Air Pollution and Health: Developments in China, India, and Mongolia

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AGU-CAS Joint Meeting

Atmospheric $PM_{2.5}$ in China: Change, Impact, Mitigation, and Global Perspective

Xi’an, China; Oct 20, 2018

Road Map

- NIMBY versus MIMBY
- Getting it wrong, but getting it done
  - China
  - India
- Mongolia may be able to do it right

NIMBY versus MIMBY

- NIMBY: “Not in my backyard”, a common problem in placement of polluting facilities
  - Everyone thinks there should be garbage dumps, but no one wants to live next to one
  - Is why it is said that the first fundamental function of public health is zoning
- MIMBY: “Must be in my backyard”, the desire to see research done locally
  - Natural desire and there can be some differences related to local factors
  - Not a reason for inaction, however.

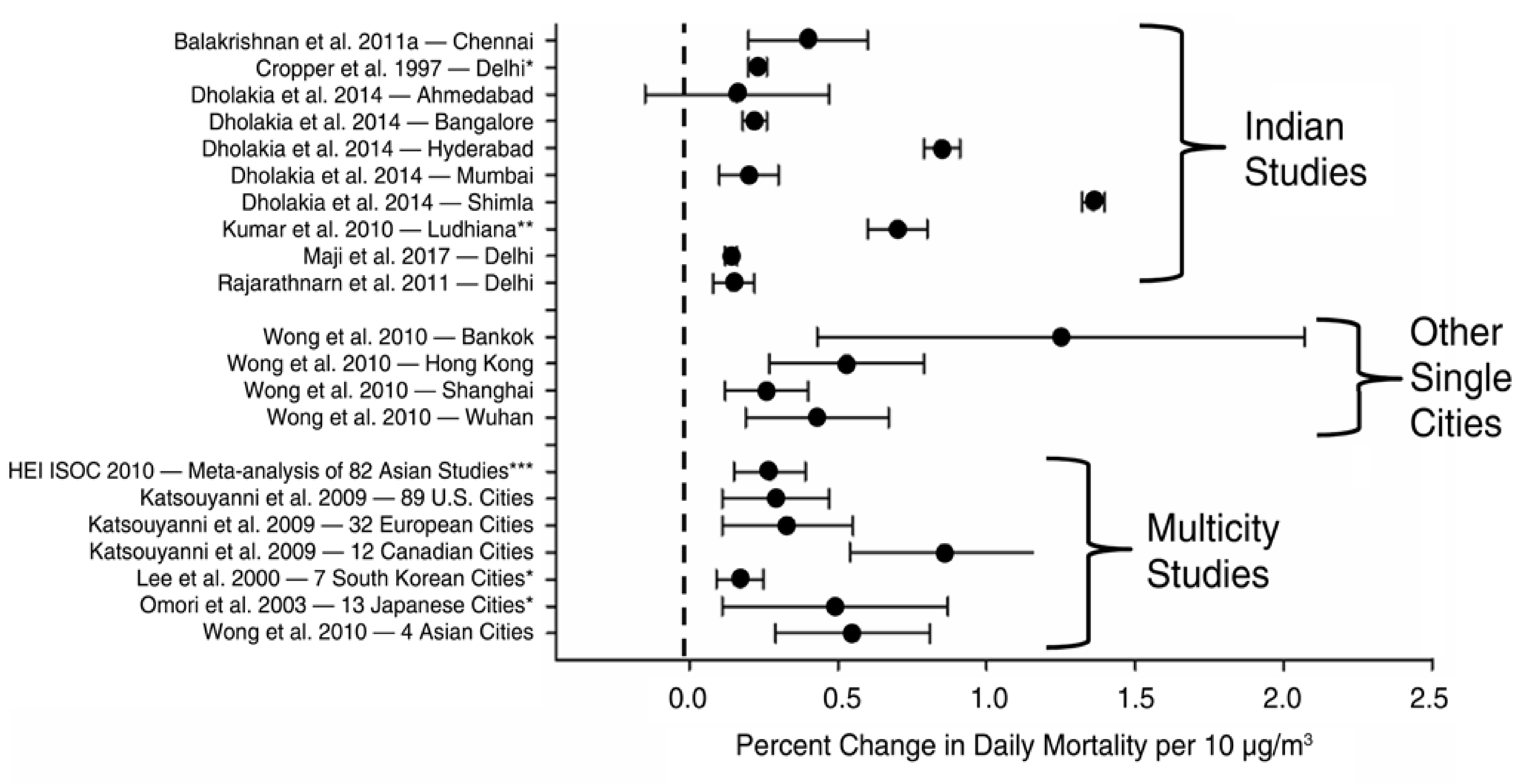
Problems with MIMBY

- Not possible to reproduce good research in all areas of the world, but still need to take action
- In the end, international guidelines do not differentiate by area or population – no separate values to protect Brazilian children and Chinese children from pollutants (sex and age, however, are differentiated)
- People react more or less the same way
- Certainly no evidence that some groups are immune, as some have said in India and China

One way to test: short-term studies

- Have been no long-term cohort studies in Asia, like those in North America and Europe (“West”)
- These are best for determining full risks
- Expensive, long, and difficult
- Short-term (time series) studies are much easier and quicker, but do not determine full risk
- Conduct short-term studies in Asia to see if they are different from those in West
- If similar, supportive of same kind of long-term results

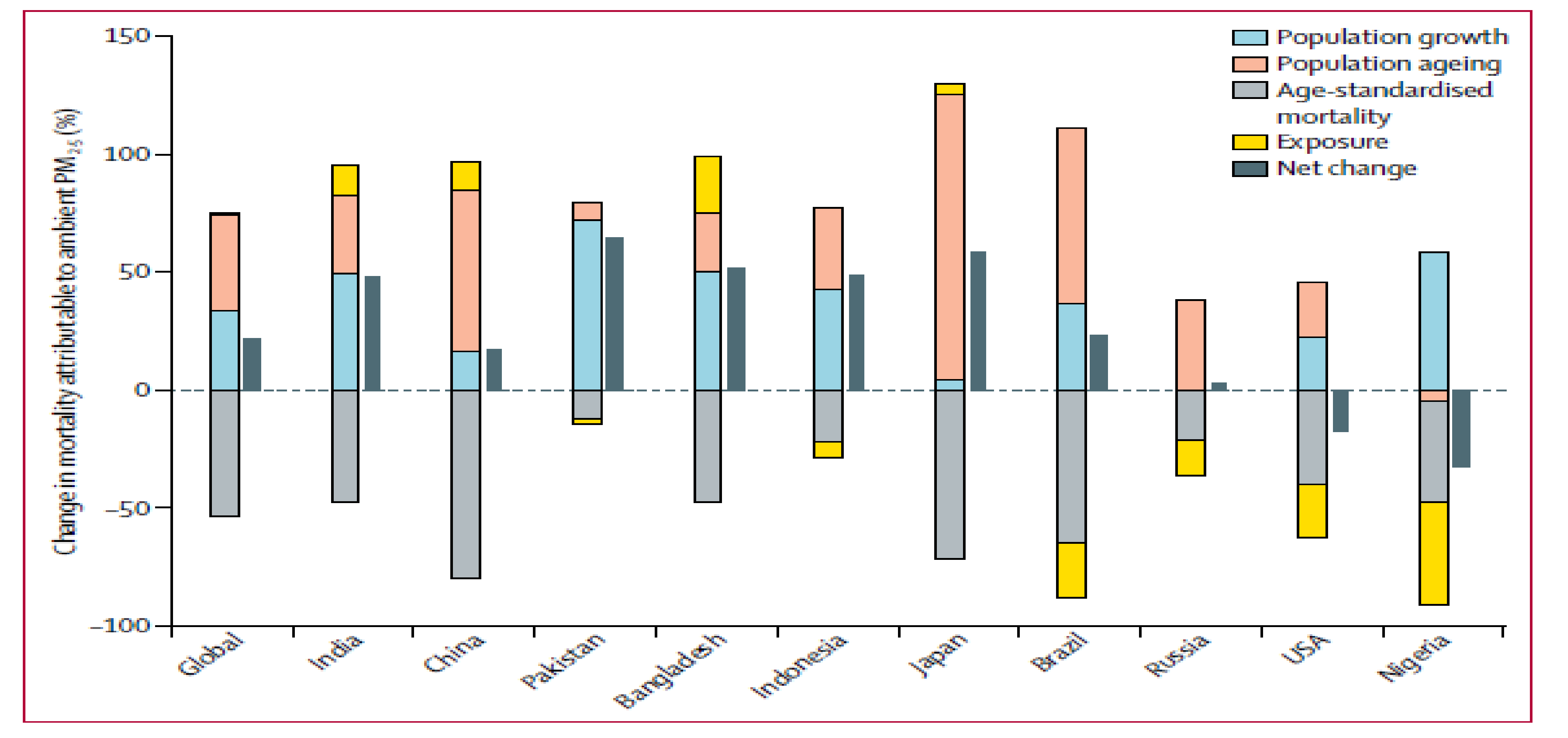
Comparability of Effects Estimates from AAP studies from the region
(Short-term effects : GBD related health endpoints)



Specifics related to air pollution

- We understand some critical issues that change the vulnerability to air pollution
- Age and sex, which is adjusted in normal estimates
- Nutrition – not currently adjusted, but thought to make Asians more susceptible to pollution, not less
- Access to medical care, similar to nutrition
- Lung function, lower in Asia and thus likely greater impact of AP

% change in AAP attributable mortality (1990-2015)



Cohen 2017

Air pollution is only of health interest if it is breathed by

the population

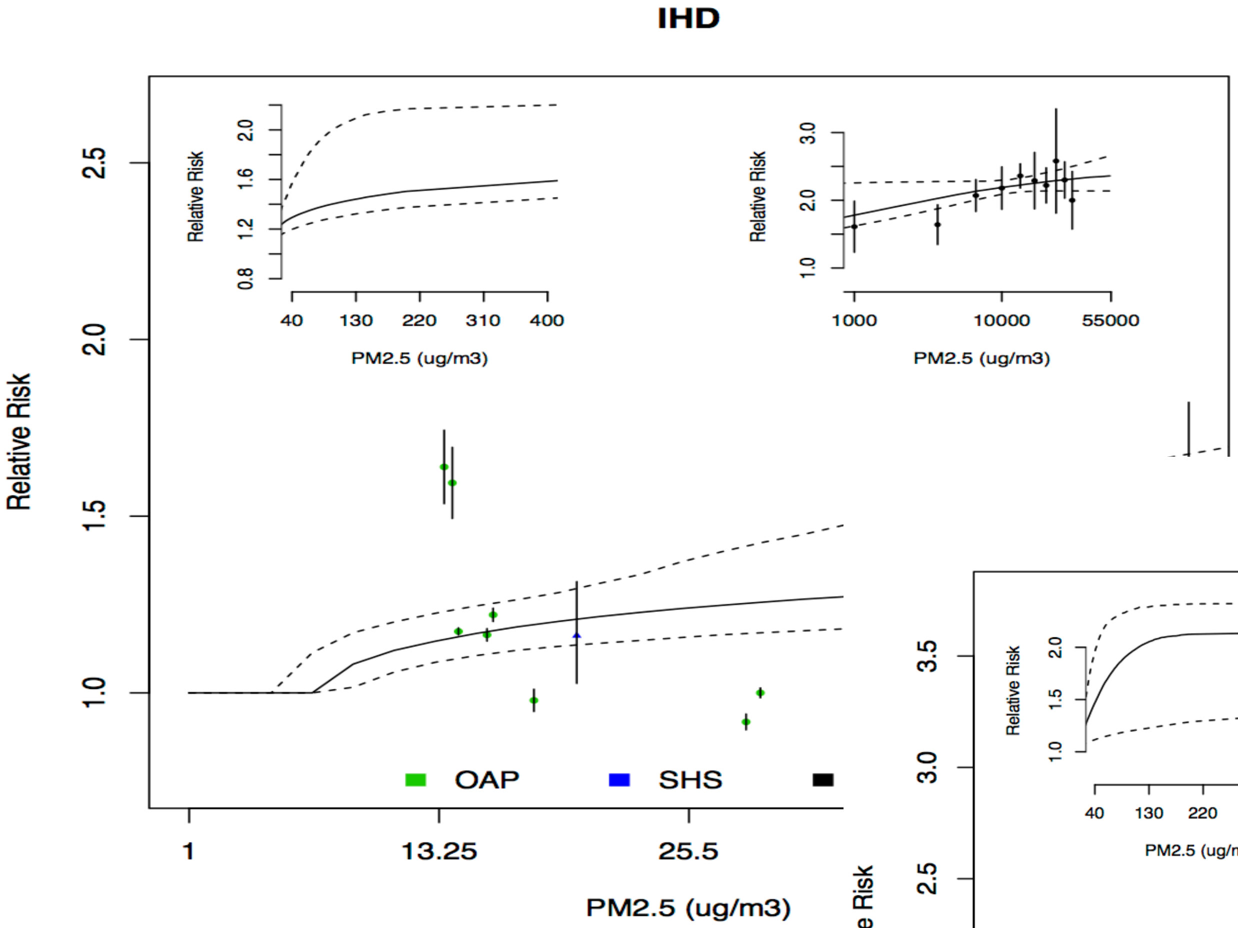
– exposure is what counts

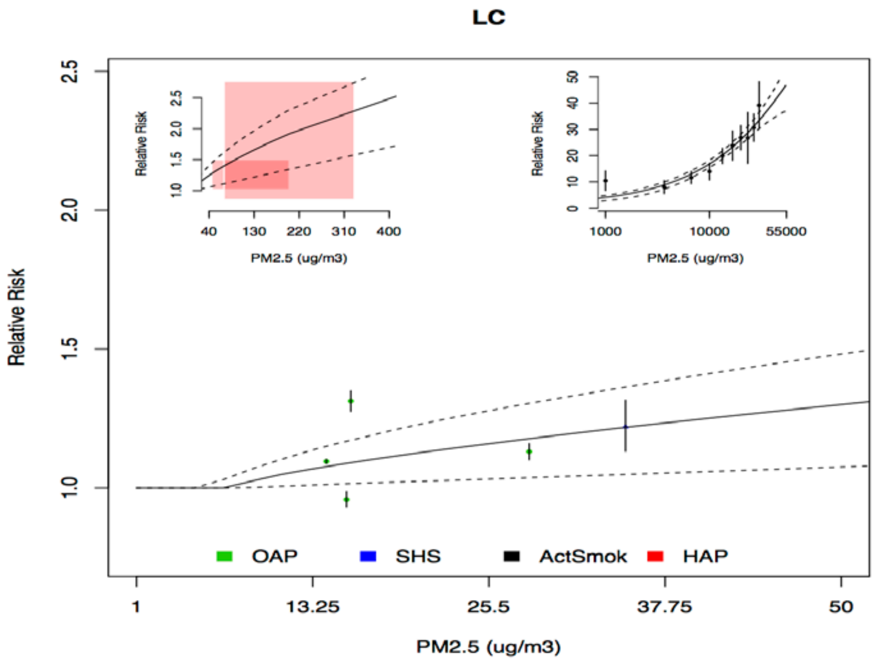
What about Exposure?

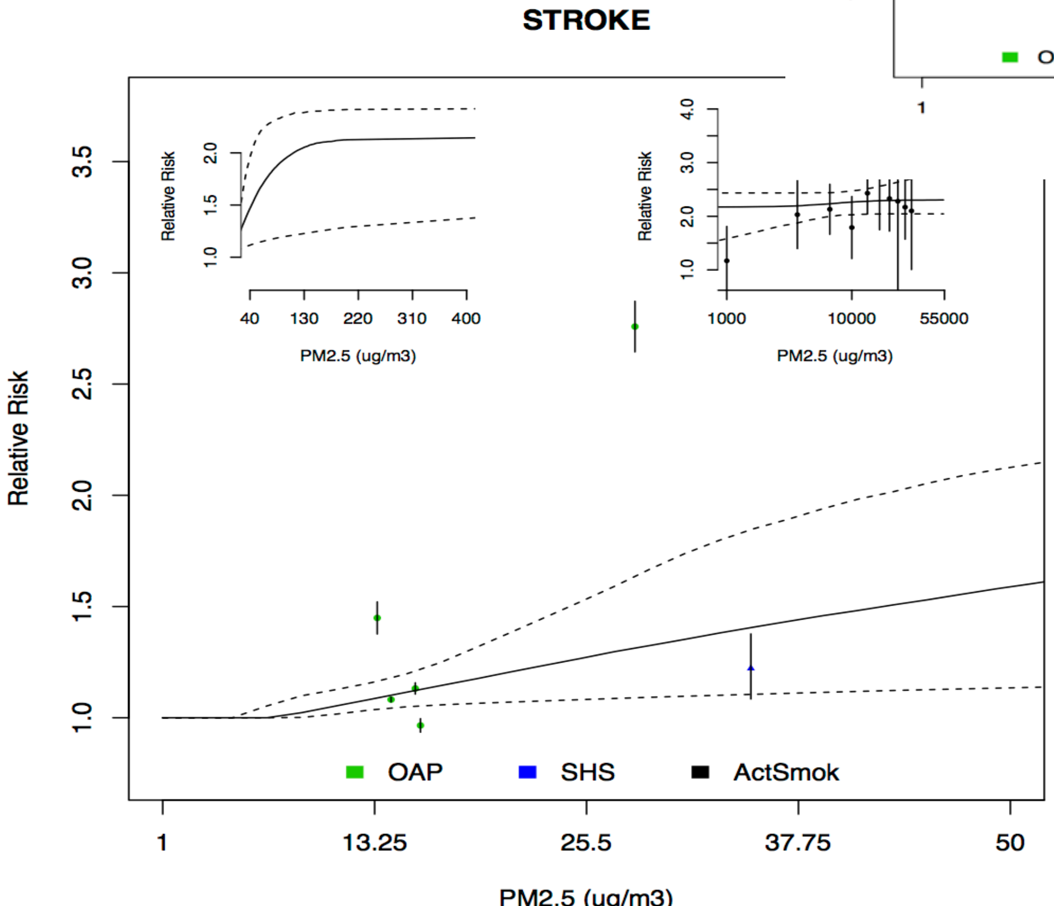
- Ambient air pollution networks do not measure exposure, but indicate outdoor levels over wide areas
- In the West, people actually breathe mostly what comes from outdoors, although less on average due to being partly blocked by housing
- In India and much of China, however, most people live in well-ventilated housing, meaning they breath closer to ambient levels
- In addition, unlike rich countries, Asians are affected more by local sources, sometimes heavily, meaning that their real exposures are higher than what is indicated by the ambient monitors.

