Air Pollution in India: Implications of Exposure

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School of Public Health, UC Berkeley
Collaborative Clean Air Policy Centre
India Habitat Centre, New Delhi

Air pollution is only of health interest if it is breathed by the population – exposure is what counts

Thus, of more interest to policy is “exposure apportionment” rather than “source apportionment”

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 most of India and much of Nepal and 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 indicated by outdoor monitors
- Local sources: stoves, garbage burning, small industry, vehicles, etc.

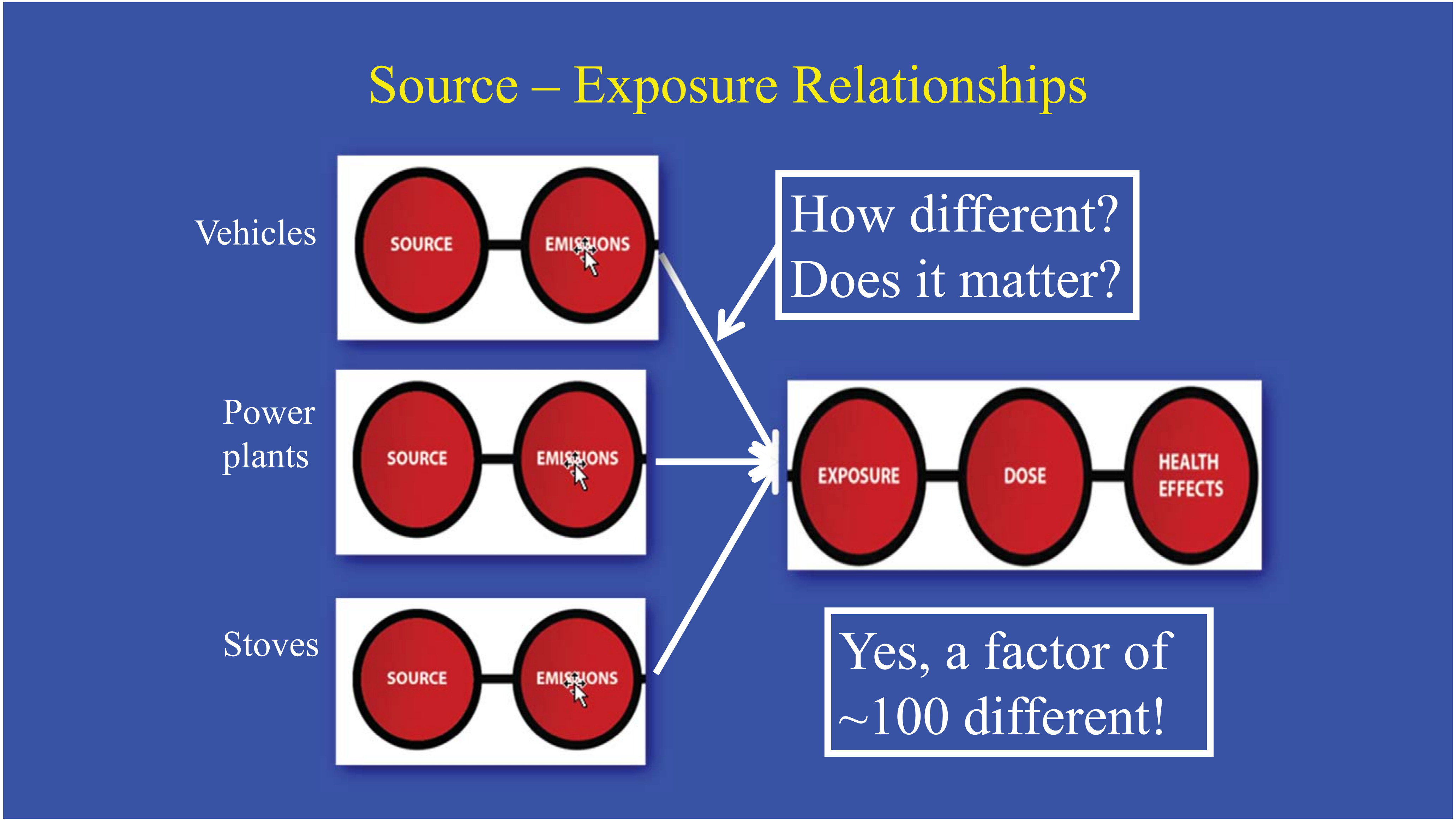
IF = one million ppm – all is breathed in

Worse thing you can do

Ambient Intake Fractions in Hyderabad (Guttikunda, 2015)

ppm – grams inhaled per tonne emitted

	Average	SD
Households	175	97
Construction	175	93
Waste.burn	140	74
Veh.exhaust	130	64
Gen.sets	123	53
Industries	65	17
Dust	18	4
Power plants	7.4	7.0
Brick.kilns	6.8	1.9


Source – Exposure Relationships
Vehicles
SOURCE
EMISSIONS
Power plants
SOURCE
EMISSIONS
Stoves
SOURCE
EMISSIONS
How different?
Does it matter?
EXPOSURE
DOSE
HEALTH EFFECTS
Yes, a factor of ~100 different!

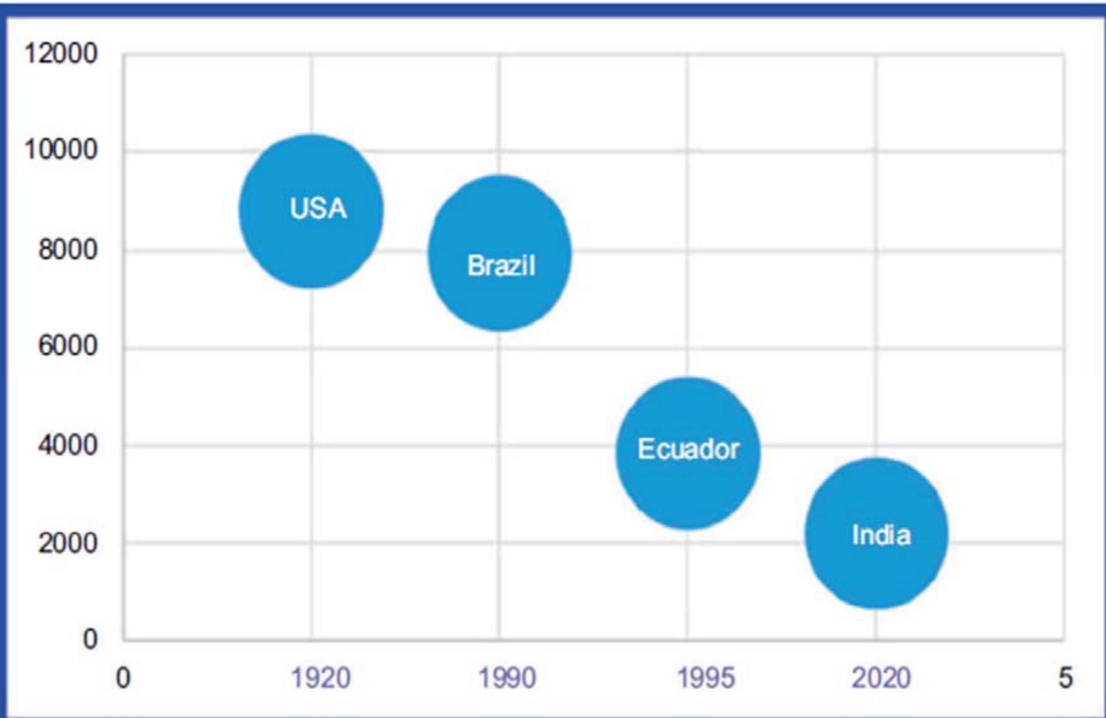
Goal for Health

- Find a way to frame policy to control air pollution emphasizing exposure rather than just concentration
- More efficient -- more protection per unit time and effort
- Without doing so, important sources can be ignored
- And important populations left behind

India

- Embarked on industrialization while still having large traditional sectors – mixed pollution sources today
- Not the case in the West
- India now at GDP/capita of the US in late 1800s
- Need to get rid of dirty household fuels soon, while dealing with modern sources
- Has started to happen, but more emphasis needed

k2



In which year did 80% of households begin cooking with gas?

Household air pollution, health, and climate change: cleaning the air

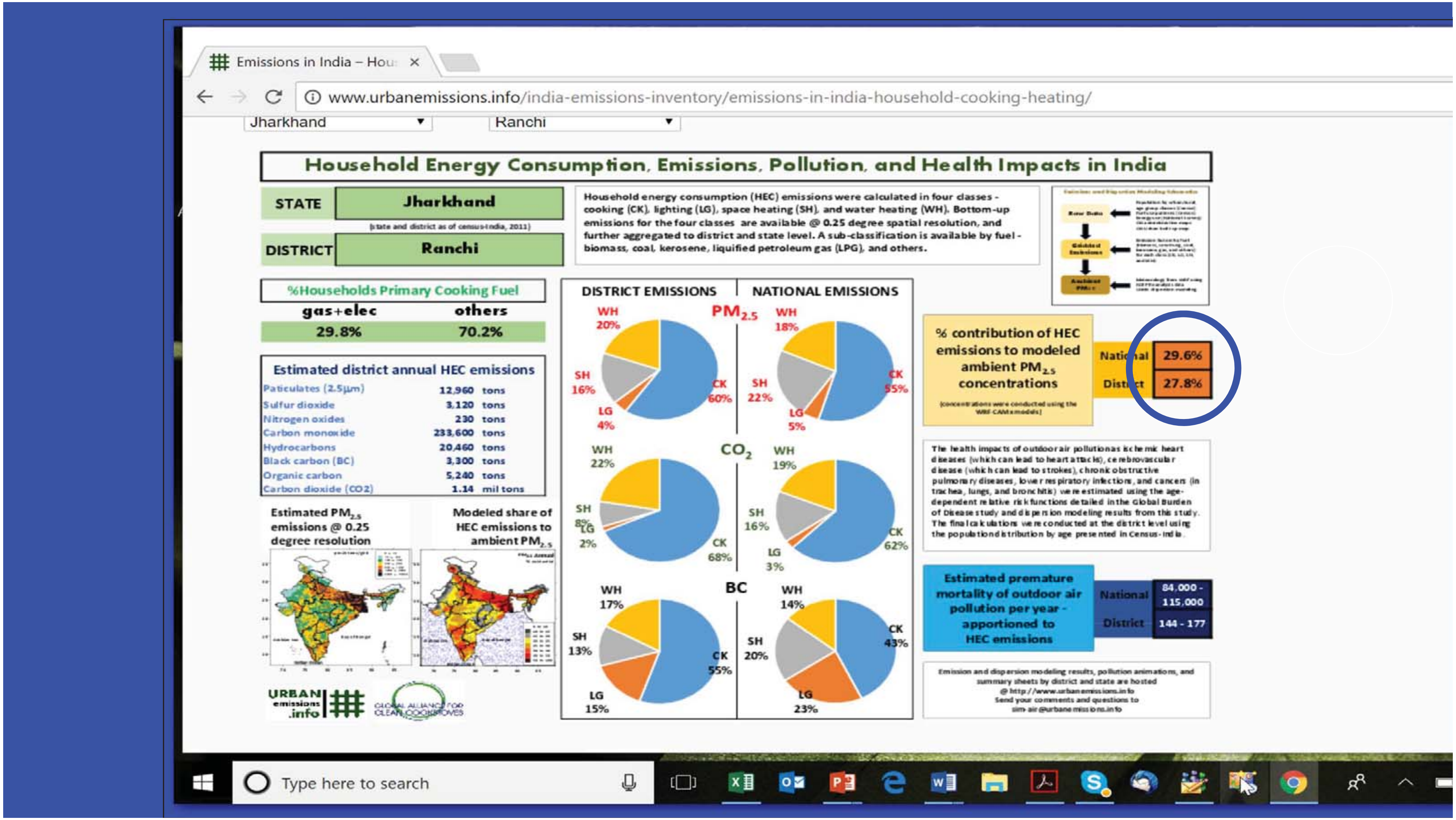
Jose Goldemberg, Javier Martinez-Gomez, Ambuj Sagar, and Kirk R Smith
Environmental Research Letters, 2018

Slide 9

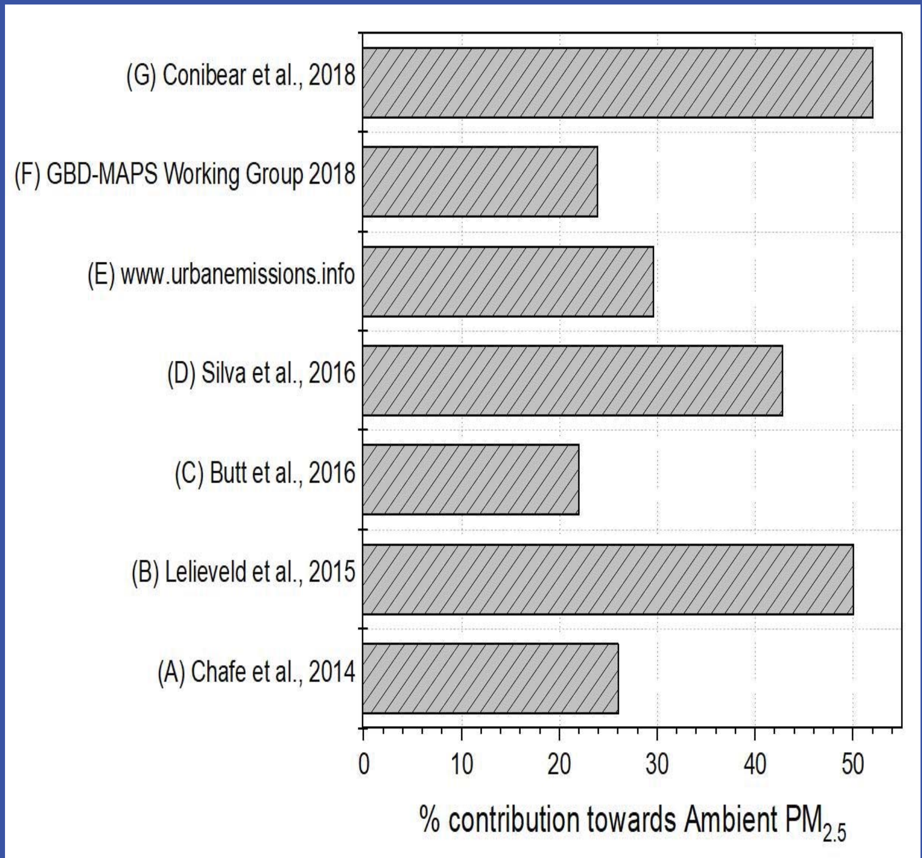
k2 krksmith, 7/17/2019

India

- Concern about “social benefits” for village households using solid fuels has led to a massive program to connect them to clean gas fuel
  - 80+ million poor households connected to LPG in 3 years
  - 90% of country now connected
  - Focus now on enhancing usage
- Households also responsible for ~30% of ambient PM2.5, but not included in national air pollution action plans
- And yet, surprisingly, cleaning up households alone will be enough to allow India to reach its national air pollution standards.



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
Estimated PM2.5 emissions @ 0.25 degree resolution
Modeled share of HEC emissions to ambient PM2.5
DISTRICT EMISSIONS
NATIONAL EMISSIONS
PM2.5
WH 20%
SH 16%
LG 4%
CK 60%
WH 18%
SH 22%
LG 5%
CK 55%
CO2
WH 22%
SH 8%
LG 2%
CK 68%
WH 19%
SH 16%
LG 3%
CK 62%
BC
WH 17%
SH 13%
LG 15%
CK 55%
WH 14%
SH 20%
LG 23%
CK 43%
% contribution of HEC emissions to modeled ambient PM2.5 concentrations
National 29.6%
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 premature mortality of outdoor air pollution per year - apportioned to HEC emissions
National 84,000 - 115,000
District 144 - 177
URBAN emissions .info
GLOBAL ALLIANCE FOR CLEAN COOKSTOVES
Type here to search



COLLABORATIVE
Clean Air
POLICY CENTRE

POLICY BRIEF

May 2019 • CCAPC/2019/01

The Contribution of Household Fuels to Ambient Air Pollution in India

A Comparison of Recent Estimates

Sourangsu Chowdhury, Zoe A. Chafe, Ajay Pillarisetti, Jos Lelieveld, Sarath Guttikunda, and Sagnik Dey

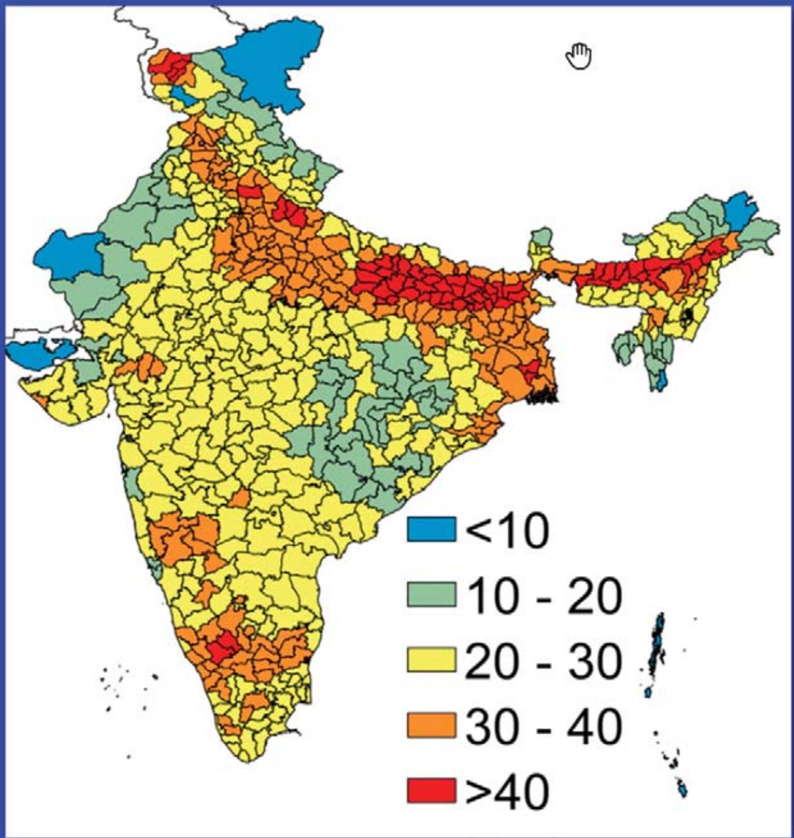
Indian annual ambient air quality standard is achievable by completely mitigating emissions from household sources

