Equilibrium Particulate Exposure

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We know that general equilibrium responses to particulates regulation occur:

The Clean Air Act;

- Reduces TSP in attainment areas by about $30\mu g/m^3$ from a base of $90\mu g/m^3$ (Chay and Greenstone [2005])
- Increases house prices in attainment areas, TSP elasticity of house price $\in [-0.20, -0.35]$ (Chay and Greenstone [2005])
- 600k reduction in non-attainment area employment from 1972-1987 (out of 75-100m national employment) (Greenstone [2002])
- Workers in dirty industries in non-attainment areas displaced to attainment areas/clean industries (Walker [2013])
- Firms in dirty industries migrate to attainment areas, firms in dirty industries shrink (Becker and Henderson [2000]).

General equilibrium responses to particulates regulation operate in complicated but intuitive ways. Are these effects economically important? How do they vary across countries?

Definitions/Units

Particulates are fine particles of solids or water in the air column. We can measure them three ways,

- Mass. This is useful for describing,
  - Sources; flows in, hydrocarbon combustion, dust, fires, chemistry(ignored).
  - Sinks; flows out, deposition.

  Economic activity/regulation affects the mass of particulates in the air at a point.
- Concentration, Units $\sim$ Mass/Volume, e.g., PM10 $\sim \mu g/m^3$. This is what we often measure as air quality. Aerosol Optical Depth (AOD) $\approx \mu g/m^3 \times 10^{-2}$ is remotely sensed concentration measure.
- Exposure $=$ people $\times$ concentration. This is what we really care about.

Mass $=$ concentration $\times$ volume, so we can go back and forth between units.

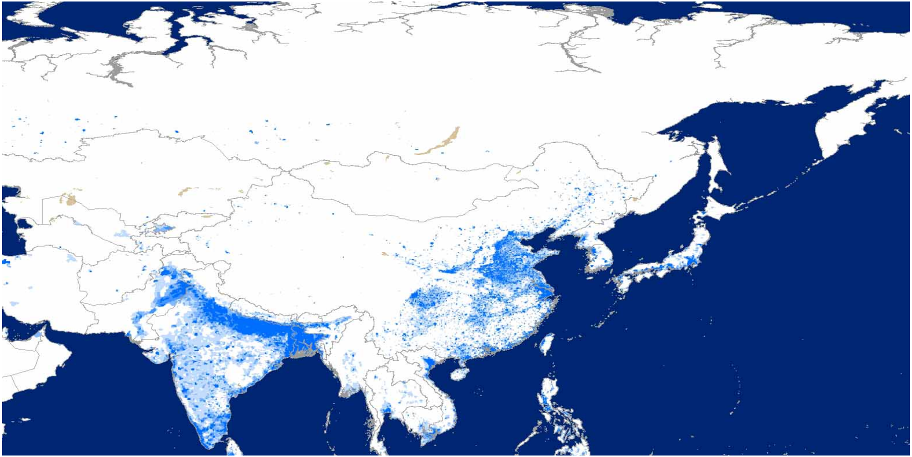
Equilibrium exposure to airborne particulates

- Document levels and changes in particulate concentration and exposure.
- Describe correlations between economic activity, particulate concentration and exposure.
- Develop country level equilibrium model (**SEPIA**) of particulate concentration and exposure, and its implications.

Main contributions: data, facts, model, policy.