Summary

- That until good local studies are done well, most evidence would indicate that Asians are substantially more vulnerable to ambient pollution than populations in the West.
- Not less!
- First good, but partial (male only), ambient cohort study in China seems to show this result.

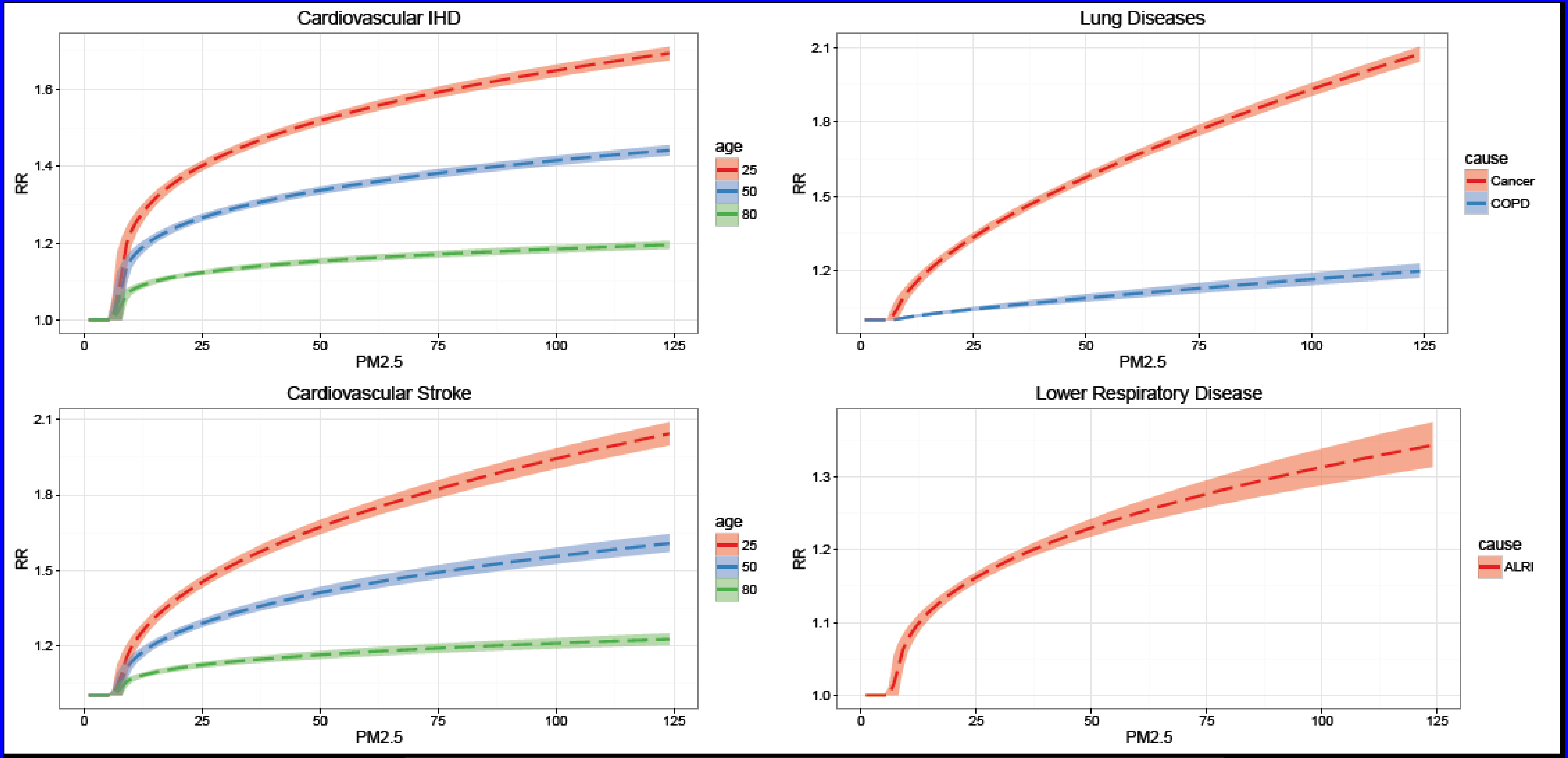






Burnett et al., 2014

GBD- PM $_{2.5}$ Integrated Exposure Response Functions



Burnett et al. 2014; Forouzanfar et al. 2015; Cohen et al. 2017

EHP Environmental Health Perspectives

Environ Health Perspect. 2017 Nov; 125(11): 117002.
Published online 2017 Nov 7. doi: 10.1289/EHP1673
PMCID: PMC5947939
PMID: 29116930
Research

Long-term Fine Particulate Matter Exposure and Nonaccidental and Cause-specific Mortality in a Large National Cohort of Chinese Men

Peng Yin,[1] Michael Brauer,[2] Aaron Cohen,[3] Richard T. Burnett,[4] Jiangmei Liu,[1] Yunning Liu,[1] Ruiming Liang,[1] Weihua Wang,[5] Jinlei Qi,[1] Lijun Wang,[1] and Maigeng Zhou[1]

National Center for Chronic Noncommunicable Disease Control and Prevention, Chinese Center for Disease Control and Prevention, Beijing, China

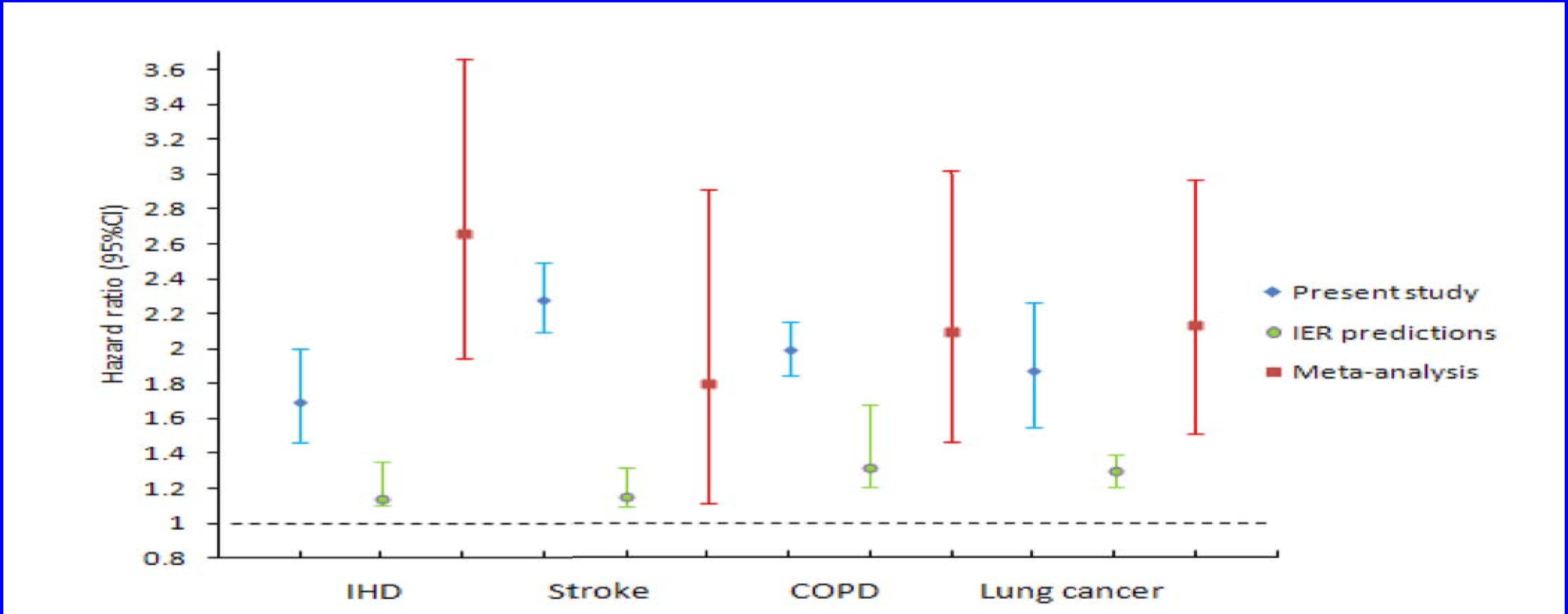
Methods

- We conducted a prospective cohort study of 189,793 men 40 y old or older from 45 areas in China. Annual average PM2:5 levels were estimated for each cohort location using a combination of satellite-based estimates, chemical transport model simulations, and ground-level measurements.
- We also assessed the shape of the concentration–response relationship and compared the risk estimates with those predicted by Integrated Exposure-Response (IER) function, which incorporated estimates of mortality risk from previous cohort studies in western Europe and North America.

Results

- The mean level of PM2:5 exposure during 2000–2005 was 43:7 ug/m3 (ranging from 4.2 to 83:8 ug/m3).
- Mortality increases per 10 ug/m3 increase in PM2:5 were 1.09 (1.08, 1.09) for non-accidental causes; 1.09 (1.08, 1.10) for CVD, 1.12 (1.10, 1.13) for COPD; and 1.12 (1.07, 1.14) for lung cancer.
- The estimate from our cohort was consistently higher than IER predictions.

Comparability of Effects Estimates from AAP studies



Comparison of cause-specific hazard ratio (HR) estimates, from Yin et al 2017. Hazard ratios are calculated based on exposures at the 5th (15.5 ug/m3) and 95th (77.1 ug/m3) percentile using three methods / data sources: Yin et al, 2017 (blue lines with diamonds), IERs (Cohen et al, 2017; green lines with circles), and previous meta-analyses (red lines with squares)

Conclusions

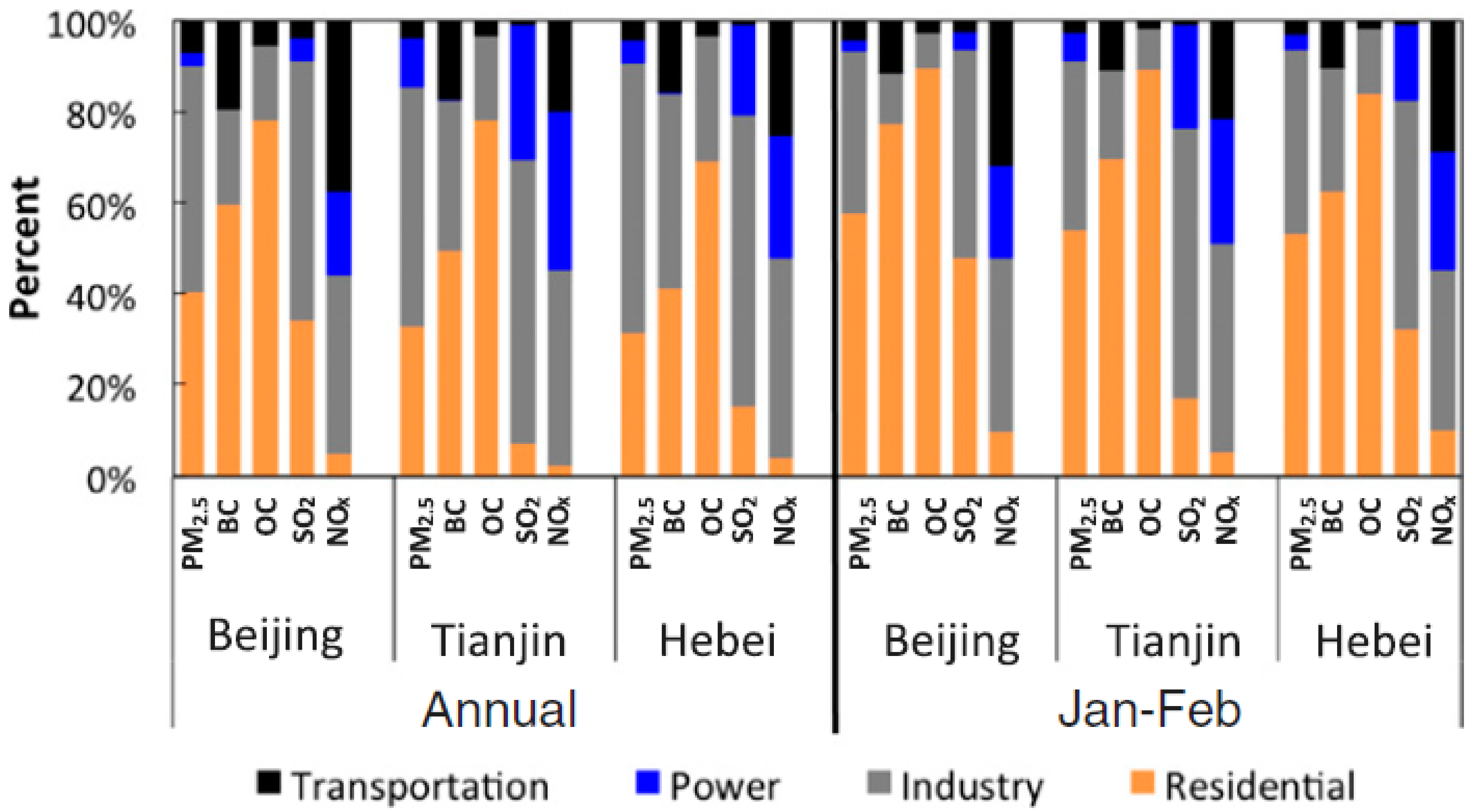
- “Long-term exposure to $PM_{2.5}$ was associated with non-accidental, CVD, lung cancer, and COPD mortality in China.
- The IER estimator may underestimate the excess relative risk of cause-specific mortality due to long-term exposure to $PM_{2.5}$ over the exposure range experienced in China and other low- and middle-income countries.”

Air pollutant emissions from Chinese households: A major and underappreciated ambient pollution source

Jun Liu[a], Denise L. Mauzerall[b,c,1], Qi Chen[a], Qiang Zhang[d], Yu Song[a], Wei Peng[b], Zbigniew Klimont[e], Xinghua Qiu[a], Shiqiu Zhang[a], Min Hu[a], Weili Lin[f], Kirk R. Smith[g,1], and Tong Zhu[a,h,1]

[a]State Key Joint Laboratory of Environmental Simulation and Pollution Control, College of Environmental Sciences and Engineering, Peking University, Beijing 100871, China; [b]Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, NJ 08544; [c]Department of Civil and Environmental Engineering, Princeton University, Princeton, NJ 08544; [d]Ministry of Education Key Laboratory for Earth System Modeling, Center for Earth System Science, Tsinghua University, Beijing 100084, China; [e]International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, A-2361 Laxenburg, Austria; [f]Chinese Academy of Meteorological Sciences, Beijing 100081, China; [g]School of Public Health, University of California, Berkeley, CA 94720-7360; and [h]Beijing Innovation Center for Engineering Science and Advanced Technology, Peking University, Beijing 100871, China

Proceedings National Academy of Sciences (2016), 114: 4887–4892.