Sourangsu Chowdhury[a,b], Sagnik Dey[a,c,1], Sarath Guttikunda[d], Ajay Pillarisetti[b], Kirk R. Smith[b,e,1], and Larry Di Girolamo[f]

[a]Centre for Atmospheric Sciences, Indian Institute of Technology Delhi, New Delhi 110016, India; [b]School of Public Health, University of California, Berkeley, CA 94720-7360; [c]School of Public Policy, Indian Institute of Technology Delhi, New Delhi 110016, India; [d]Urban Emissions, New Delhi 110019, India; [e]Collaborative Clean Air Policy Centre, Delhi 110003, India; and [f]Department of Atmospheric Sciences, University of Illinois at Urbana–Champaign, Urbana, IL 61801

Proceedings of the National Academy of Sciences

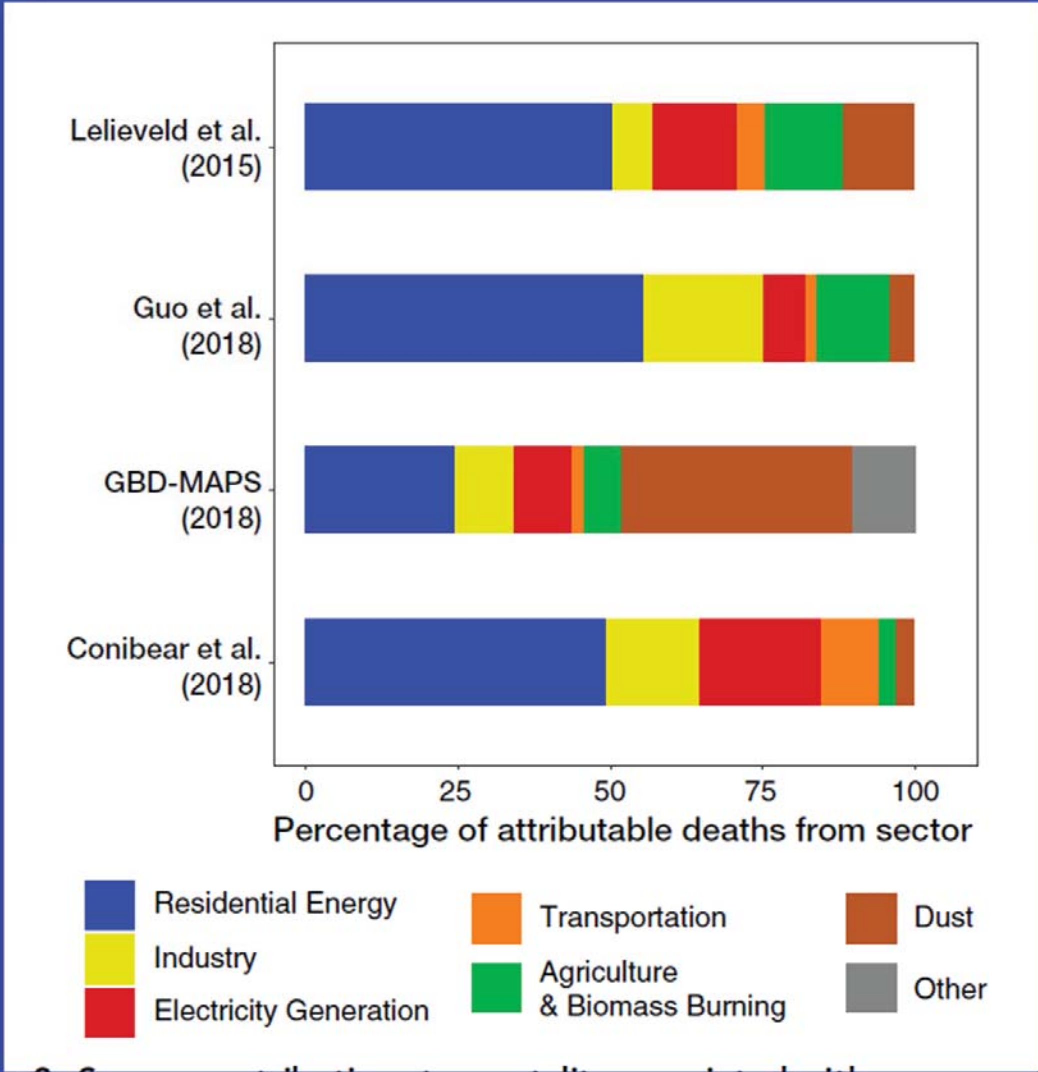
April, 2019



Percent of ambient pollution from households

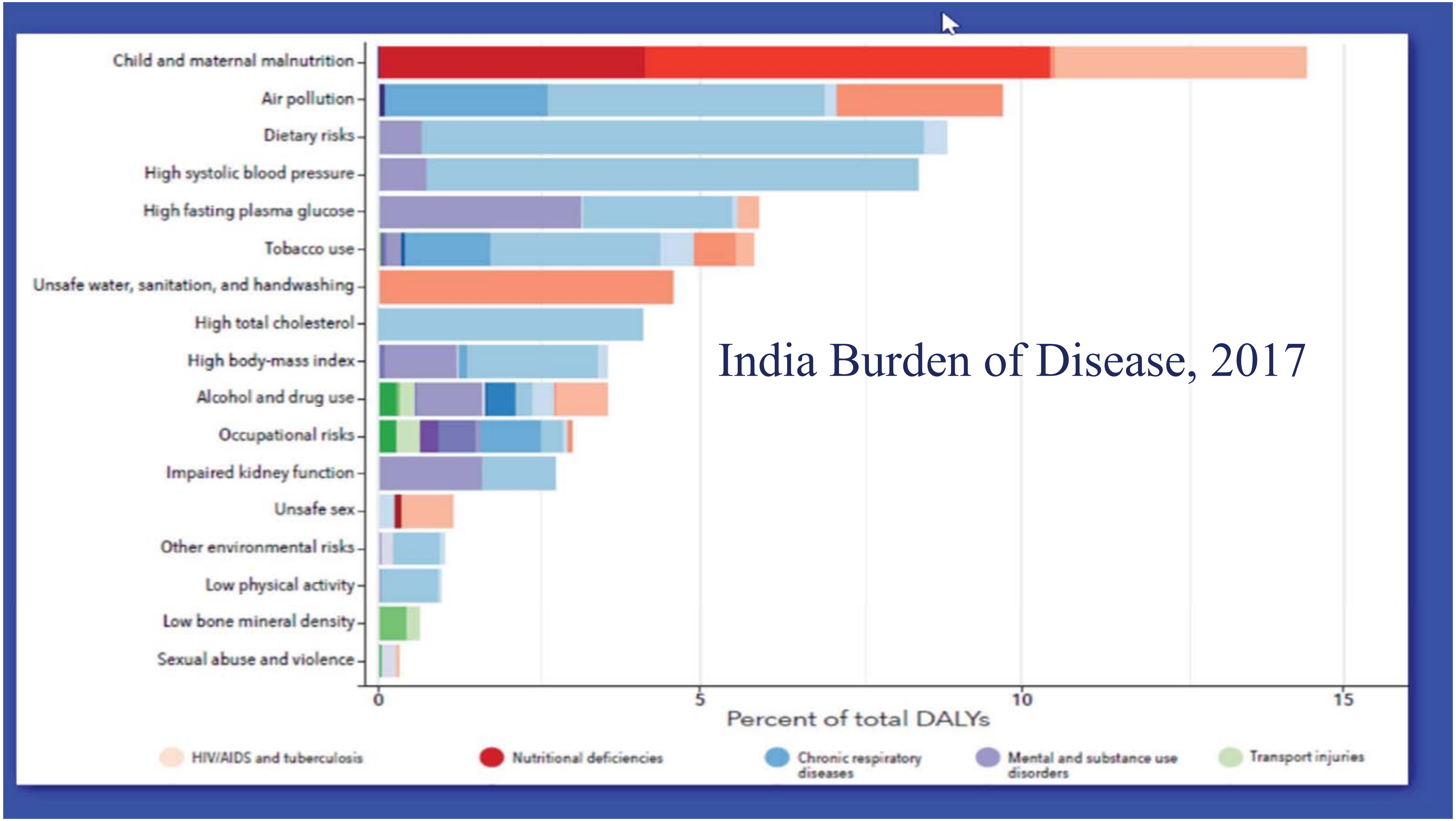
If PM2.5 emissions from all household sources are completely mitigated, 187 million Additional people would meet the Indian annual air-quality standard (40 µg/m3) compared with baseline (2015) when 239 million people met the standard.

At 38 µg/m3, after complete mitigation of household sources, the mean annual national population-based concentration would meet the national standard, although highly polluted areas, such as Delhi, would remain out of attainment

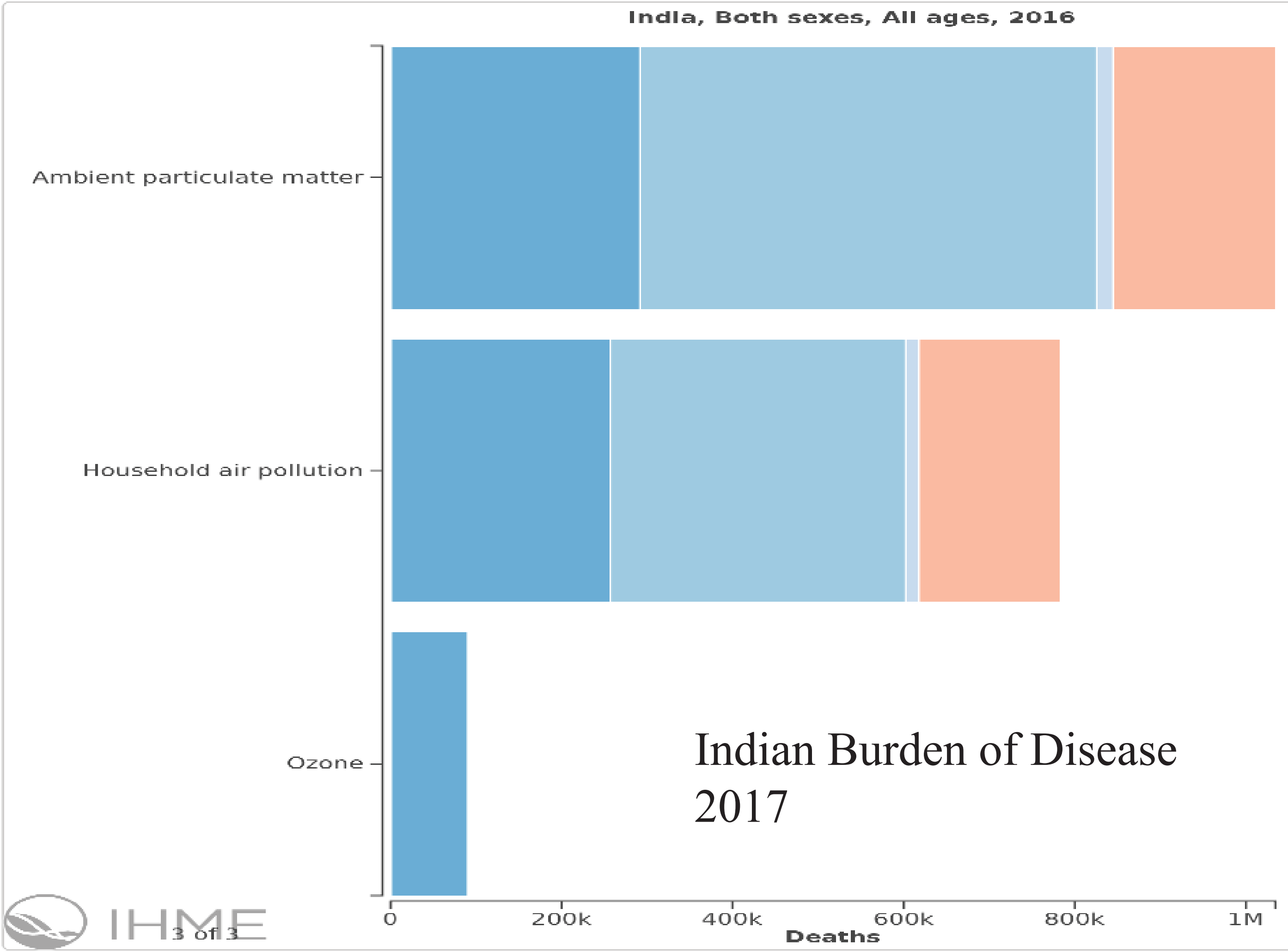


Households largest single contributor to outdoor air pollution exposure in Indian

