# Health effects of household and ambient air pollution: How was it determined for Ulaanbaatar under alternative policy pathways?

Prof Kirk R. Smith, UC Berkeley with a
US and Mongolian Research Team

**Workshop on Accelerating Clean Heating and Cooking Access**

**Tsinghua/ADB, Beijing**

**Jan 29, 2018**

Report of the Project:

**Impact of Urban Air Pollution on Public Health**

For the Ministry of Environment and Green Development, Ulaanbaatar

# A US/Mongolia Collaboration

University of California, Berkeley

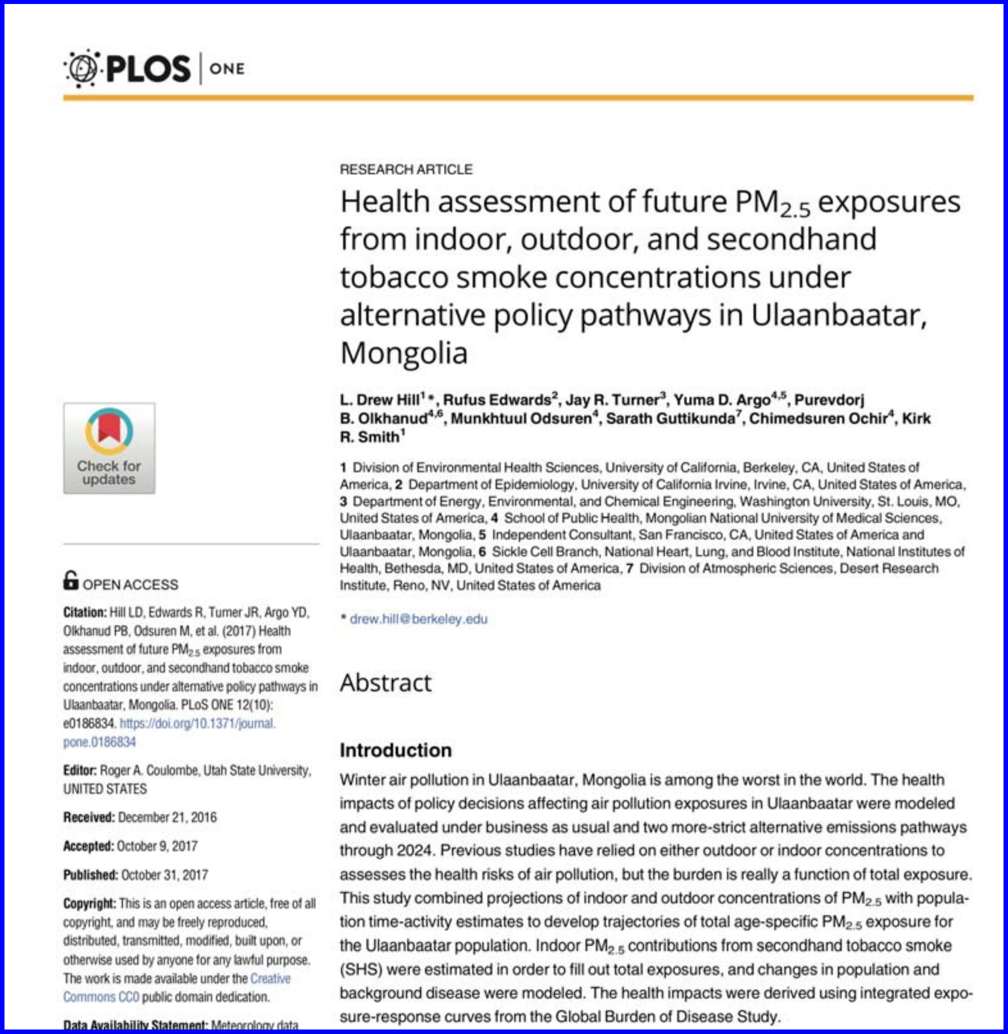
University of California, Irvine

Washington University in St. Louis

Mongolia National University of Medical Sciences

National Institutes of Health

Desert Research Institute



PLOS | ONE

RESEARCH ARTICLE

## Health assessment of future $PM_{2.5}$ exposures from indoor, outdoor, and secondhand tobacco smoke concentrations under alternative policy pathways in Ulaanbaatar, Mongolia