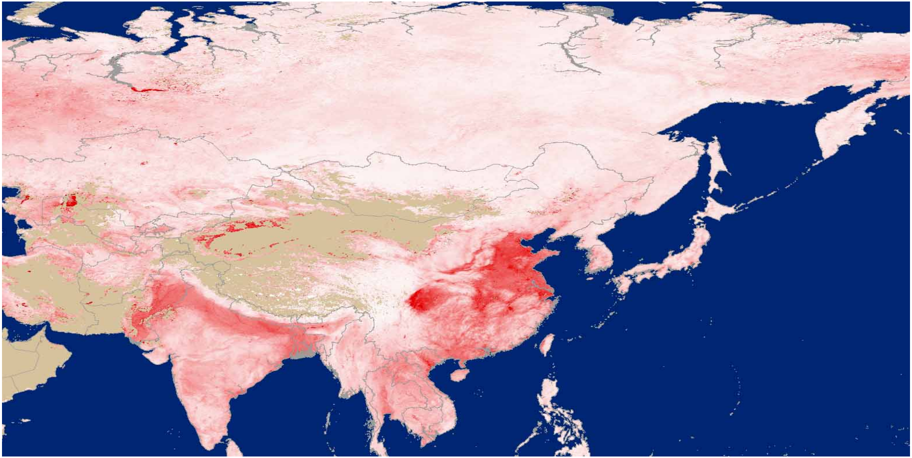
This is important: particulates are poisonous and jointly produced with energy.

Exposure 1: Population in China, Russia and India, 2010.



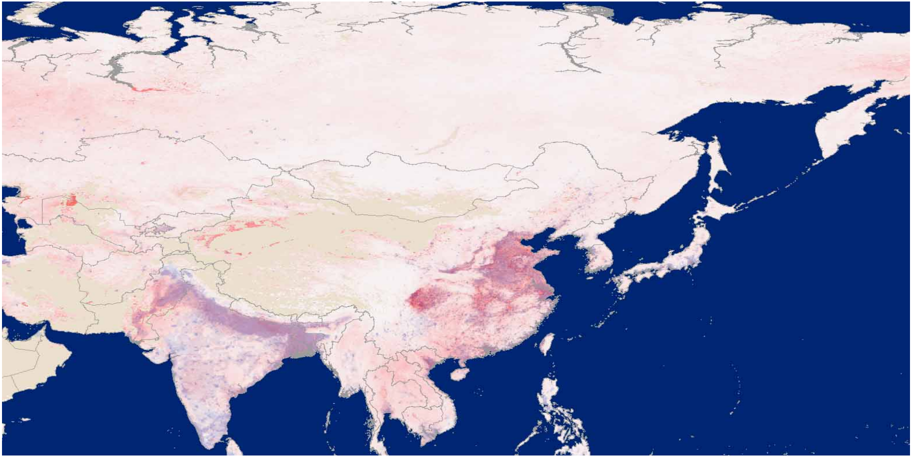
Note: Blue is population.

Exposure 2: Concentration/AOD in China, Russia and India, 2010.



Note: Red is AOD.

Exposure 3: Exposure in China, Russia and India, 2010.



Note: Red is AOD, Blue is population. Purple is exposure. In India, people are more dispersed than pollution. In China, pollution is more dispersed than people. Pollution and population are separate in Russia. What is the effect of an urban coal tax in China?

AOD and Exposure

Levels and changes, selected countries

	AOD 2000	Exposure 2000	%Δ AOD 2000-10	%Δ Exposure 2000-10	$\frac{\%\Delta AOD}{\%\Delta Exposure}$
Indonesia	0.20	0.27	-15.71	-1.83	8.58
Brazil	0.13	0.12	65.55	28.18	2.33
US	0.14	0.20	-20.48	-11.89	1.72
India	0.28	0.36	30.58	29.03	1.05
Russia	0.12	0.17	52.21	72.66	0.72
China	0.31	0.53	13.58	22.96	0.59
Poland	0.20	0.22	-4.46	-8.39	0.53

- Country heterogeneity in concentration and exposure is large relative to the level.
- The relationship between concentration and exposure differs dramatically across countries. This is true in levels and changes.

$\Longrightarrow$ The equilibrium process that selects the locations of people and pollution sources looks important.

- This invites questions like, 'How important is general equilibrium? For example, how likely is it that taxes on agricultural burning increase exposure?'

