Air Pollution Burden Around the World: Distributions, Inequalities, and the Economic Benefits of Clean Air

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Introduction

- High levels of air pollution contribute to millions of deaths annually and are negatively associated with labor productivity and human capital accumulation (Bedi 2021; Cook 2022; Fisher et al. 2021; Odo et al. 2023; Sager 2025).
- More than 90% of the world's population is exposed to unhealthy $PM_{2.5}$ levels exceeding 10 μg/m³ (Pirlea & Huang 2019; WHO 2021).
- Unequal exposure across population groups is well-documented within countries, but global, population-weighted evidence on across- and within-country disparities remains scarce (Hajat et al. 2015; Sager 2025; Sager & Singer 2025).
- We document the global relative distribution of air pollution by aerosols, the overlap of pollution-income inequalities, and the welfare gains from clean air across and within countries.

This paper

1. Uses satellite pollution and population data to analyze the global burden of pollution across and within locations, with population weighting.
2. Investigates the overlap of air pollution exposure and income inequalities across global regions.
3. Estimates the welfare benefits of clean air for subnational units globally.

We provide the first global, subnational assessment of air pollution by aerosol exposure, its intersection with income inequality, and the welfare benefits of achieving clean air standards.

Data

1. Air pollution by aerosols is measured using Aerosol Optical Depth (AOD) data obtained from NASA Earthdata.
   - 3km × 3km cells (≈ 0.027°).
   - Multiple observations per day.
   - 0.1 indicates a clear sky, and 1 indicates very hazy conditions.
   - Aggregate cells to 1° latitude and longitude combinations.
2. Global-gridded population data from Socioeconomic Data and Applications Center (SEDAC).
   - Population count estimates by gender and 5-year age groups.
   - Use the 110km × 110km grid version (1° combination).
   - Gender and age groups are combined into a single demographic category.
3. National and subnational from the Gridded Global Datasets for GDP (Kummu, Taka, and Guillaume 2018).
4. Three papers on Willingness to Pay for cleaner air : Freeman et al. 2019; Guo et al. 2020; Gao et al. 2023.

Pollution, Inequality and Welfare measures

- Population-weighted AOD distributions:

$$\mu_r = \sum_{c \in C_r} s_{c,r} \cdot a_c$$

- Excess burden of pollution:

$$e_{r,\text{global}} = \frac{\overbrace{\left(\frac{\left(\sum_{c \in C_r} s_c\right) \cdot \mu_r}{\mu_{\text{global}}}\right)}^{\text{Location } r \text{ pop-weighted pollution share}}}{\underbrace{\left(\sum_{c \in C_r} s_c\right)}_{\text{Location } r \text{ population share}}} - 1 = \frac{\mu_r}{\mu_{\text{global}}} - 1 \ .$$

- We estimate pollution, income gap, and the ratios of these gaps using the following:

$$PG_\tau = \frac{\left(\frac{\sum_{r \in R_{\tau u}} s_r \cdot \mu_r}{\sum_{r \in R_{\tau u}} s_r}\right)}{\left(\frac{\sum_{r \in R_{\tau l}} s_r \cdot \mu_r}{\sum_{r \in R_{\tau l}} s_r}\right)} \qquad IG_\tau = \frac{\left(\frac{\sum_{r \in R_{\tau u}} s_r \cdot \text{GDP}_r}{\sum_{r \in R_{\tau u}} s_r}\right)}{\left(\frac{\sum_{r \in R_{\tau l}} s_r \cdot \text{GDP}_r}{\sum_{r \in R_{\tau l}} s_r}\right)} \qquad RR_\tau = \frac{PG_\tau}{IG_\tau}$$

Welfare analysis

- We assume a CES utility function reflecting units' preference between consumption (C) and pollution (P):

$$U(C,P) = \left(C^{1+\epsilon} - \exp(\Lambda) \cdot P^{1+\epsilon}\right)^{\frac{1}{1+\epsilon}}$$

- We recover Λ and ϵ from three China willingness-to-pay papers (Freeman et al. 2019; Guo et al. 2020; Gao et al. 2023).
- We estimate welfare gains of clean air via the Consumption Equivalent Variation (CEV), the share of income a unit would forgo to achieve zero air pollution ($P = 0$):

$$U(C^*, 0) = U(C, P)$$

$$CEV = \frac{C^* - C}{C} = \left(1 - \exp(\Lambda)\left(\frac{P}{C}\right)^{1+\epsilon}\right)^{\frac{1}{1+\epsilon}} - 1$$

Distributional results

- Asia is the region with the highest air pollution; Australia and Oceania have the lowest burden.
- Africa exhibits the highest inequality in air pollution exposure, whereas Europe shows the least inequality.
- Average exposures vary dramatically across regions. Asia, the most polluted continent, experiences exposure levels 3.3 times higher than Oceania, the least polluted continent.
- Exposures vary dramatically within regions. The 80/20 exposure ratios are 141% in Africa and 28% in Europe.