L. Drew Hill[1] *, Rufus Edwards[2], Jay R. Turner[3], Yuma D. Argo[4,5], Purevdorj B. Olkhanud[4,6], Munkhtuul Odsuren[4], Sarath Guttikunda[7], Chimedsuren Ochir[4], Kirk R. Smith[1]

1 Division of Environmental Health Sciences, University of California, Berkeley, CA, United States of America, 2 Department of Epidemiology, University of California Irvine, Irvine, CA, United States of America, 3 Department of Energy, Environmental, and Chemical Engineering, Washington University, St. Louis, MO, United States of America, 4 School of Public Health, Mongolian National University of Medical Sciences, Ulaanbaatar, Mongolia, 5 Independent Consultant, San Francisco, CA, United States of America and Ulaanbaatar, Mongolia, 6 Sickle Cell Branch, National Heart, Lung, and Blood Institute, National Institutes of Health, Bethesda, MD, United States of America, 7 Division of Atmospheric Sciences, Desert Research Institute, Reno, NV, United States of America

* drew.hill@berkeley.edu

Check for updates

OPEN ACCESS

**Citation:** Hill LD, Edwards R, Turner JR, Argo YD, Olkhanud PB, Odsuren M, et al. (2017) Health assessment of future $PM_{2.5}$ exposures from indoor, outdoor, and secondhand tobacco smoke concentrations under alternative policy pathways in Ulaanbaatar, Mongolia. PLoS ONE 12(10): e0186834. https://doi.org/10.1371/journal.pone.0186834

**Editor:** Roger A. Coulombe, Utah State University, UNITED STATES

**Received:** December 21, 2016

**Accepted:** October 9, 2017

**Published:** October 31, 2017



**Data Availability Statement:** Meteorology data

### Abstract

#### Introduction

Winter air pollution in Ulaanbaatar, Mongolia is among the worst in the world. The health impacts of policy decisions affecting air pollution exposures in Ulaanbaatar were modeled and evaluated under business as usual and two more-strict alternative emissions pathways through 2024. Previous studies have relied on either outdoor or indoor concentrations to assesses the health risks of air pollution, but the burden is really a function of total exposure. This study combined projections of indoor and outdoor concentrations of $PM_{2.5}$ with population time-activity estimates to develop trajectories of total age-specific $PM_{2.5}$ exposure for the Ulaanbaatar population. Indoor $PM_{2.5}$ contributions from secondhand tobacco smoke (SHS) were estimated in order to fill out total exposures, and changes in population and background disease were modeled. The health impacts were derived using integrated exposure-response curves from the Global Burden of Disease Study.

Hill et al Oct 2017, PLOSOne

# Study objectives

- Develop 3 emissions policy pathways for Ulaanbaatar (UB), 2014-2024
  1. Business as usual, or BAU: no major changes from 2013 emissions trends
  2. Pathway 1: moderate emissions reductions
  3. Pathway 2: major but feasible emissions reductions
- Estimate demographics and background disease values, 2014-2024
  - Diseases considered: stroke, lung cancer, ischemic heart disease, chronic obstructive pulmonary disease, and acute lower respiratory illness in children
- Estimate UB-wide $PM_{2.5}$ exposures under each pathway
- Convert exposures into estimates of health effects

Findings from Hill et al 2017

# Summary of key baseline and pathway features

| 2014 | 2024 | | |
|---|---|---|---|
| Baseline | Business as Usual (BAU) | Pathway 1 | Pathway 2 |
| • "Clean indoor" heat in apartments<br>  ◦ assumes no indoor emissions<br>• Some heat-only boilers (HOB)<br>• Houses & ger heat with "improved" MCA stove or similar (e.g. low pressure boiler, [LPB])<br>• 4 combined heat & power plants (CHP)<br>• Nearly 100% growth in traffic from 2010 values | • Not much change from home heating schema of 2014<br>• Add 1 CHP, meets US standards (NSPS)<br>• 2.5% traffic growth per year from 2014, Euro III emissions standards | • "Clean indoor" heat in many houses, all apartments<br>• 50% HOB retired, others retrofitted<br>• New "Future Tech" improved coal stove in many houses, all ger<br>• LPB still in some houses<br>• 4 CHP retrofitted<br>• Add 1 CHP at US NSPS<br>• Same traffic growth as BAU, Euro V standards | • **"Clean indoor" heat in all homes**<br>• All HOB retired<br>• 3 original CHP retrofitted<br>• Add 1 CHP at US NSPS<br>• 1 CHP replaced by renewables and/or imports<br>• 50% reduction in traffic emissions from Pathway 1 |