Concentration from different sources, in kt/km3 (2010)

	Ambient	Coal	Oil	Ag burnin	Flow out	Flow in	Service process	Ind process	Natural	Deposition
Pixel avg.	23	958	104	155	200	227	17	357	26358	27976
Indonesia	17	1	19	205	321	354	0	4	19373	19635
Brazil	22	2	28	52	138	161	6	26	24281	24416
US	11	49	53	38	128	129	33	24	12891	13090
India	36	1481	286	379	249	379	17	436	41239	43967
China	36	3256	208	318	311	324	17	1301	41009	46122
Poland	19	3875	107	12	195	214	42	59	20651	24767
Country avg	23	1444	117	167	224	260	19	308	26574	28666

- Mean stock, 'Ambient', is tiny next to annual flows.
- Coal is much larger than other anthropogenic sources. Oil. Ag. Burning, and international flows are also all large.
- Deposition is model based estimate. Natural particulates are a residual.
- Country level heterogeneity in levels and sectors is large compared to stock.

maps

Reduced form results (summary)

- Country-year and climate variation explains about 50% of variation in 10 km^2 pixels. This seems remarkable. Most variation is at country level. Year effects add little explanatory power.

$\Longrightarrow$ the static, country level problem that our model addresses is economically important.

- Pixel level observables have little explanatory power. This variation is not driven by economics (that we can observe).

$\Longrightarrow$ Coarse model geography seems defensible (and matches energy data).

- Economic geography is important and a few country-year level variables explain most country-year exposure variation. Order of importance; Ag GDP $>$ Urban Share$>$ Ag Burning $>$ Coal $>$Flows.

$\Longrightarrow$ We know the variables to focus on in our model, and we want to allow people/firms to move.

Causal inference in this context looks really hard. This is macro. We want an 'integrated assessment model'.

SEPIA model goals

Spatial Equilibrium Particulate Integrated Assessment model

- Is importance of, e.g., coal consistent with other basic facts about how economies operate? Are reduced form correlations plausibly causal?
- Is it easy to generate complicated general equilibrium responses to particulates regulation? Alternatively, when will partial equilibrium policy analysis be seriously wrong?
- Rank particulates policies and think about the value of better information about structural parameters.

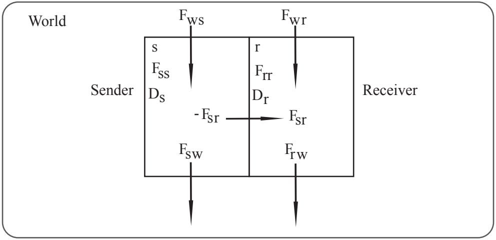
We want to aggregate what we know to make an educated guess. Where relevant, we discipline the model by calibrating it to match certain observed country outcomes for 2010.

SEPIA model, basic structure

Goal: Reflect stylized facts and data limitations, but allow enough margins for adjustment to policy that perverse responses are not ruled out; migration, firm mobility, sector mobility, fuel mix, factor intensity.

- Each country j is a small, open, static economy. Two regions per country:Urban, u, rural/agricultural, a, plus rest of world (ROW)
- Four sectors of production:
  - Industry (I_u, I_a): Urban and agricultural, tradeable
  - Services (S): Urban, non-tradeable
  - Agriculture (M): Rural, tradeable
  - Energy (J): (Rural,Urban) $\times$ sector, non-tradeable
- Equilibrium mobility of labor (agricultural utility premium), industry, AOD
- Fossil energy inputs (coal, oil, gas) imported
- ROW AOD and prices for capital, tradeables, fossil fuels: exogenous

SEPIA steady state particulate transport model



'Sending region' (agricultural or urban) exports to 'Receiving region'. In a steady state the conservation of mass requires,

$$0 = F_{ss} - D_s + F_{ws} - F_{sw} - F_{sr}$$
$$0 = F_{rr} - D_r + F_{wr} - F_{rw} + F_{sr}.$$

$F_{kk} \sim$ source in region k, $D_k \sim$ deposition in region k, $F_{kk'} \sim$ flow from region k to k'.
N.B.: Two types of economy, urban-sender, urban-receiver.