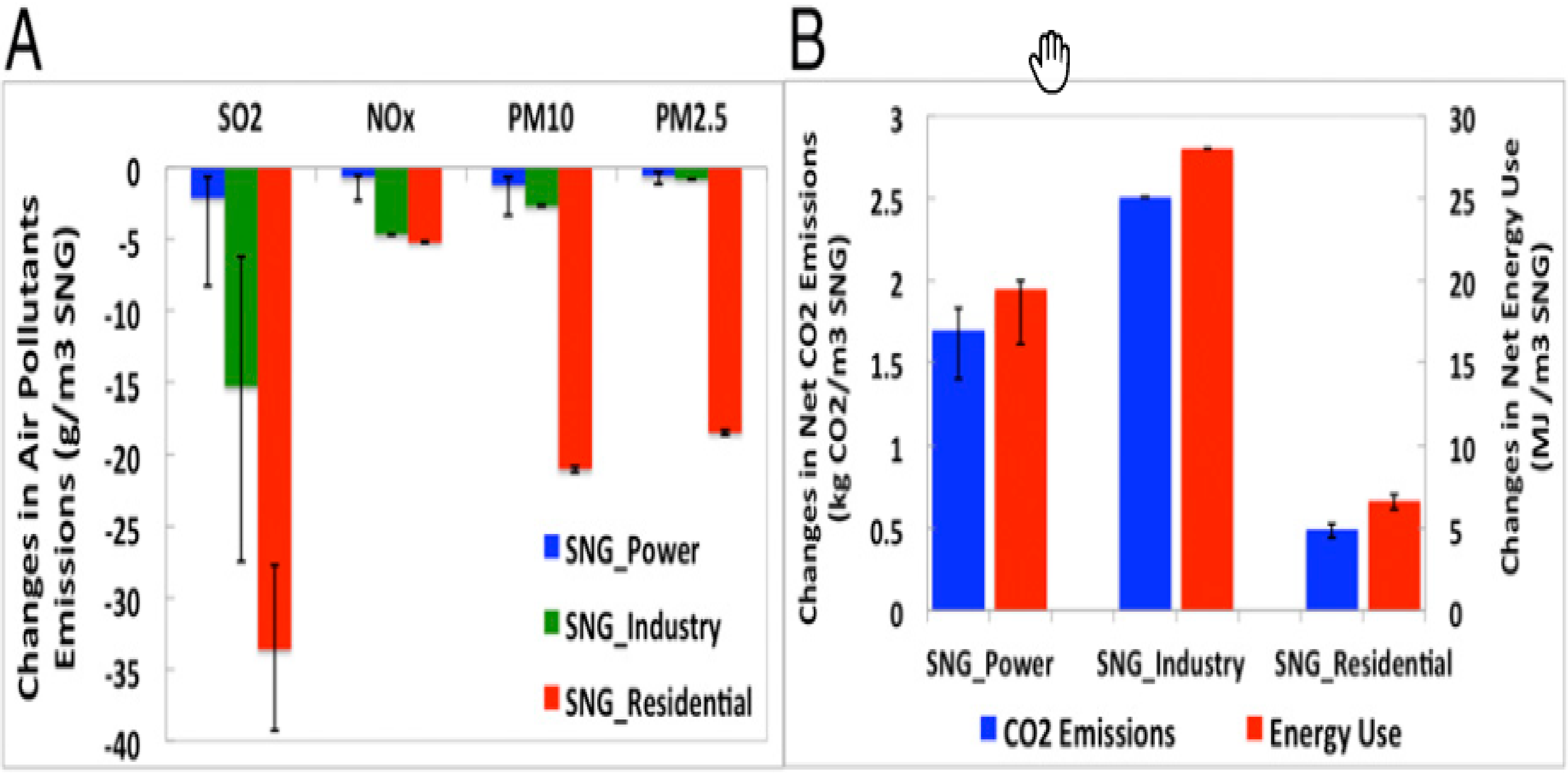
100%
80%
60%
40%
20%
0%
Percent
PM2.5
BC
OC
SO2
NOx
Beijing
Tianjin
Hebei
Annual
Jan-Feb
Transportation
Power
Industry
Residential

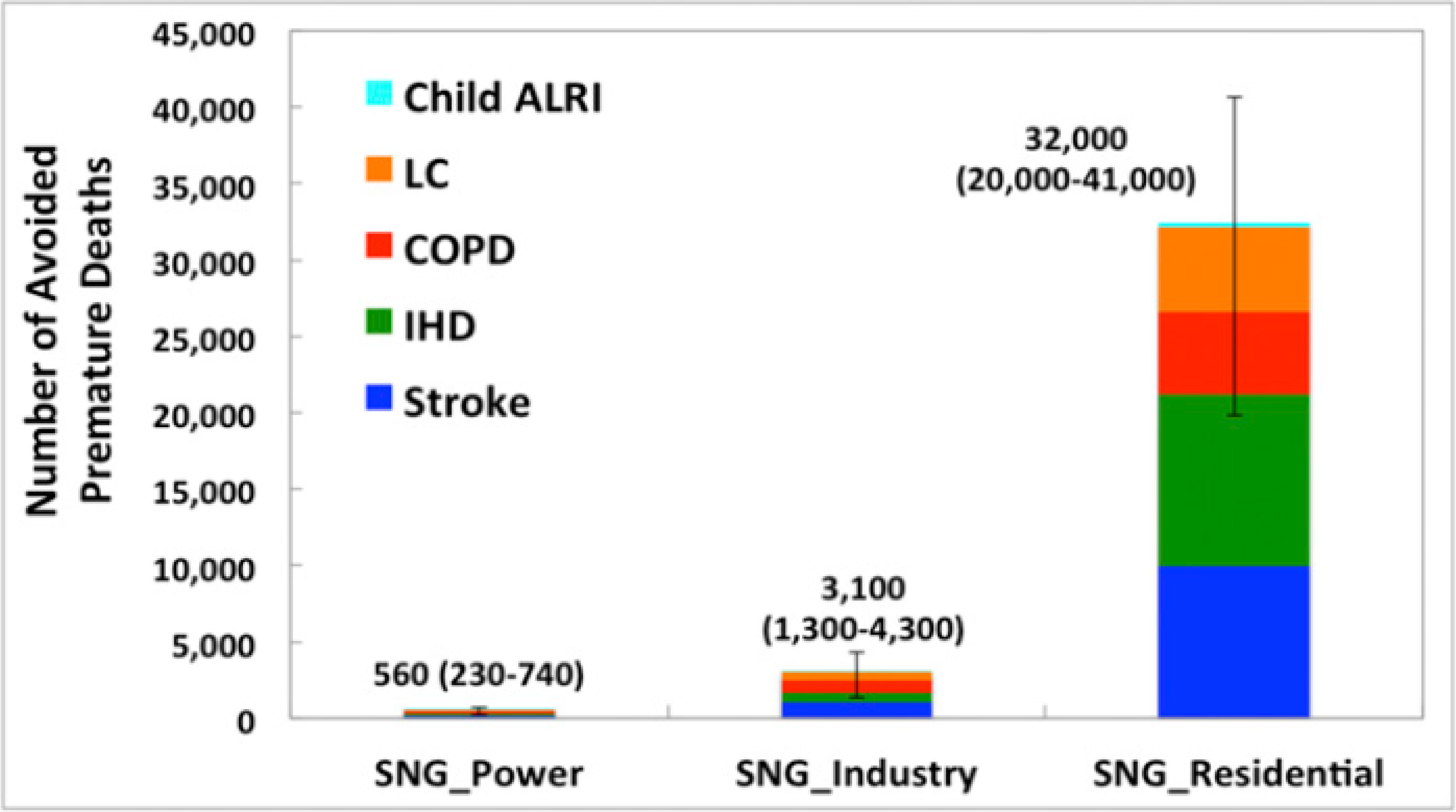
Air quality, health, and climate implications of China's synthetic natural gas development

Yue Qin[a], Fabian Wagner[a,b,c], Noah Scovronick[a], Wei Peng[a,1], Junnan Yang[a], Tong Zhu[d,e], Kirk R. Smith[f,2], and Denise L. Mauzerall[a,g,2]

[a]Woodrow Wilson School of Public and International Affairs, Princeton University, Princeton, NJ 08544; [b]Andlinger Center for Energy and the Environment, Princeton University, Princeton, NJ 08544; [c]International Institute for Applied Systems Analysis, A-2361 Laxenburg, Austria; [d]State Key Joint Laboratory of Environmental Simulation and Pollution Control, College of Environmental Sciences and Engineering, Peking University, Beijing 100871, China; [e]Beijing Innovation Center for Engineering Science and Advanced Technology, Peking University, Beijing 100871, China; [f]School of Public Health, University of California, Berkeley, CA 94720-7360; and [g]Department of Civil and Environmental Engineering, Princeton University, Princeton, NJ 08544

Proceedings National Academy of Sciences (2017), 113:7756-61.


A
B
SO2
NOx
PM10
PM2.5
Changes in Air Pollutants Emissions (g/m3 SNG)
0
-5
-10
-15
-20
-25
-30
-35
-40
SNG_Power
SNG_Industry
SNG_Residential
Changes in Net CO2 Emissions (kg CO2/m3 SNG)
Changes in Net Energy Use (MJ /m3 SNG)
3
2.5
2
1.5
1
0.5
0
30
25
20
15
10
5
0
SNG_Power
SNG_Industry
SNG_Residential
CO2 Emissions
Energy Use



Number of Avoided Premature Deaths
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Child ALRI
LC
COPD
IHD
Stroke
560 (230-740)
3,100
(1,300-4,300)
32,000
(20,000-41,000)
SNG_Power
SNG_Industry
SNG_Residential

Change in household fuels dominates the decrease in PM2.5 exposure and premature mortality in China in 2005-2015

Bin Zhao[1,2], Haotian Zheng[1], Shuxiao Wang[1,3,*], Kirk R. Smith[4,*], Xi Lu[1,3], Kristin Aunan[5], Yu Gu[2], Yuan Wang[6], Dian Ding[1], Jia Xing[1,3], Xiao Fu[7], Xudong Yang[8], Kuo-Nan Liou[2], and Jiming Hao[1,3]

[1]School of Environment, and State Key Joint Laboratory of Environment Simulation and Pollution Control, Tsinghua University, Beijing 100084, China [2]Joint Institute for Regional Earth System Science and Engineering and Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, CA 90095, USA [3]State Environmental Protection Key Laboratory of Sources and Control of Air Pollution Complex, Beijing 100084, China [4]Environmental Health Sciences, School of Public Health, University of California, Berkeley, CA 94720-7360, USA [5]CICERO Center for International Climate Research, P.O. Box 1129 Blindern, N-0318 Oslo, Norway. [6]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA [7]Department of Civil and Environmental Engineering, Hong Kong Polytechnic University, Hong Kong 99907, China [8]Department of Building Science, Tsinghua University, Beijing 100084, China

Proceedings National Academy Sciences (2018, accepted)

$$IPWE = PWE_{AAP} + PWE_{HAP}$$

where PWE_{AAP} is the population-weighted exposure to AAP and PWE_{HAP} is the additional population-weighted exposure to HAP. (excluding any contribution from AAP)

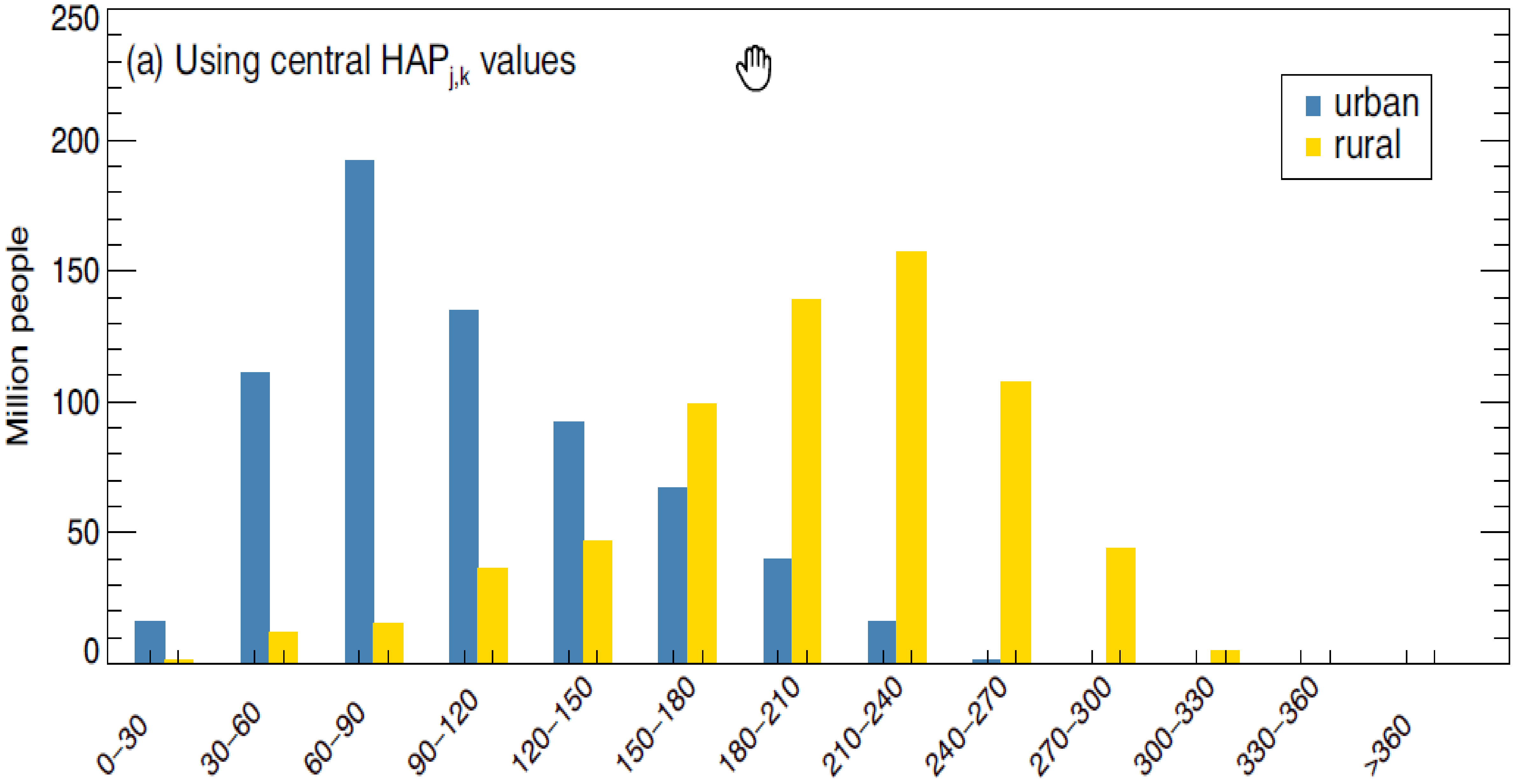
$$PWE_{AAP} = \frac{1}{P}\sum_{i}(P_i \cdot C_i)$$