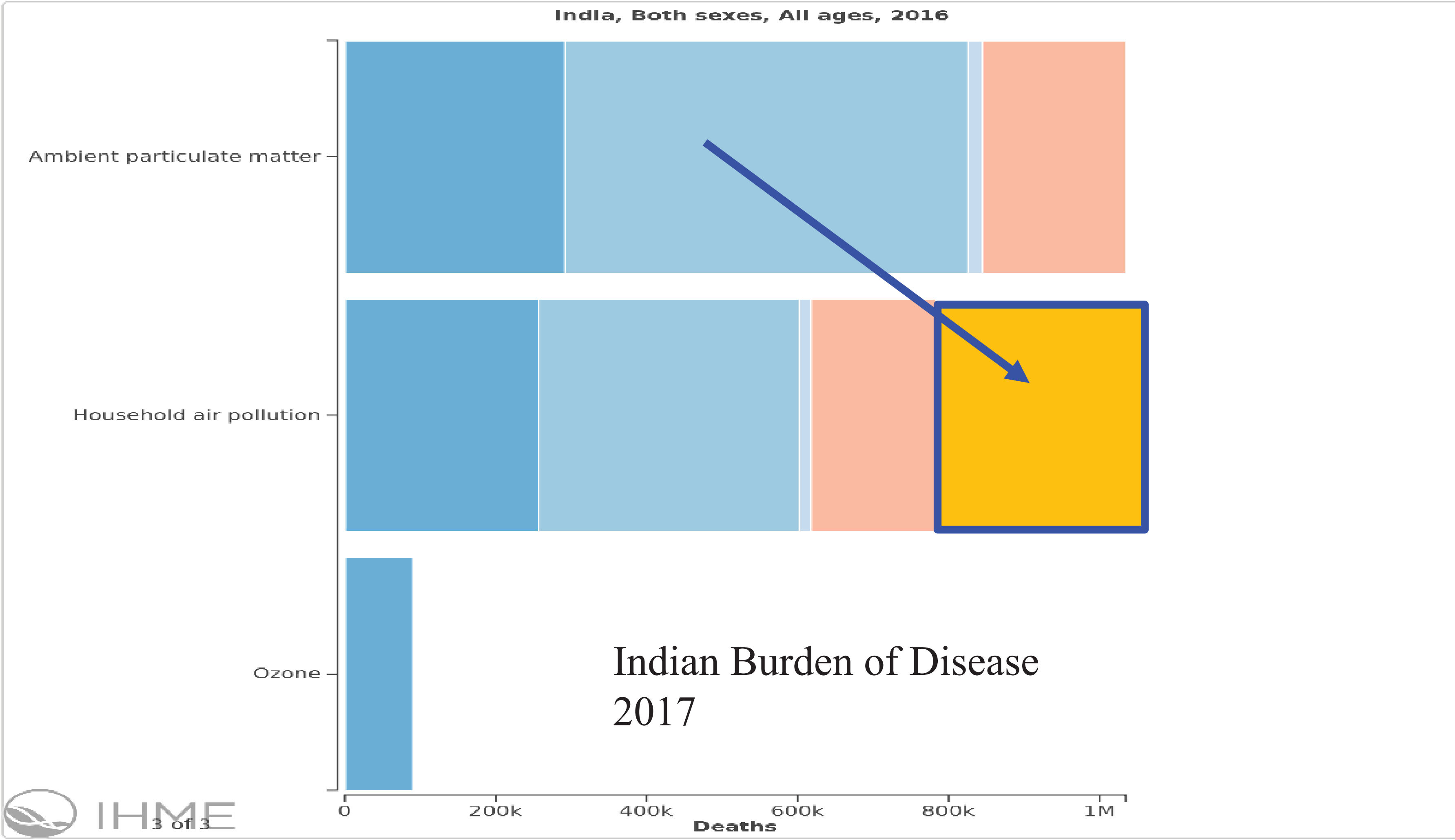
Apte and Pant, PNAS, 2019



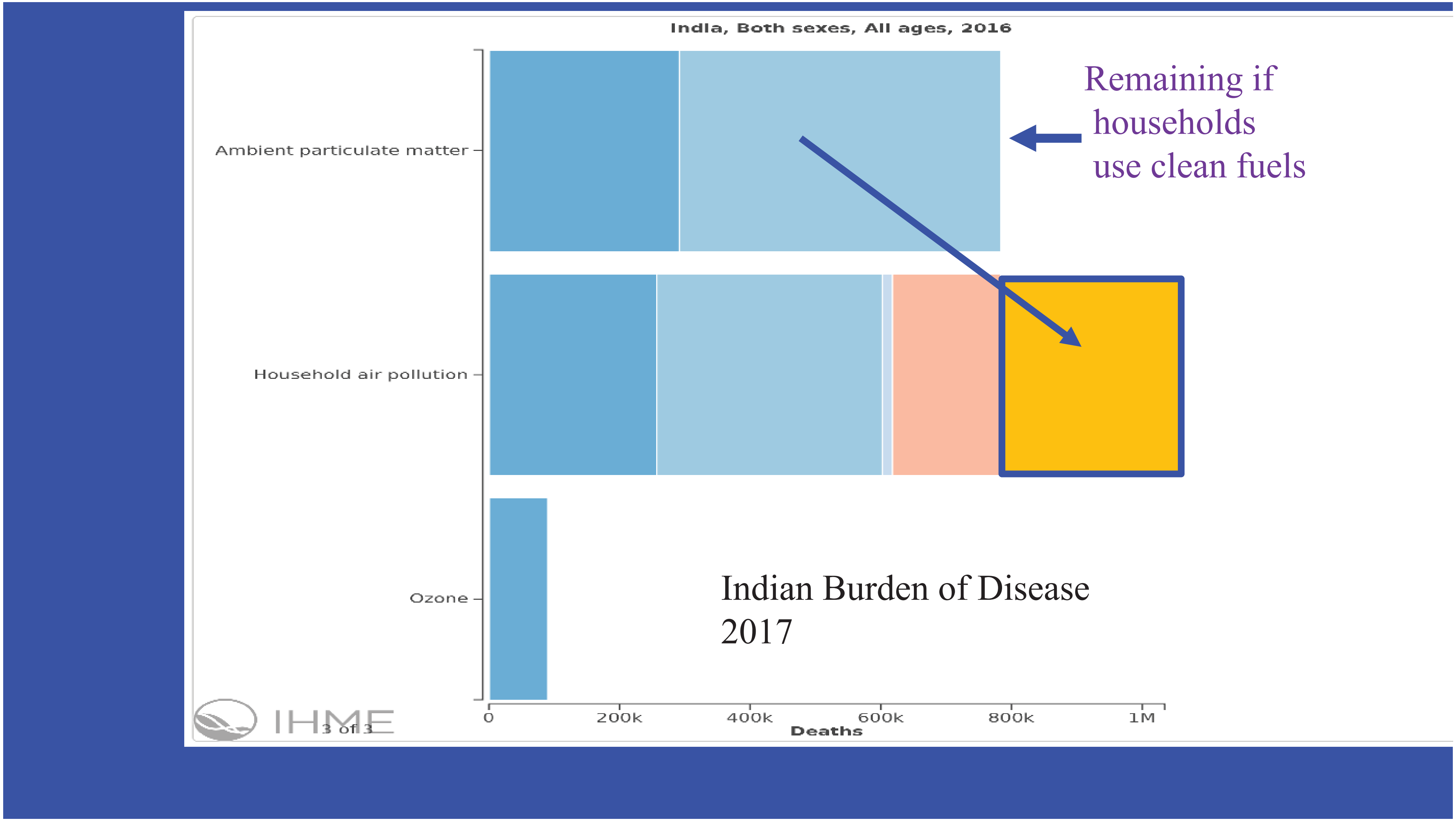
Child and maternal malnutrition
Air pollution
Dietary risks
High systolic blood pressure
High fasting plasma glucose
Tobacco use
Unsafe water, sanitation, and handwashing
High total cholesterol
High body-mass index
Alcohol and drug use
Occupational risks
Impaired kidney function
Unsafe sex
Other environmental risks
Low physical activity
Low bone mineral density
Sexual abuse and violence
0
5
10
15
Percent of total DALYs
India Burden of Disease, 2017
HIV/AIDS and tuberculosis
Nutritional deficiencies
Chronic respiratory diseases
Mental and substance use disorders
Transport injuries



Indian Burden of Disease 2017



Indian Burden of Disease
2017



India, Both sexes, All ages, 2016
Ambient particulate matter
Household air pollution
Ozone
Remaining if
households
use clean fuels
Indian Burden of Disease
2017
IHME
3 of 3
0
200k
400k
600k
800k
1M
Deaths

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, Oct)

$IPWE = \mathrm{PWE}_{AAP} + \mathrm{PWE}_{HAP}$

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)

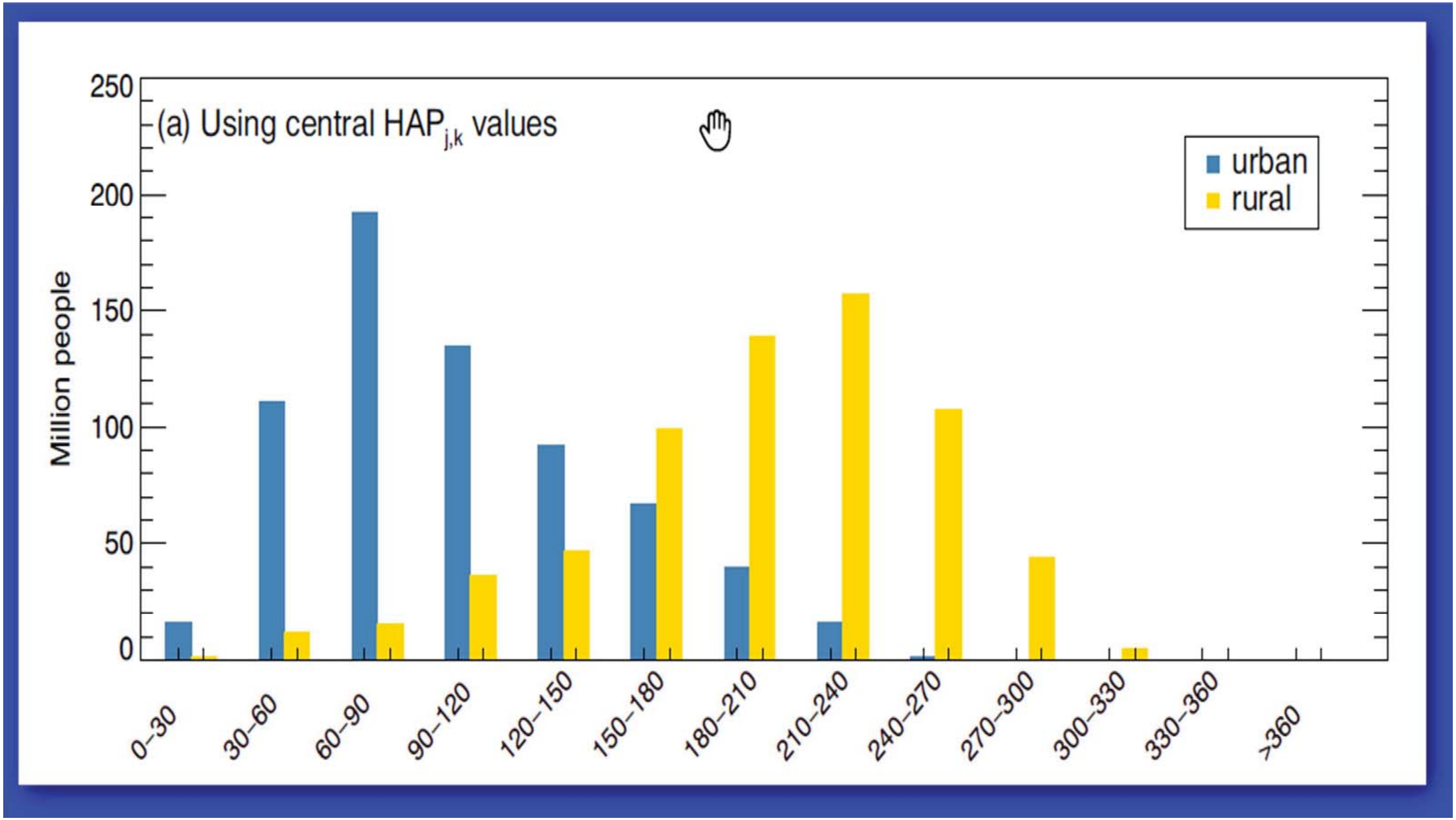
$$PWE_{AAP} = \frac{1}{P} \sum_{i} (P_i \cdot C_i)$$

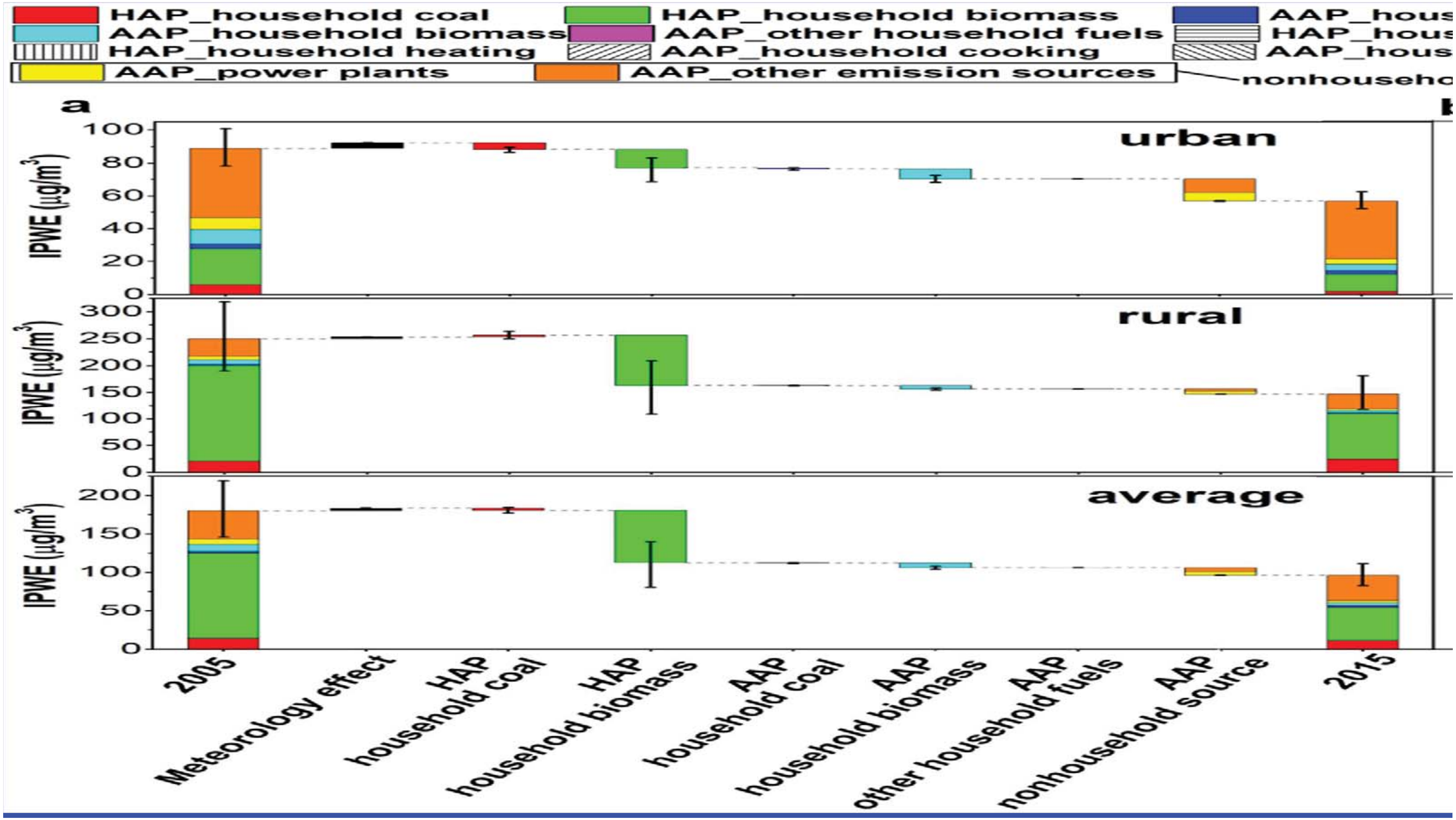
$$PWE_{HAP} = \frac{1}{P} \sum_{i,j} (P_{i,j,k} \cdot HAP_{j,k})$$

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



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

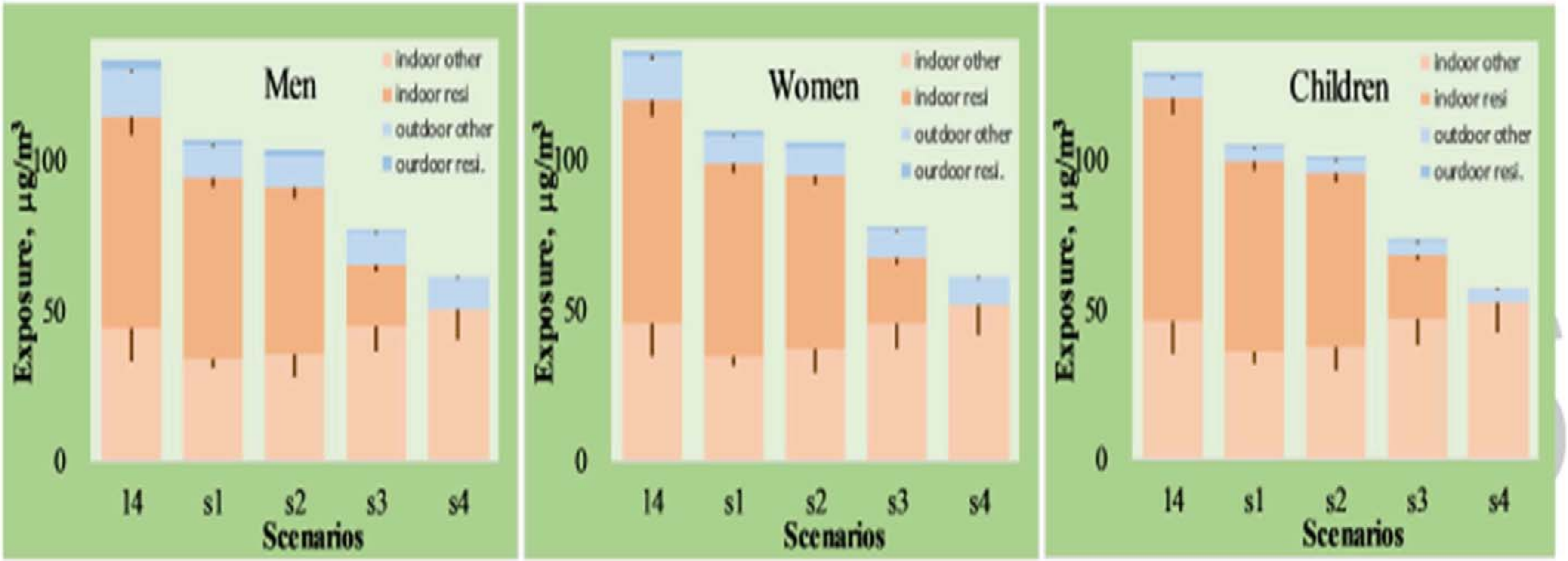
Energy-environment-health benefits of rural residential coal-substitution in northern China

Meng Wenjun[a], Zhong Qirui[a], Chen Yilin[b], Shen Huizhong[b], Yun Xiao[a], Kirk R. Smith[c*], Li Bengang[a], Liu Junfeng[a], Wang Xilong[a], Ma Jianmin[a], Cheng Hefa[a], Zeng Y. Eddy[d], Guan Dabo[e], Armistead G. Russell[b], Tao Shu[a*]

[a] College of Urban and Environmental Sciences, Laboratory for Earth Surface Processes, Sino-French Institute for Earth System Science, Peking University, Beijing 100871, China [b] School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, GA30332, USA [c] School of Public Health, University of California, Berkeley, CA 94720, USA, [d] School of Environment, Guangzhou Key Laboratory of Environmental Exposure and Health and Guangdong Key Laboratory of Environmental Pollution and Health, Jinan University, Guangzhou 510632, China [e] School of International Development, University of East Anglia, Norwich, Norfolk, NR4 7TJ, UK