SEPIA model equilibrium

- Profits are maximized in each sector given prices and policies
- Household utility is maximized in each location given prices and policies
- The marginal household with threshold agricultural amenity value ϵ^* is just indifferent between each location
- AOD concentrations obey the laws of nature
- Service sector output market clears
- Labor markets clear
- The aggregate budget constraint is satisfied
- Capital price, ag. output price, manufacturing output price, rest of world AOD all exogenous
- Ag. land rent discarded. Tax revenue discarded or recycled.

Calibration Summary

- Literature: Production factor shares, fuel substitution elasticity, fire abatement costs, mixing height, deposition rate.
- Directly from data: Fire intensity, fossil energy prices, consumer expenditure shares
- All remaining parameters: Simultaneously match model's initial equilibrium conditions and data moments:
  - Sectoral outputs: World Bank WDI
  - Initial population distribution (u, a): GPW
  - Initial agricultural labor share: ILOSTAT
  - Sectoral coal, petroleum, gas inputs: IEA
  - Willingess to pay for AOD reduction: Ito and Shuang (2016)

Counterfactual policy evaluation

We use our model to evaluate three counterfactual policies,

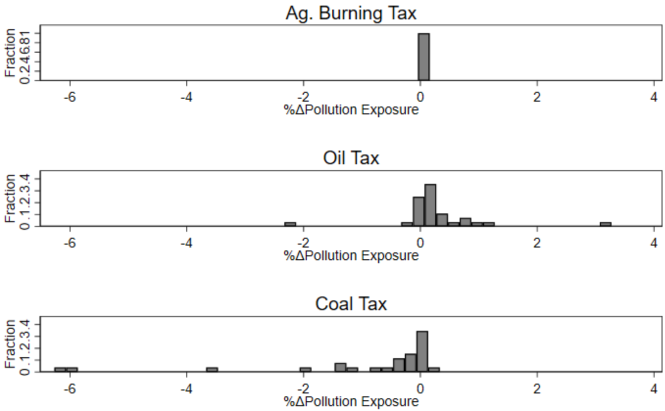
1. 15% tax on coal.
2. 10% tax on petroleum.
3. 30$/Mt on Ag. Burning Emissions.

We want to address three questions.

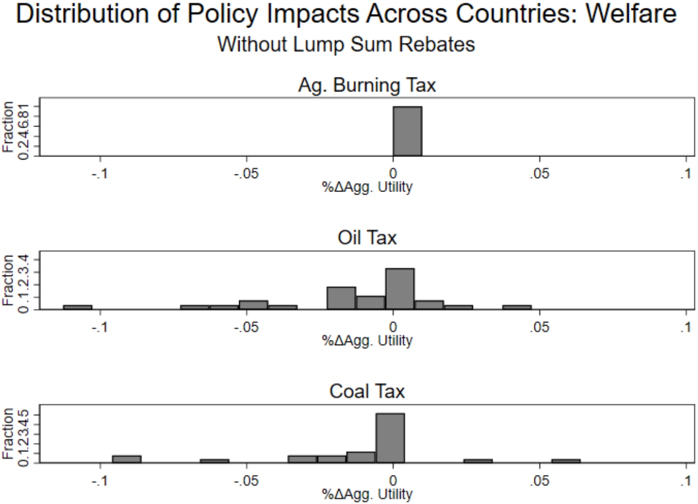
1. What happens in response to policy?
2. Is partial equilibrium good enough?
3. Which policy, where?

Distribution of Policy Impacts Across Countries: Exposure

Without Lump Sum Rebates

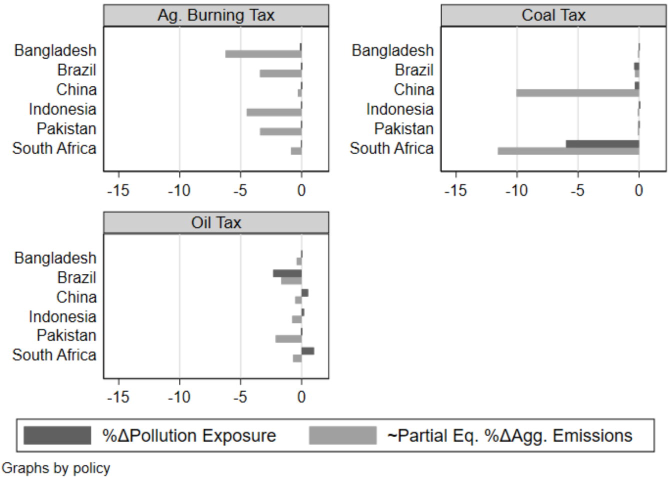


Ag Burning and Oil tax push rural residents into the city and increase exposure. The coal tax generally leads to reductions in exposure. Lump sum returns of tax revenue give larger decreases in exposure. Rural residents stay put.