$$PWE_{HAP} = \frac{1}{P}\sum_{i,j}(P_{i,j,k} \cdot HAP_{j,k})$$

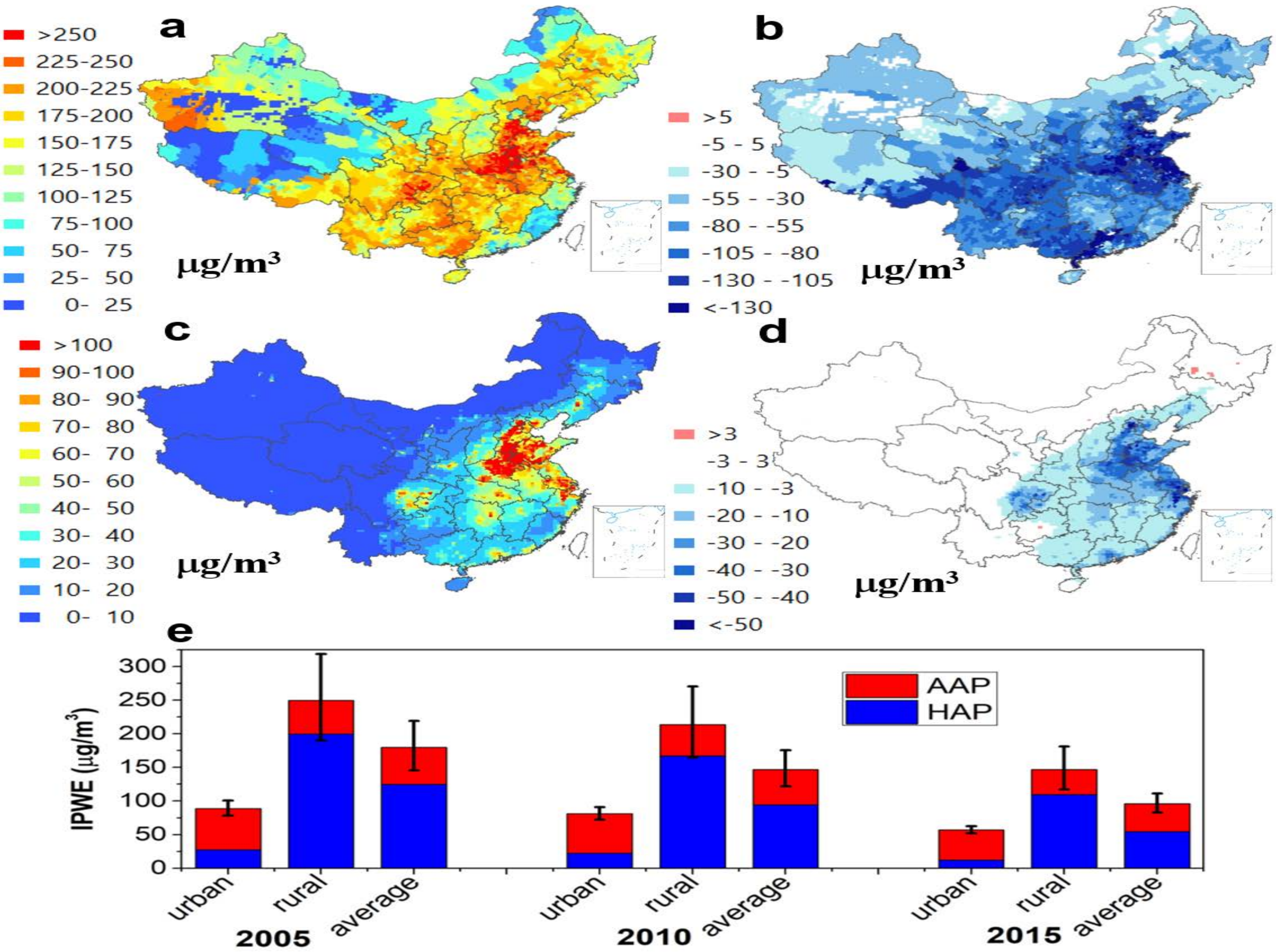
i = county

j = urban/rural

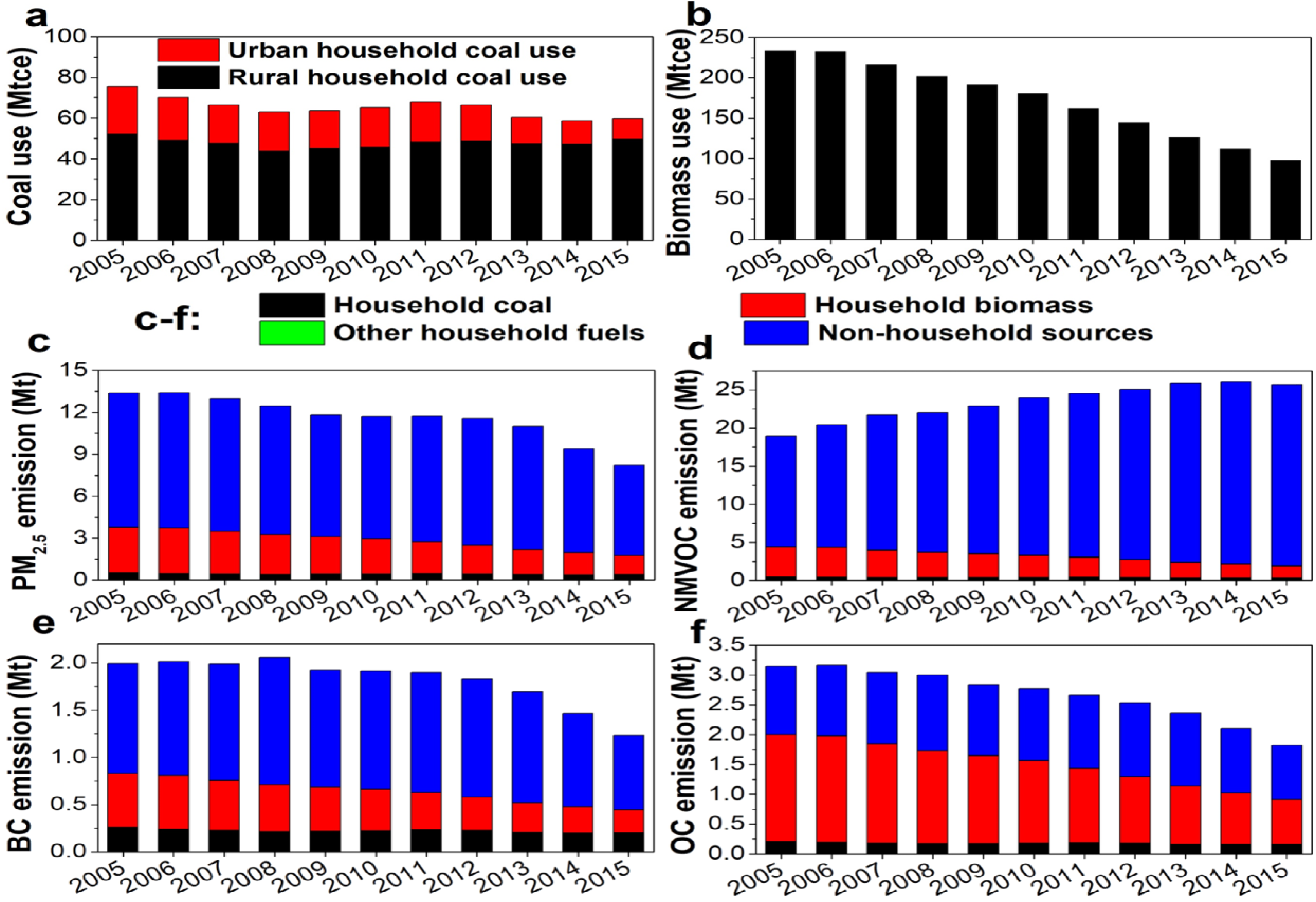
k – fuel type

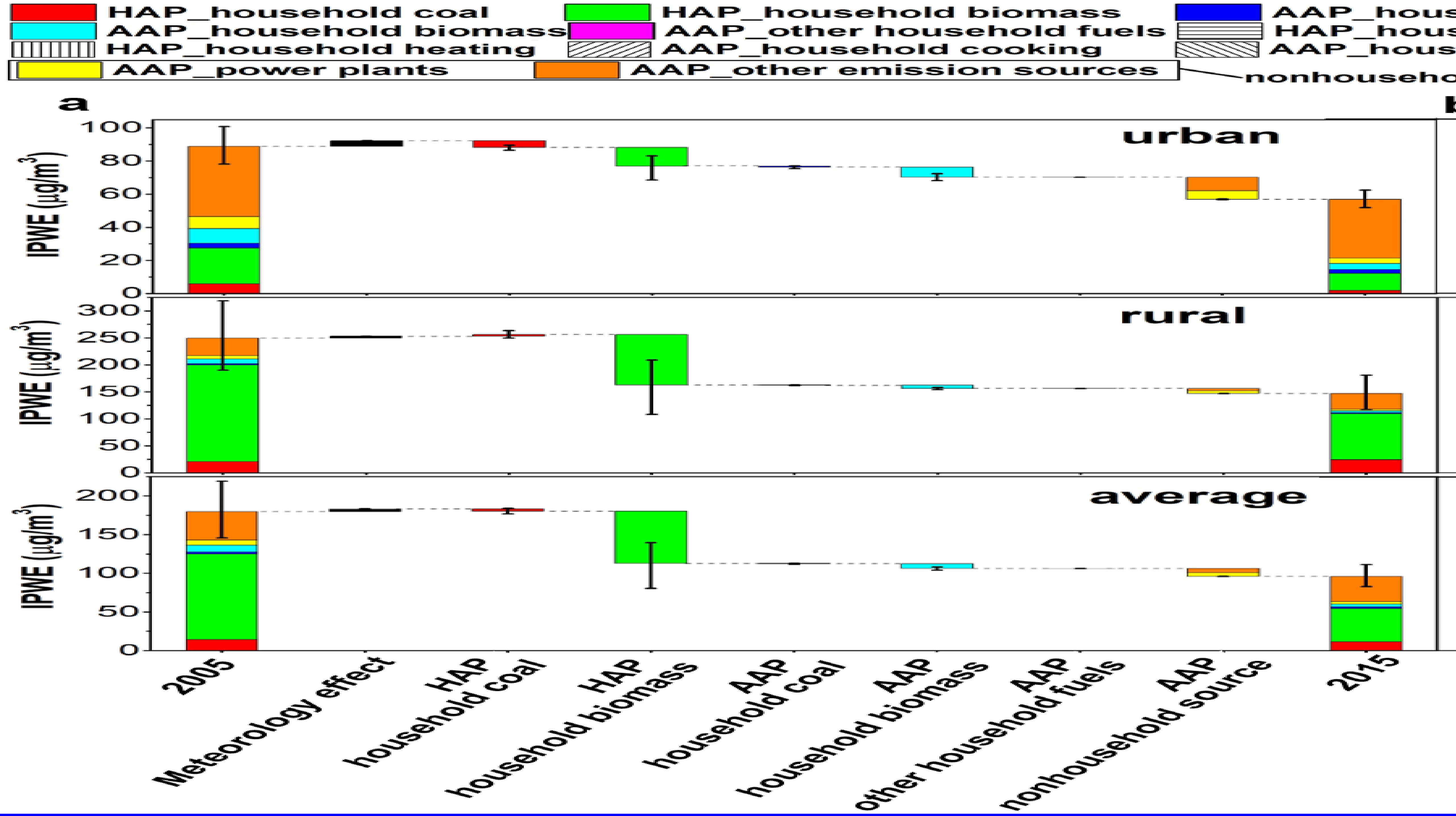


(a) Using central $HAP_{j,k}$ values
urban
rural
Million people
0
50
100
150
200
250
0–30
30–60
60–90
90–120
120–150
150–180
180–210
210–240
240–270
270–300
300–330
330–360
>360

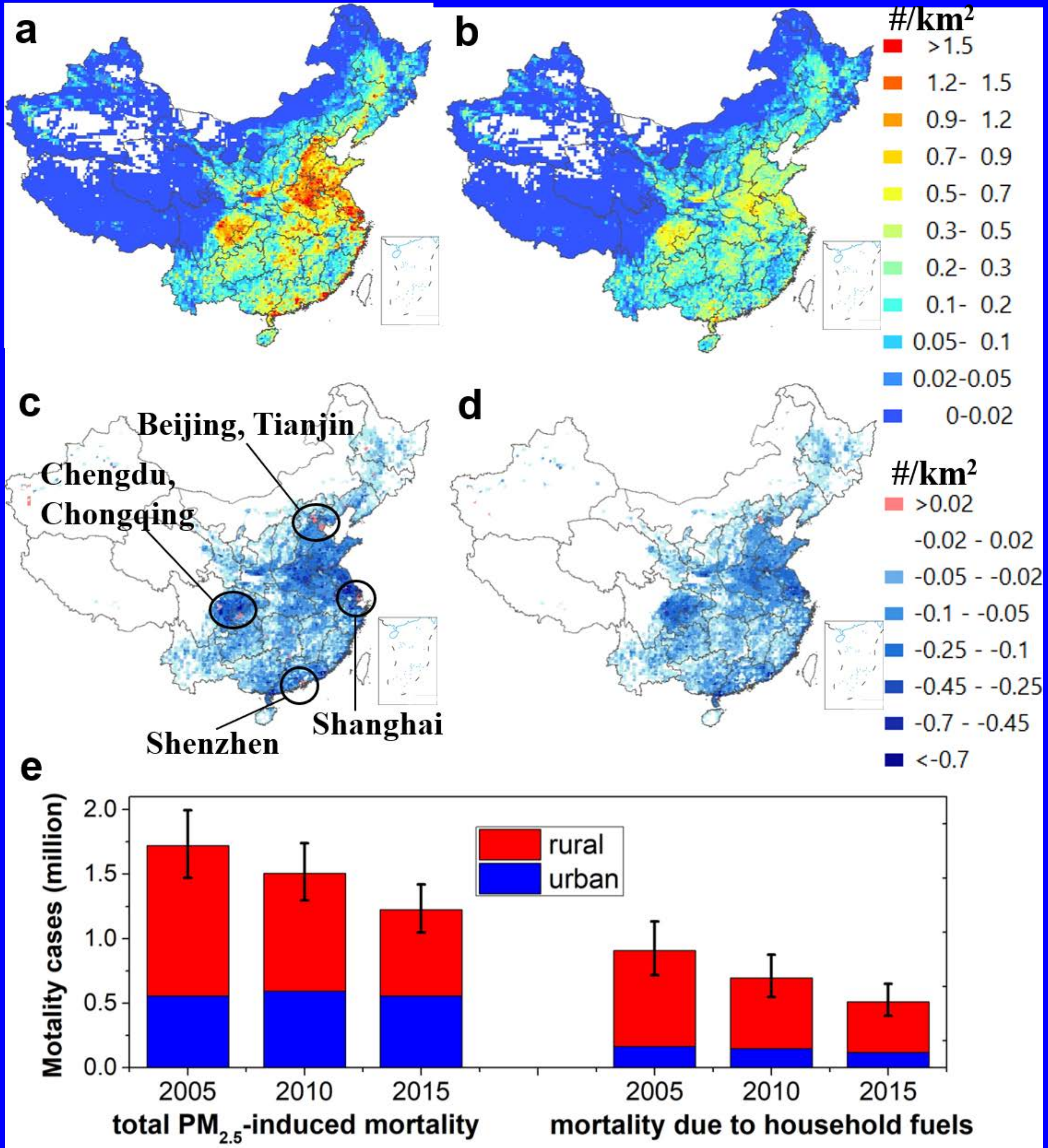


a
>250
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50- 75
25- 50
0- 25
μg/m³
b
>5
-5 - 5
-30 - -5
-55 - -30
-80 - -55
-105 - -80
-130 - -105
<-130
μg/m³
c
>100
90-100
80- 90
70- 80
60- 70
50- 60
40- 50
30- 40
20- 30
10- 20
0- 10
μg/m³
d
>3
-3 - 3
-10 - -3
-20 - -10
-30 - -20
-40 - -30
-50 - -40
<-50
μg/m³
e
IPWE (μg/m³)
0
50
100
150
200
250
300
AAP
HAP
urban
rural
average
2005
urban
rural
average
2010
urban
rural
average
2015

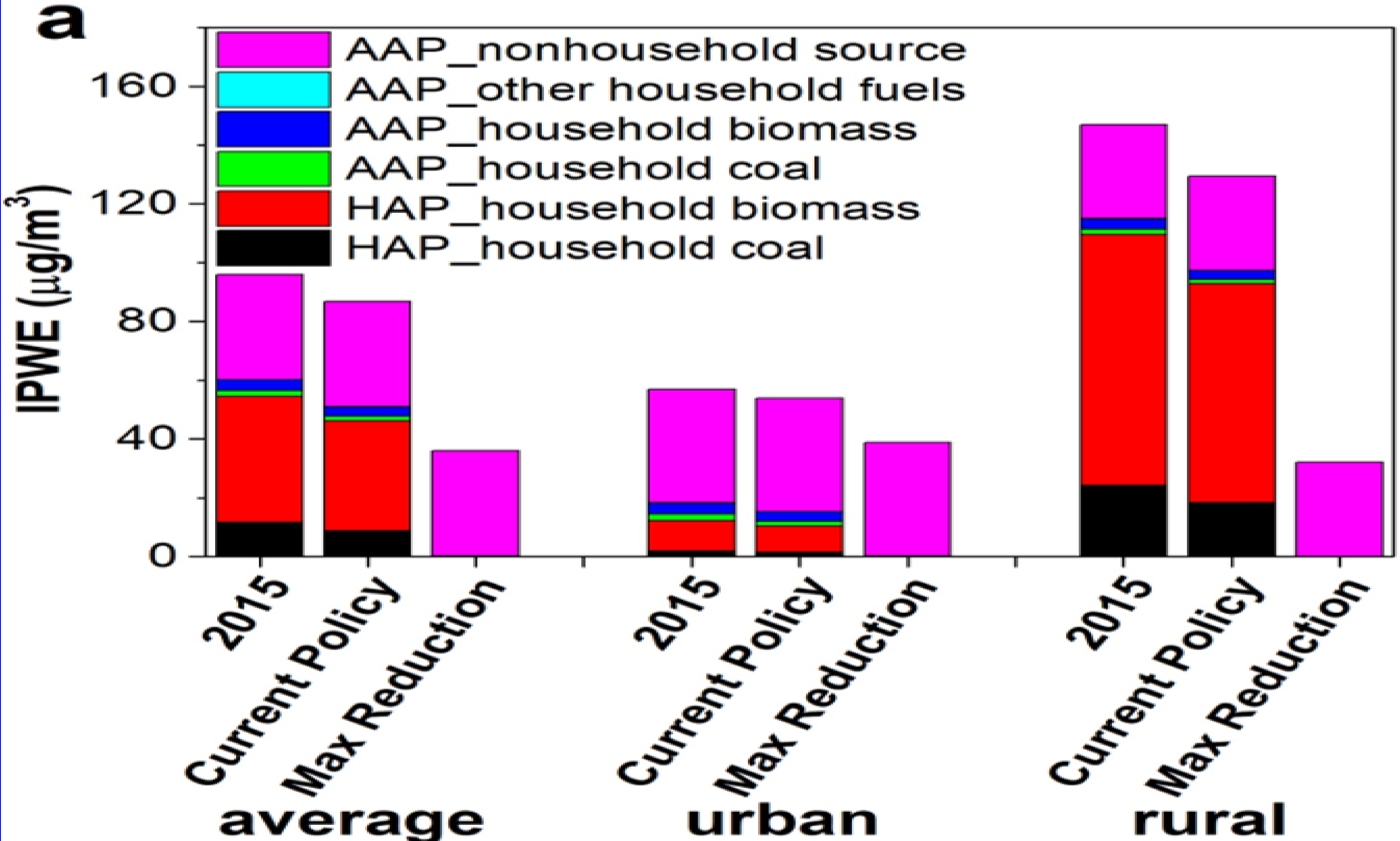

a
Urban household coal use
Rural household coal use
Coal use (Mtce)
b
Biomass use (Mtce)
c-f:
Household coal
Other household fuels
Household biomass
Non-household sources
c
$PM_{2.5}$ emission (Mt)
d
NMVOC emission (Mt)
e
BC emission (Mt)
f
OC emission (Mt)
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015



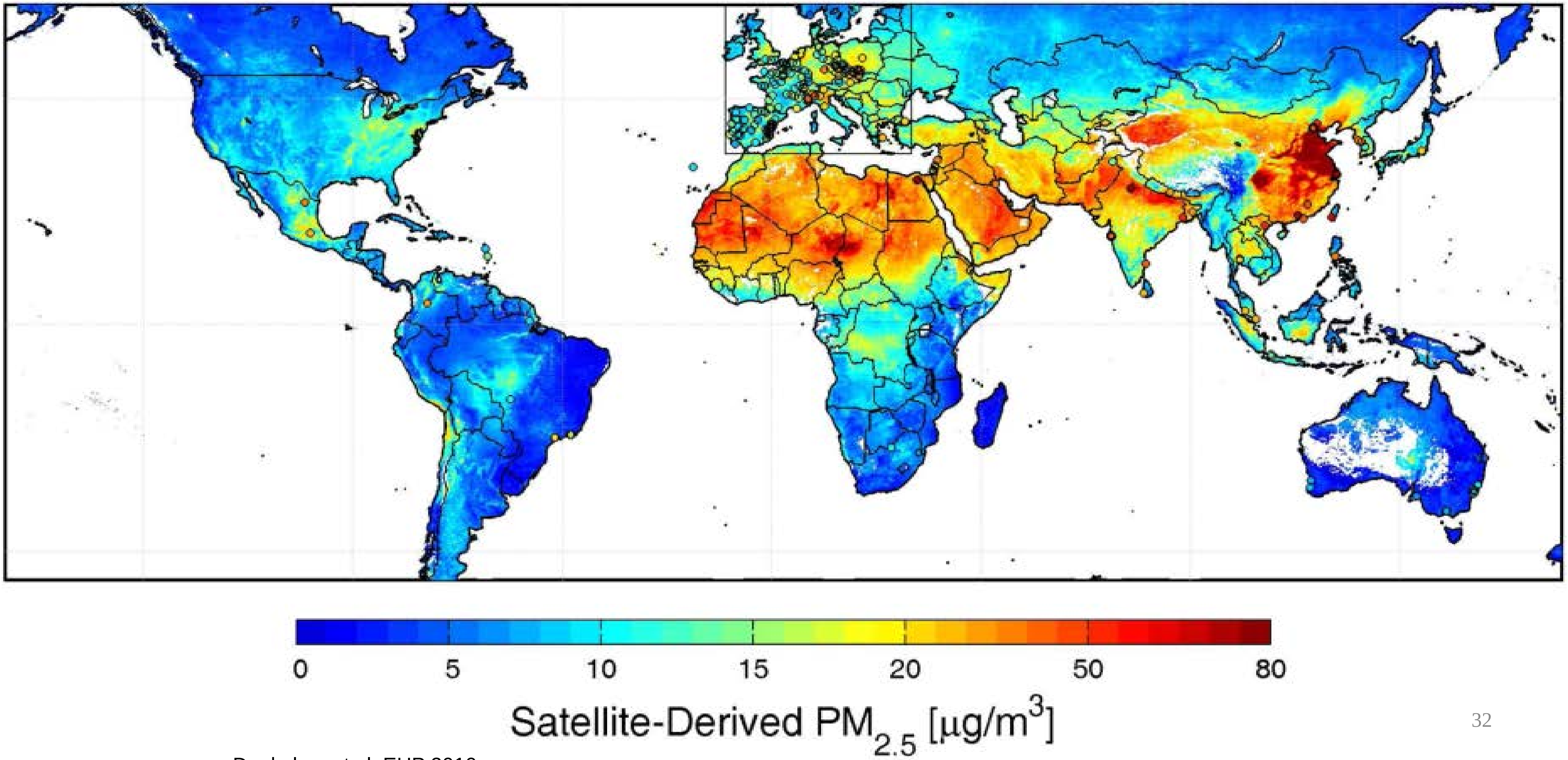
HAP_household coal
HAP_household biomass
AAP_hous
AAP_household biomass
AAP_other household fuels
HAP_hous
HAP_household heating
AAP_household cooking
AAP_hous
AAP_power plants
AAP_other emission sources
nonhouseho
a
urban
rural
average
IPWE (μg/m³)
2005
Meteorology effect
HAP household coal
HAP household biomass
AAP household coal
AAP household biomass
AAP other household fuels
AAP nonhousehold source
2015



a
b
c
d
e
#/km2
>1.5
1.2- 1.5
0.9- 1.2
0.7- 0.9
0.5- 0.7
0.3- 0.5
0.2- 0.3
0.1- 0.2
0.05- 0.1
0.02-0.05
0-0.02
Beijing, Tianjin
Chengdu, Chongqing
Shenzhen
Shanghai
#/km2
>0.02
-0.02 - 0.02
-0.05 - -0.02
-0.1 - -0.05
-0.25 - -0.1
-0.45 - -0.25
-0.7 - -0.45
<-0.7
Motality cases (million)
rural
urban
2005
2010
2015
total PM2.5-induced mortality
mortality due to household fuels