Proceedings of the National Academy of Sciences

In press, 2019

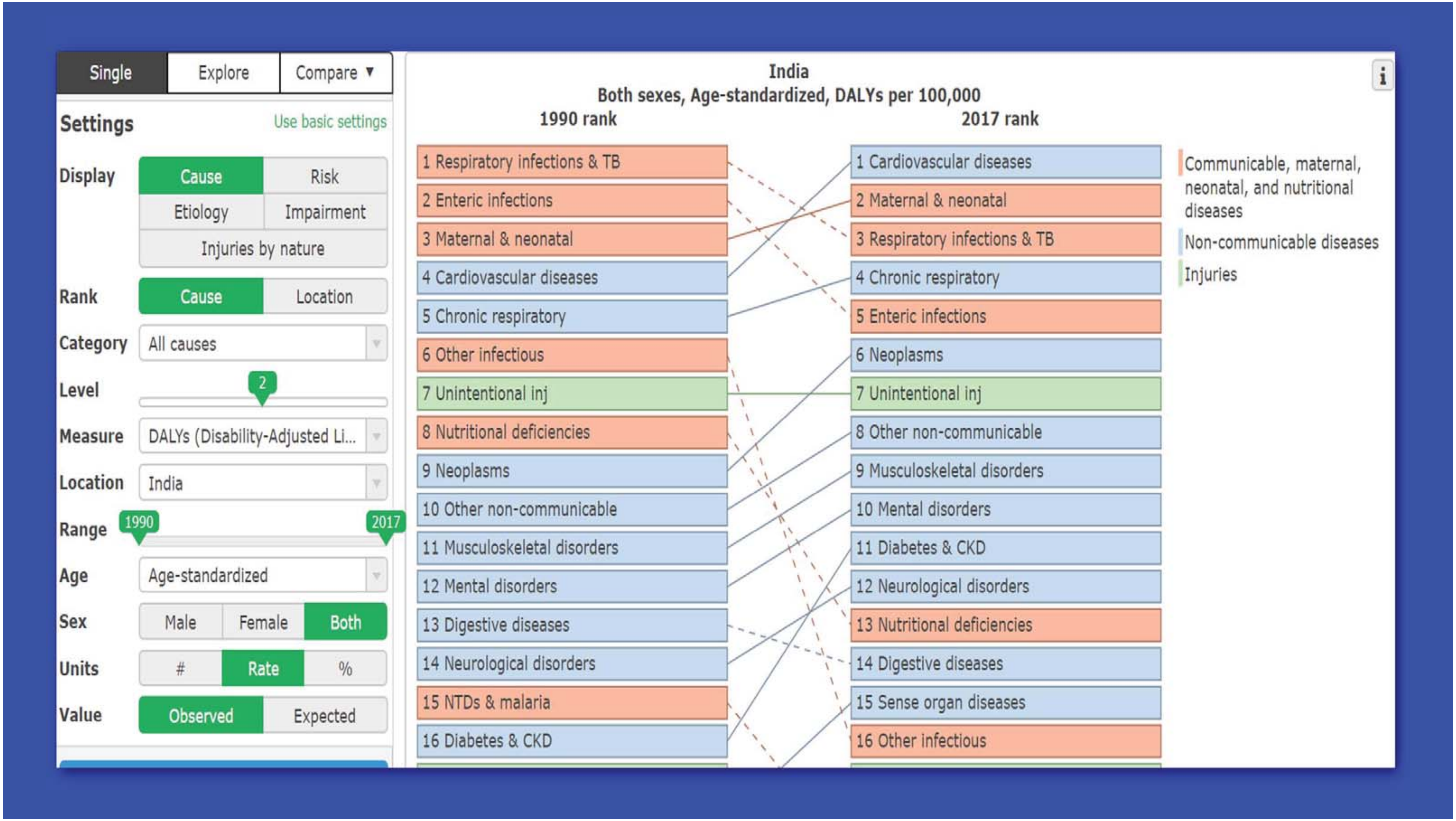


Scenario 3 – current plan
Scenario 4 – full substitution of solid household fuel

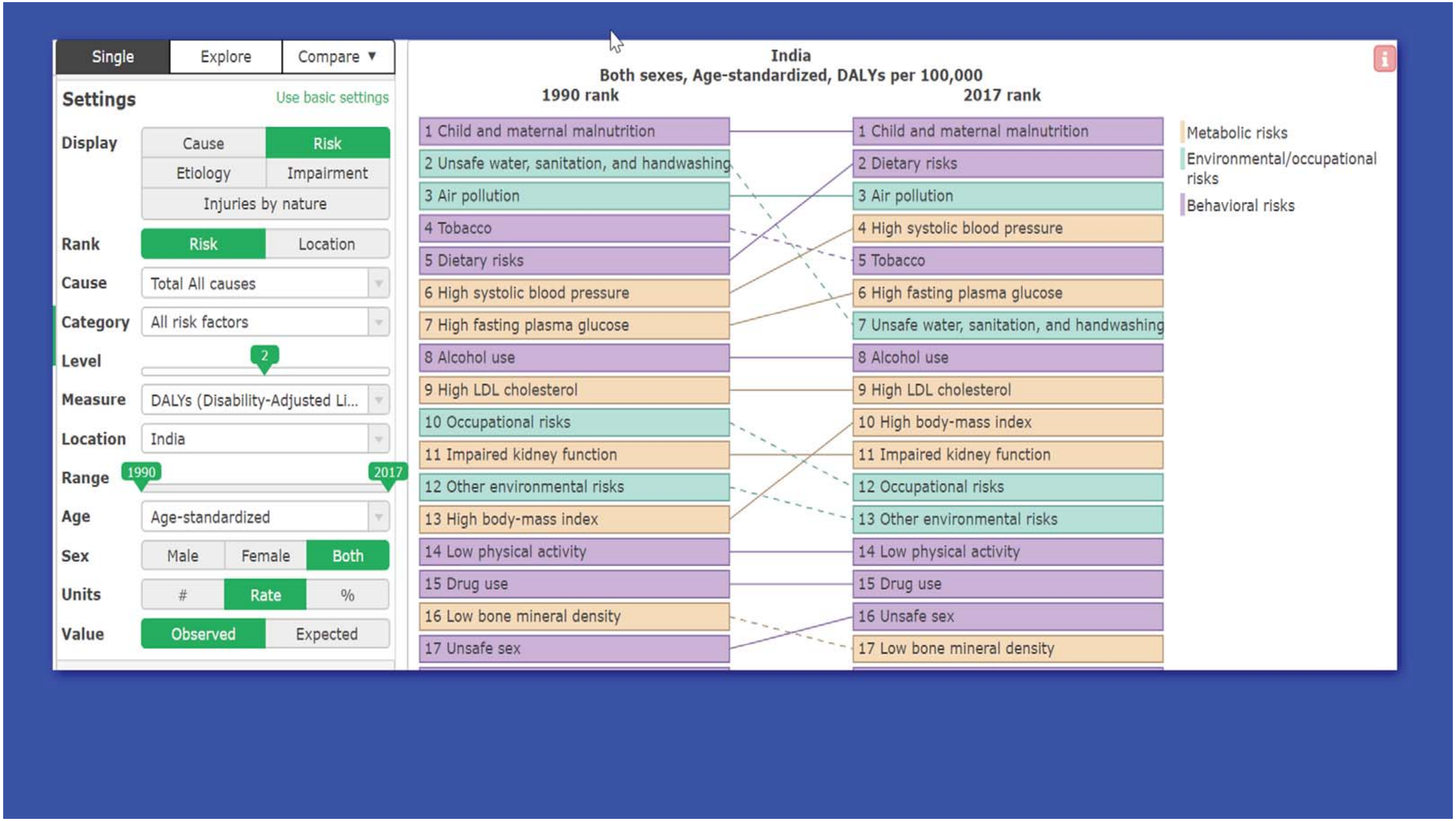
Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015

GBD 2015 Risk Factors Collaborators*

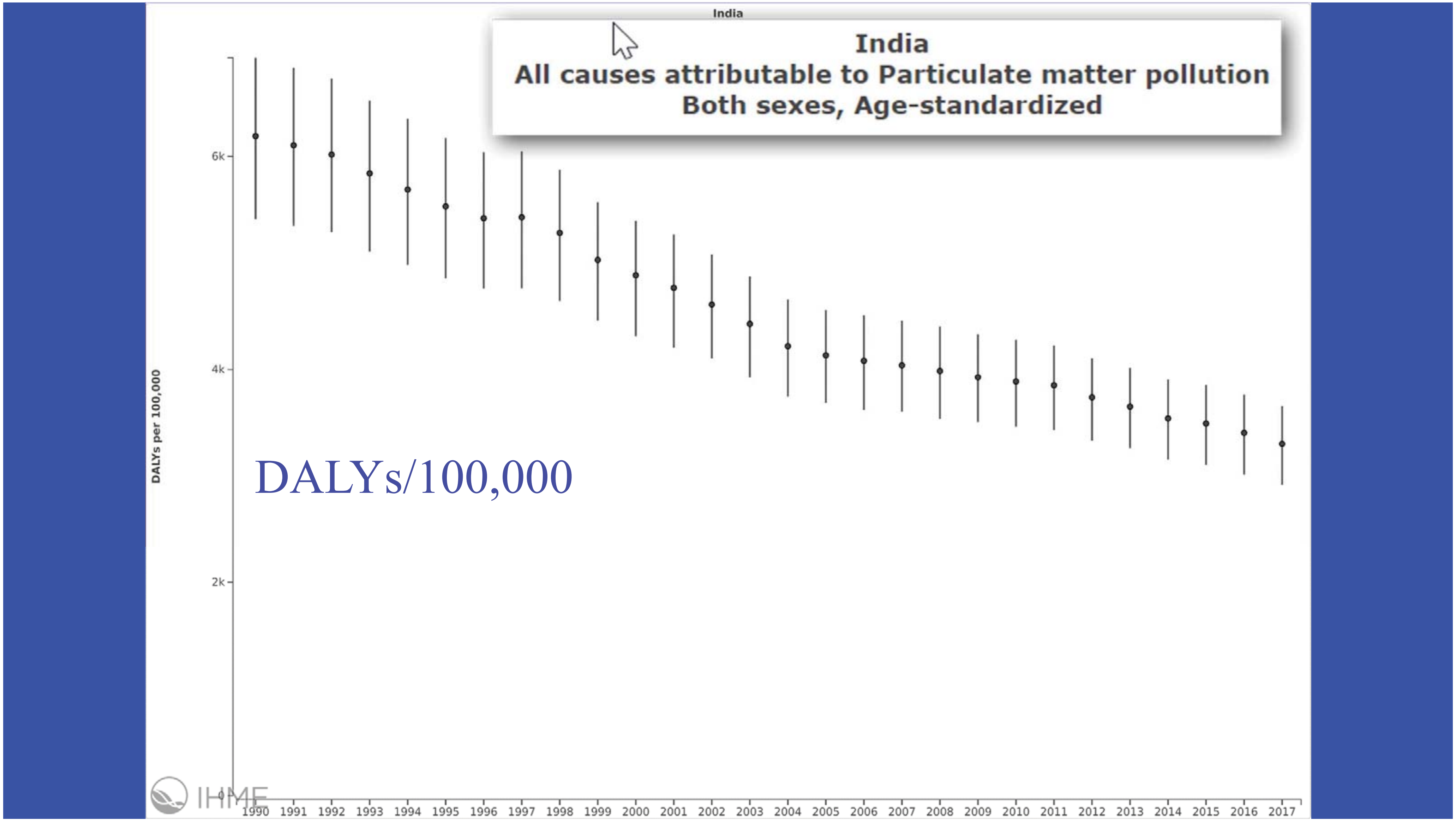
Recent CRA published 2017 in *The Lancet*

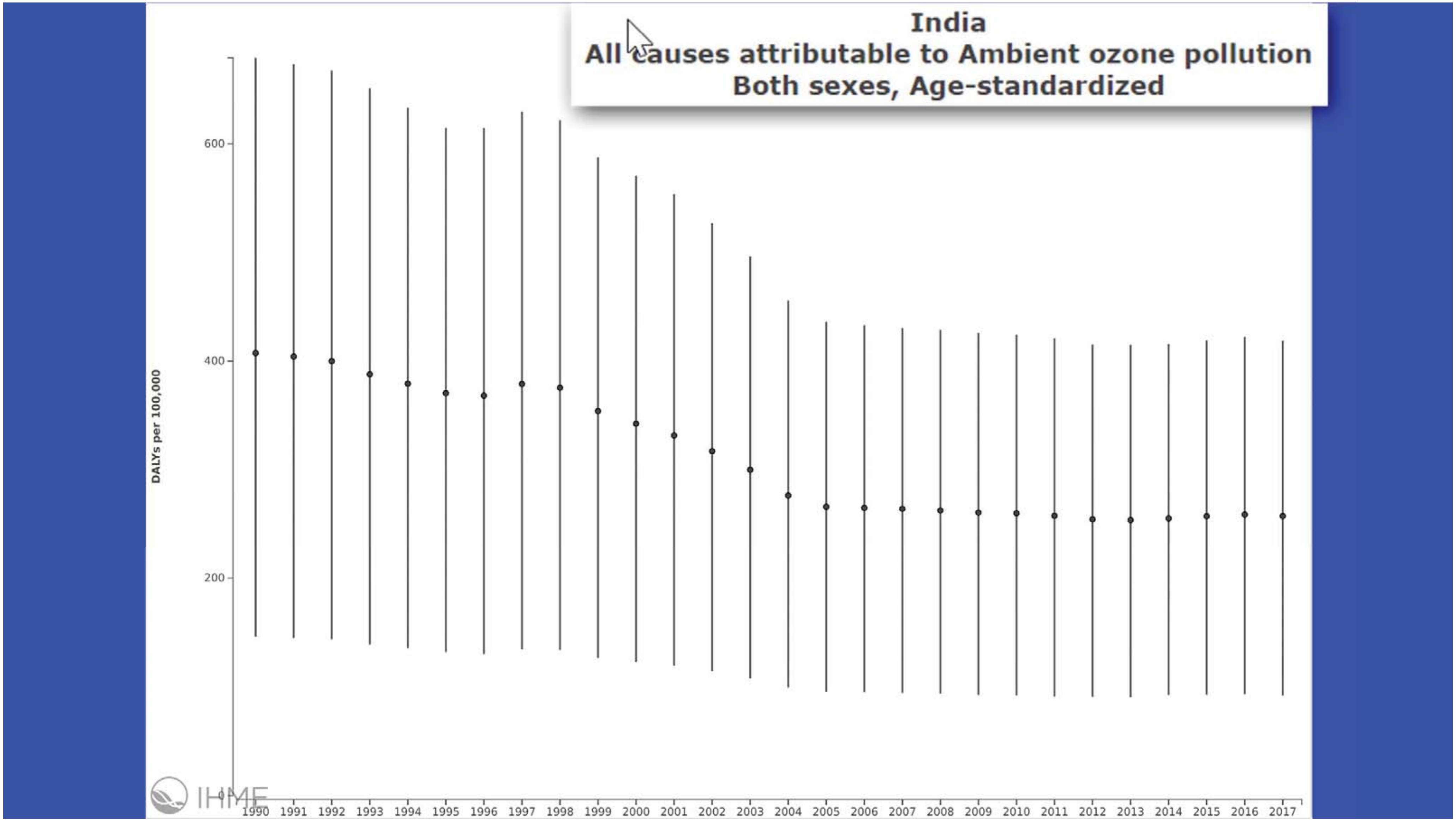


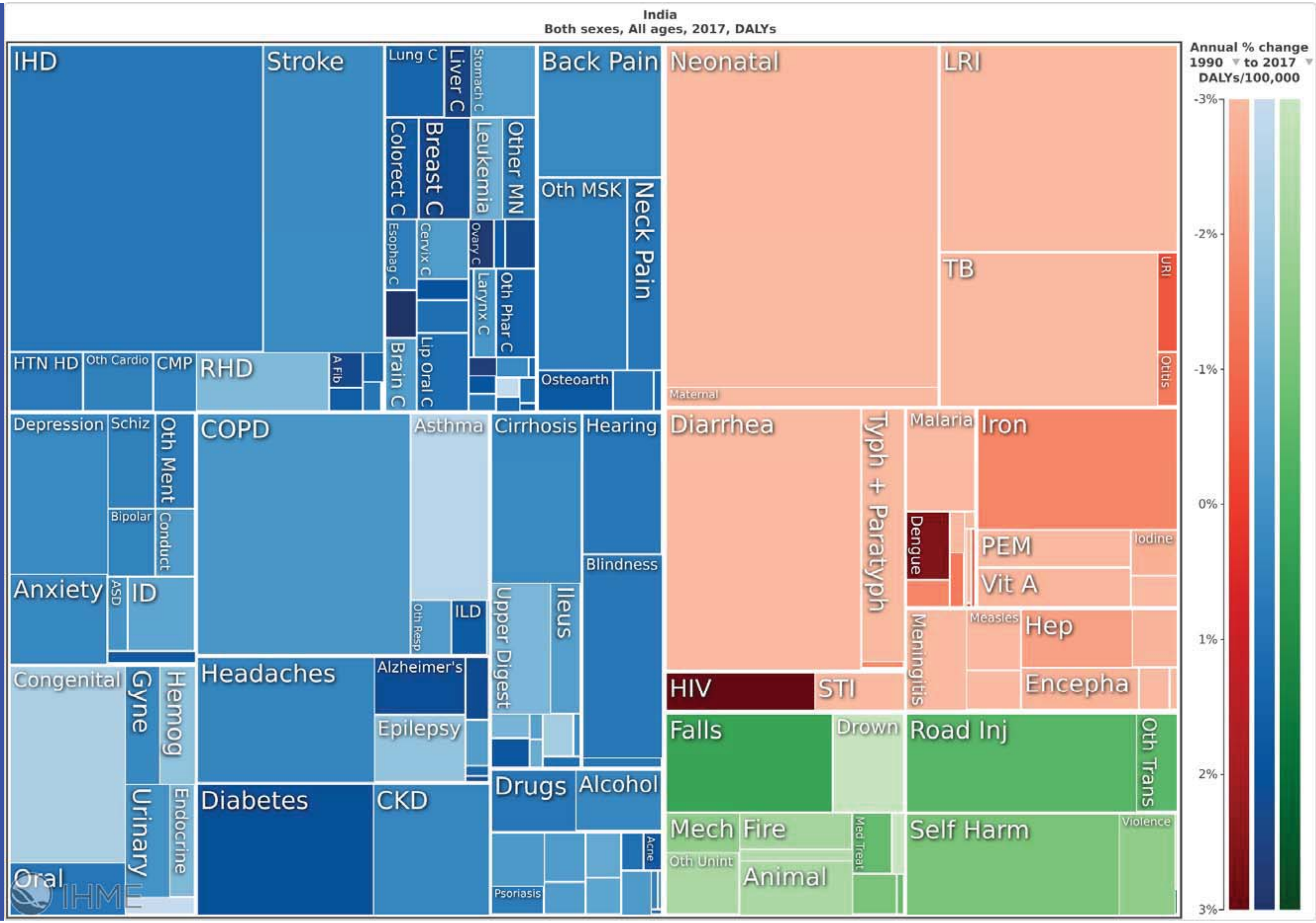
Single
Explore
Compare
Settings
Use basic settings
Display
Cause
Risk
Etiology
Impairment
Injuries by nature
Rank
Cause
Location
Category
All causes
Level
2
Measure
DALYs (Disability-Adjusted Li...
Location
India
Range
1990
2017
Age
Age-standardized
Sex
Male
Female
Both
Units
#
Rate
%
Value
Observed
Expected
India
Both sexes, Age-standardized, DALYs per 100,000
1990 rank
2017 rank
1 Respiratory infections & TB
2 Enteric infections
3 Maternal & neonatal
4 Cardiovascular diseases
5 Chronic respiratory
6 Other infectious
7 Unintentional inj
8 Nutritional deficiencies
9 Neoplasms
10 Other non-communicable
11 Musculoskeletal disorders
12 Mental disorders
13 Digestive diseases
14 Neurological disorders
15 NTDs & malaria
16 Diabetes & CKD
1 Cardiovascular diseases
2 Maternal & neonatal
3 Respiratory infections & TB
4 Chronic respiratory
5 Enteric infections
6 Neoplasms
7 Unintentional inj
8 Other non-communicable
9 Musculoskeletal disorders
10 Mental disorders
11 Diabetes & CKD
12 Neurological disorders
13 Nutritional deficiencies
14 Digestive diseases
15 Sense organ diseases
16 Other infectious
Communicable, maternal, neonatal, and nutritional diseases
Non-communicable diseases
Injuries