All three taxes often lead to (Benthamite) welfare improvements even if revenue is dissipated.

Partial vs. general equilibrium



General equilibrium appears to be of first order importance. Policies often have dramatically different effects on emissions and exposure. That is, general equilibrium adjustments are economically important.

Conclusion

- Country-year level variation in exposure and concentration is important and easy to explain statistically with contry level economic fundamentals.
- Within country pixel level variation is about half of variation. It is hard to explain with pixel level variables.
- Cross-country variation in the relationship between concentration and exposure is economically important: Spatial equilibrium processes seem important for exposure (and previously unstudied).
- Our spatially integrated model of particulates and the economy exhibits important general equilibrium effects of regulation. We didn't look hard to find them.
- Still to go, sensitivity analysis.
- We probably need to worry a lot more about general equilibrium responses to particulates regulation than we do.

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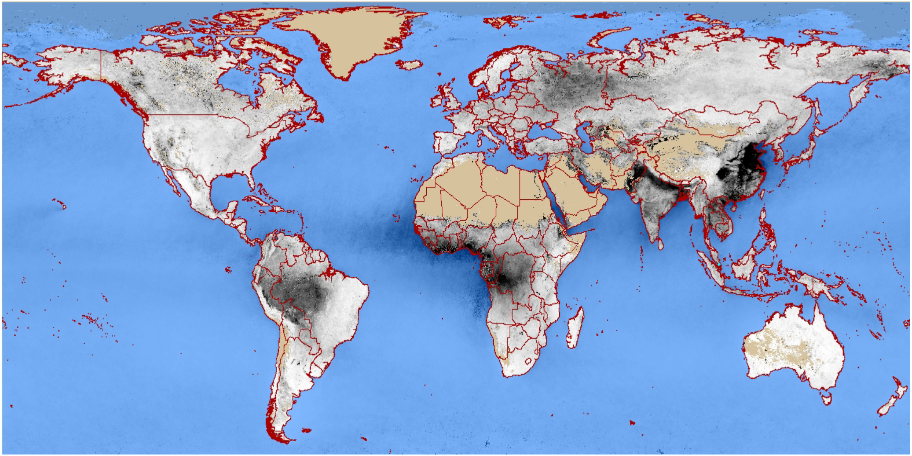
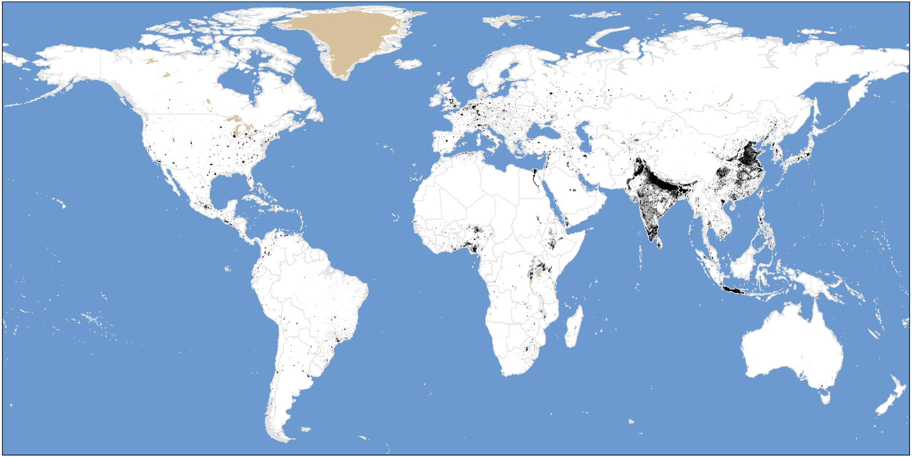
Aerosol Optical Depth 2010