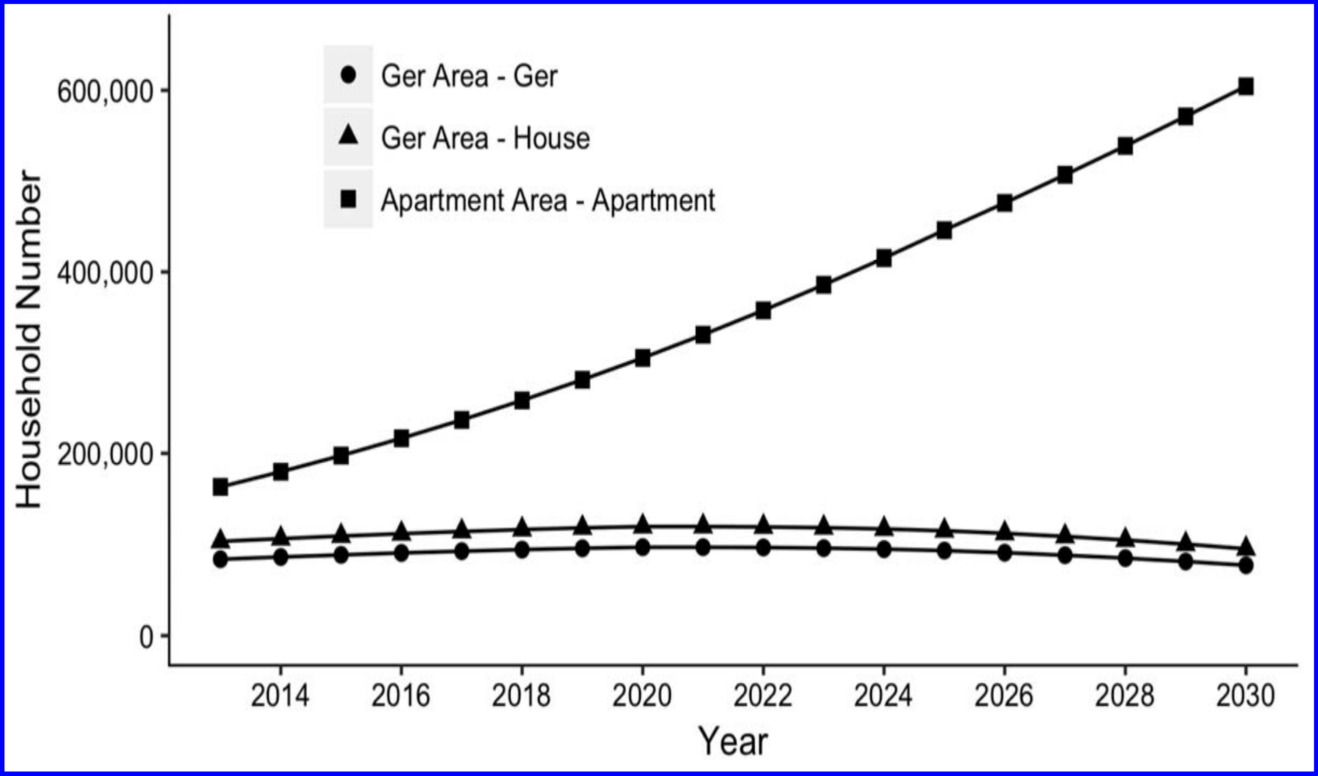
Adapted from Table 1, Hill et al 2017. Summary of the assumptions made for emissions sources, by category.

