NH_x , NO_y , and total nitrogen deposition at the national scale, respectively. This confirms that nitrogen deposition responds largely linearly to emission changes within our model framework and that interaction effects are negligible.

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