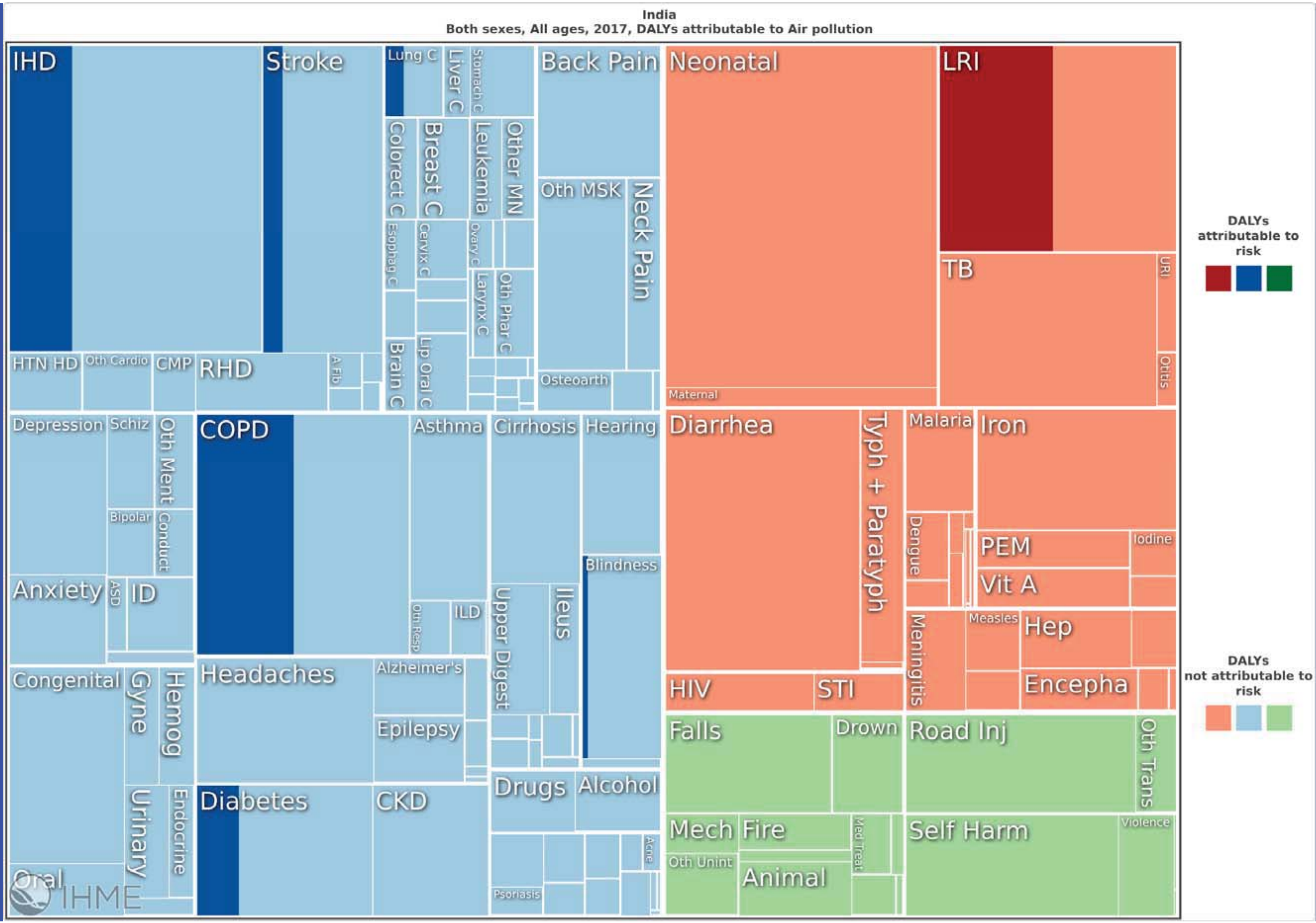


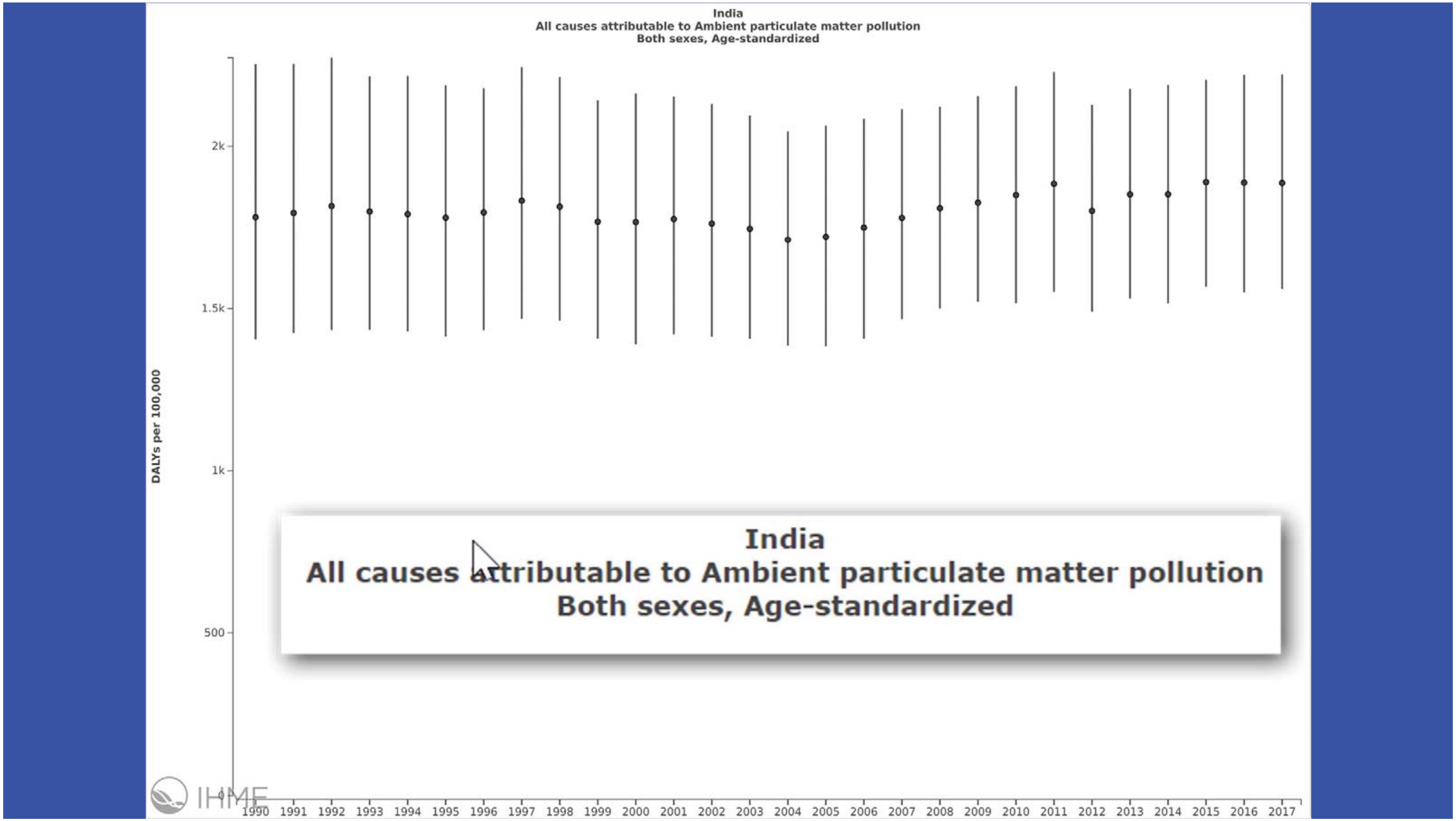
Single
Explore
Compare ▼
Settings
Use basic settings
Display
Cause
Risk
Etiology
Impairment
Injuries by nature
Rank
Risk
Location
Cause
Total All causes
Category
All risk factors
Level
2
Measure
DALYs (Disability-Adjusted Li...
Location
India
Range
1990
2017
Age
Age-standardized
Sex
Male
Female
Both
Units
#
Rate
%
Value
Observed
Expected
India
Both sexes, Age-standardized, DALYs per 100,000
1990 rank
2017 rank
1 Child and maternal malnutrition
2 Unsafe water, sanitation, and handwashing
3 Air pollution
4 Tobacco
5 Dietary risks
6 High systolic blood pressure
7 High fasting plasma glucose
8 Alcohol use
9 High LDL cholesterol
10 Occupational risks
11 Impaired kidney function
12 Other environmental risks
13 High body-mass index
14 Low physical activity
15 Drug use
16 Low bone mineral density
17 Unsafe sex
1 Child and maternal malnutrition
2 Dietary risks
3 Air pollution
4 High systolic blood pressure
5 Tobacco
6 High fasting plasma glucose
7 Unsafe water, sanitation, and handwashing
8 Alcohol use
9 High LDL cholesterol
10 High body-mass index
11 Impaired kidney function
12 Occupational risks
13 Other environmental risks
14 Low physical activity
15 Drug use
16 Unsafe sex
17 Low bone mineral density
Metabolic risks
Environmental/occupational risks
Behavioral risks


India
India
All causes attributable to Particulate matter pollution
Both sexes, Age-standardized
DALYs per 100,000
6k
4k
2k
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
IHME
DALYs/100,000


India
All causes attributable to Ambient ozone pollution
Both sexes, Age-standardized
DALYs per 100,000
600
400
200
0
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
IHME


India
Both sexes, All ages, 2017, DALYs
IHD
Stroke
Lung C
Liver C
Stomach C
Colorect C
Breast C
Leukemia
Other MN
Esophag C
Cervix C
Ovary C
Larynx C
Oth Phar C
Brain C
Lip Oral C
HTN HD
Oth Cardio
CMP
RHD
A Fib
Back Pain
Oth MSK
Neck Pain
Osteoarth
Neonatal
Maternal
LRI
TB
URI
Otitis
Depression
Schiz
Oth Ment
Bipolar
Conduct
Anxiety
ASD
ID
COPD
Asthma
Oth Resp
ILD
Cirrhosis
Hearing
Blindness
Upper Digest
Ileus
Congenital
Gyne
Hemog
Urinary
Endocrine
Oral
Headaches
Alzheimer's
Epilepsy
Diabetes
CKD
Drugs
Alcohol
Acne
Psoriasis
Diarrhea
Typh + Paratyph
Malaria
Iron
Dengue
PEM
Iodine
Vit A
Meningitis
Measles
Hep
Encepha
HIV
STI
Falls
Drown
Road Inj
Oth Trans
Mech
Fire
Med Treat
Oth Unint
Animal
Self Harm
Violence
Annual % change 1990 to 2017 DALYs/100,000
-3%
-2%
-1%
0%
1%
2%
3%
IHME


India
Both sexes, All ages, 2017, DALYs attributable to Air pollution
IHD
Stroke
Lung C
Liver C
Stomach C
Back Pain
Neonatal
LRI
Colorect C
Breast C
Leukemia
Other MN
Esophag C
Cervix C
Ovary C
Larynx C
Oth Phar C
Brain C
Lip Oral C
Oth MSK
Neck Pain
Osteoarth
Maternal
TB
URI
Otitis
HTN HD
Oth Cardio
CMP
RHD
A Fib
Depression
Schiz
Oth Ment
Bipolar
Conduct
Anxiety
ASD
ID
COPD
Asthma
Oth Resp
ILD
Cirrhosis
Hearing
Blindness
Upper Digest
Ileus
Diarrhea
Typh + Paratyph
Malaria
Iron
Dengue
PEM
Iodine
Vit A
Meningitis
Measles
Hep
Encepha
HIV
STI
Congenital
Gyne
Hemog
Headaches
Alzheimer's
Epilepsy
Urinary
Endocrine
Diabetes
CKD
Drugs
Alcohol
Acne
Psoriasis
Oral
IHME
Falls
Drown
Road Inj
Oth Trans
Mech
Fire
Med Treat
Oth Unint
Animal
Self Harm
Violence
DALYs attributable to risk
DALYs not attributable to risk


India
All causes attributable to Ambient particulate matter pollution
Both sexes, Age-standardized
DALYs per 100,000
2k
1.5k
1k
500
0
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
IHME
India
All causes attributable to Ambient particulate matter pollution
Both sexes, Age-standardized

Needed a **C**omparative Economic Assessment

- Common databases and time periods
- Common models and parameters
- Common agreement on what is included and why
- Common representation of uncertainty
- Peer-reviewed systematically
- Agreed update procedures and time lines

Thanks to
many
colleagues in

China,
India,
and the USA

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

HEALTH
EFFECTS
INSTITUTE

SPECIAL REPORT 21

January 2018

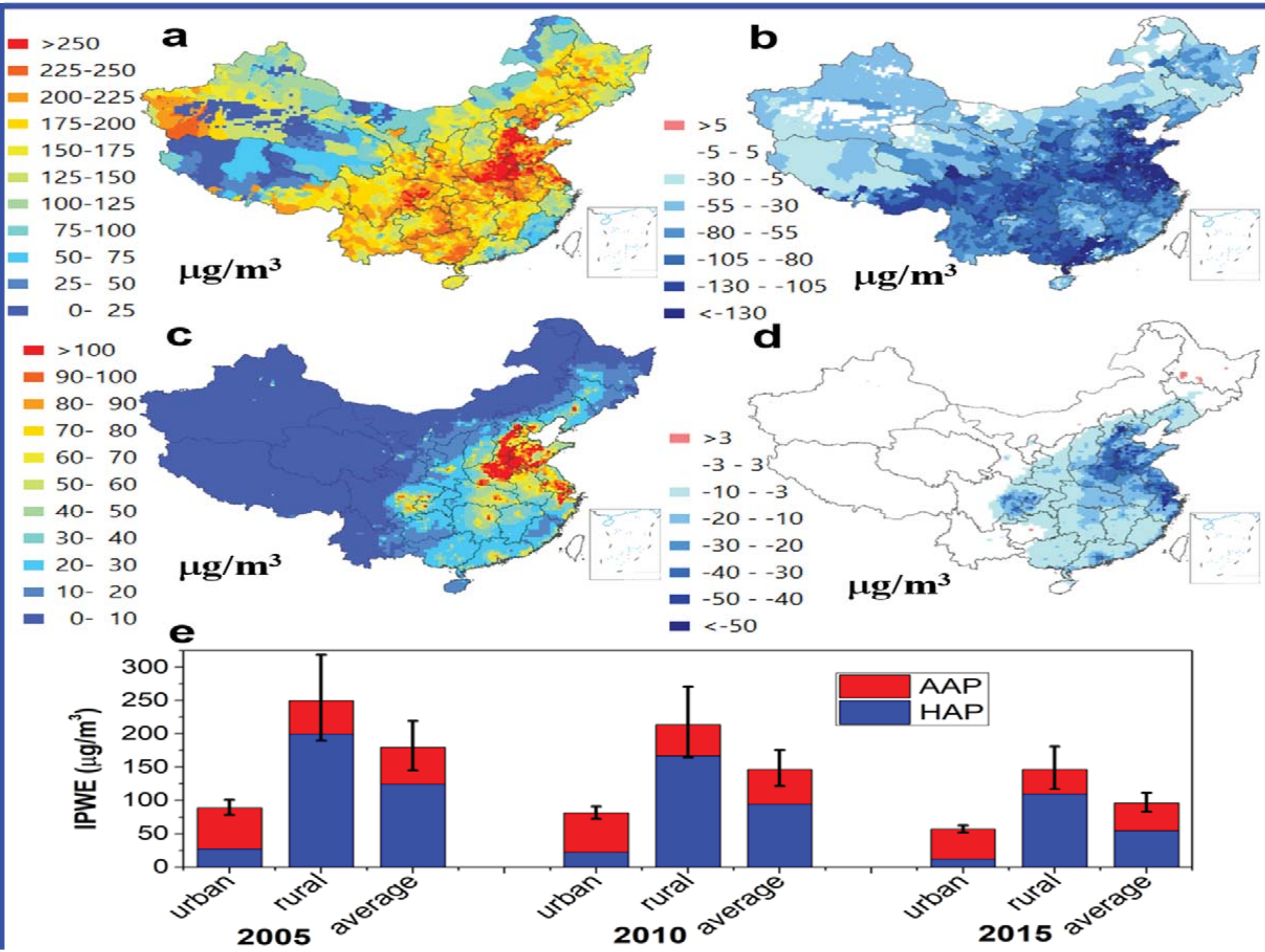
Burden of Disease Attributable to Major Air Pollution Sources in India