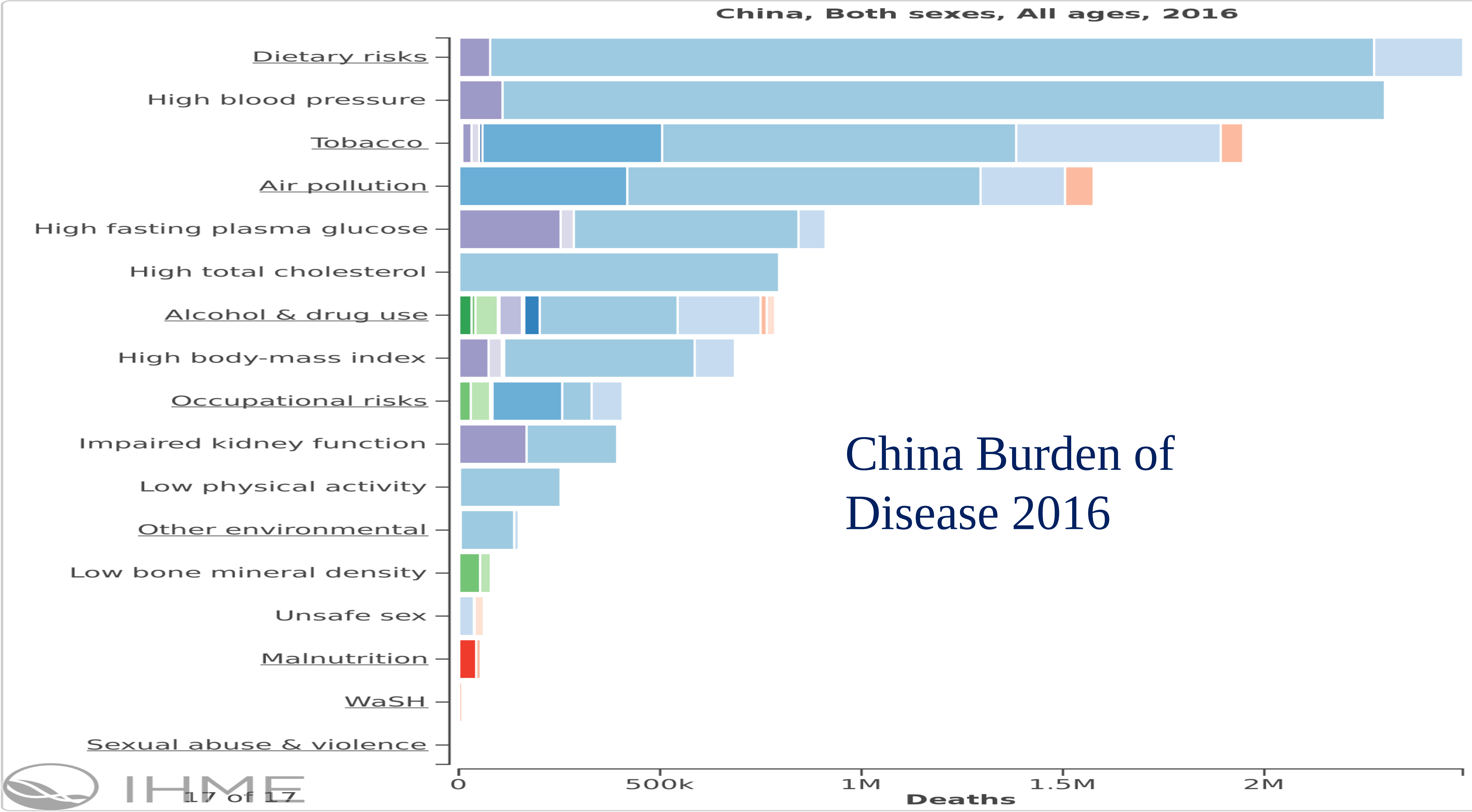

a
AAP_nonhousehold source
AAP_other household fuels
AAP_household biomass
AAP_household coal
HAP_household biomass
HAP_household coal
IPWE (μg/m3)
0
40
80
120
160
2015
Current Policy
Max Reduction
average
urban
rural

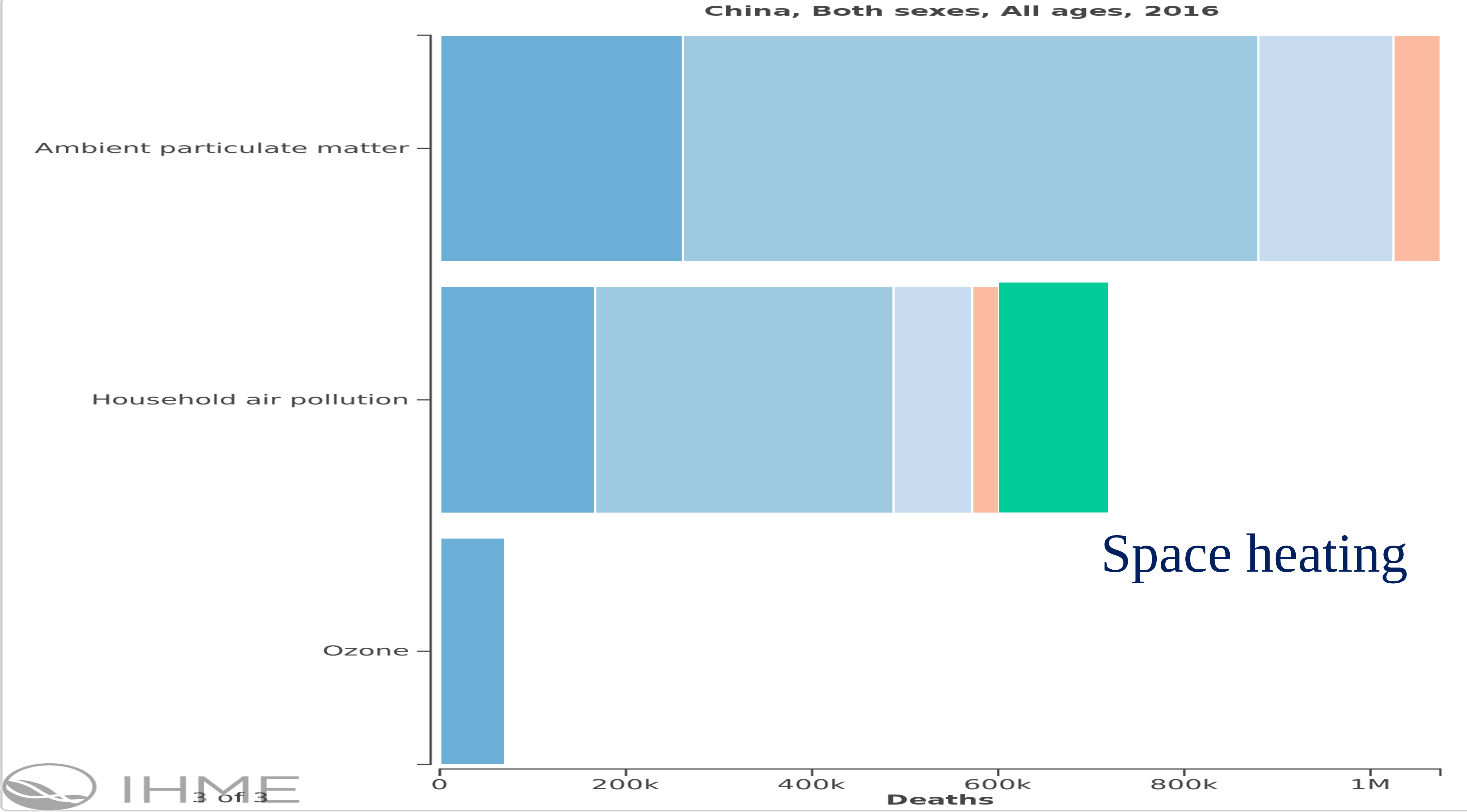
Satellite-based ambient $PM_{2.5}$

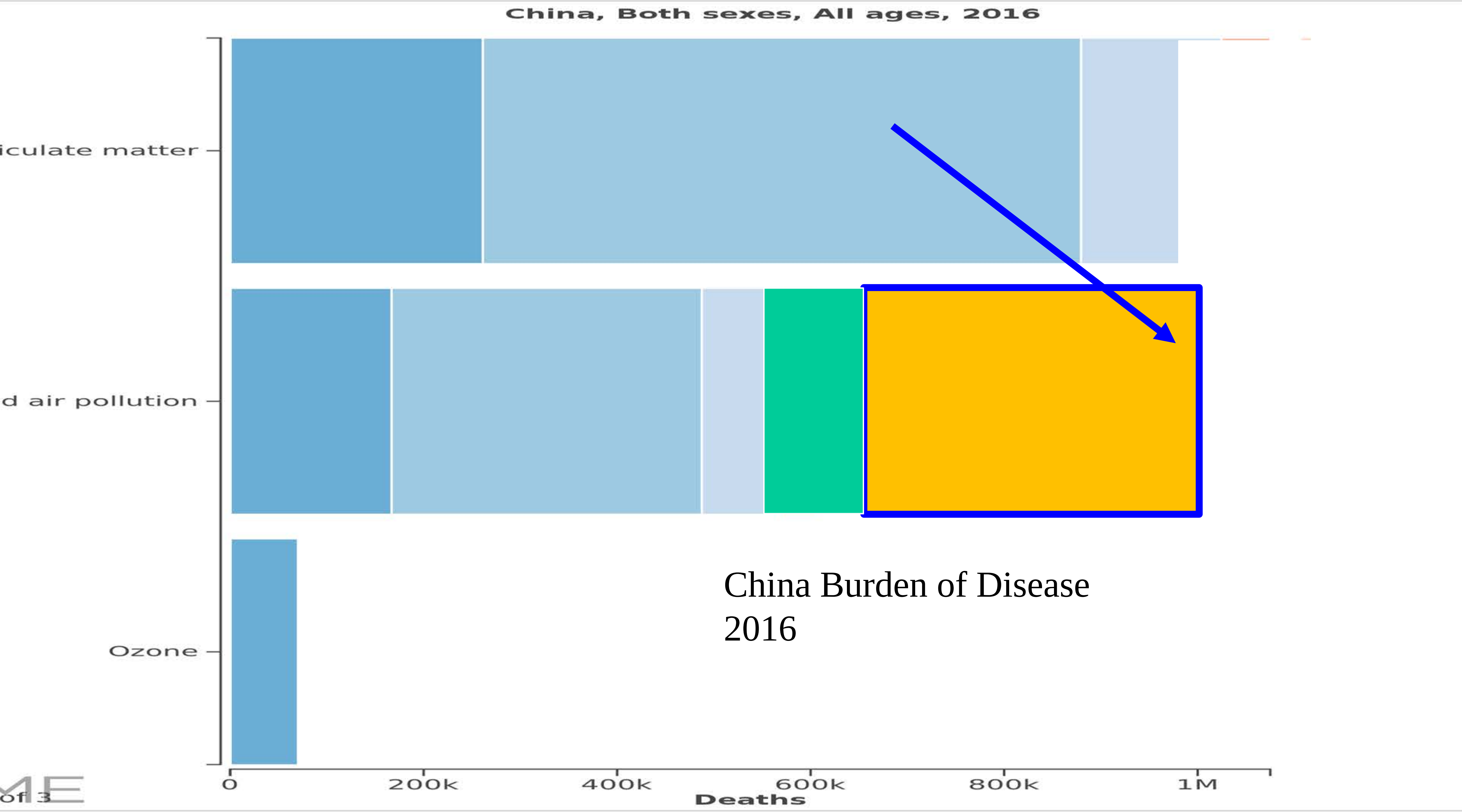


van Donkelaar et al, EHP 2010

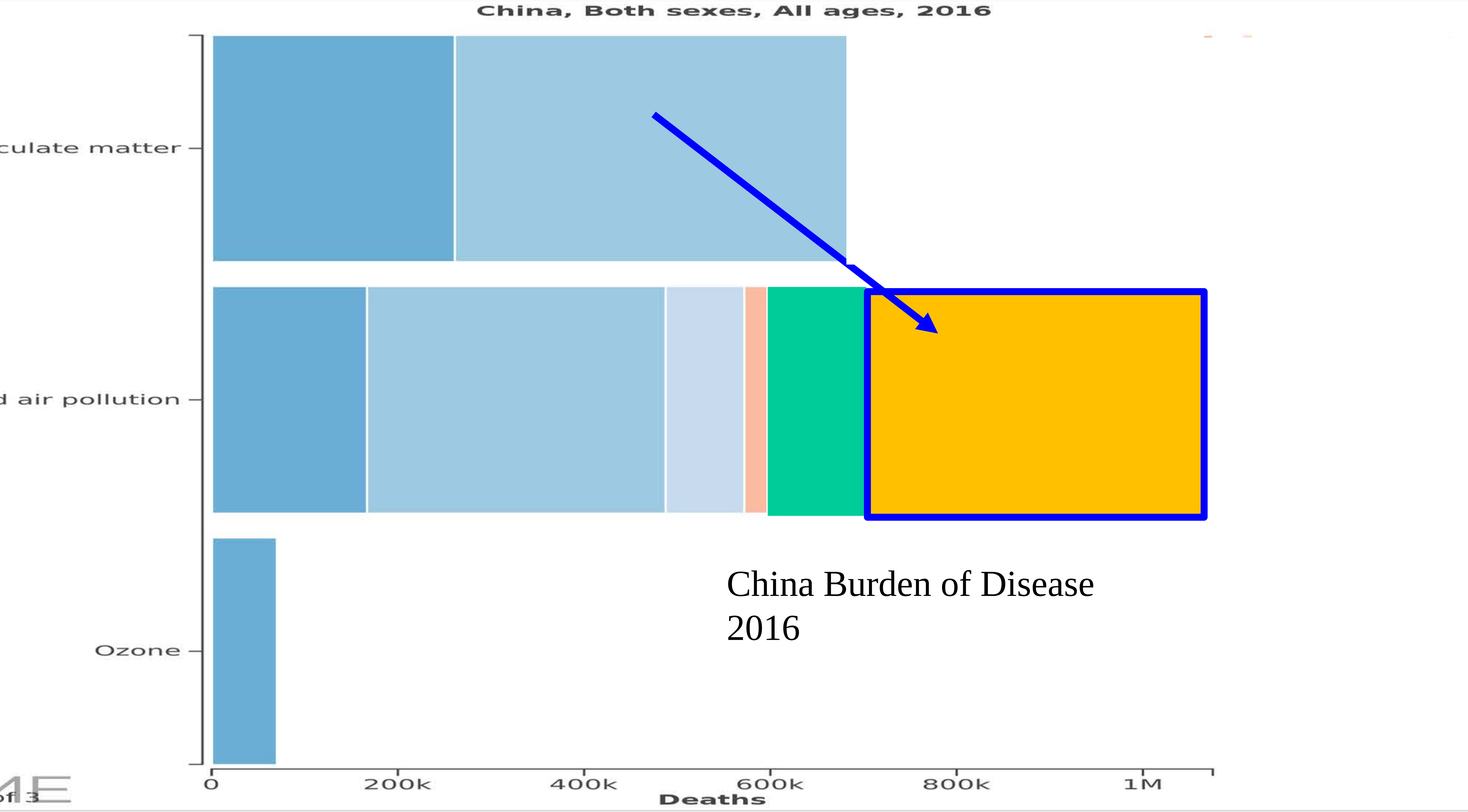
China Burden of Disease 2016




China, Both sexes, All ages, 2016
Ambient particulate matter
Household air pollution
Ozone
0
200k
400k
600k
800k
1M
Deaths
Space heating
IHME