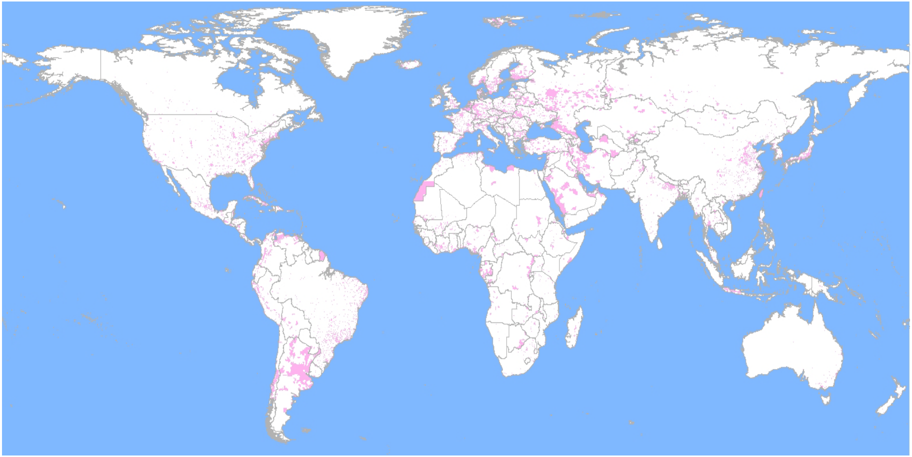
Note: Darker indicates larger AOD value.

Gridded population of the world, 2010.



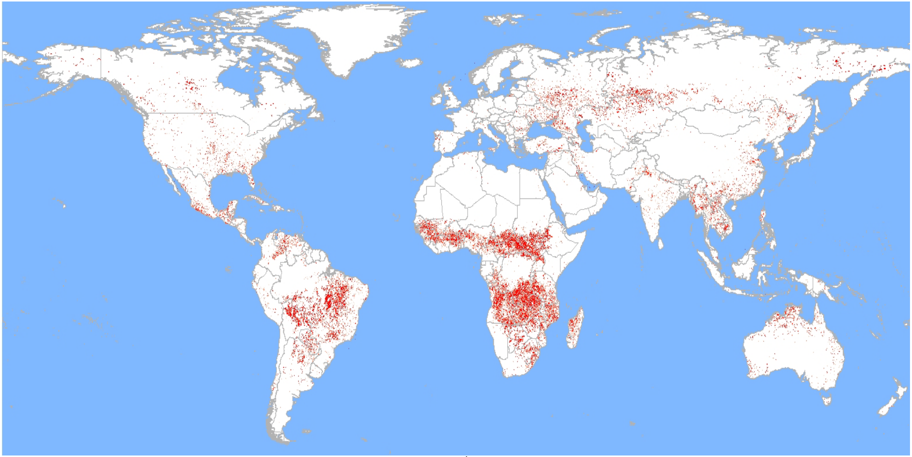
Note: Darker indicates more people per cell.