GBD MAPS Working Group

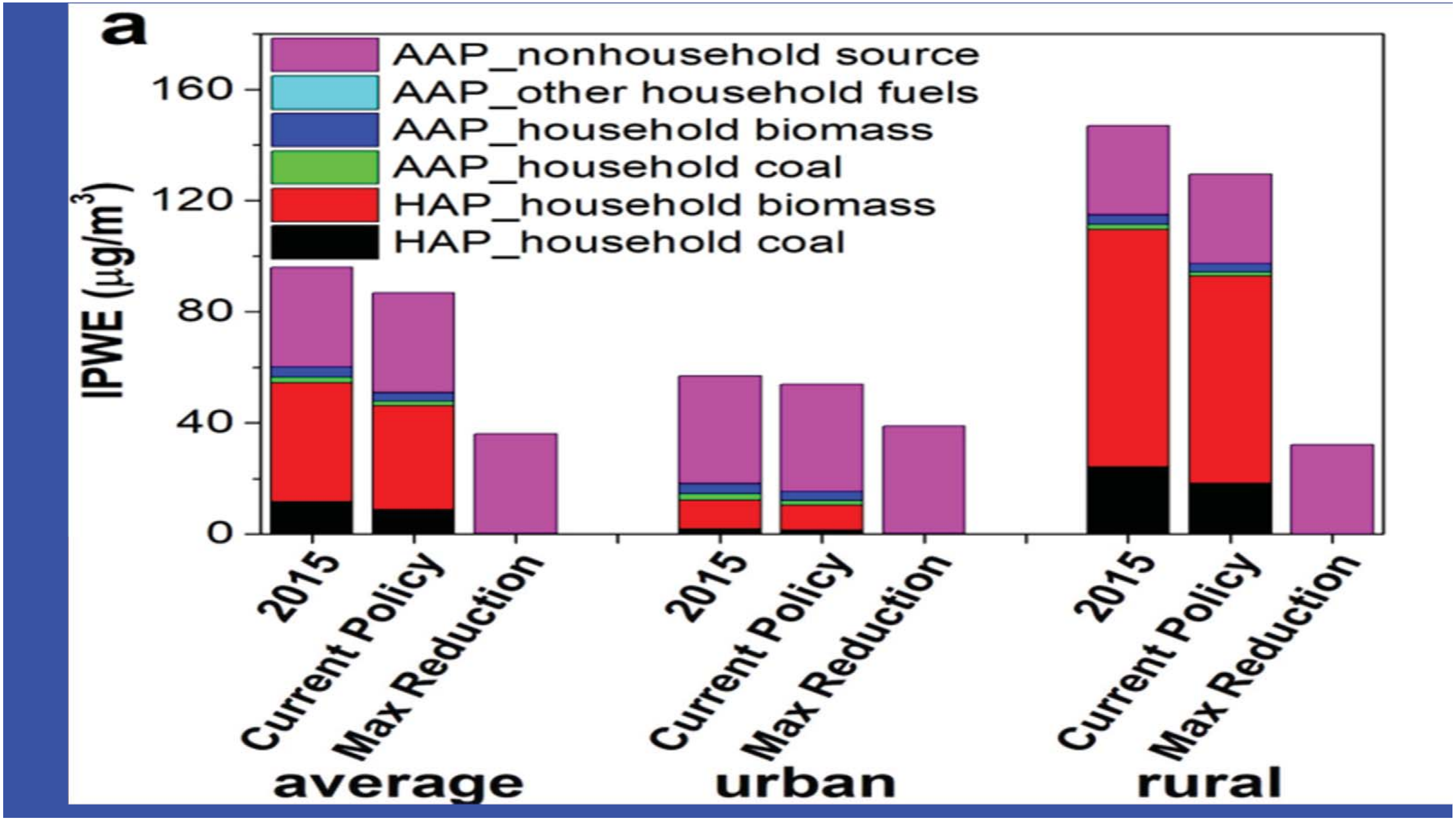
Table 2. Mean Percentage Contribution of Different Source Sectors to Population-Weighted Ambient $PM_{2.5}$ in India for 2015[a]

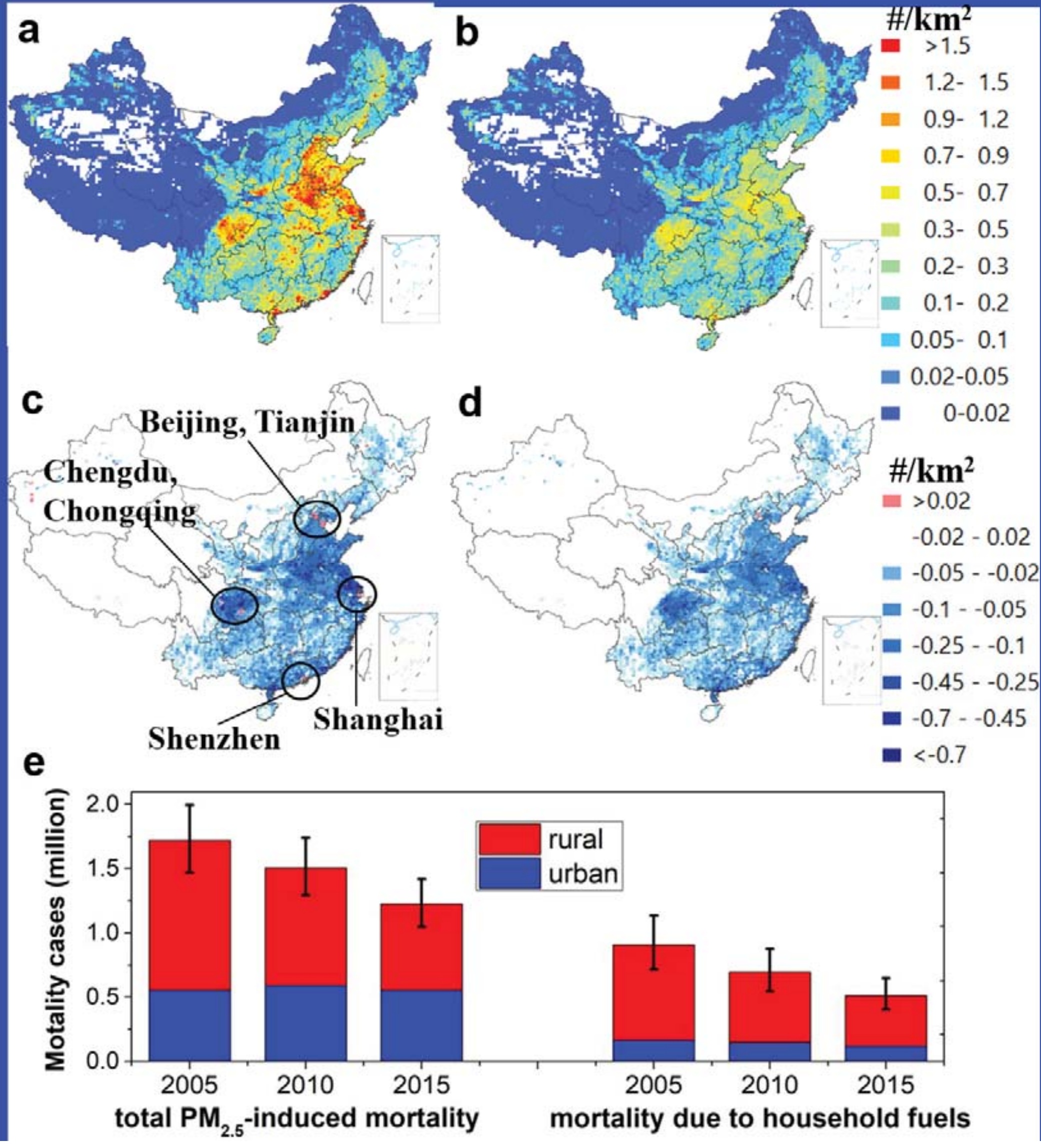
Source Sector	All India (%)	Rural India (%)	Urban India (%)
Residential biomass	23.9	24.2	22.1
Total coal	15.7	15.5	17.1
Industrial coal	7.7	7.6	8.5
Power plant coal	7.6	7.5	8.0
Open burning	5.5	5.5	5.6
Transportation	2.1	2.1	2.1
Brick production	2.2	2.1	2.2
Distributed diesel	1.8	1.8	1.4
Anthropogenic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

GBD MAPs Study, Jan 2018



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)
300
250
200
150
100
50
0
AAP
HAP
urban
rural
average
2005
urban
rural
average
2010
urban
rural
average
2015


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

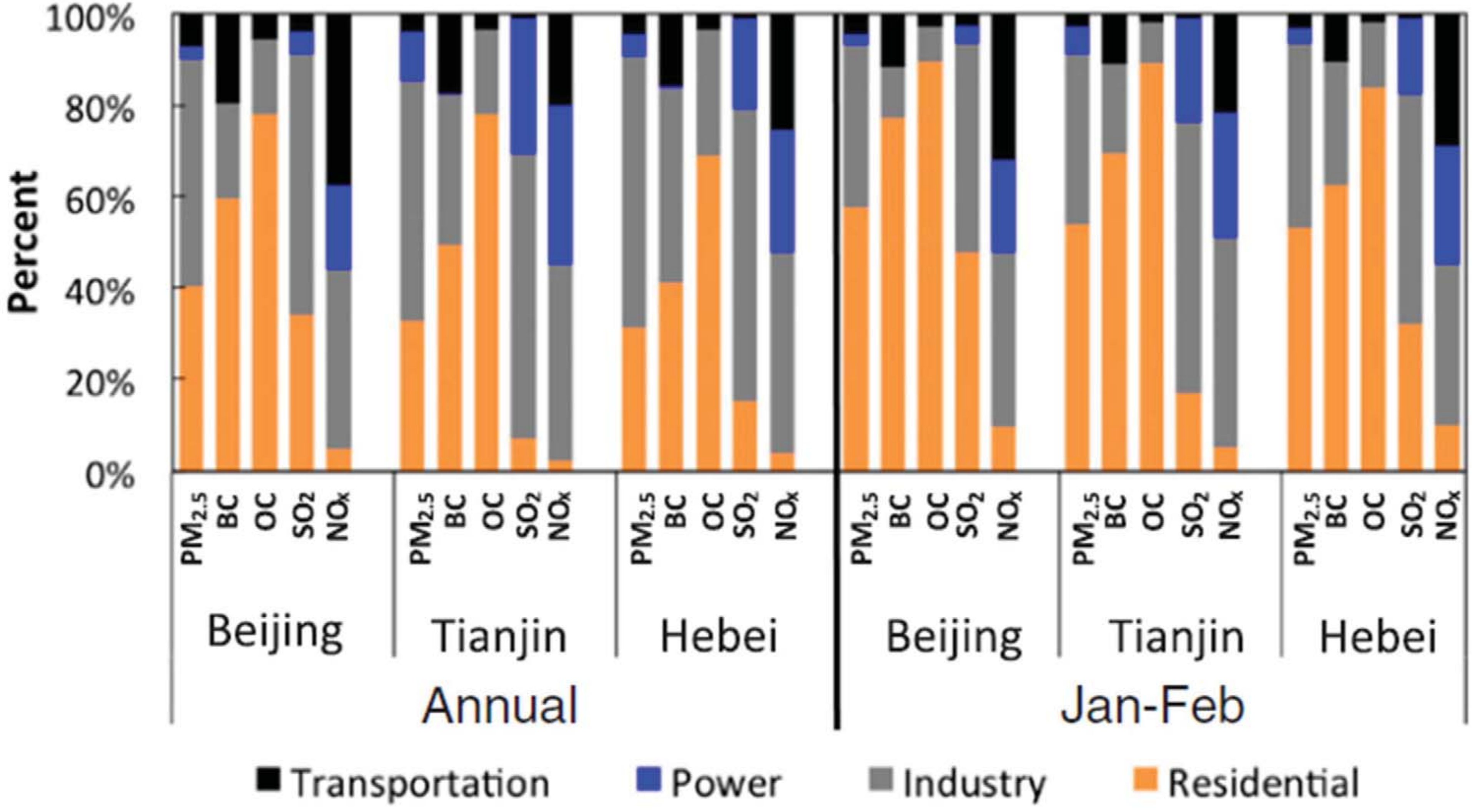

a
b
#/km²
>1.5
1.2- 1.5
0.9- 1.2
0.7- 0.9
0.5- 0.7
0.3- 0.5
0.2- 0.3
0.1- 0.2
0.05- 0.1
0.02-0.05
0-0.02
c
Beijing, Tianjin
Chengdu, Chongqing
Shanghai
Shenzhen
d
#/km²
>0.02
-0.02 - 0.02
-0.05 - -0.02
-0.1 - -0.05
-0.25 - -0.1
-0.45 - -0.25
-0.7 - -0.45
<-0.7
e
Motality cases (million)
rural
urban
2005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

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.

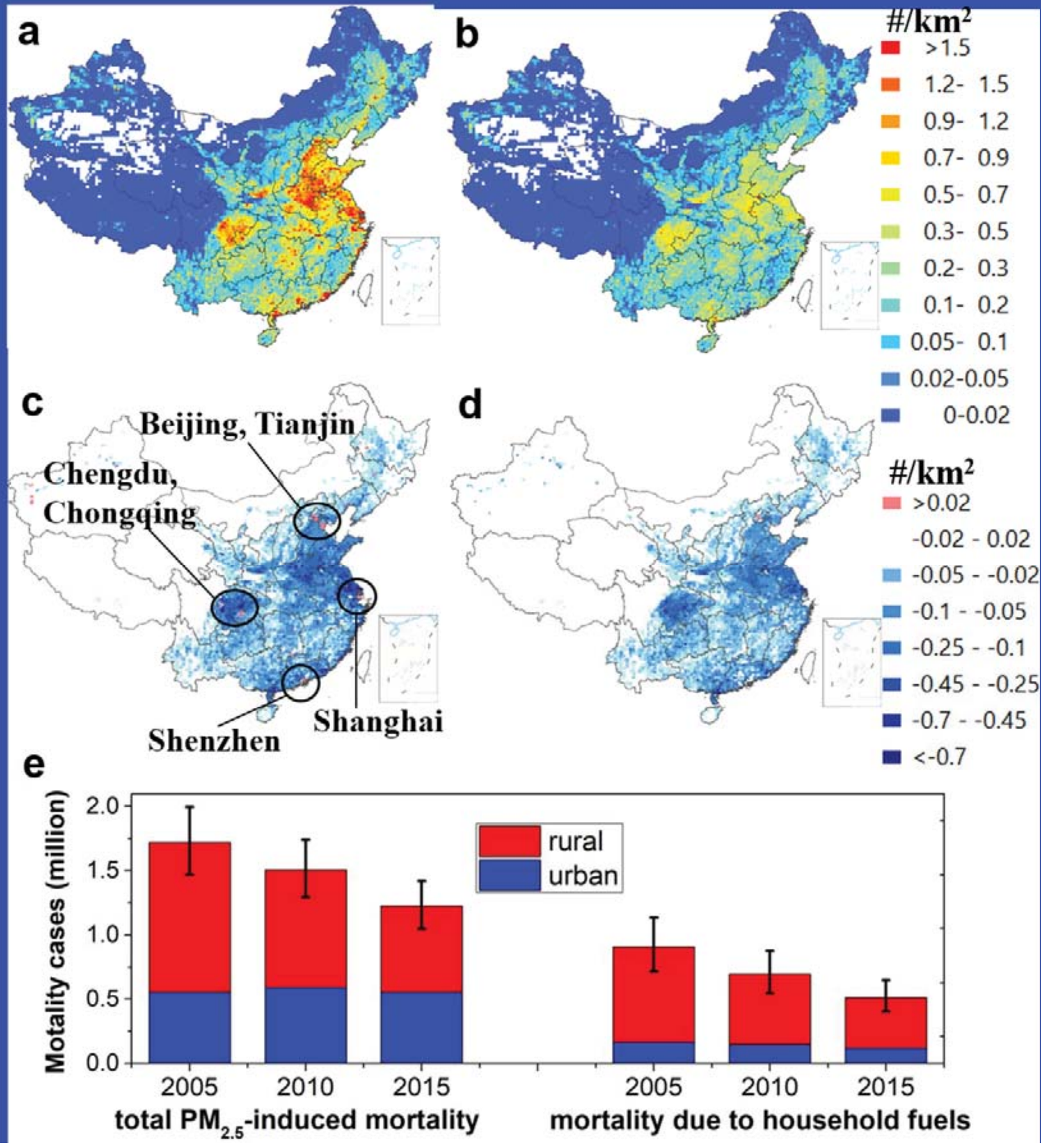

100%
80%
60%
40%
20%
0%
Percent
PM2.5
BC
OC
SO2
NOx
Beijing
Tianjin
Hebei
Annual
Jan-Feb
Transportation
Power
Industry
Residential

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]

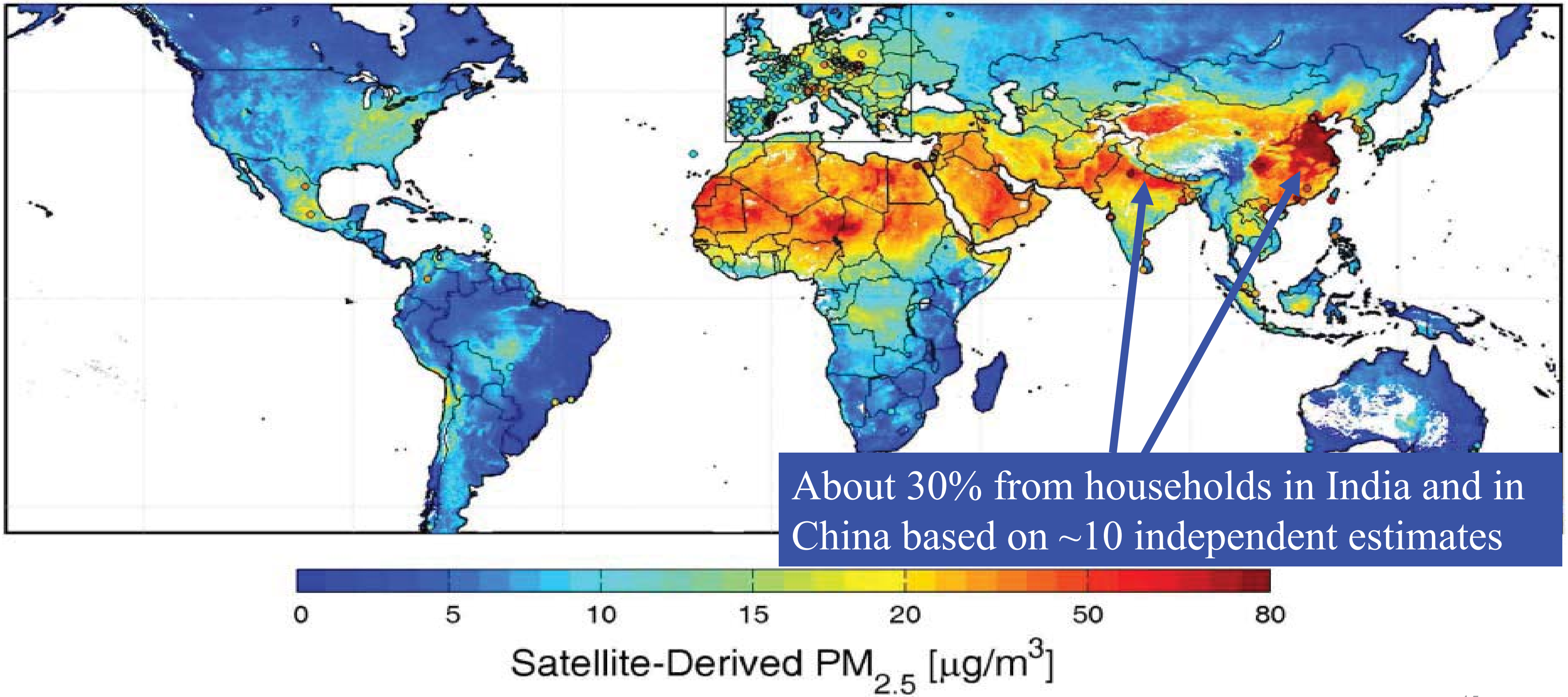
[1]School of Environment, and State Key Joint Laboratory of Environment Simulation and Pollution Control, Tsinghua University, Beijing 100084, China [2]Joint Institute for Regional Earth System Science and Engineering and Department of Atmospheric and Oceanic Sciences, University of California, Los Angeles, 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, Nov)



a
b
#/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
c
d
Beijing, Tianjin
Chengdu, Chongqing
Shanghai
Shenzhen
#/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
e
Motality cases (million)
rural
urban
2005
2010
2015
total PM2.5-induced mortality
mortality due to household fuels