China Burden of Disease 2016



China Burden of Disease 2016

SPECIAL REPORT 21

HEALTH
EFFECTS
INSTITUTE

January 2018

Burden of Disease Attributable to Major Air Pollution Sources in India

GBD MAPS Working Group

Table 2. Mean Percentage Contribution of Different Source Sectors to Population-Weighted Ambient $PM_{2.5}$ in India for 2015[a]

Source Sector	All India (%)	Rural India (%)	Urban India (%)
Residential biomass	23.9	24.2	22.1
Total coal	15.7	15.5	17.1
Industrial coal	7.7	7.6	8.5
Power plant coal	7.6	7.5	8.0
Open burning	5.5	5.5	5.6
Transportation	2.1	2.1	2.1
Brick production	2.2	2.1	2.2
Distributed diesel	1.8	1.8	1.4
Anthropogenic dust[b]	8.9	8.8	9.6
Total dust[c]	38.8	38.7	39.5

GBD MAPs Study, Jan 2018

Emissions in India – Hou

www.urbanemissions.info/india-emissions-inventory/emissions-in-india-household-cooking-heating/

Jharkhand ▼ Ranchi ▼

Household Energy Consumption, Emissions, Pollution, and Health Impacts in India

STATE	Jharkhand
	(state and district as of census-India, 2011)
DISTRICT	Ranchi

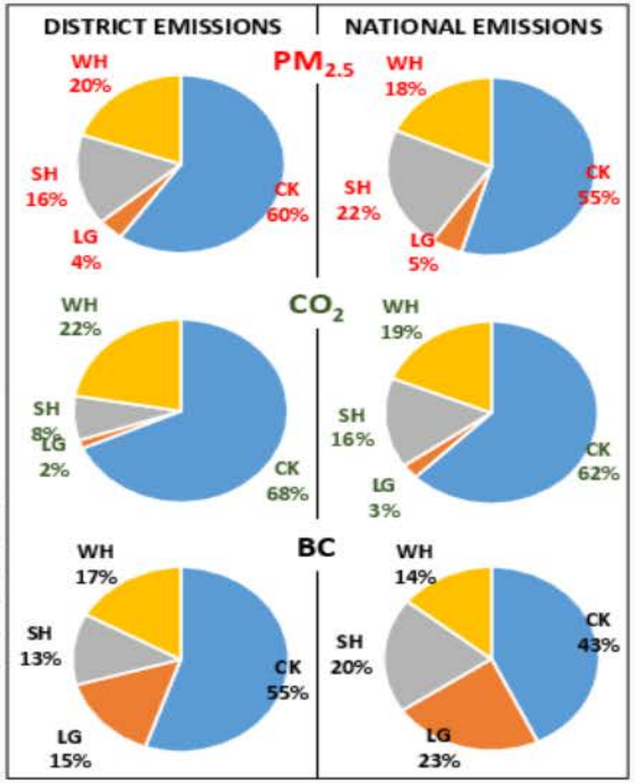
Household energy consumption (HEC) emissions were calculated in four classes - cooking (CK), lighting (LG), space heating (SH), and water heating (WH). Bottom-up emissions for the four classes are available @ 0.25 degree spatial resolution, and further aggregated to district and state level. A sub-classification is available by fuel - biomass, coal, kerosene, liquified petroleum gas (LPG), and others.

%Households Primary Cooking Fuel

gas+elec	others
29.8%	70.2%

Estimated district annual HEC emissions

Paticulates (2.5µm)	12,960	tons
Sulfur dioxide	3,120	tons
Nitrogen oxides	230	tons
Carbon monoxide	233,600	tons
Hydrocarbons	20,460	tons
Black carbon (BC)	3,300	tons
Organic carbon	5,240	tons
Carbon dioxide (CO2)	1.14	mil tons

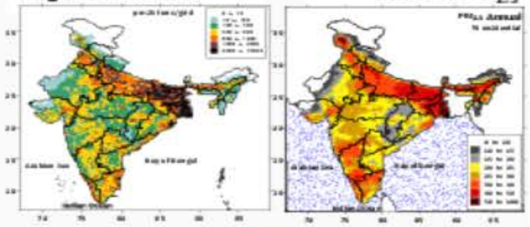


% contribution of HEC emissions to modeled ambient $PM_{2.5}$ concentrations		
	National	29.6%
(concentrations were conducted using the WRF-CAMx models)	District	27.8%

The health impacts of outdoor air pollution as ischemic heart diseases (which can lead to heart attacks), cerebrovascular disease (which can lead to strokes), chronic obstructive pulmonary diseases, lower respiratory infections, and cancers (in trachea, lungs, and bronchitis) were estimated using the age-dependent relative risk functions detailed in the Global Burden of Disease study and dispersion modeling results from this study. The final calculations were conducted at the district level using the population distribution by age presented in Census-India.

Estimated $PM_{2.5}$ emissions @ 0.25 degree resolution

Modeled share of HEC emissions to ambient $PM_{2.5}$



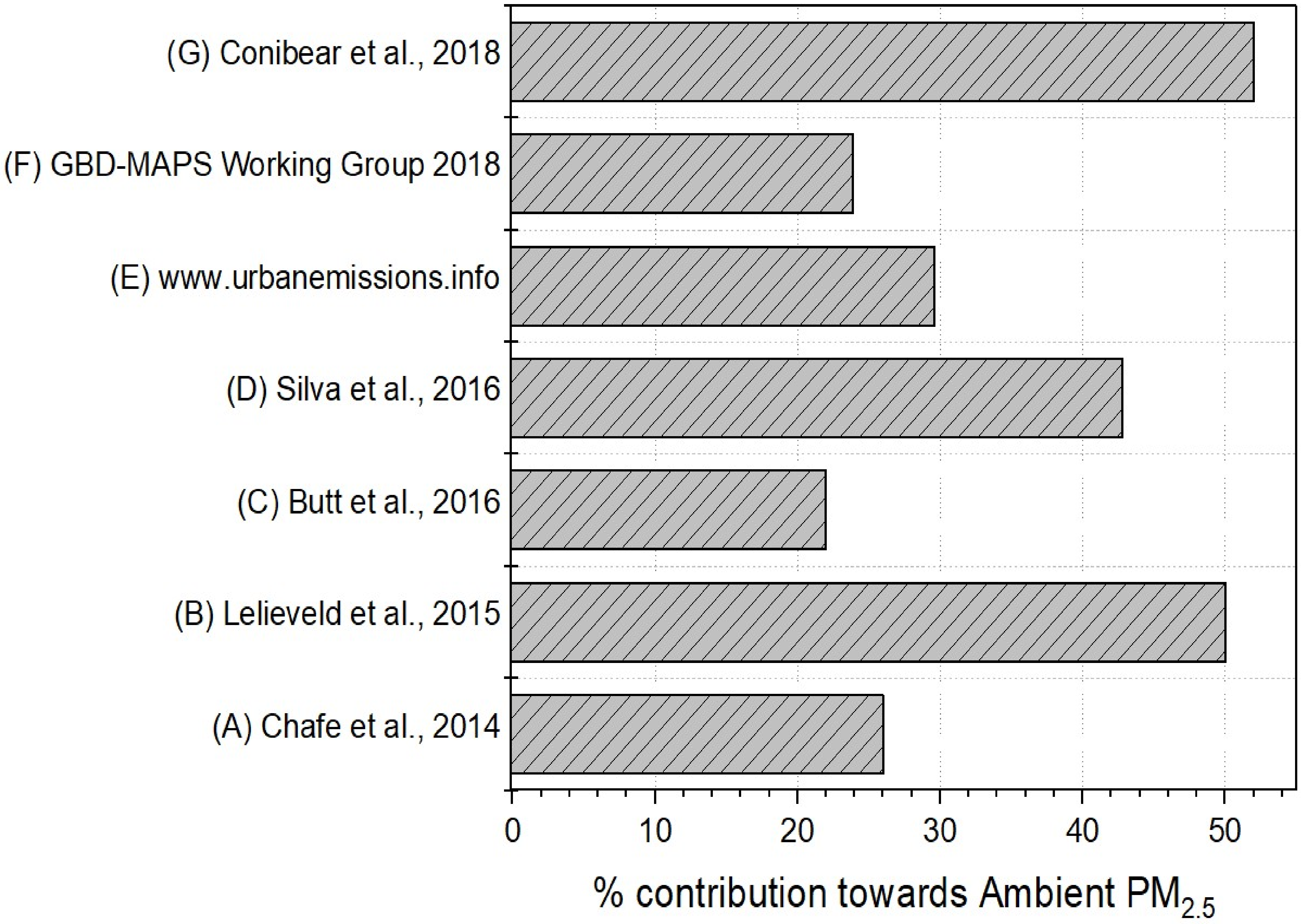
Estimated premature mortality of outdoor air pollution per year - apportioned to HEC emissions		
	National	84,000 - 115,000
	District	144 - 177

Emission and dispersion modeling results, pollution animations, and summary sheets by district and state are hosted @ http://www.urbanemissions.info
Send your comments and questions to sim-air@urbanemissions.info

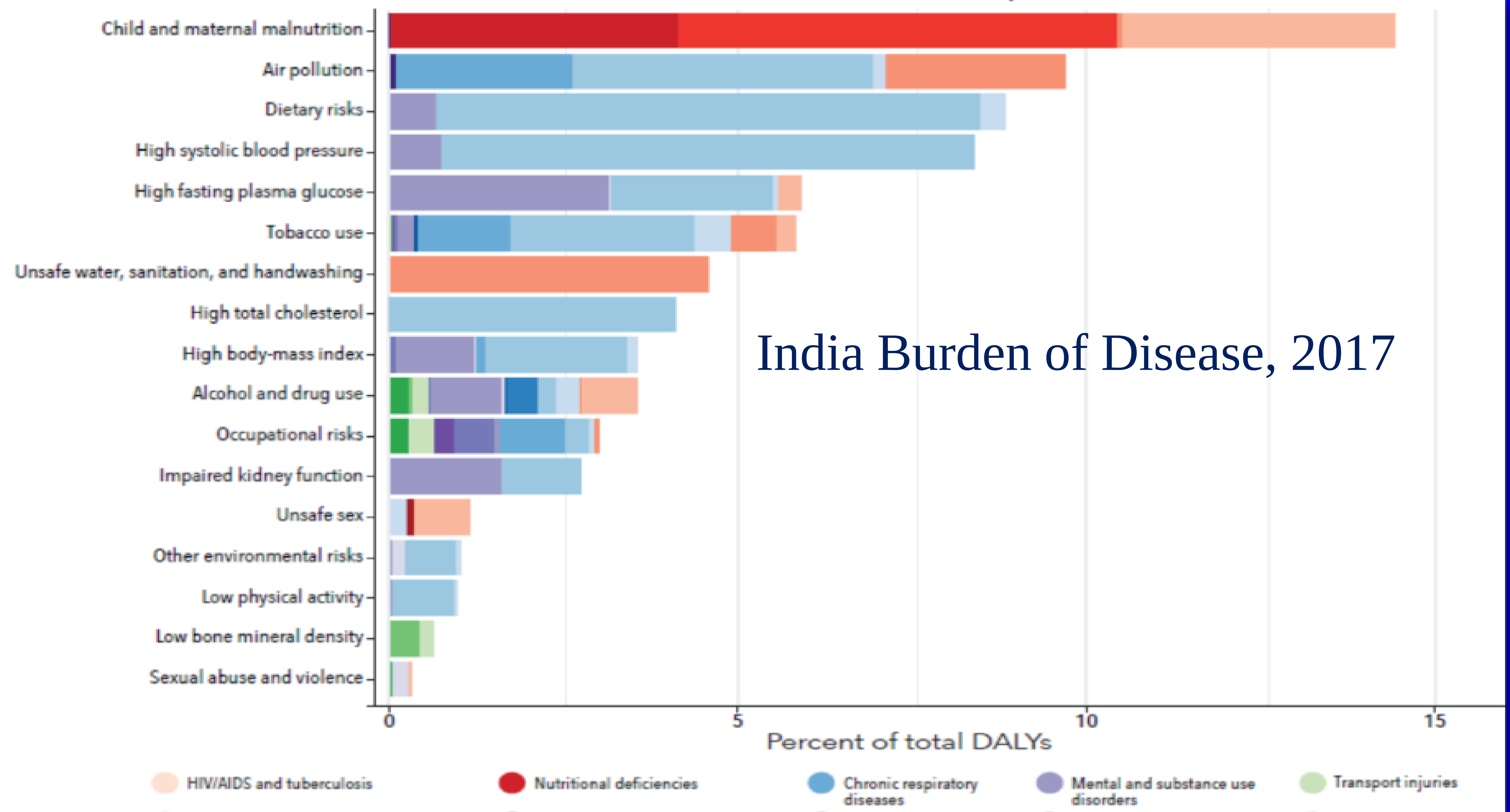
URBAN emissions .info

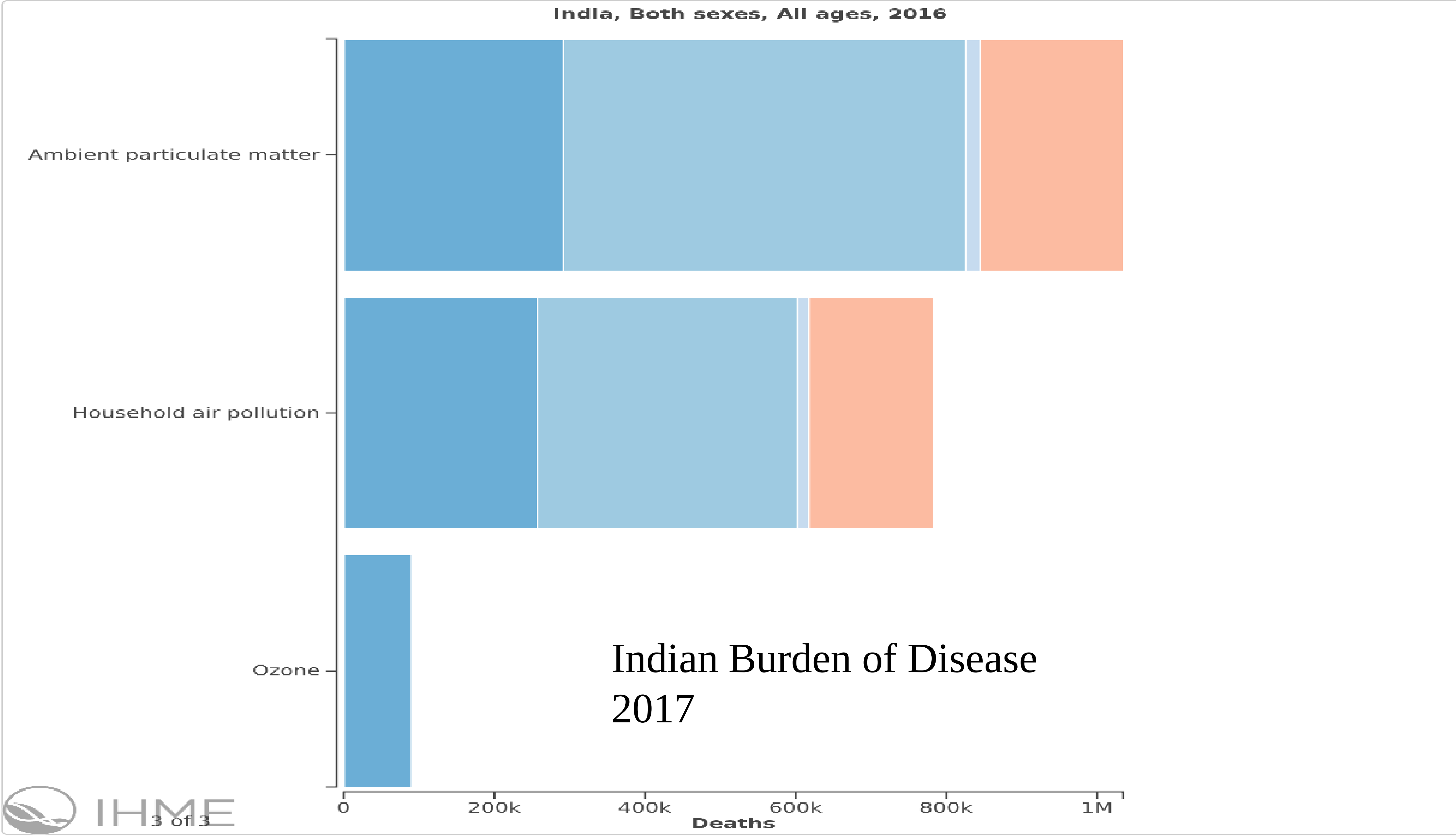
GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