Urban Areas from GPW and World Bank urban share



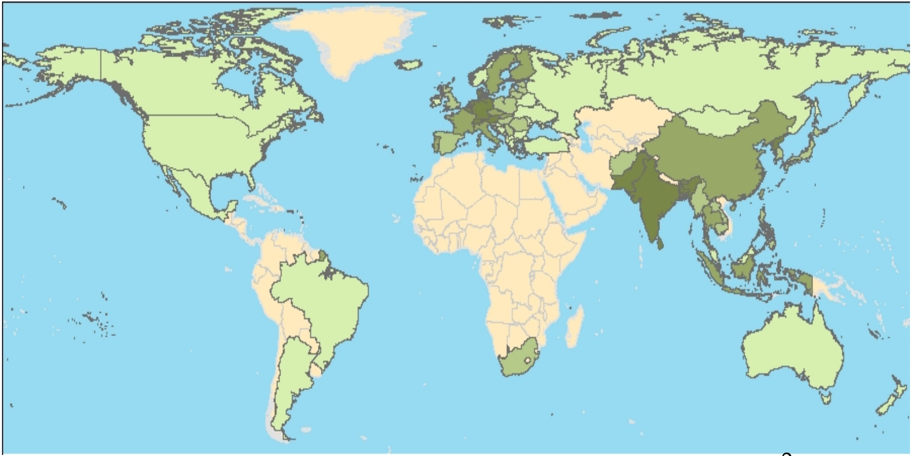
Note: ‘urban regions’ for each country. Model geography is rural, urban, rest-of-world, by country.

MODIS Fires, 2010.



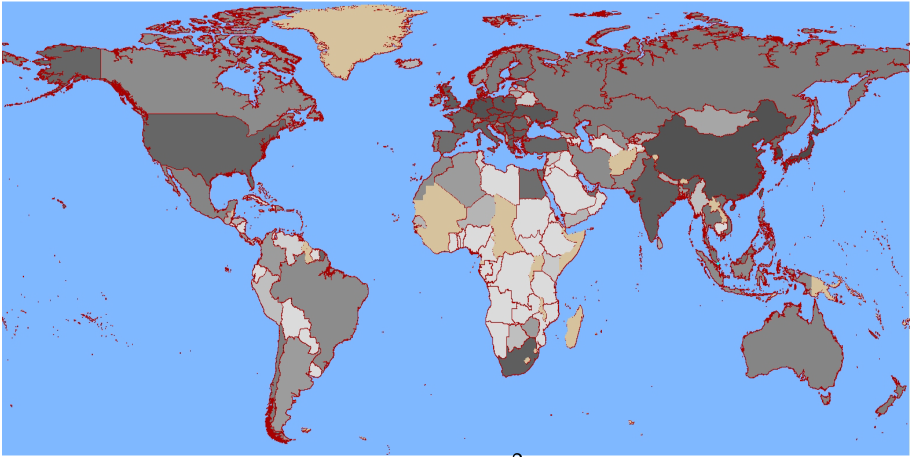
Note: Darker indicates more days/year of fire.

Biomass combustion per km^2 2010 (IIASA)



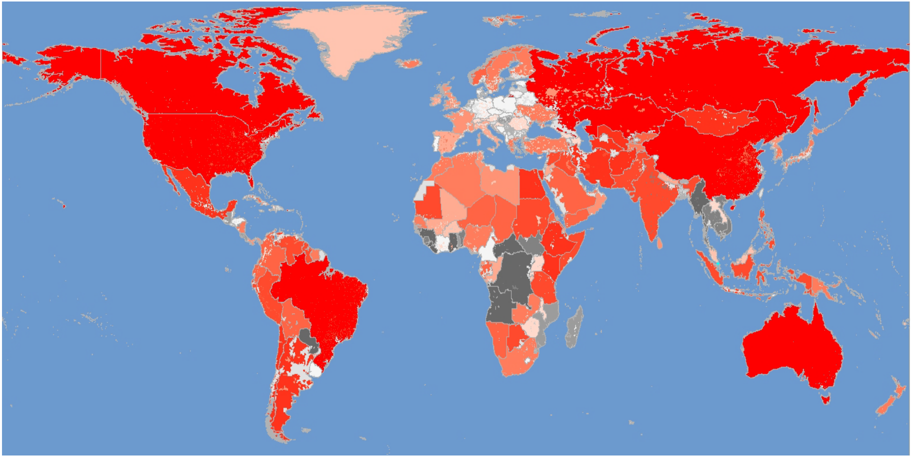
Note: Darker = more biomass fuel and crop burning per km^2 in 2010.

Coal per km^2 2010 (IEA)



Note: Darker = more coal use per km^2 in 2010.

AOD flows per km^2 by country-region, 2010.



Note: Red is net flow out of region divided by source country-region area. back