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

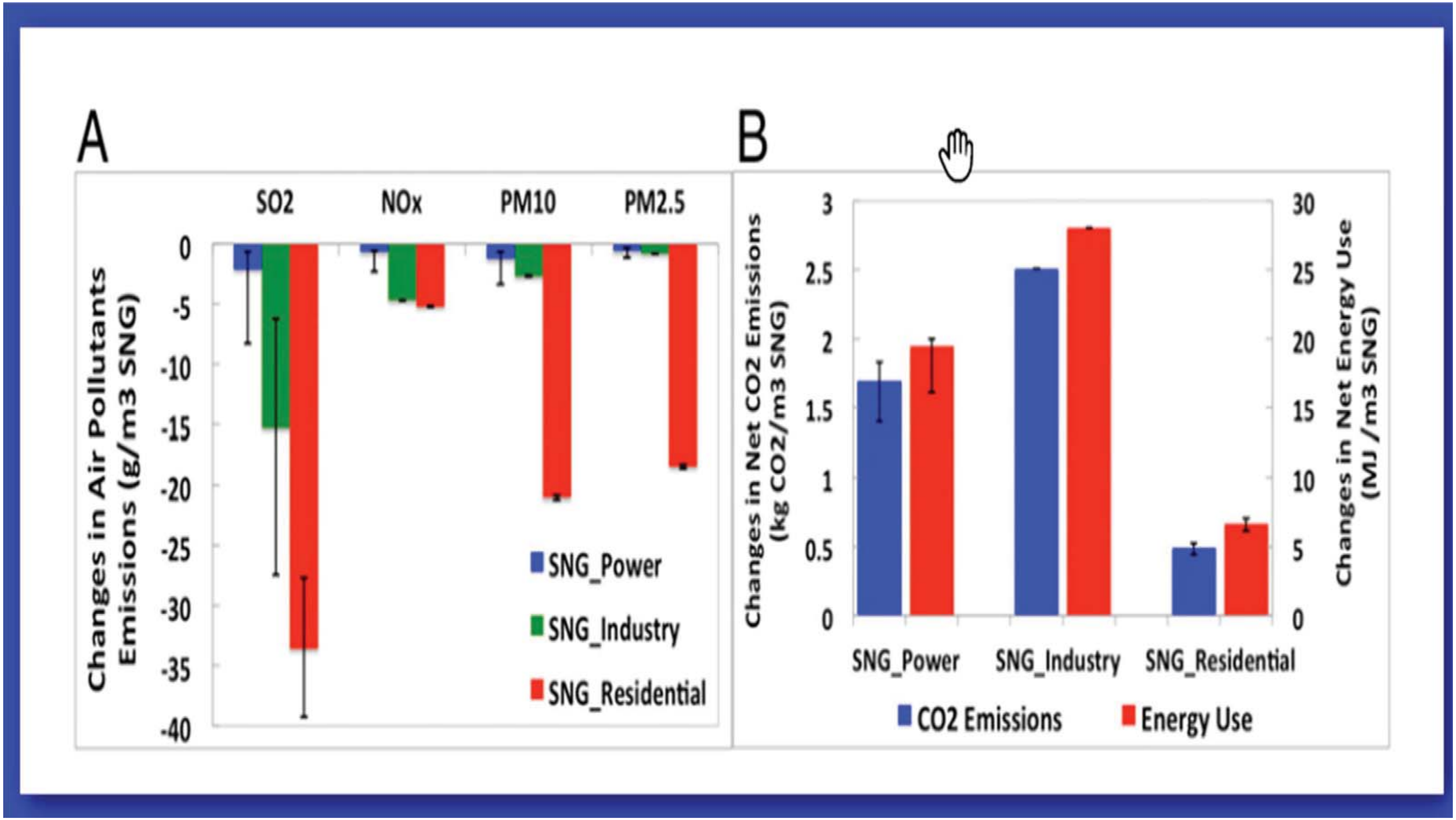
- Clean household fuels has become part of recent air pollution control policies in northern China – wide area around Beijing – BTH region
- With a requirement for 70-80% reduction in use of household solid fuels in three years – to gas and electricity
- 4 million households by 2017
- Should be part 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"

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

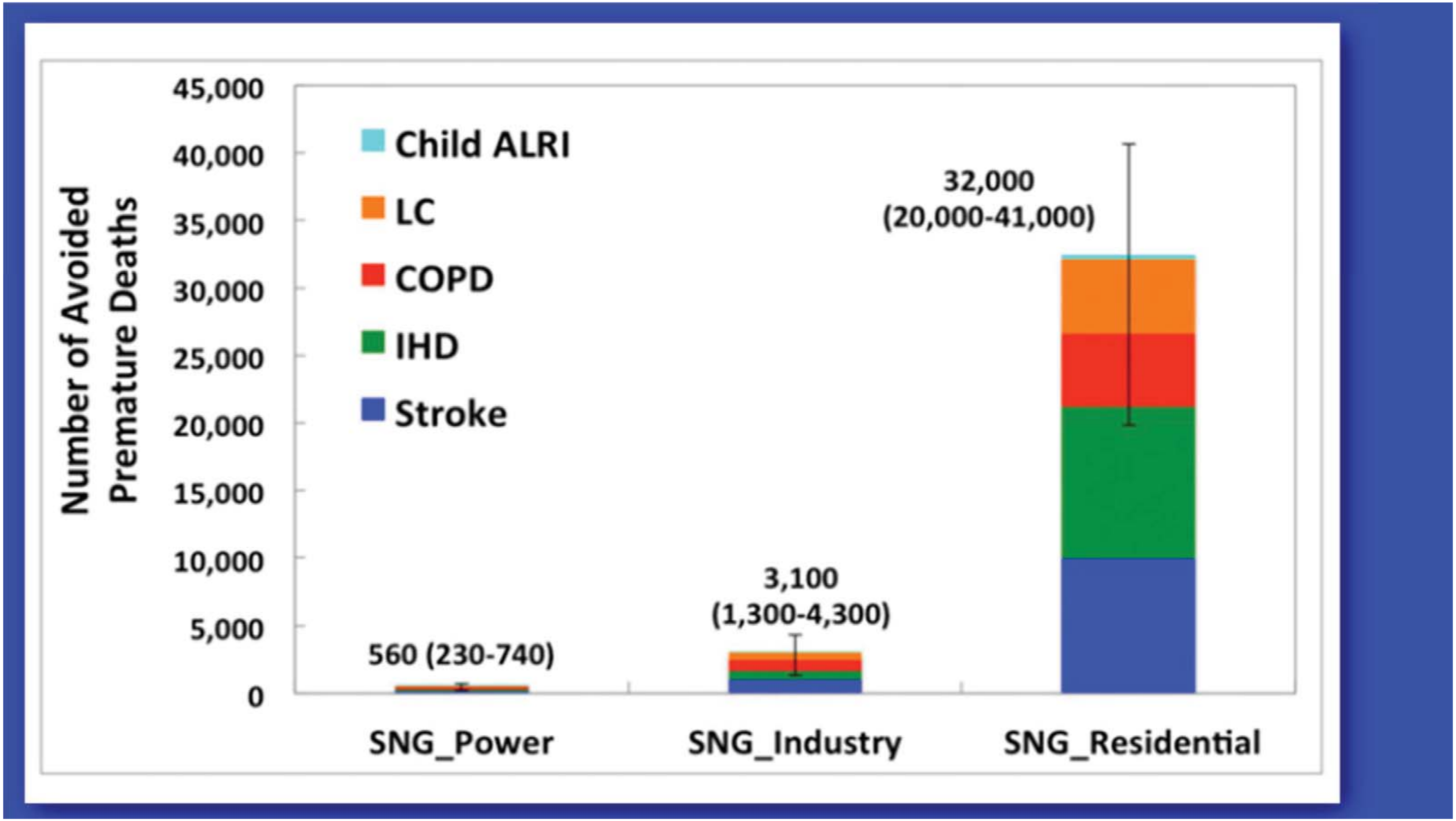
Yue Qin[a], Fabian Wagner[a,b,c], Noah Scovronick[a], Wei Peng[a,1], Junnan Yang[a], Tong Zhu[d,e], Kirk R. Smith[f,2], and Denise L. Mauzerall[a,g,2]

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

$IPWE = \mathrm{PWE}_{\mathrm{AAP}} + \mathrm{PWE}_{\mathrm{HAP}}$

where $\mathrm{PWE}_{\mathrm{AAP}}$ is the population-weighted exposure to AAP and $\mathrm{PWE}_{\mathrm{HAP}}$ is the additional population-weighted exposure to HAP. (excluding any contribution from AAP)

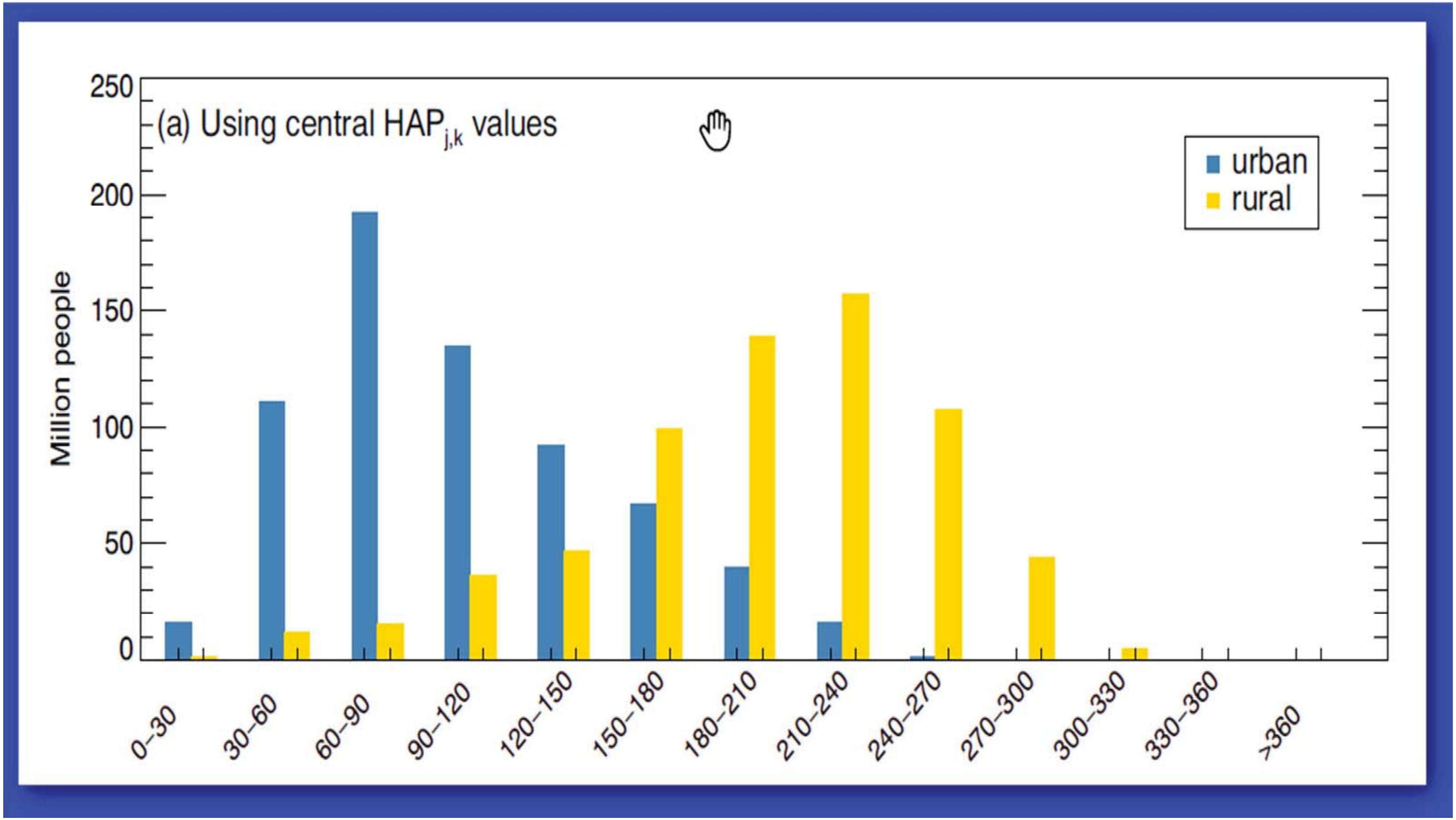
$$PWE_{AAP} = \frac{1}{P} \sum_{i} (P_i \cdot C_i)$$