Type here to search

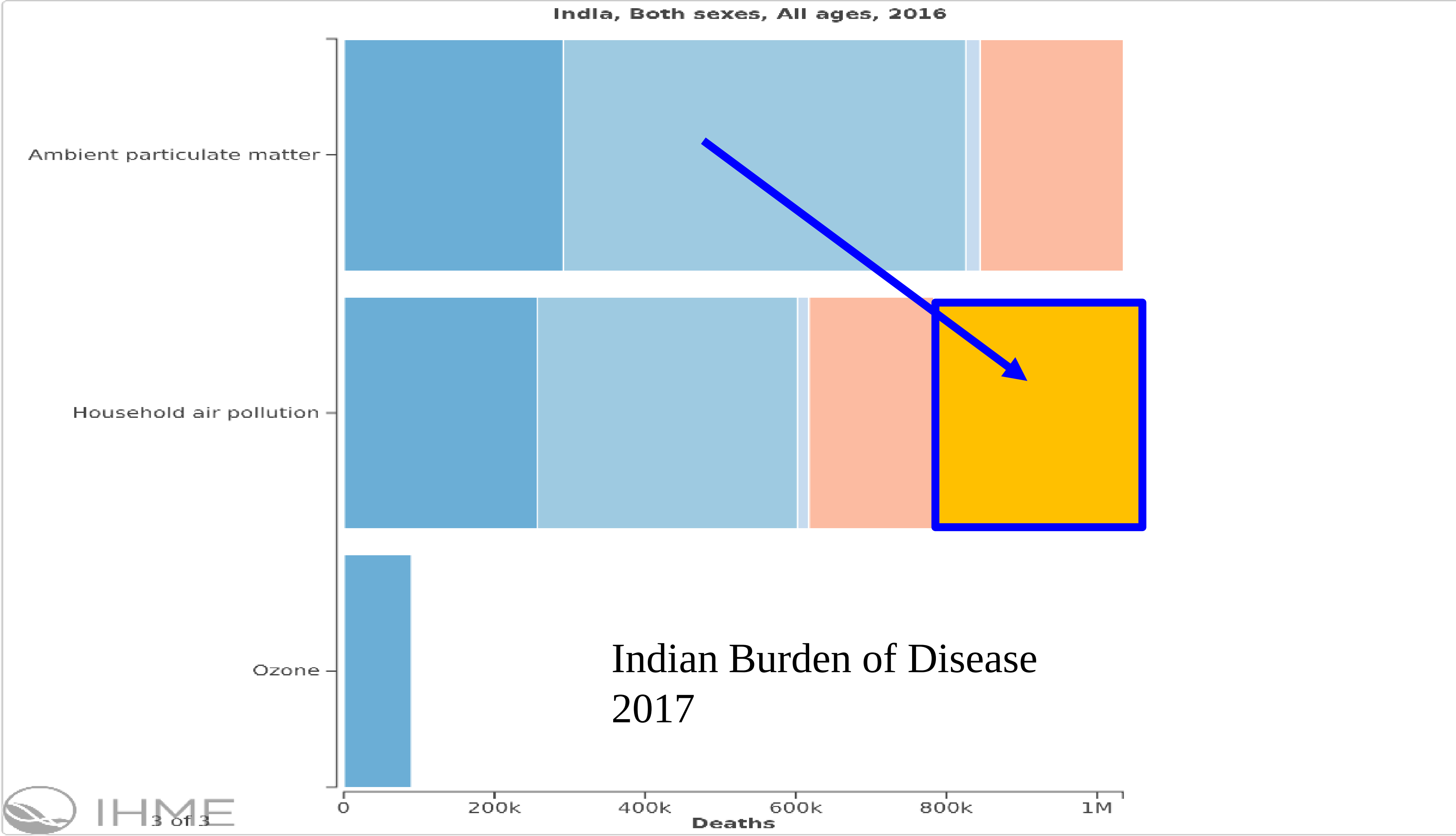

(G) Conibear et al., 2018
(F) GBD-MAPS Working Group 2018
(E) www.urbanemissions.info
(D) Silva et al., 2016
(C) Butt et al., 2016
(B) Lelieveld et al., 2015
(A) Chafe et al., 2014
0
10
20
30
40
50
% contribution towards Ambient $PM_{2.5}$

India Burden of Disease, 2017

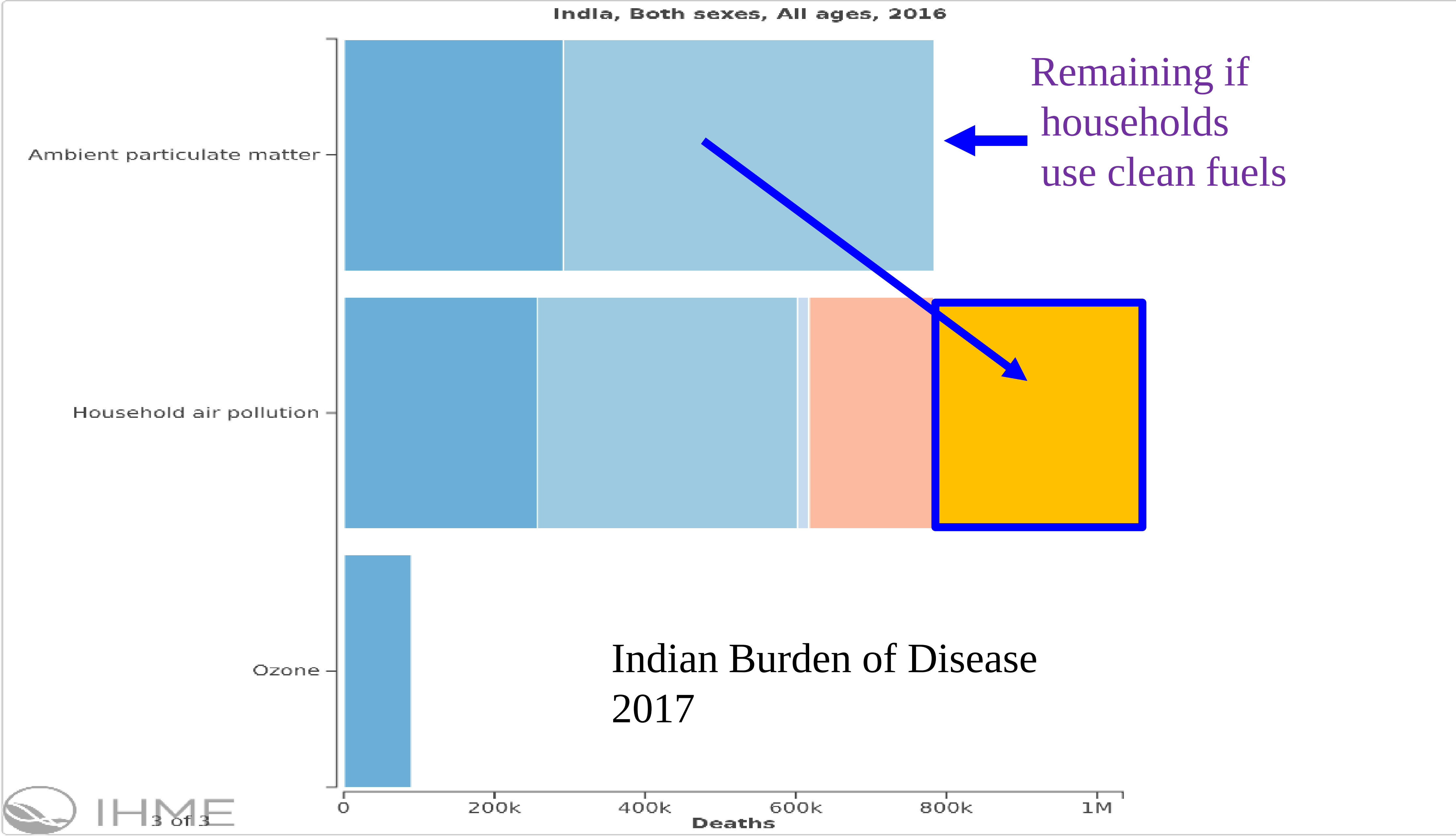




Indian Burden of Disease 2017

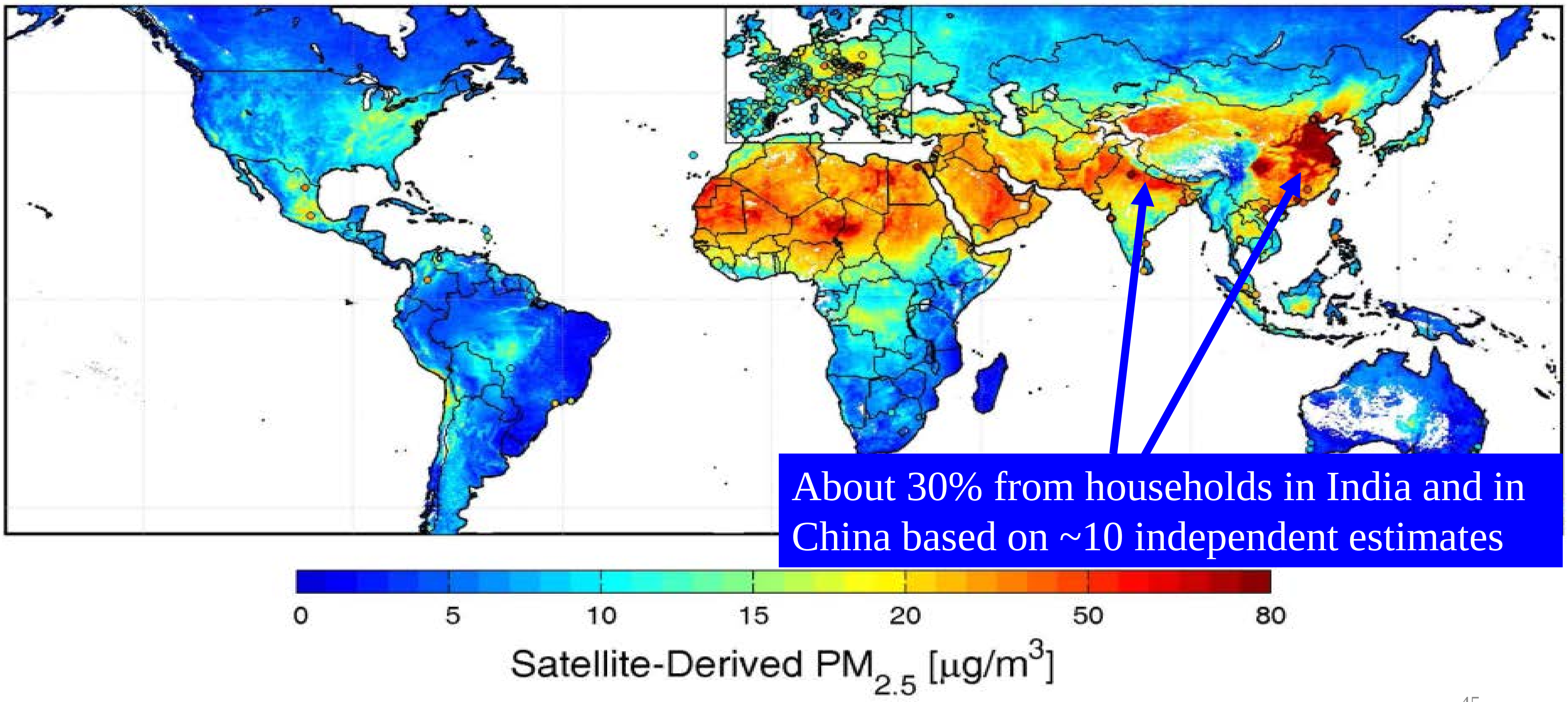


Indian Burden of Disease 2017



Indian Burden of Disease 2017

Satellite-based ambient $PM_{2.5}$



van Donkelaar et al, EHP 2010

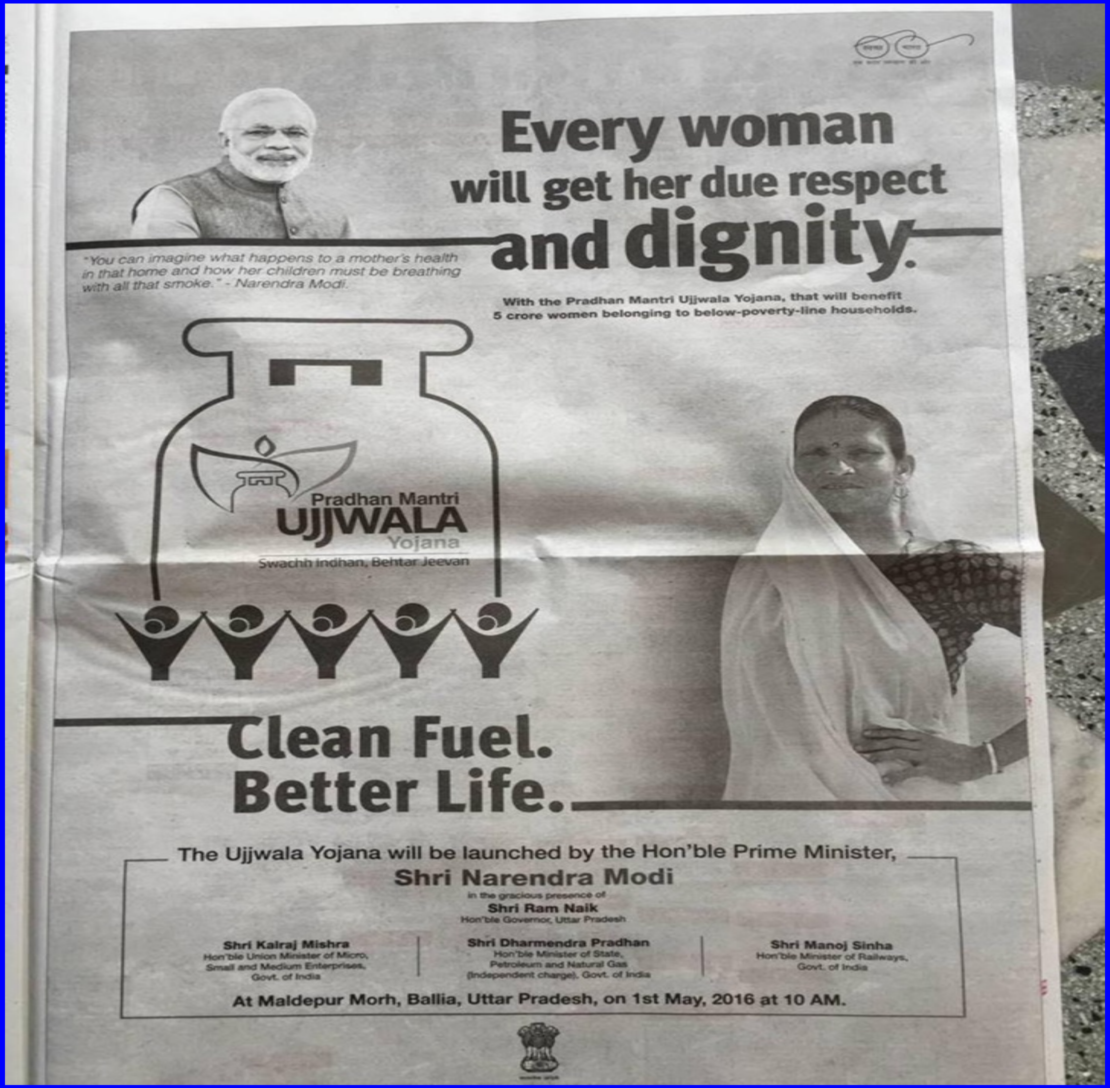
China recently

- Reduced household solid-fuel consumption was the leading contributor to the decrease in national exposure to $PM_{2.5}$ pollution (2005-2015) -- 90% of reduction
- Even though there was no explicit household control policy.
- In contrast, the emission reductions from power plants, industry, and transportation contributed less to the decrease of exposure during this period – 10%.

China today

- Clean household fuels has become part of recent air pollution control policies in northern China – wide area around Beijing – BTH region
- With a requirement for 70-80% reduction in use of household solid fuels in three years
- 4 million households by 2017
- Should be part of national policies
- Ironically, being done not because it helps the villagers, but because it helps reduce outdoor air pollution in cities
- “Type I error”

Scaling up LPG Use in India



- In 2015, 15 million new LPG connections were provided (6 million to poor households)
- Starting in 2016, target to provide 100 million new LPG connections in 3 years (80 million for poor households)
- Connections given only to poor women beneficiaries
- 10,000 new LPG distributorships to be commissioned primarily in rural areas
- National LPG coverage to increase significantly from 61% in 2015 to over 95%

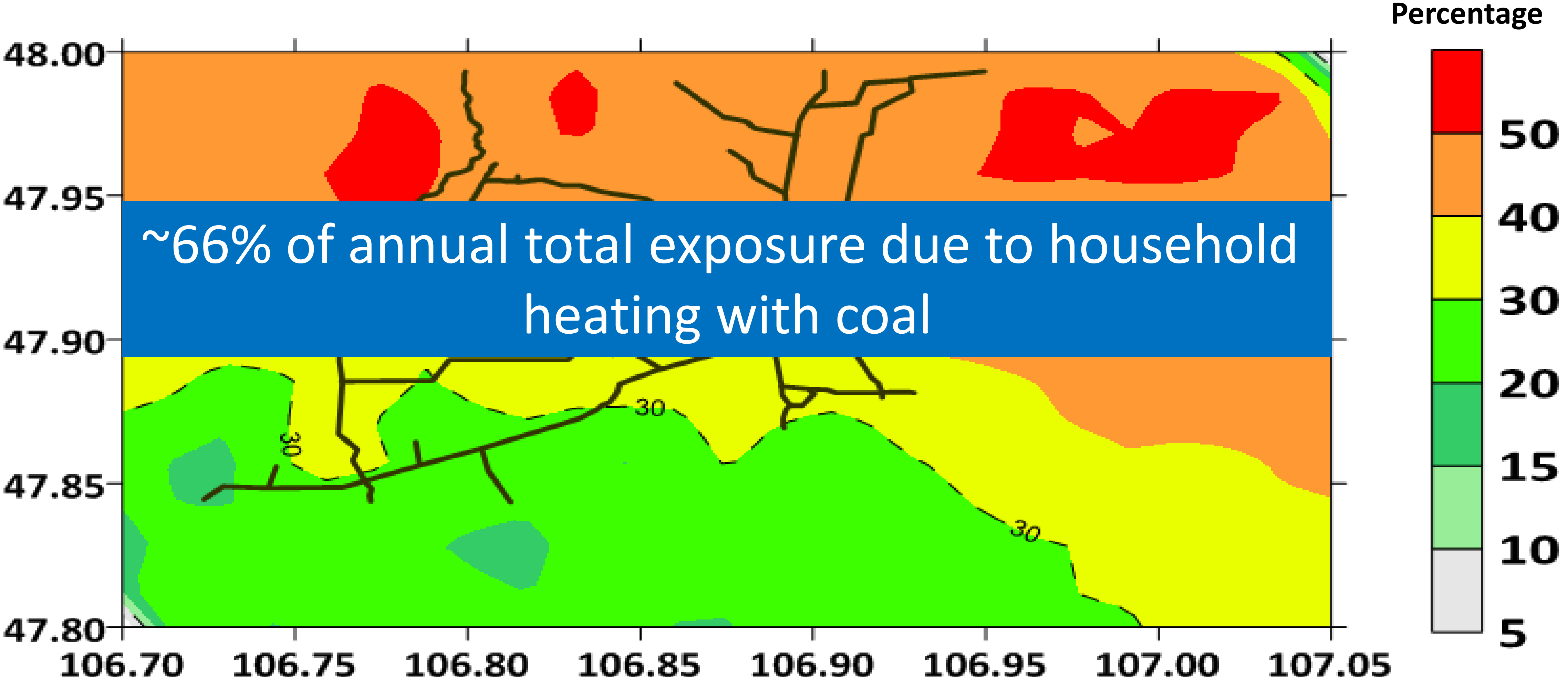
India, cont.