Figure 1. Population-weighted distribution of air pollution by aerosols, 2010.

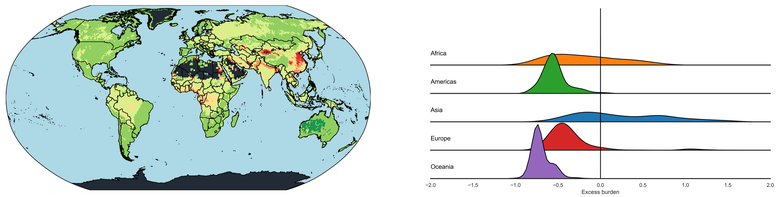
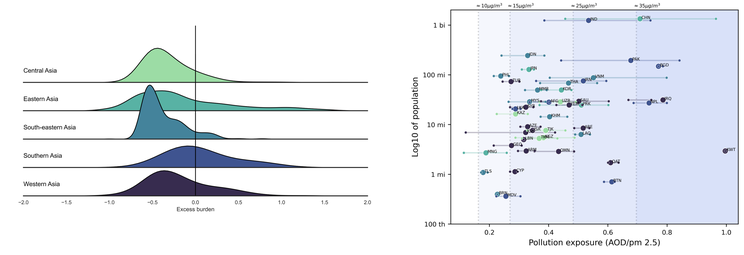
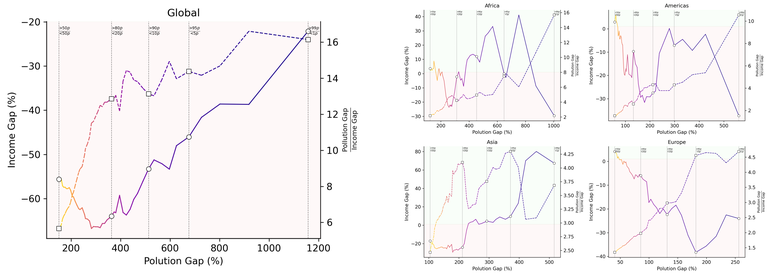


Figure 2. Population-weighted distribution of air pollution by aerosols in Asia, 2010.



Overlapping inequalities

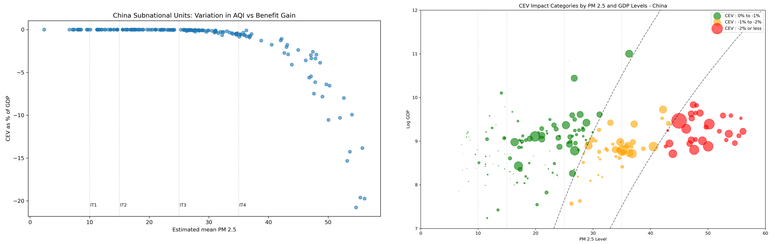
Figure 3. Correlation between percentile ratios, overlapping inequality ratio, and pollution gap across subnational units.



- Globally, more polluted subnational units concentrate less income, a compounding pattern. However, this differs by continent.
- In Asia, more polluted areas are richer (compensating pattern).
- In the Americas and Europe, more polluted areas are also poorer (compounding pattern).

Welfare gains of clean air

Figure 4. Chinese Subnational Units Consumption Equivalent Variation (CEV) - CES.



- Welfare gains from clean air increase exponentially near $PM_{2.5} \approx 20$ μg/m³.
- Chinese subnational units' CEV ranges from 0% to 20% of annual income, with gains concentrated in the most polluted locations.

Conclusions

- **Global exposure disparities are substantial:**
  - The average individual in Asia is 3.32 times more exposed than in Oceania; across subcontinental regions, 80/20 exposure ratios range from 2% to 208%.
  - Within countries, 80/20 exposure ratios range from 0% to 359%, with Africa (141%) the most unequal and Europe (28%) the least.
- **Overlapping inequalities differ by continent:**
  - Globally and in the Americas/Europe: *compounding* — more polluted areas are also poorer.
  - In Asia: *compensating* — more polluted areas concentrate higher income.
- **Welfare gains from clean air are large and concentrated:**
  - Gains are concentrated in the most polluted subnational units in Africa and Asia, strongly motivating *targeted* pollution-abatement policies.

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