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

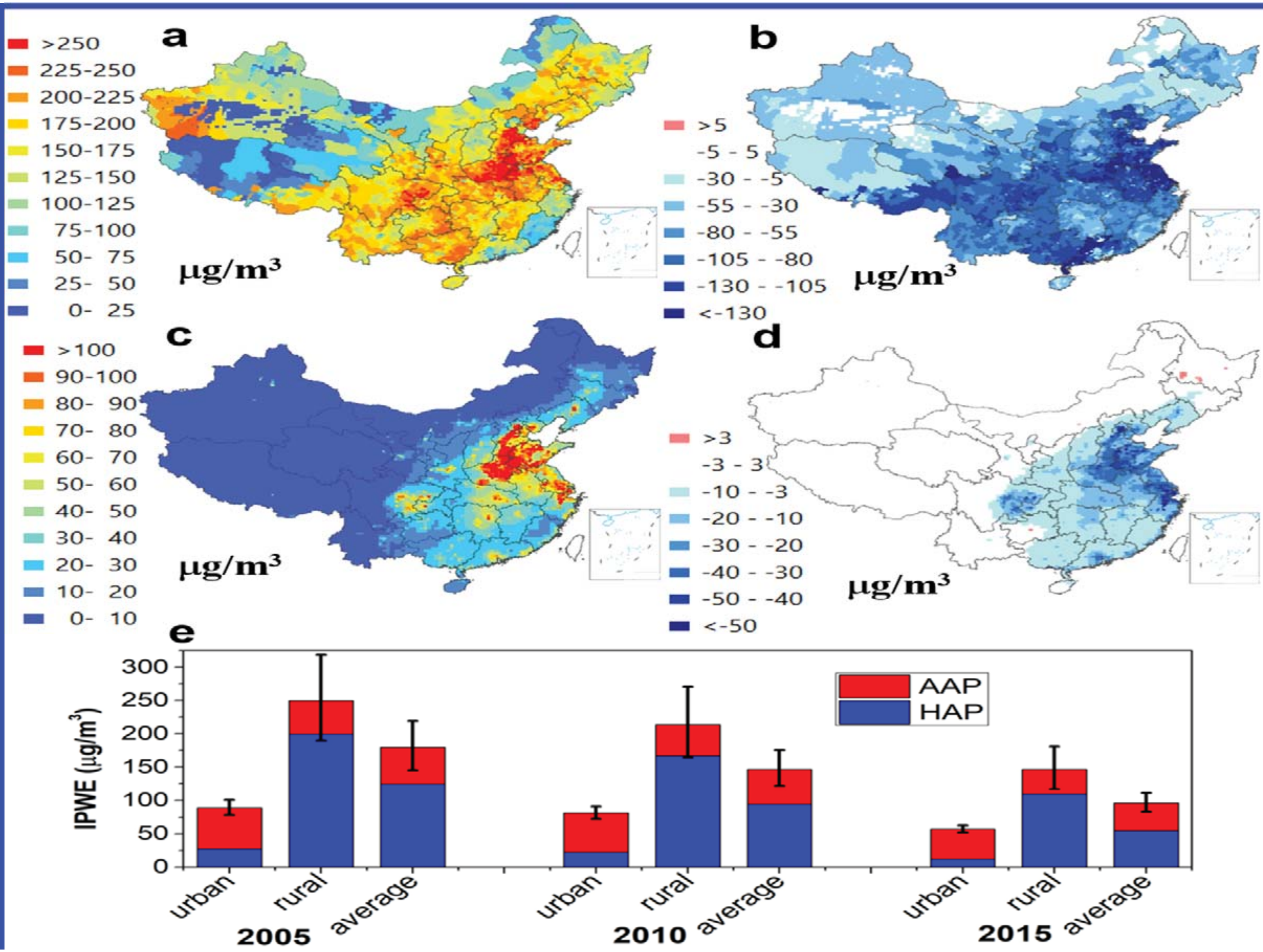
i = county

j = urban/rural

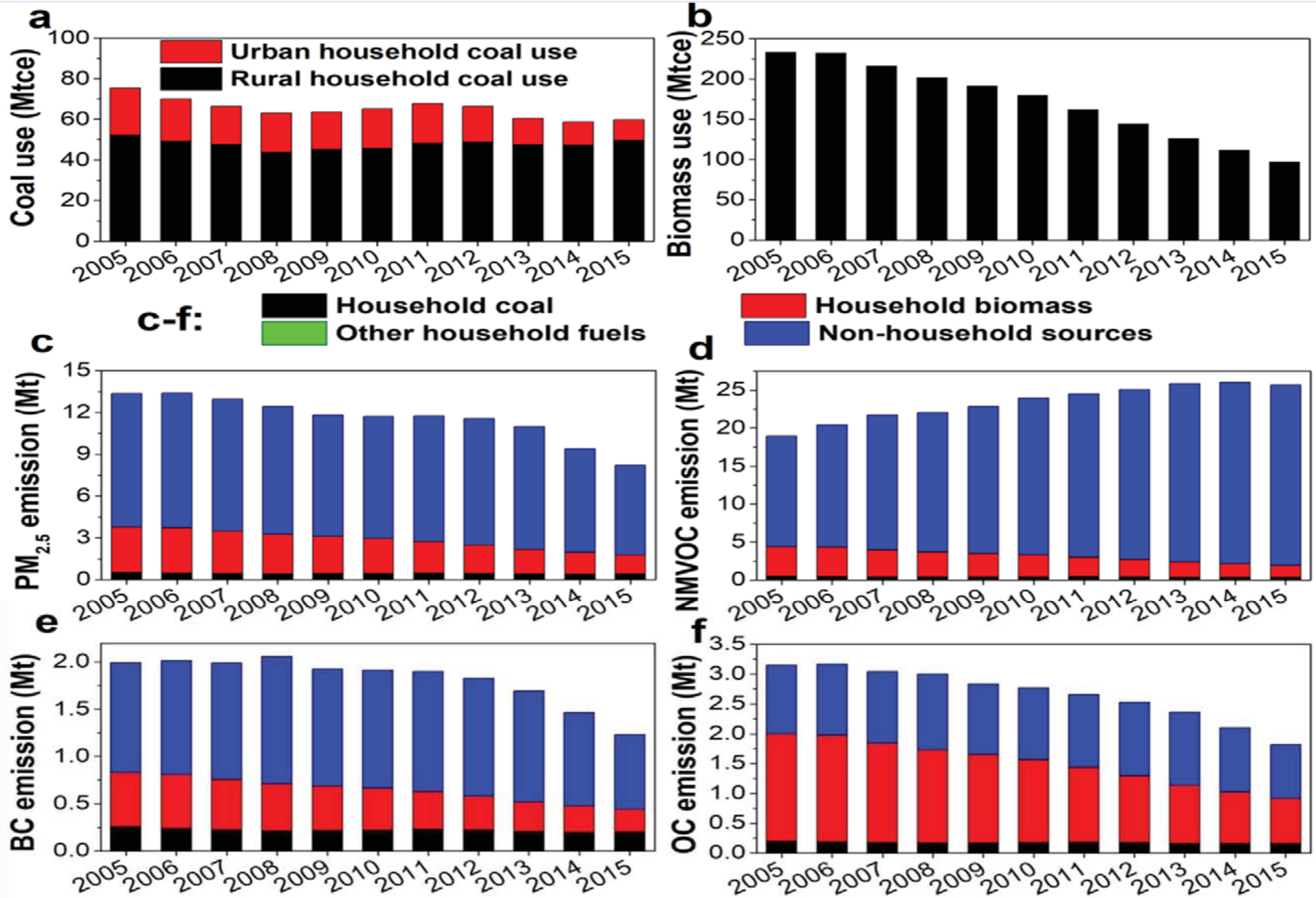
k – fuel type



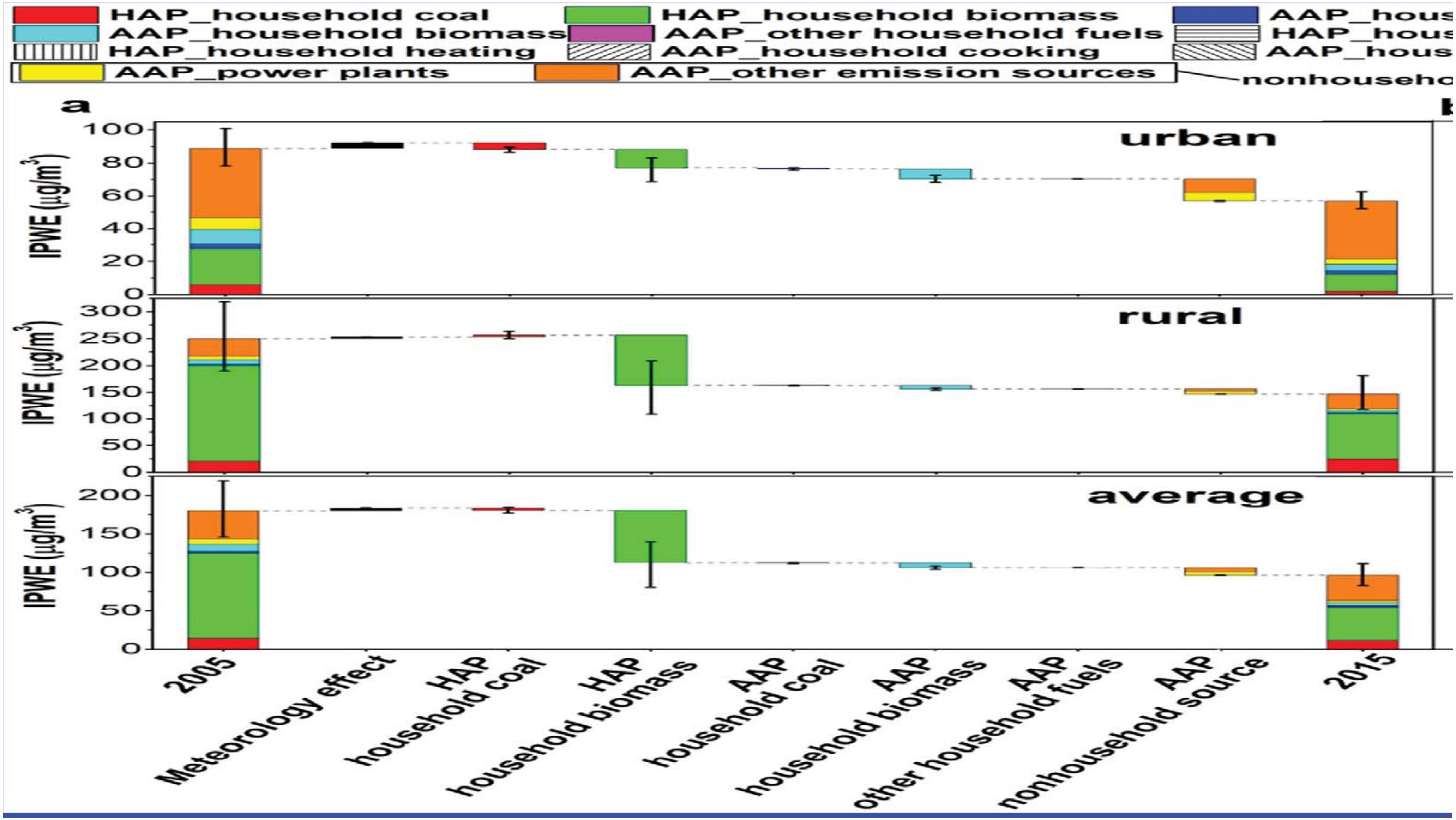
(a) Using central $HAP_{j,k}$ values
urban
rural
Million people
0
50
100
150
200
250
0–30
30–60
60–90
90–120
120–150
150–180
180–210
210–240
240–270
270–300
300–330
330–360
>360

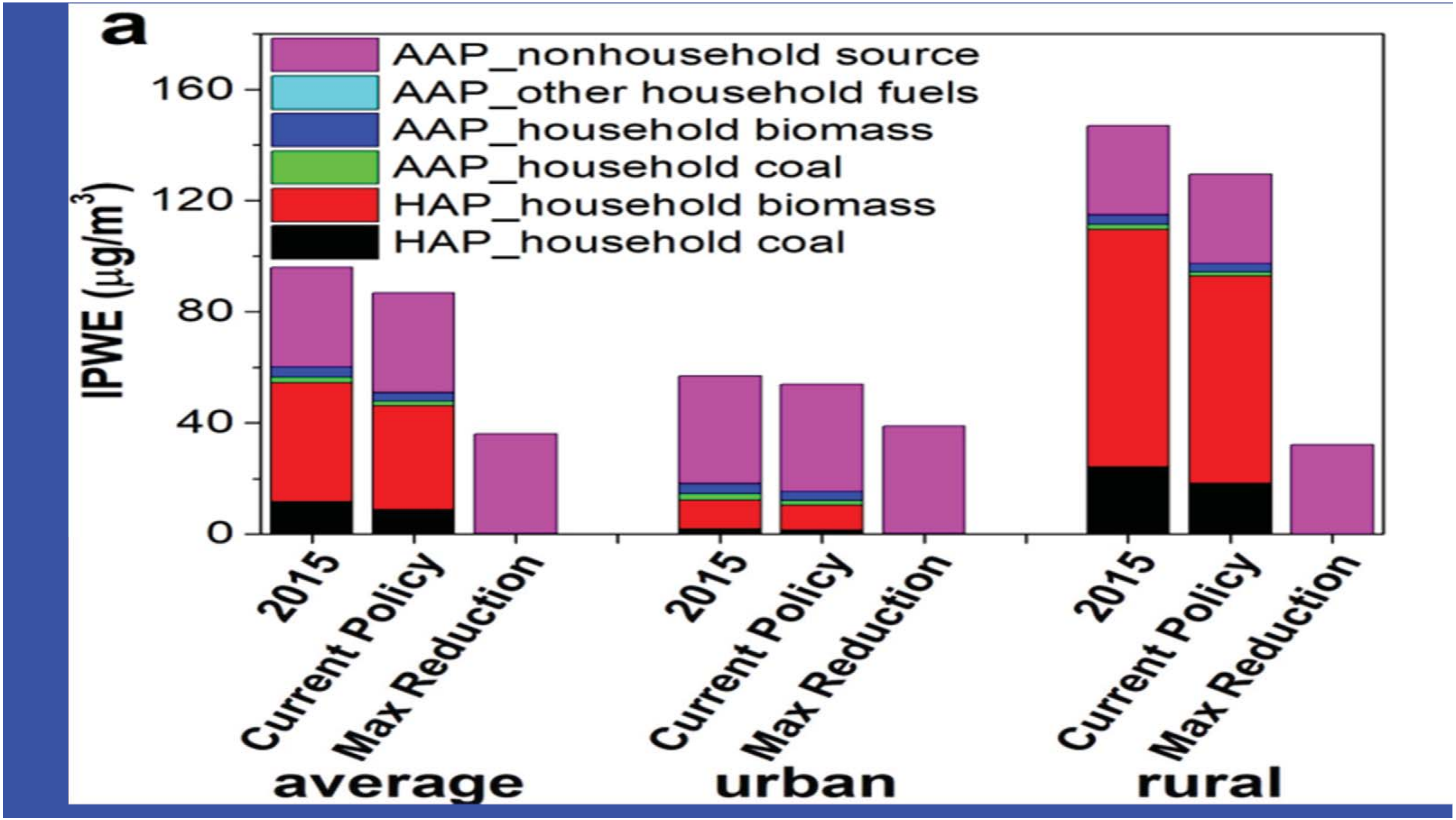


a
>250
225-250
200-225
175-200
150-175
125-150
100-125
75-100
50- 75
25- 50
0- 25
μg/m³
b
>5
-5 - 5
-30 - -5
-55 - -30
-80 - -55
-105 - -80
-130 - -105
<-130
μg/m³
c
>100
90-100
80- 90
70- 80
60- 70
50- 60
40- 50
30- 40
20- 30
10- 20
0- 10
μg/m³
d
>3
-3 - 3
-10 - -3
-20 - -10
-30 - -20
-40 - -30
-50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

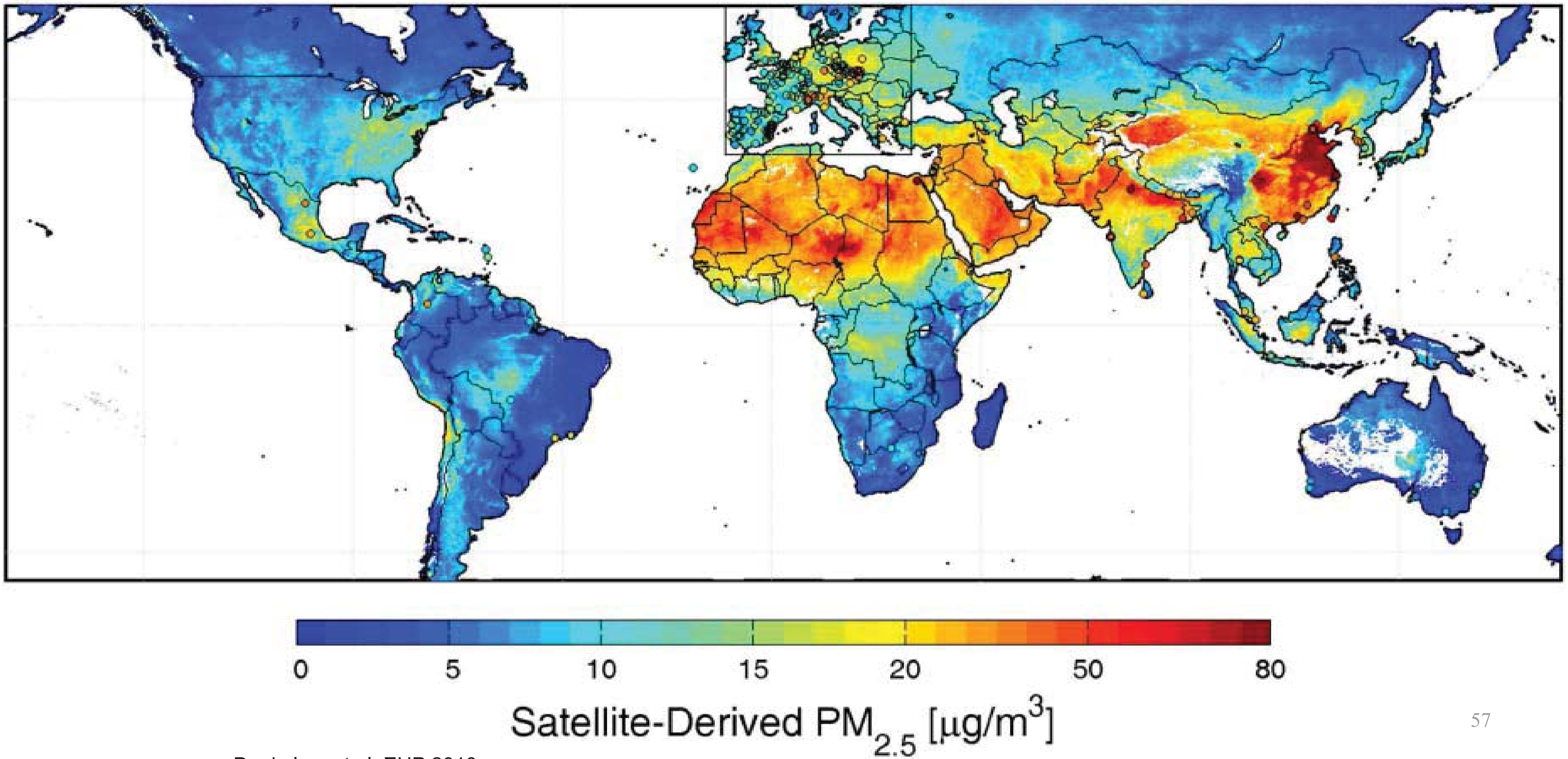


a
Urban household coal use
Rural household coal use
Coal use (Mtce)
b
Biomass use (Mtce)
c-f:
Household coal
Other household fuels
Household biomass
Non-household sources
c
PM2.5 emission (Mt)
d
NMVOC emission (Mt)
e
BC emission (Mt)
f
OC emission (Mt)


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
b
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
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

Formaldehyde in California in early 2000s

- Wallboard and similar indoor products were producing large human exposures to this carcinogen
- California Air Resources Board requested, but was denied authority to control indoor air pollution
  - Due to consumer-product and tobacco industry opposition
- The CARB staff, therefore, wrote control regulations based on ambient emissions
- Was not the right framing, but did the job

Formaldehyde in California: 2007*

- "Current annual average concentrations of formaldehyde in ambient air range from 3 to 4 μg/m3 across California, with indoor and in-vehicle concentrations typically many times higher."
- "The risk from exposure to annual average concentrations of formaldehyde in ambient air is about 20 to 24 potential excess cancer cases per year."

*PROPOSED AIRBORNE TOXIC CONTROL MEASURE TO REDUCE FORMALDEHYDE EMISSIONS FROM COMPOSITE WOOD PRODUCTS, CARB, Sacramento, March 9, 2007

Formaldehyde, Cont.

- "Within the category of area-wide sources, formaldehyde emissions from (various indoor products) in California are estimated to be about 900 tons per year."
- "The (proposed standard) would reduce emissions of formaldehyde by about 57%."
- <u>Health benefit from reduction in outdoor air, however, is less than 10% of the total benefit in lower cancer risk with a total exposure approach, which is dominated by indoor exposures.</u>

Formaldehyde in California – Concentration versus Exposure

A. Mean Exposure Scenario -- Adult			
Place	Time (hr/d)	Concentration (ug/m3)	Weighted Exposure
Indoor	20.82	17.2	358.1
In-vehicle	1.71	9.6	16.4
Outdoor	1.47	3.7	5.4
Total	24	-----	379.9
			15.8 μg/m^3

Strategies

- Type I: Ignore impact on ambient air, but get rid of indoor exposures from solid fuel – India
- Type II: Ignore impact on indoor exposures, but eliminate solid fuels to help control ambient air – China
- Type III: Use jurisdiction over ambient air to control indoor exposures – California