- LPG program has reached 60 million poor households so far, and is only factor seen in recent shifts in pollution
- Cost-effective was to deal with ambient, as well as household pollution
- Focus on household benefits, but so far ignored in national air pollution policy
- Household fuels policy needs to be included as part of national air pollution control strategies
- “Type II error”

Ulaanbaatar, Mongolia

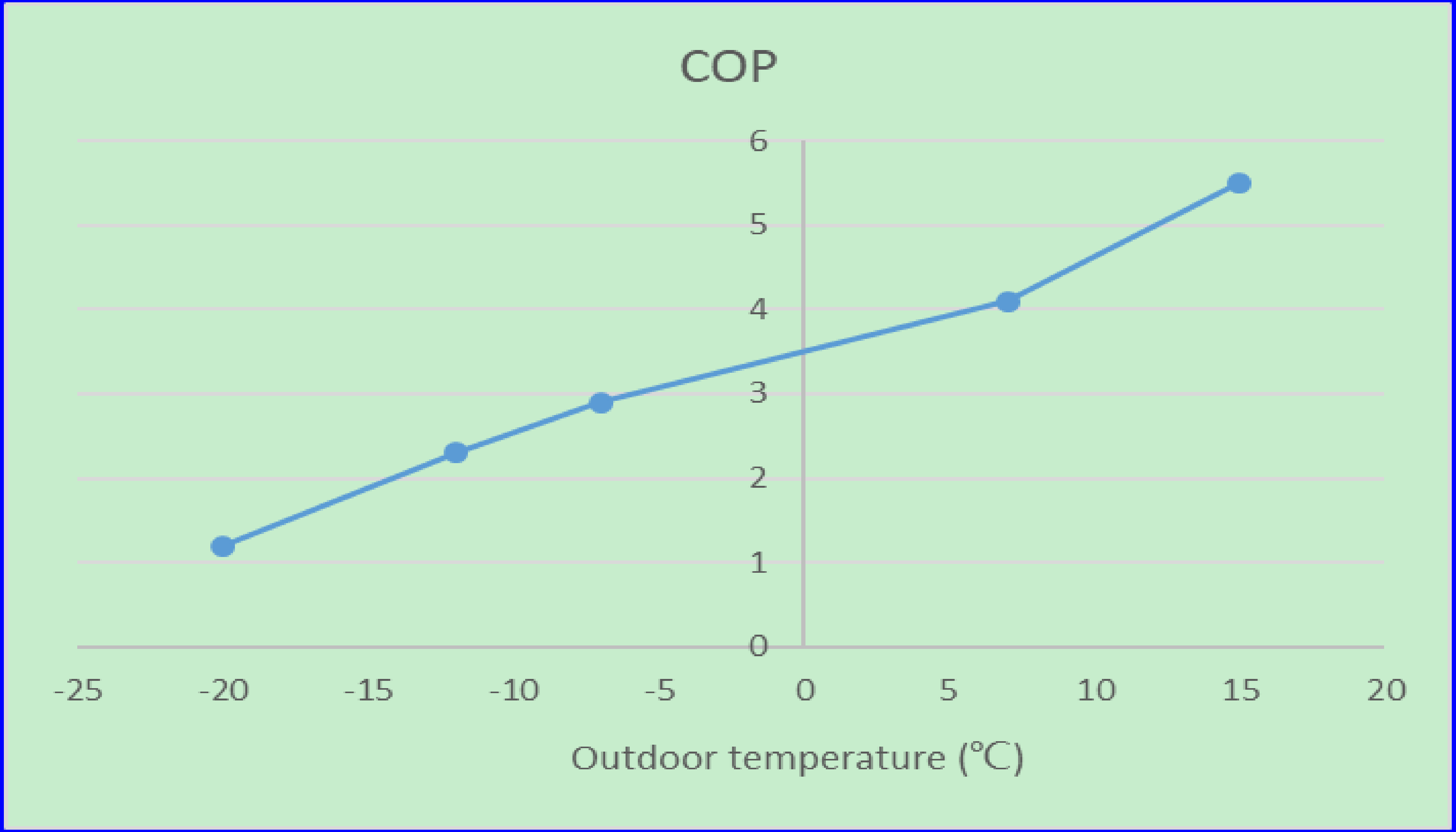
Worst wintertime pollution in the world

Modelled Stove Contributions to $PM_{2.5}$ Winter Months: Ulaanbaatar

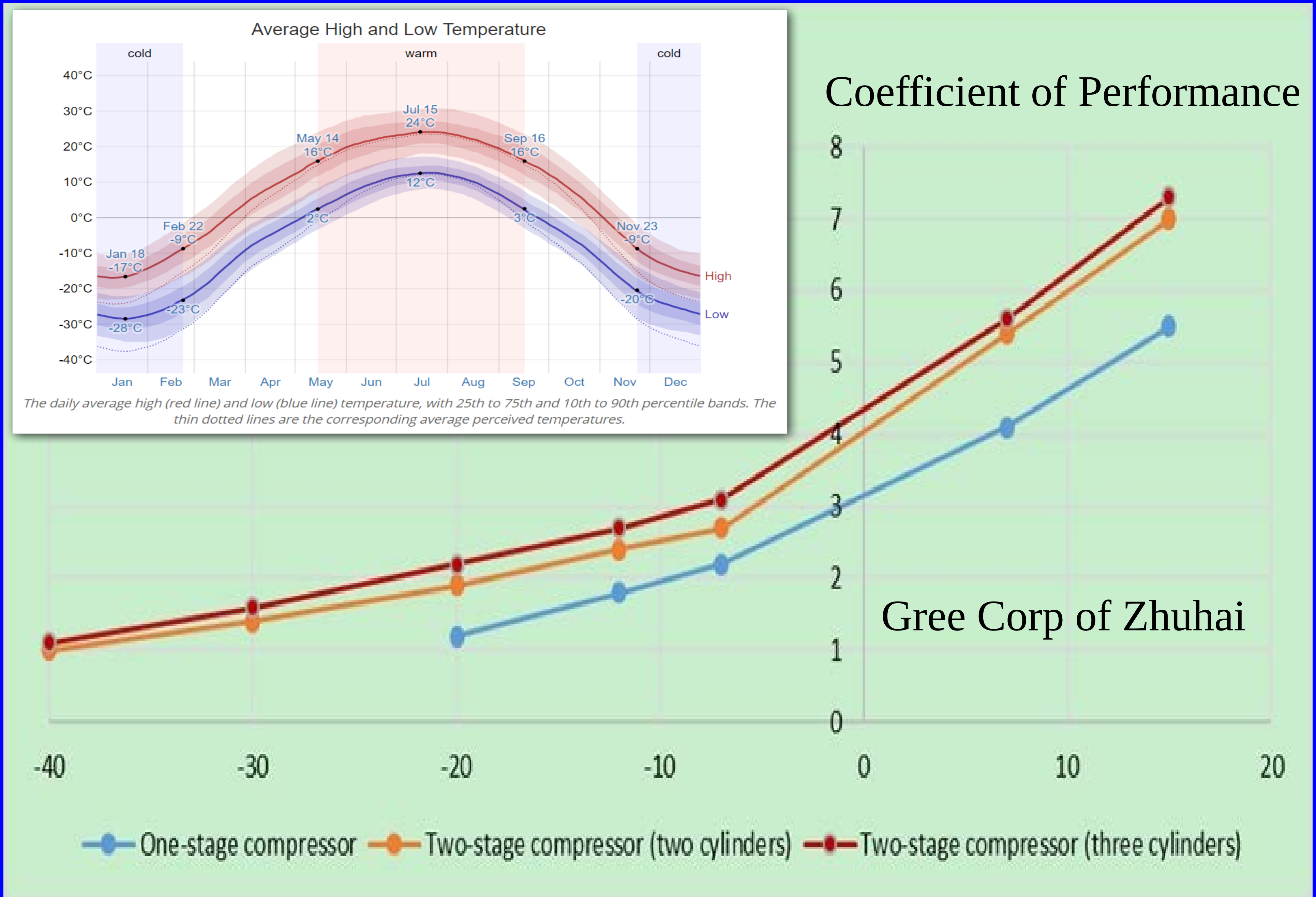


Guttikunda, 2014

COP: Normal Heat Pump



Benefits of Double Compression Heat Pumps



Improvement by changing compressor

Traditional single stage compressor (one cylinder)

Improved double stage enthalpy-added compressor

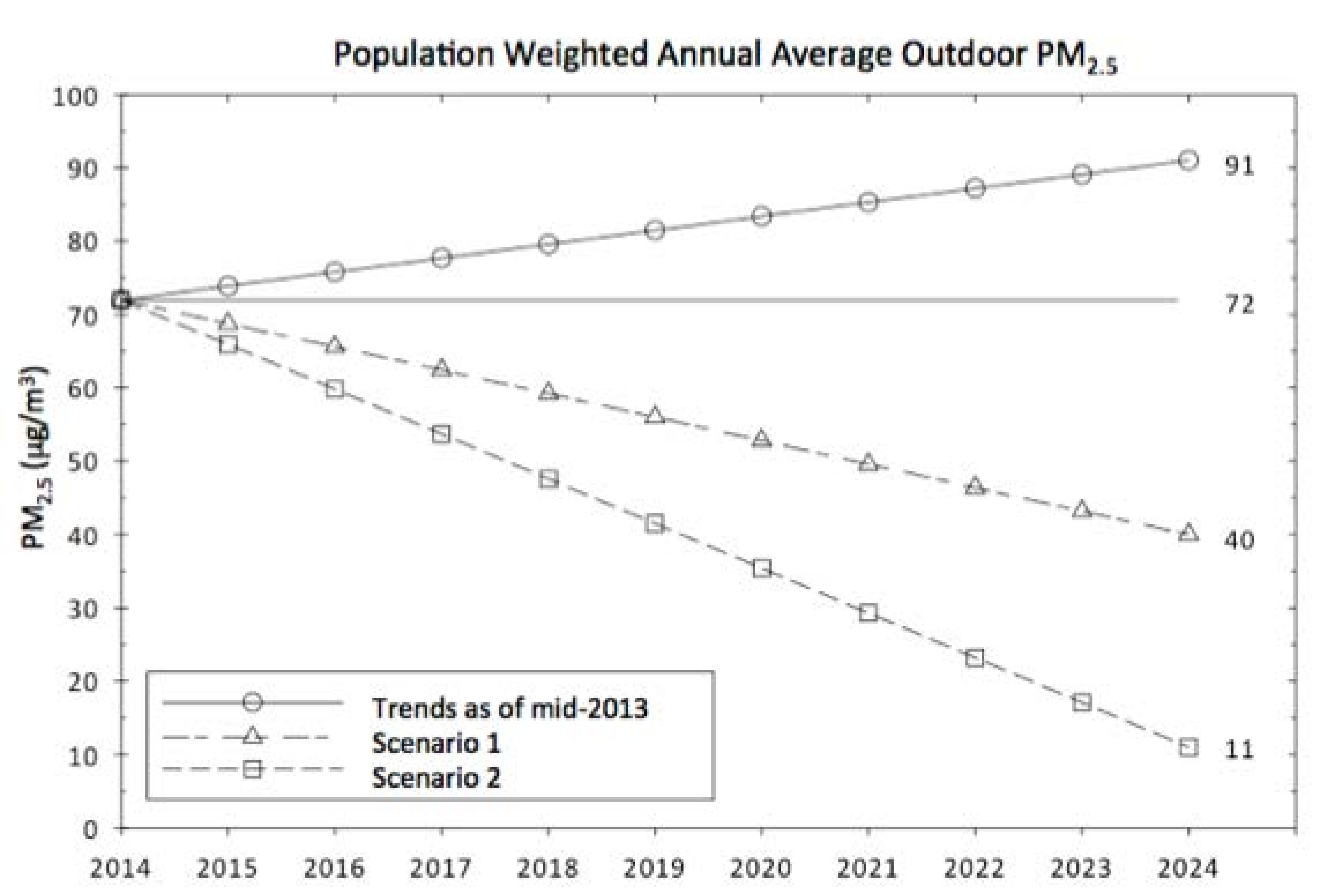
Two cylinders

Three cylinders

- Enhanced capacity in cold ambient conditions
- COP is up to 2.0+ at the outdoor temperature of -20℃
- Can run normally at the outdoor temperature of -35℃
- Includes automatic defrost
- Working fluid is R-32, Difluoromethane (HFC-32); ODP=zero

Winter
2018 Pilot
Study

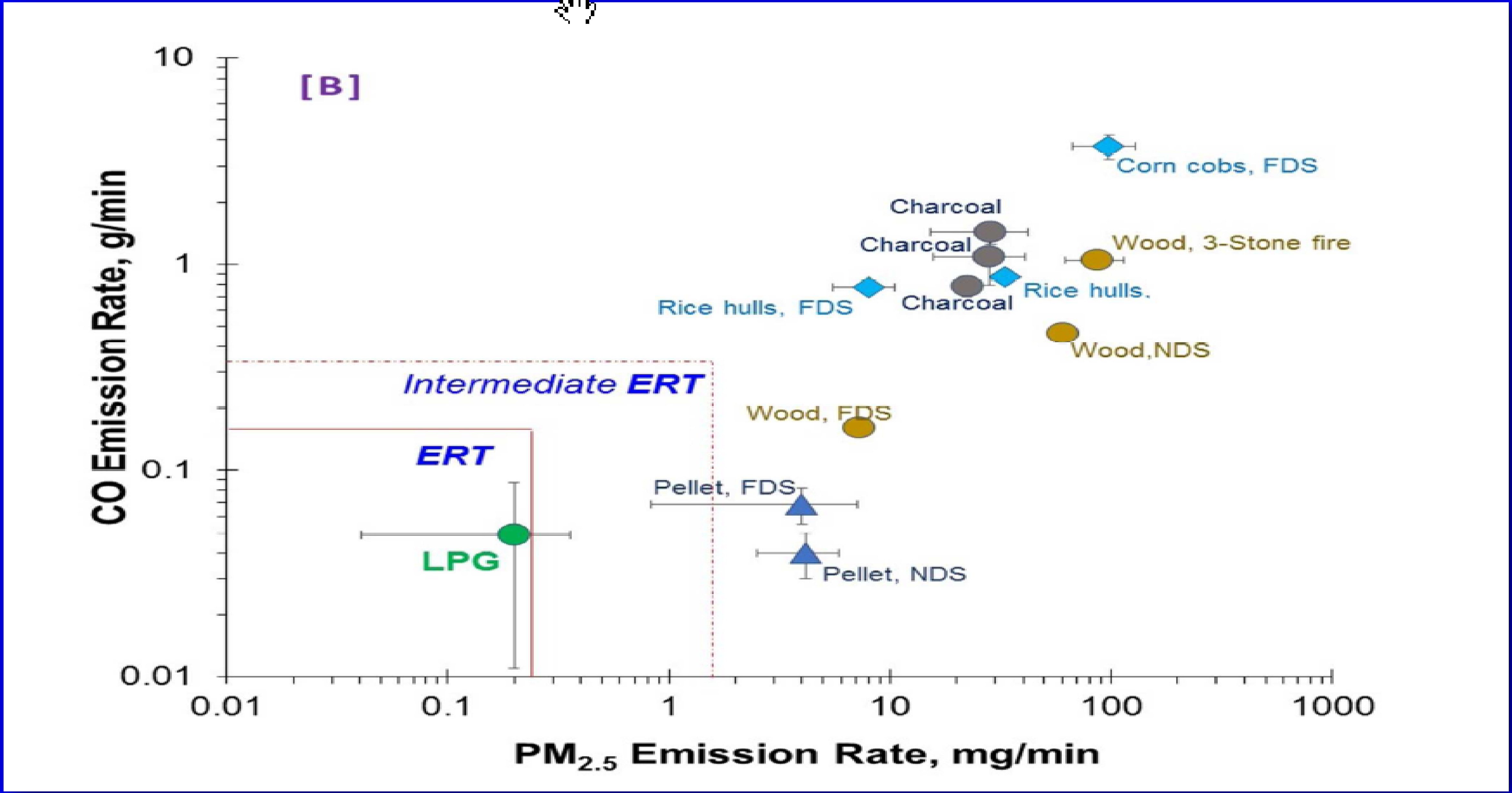
Mongolian U of Sci & Tech,
Tsinghua U, UC Berkeley,
Gree Corp of Zhuhai



Note: models were run for only 2014 and 2024 and a linear change is assumed between the two results (Hill et al., PLOS One, 2017)

Ulaanbaatar (UB)

- Indoor or outdoor, all bad
- Total exposure evaluation is clearly needed
- Serious improvement across sectors driven by electrification
- Could make UB one of cleanest cities in Asia
- Is achievable, but not without major household interventions with zero emissions.



Guofeng et al., EHP. 2018

China and India

- Embarked on industrialization while still having large traditional sectors – mixed pollution sources today
- Not the case in the West
- Need to get rid of dirty household fuels soon, while dealing with modern sources
- Getting it wrong now (Type I and II errors) but starting to get it done
- Would greatly improve efficiency if the framing was fixed

Thanks to many colleagues in

China,
India,
Mongolia,
Norway,
and the USA

Best to google "Kirk R. Smith" to find my website with publications