# Estimates of demographic and disease trends

Findings from Hill et al 2017

Anticipate major growth in total population and household number

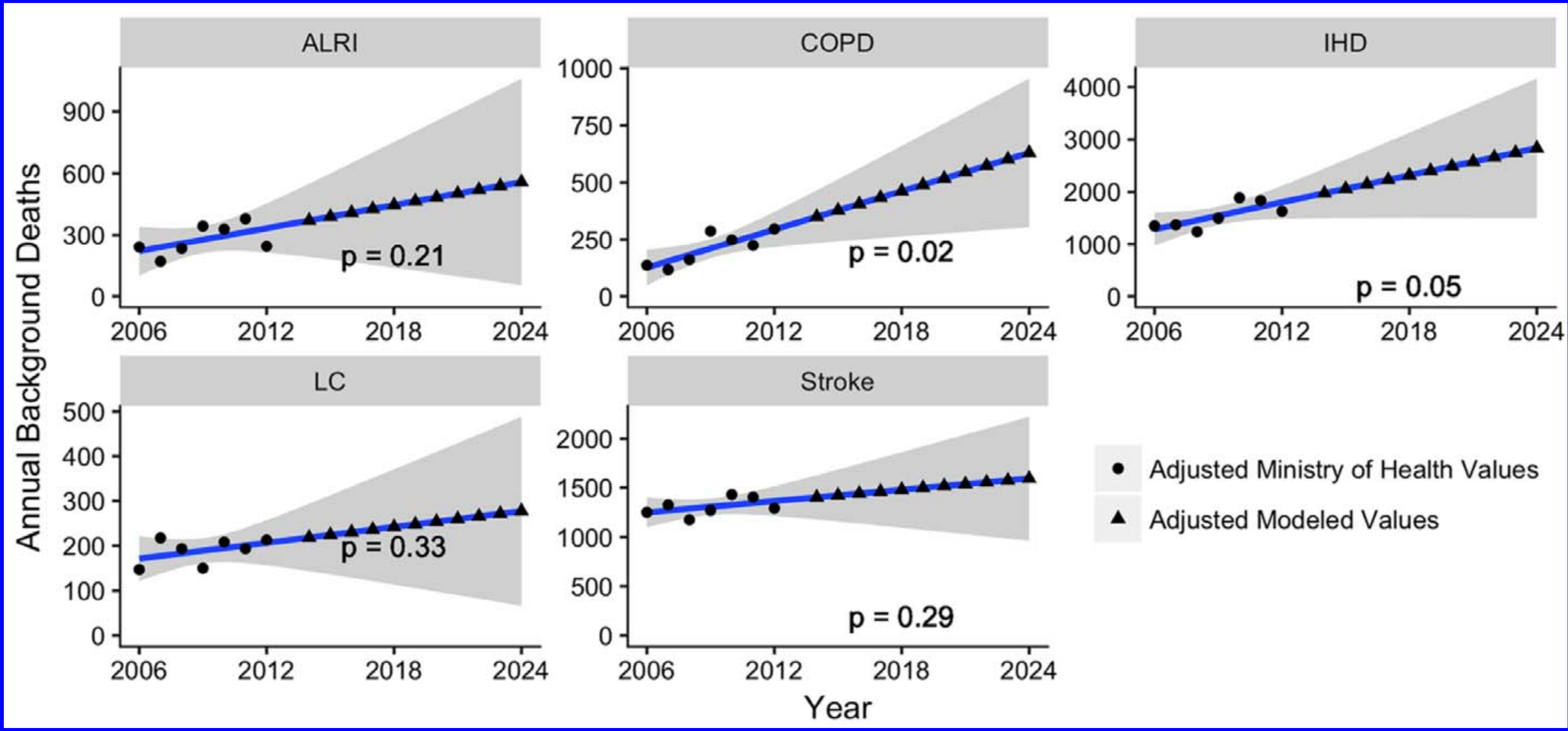
Expect increase in % population living in Apartments




*see manuscript for methods, data sources, assumptions*

Findings from Hill et al 2017

# Projected annual background mortality for 5 diseases




*see manuscript for methods, data sources, assumptions*

Findings from Hill et al 2017

# Key aspects of the exposure assessment

Findings from Hill et al 2017

# Total exposure approach

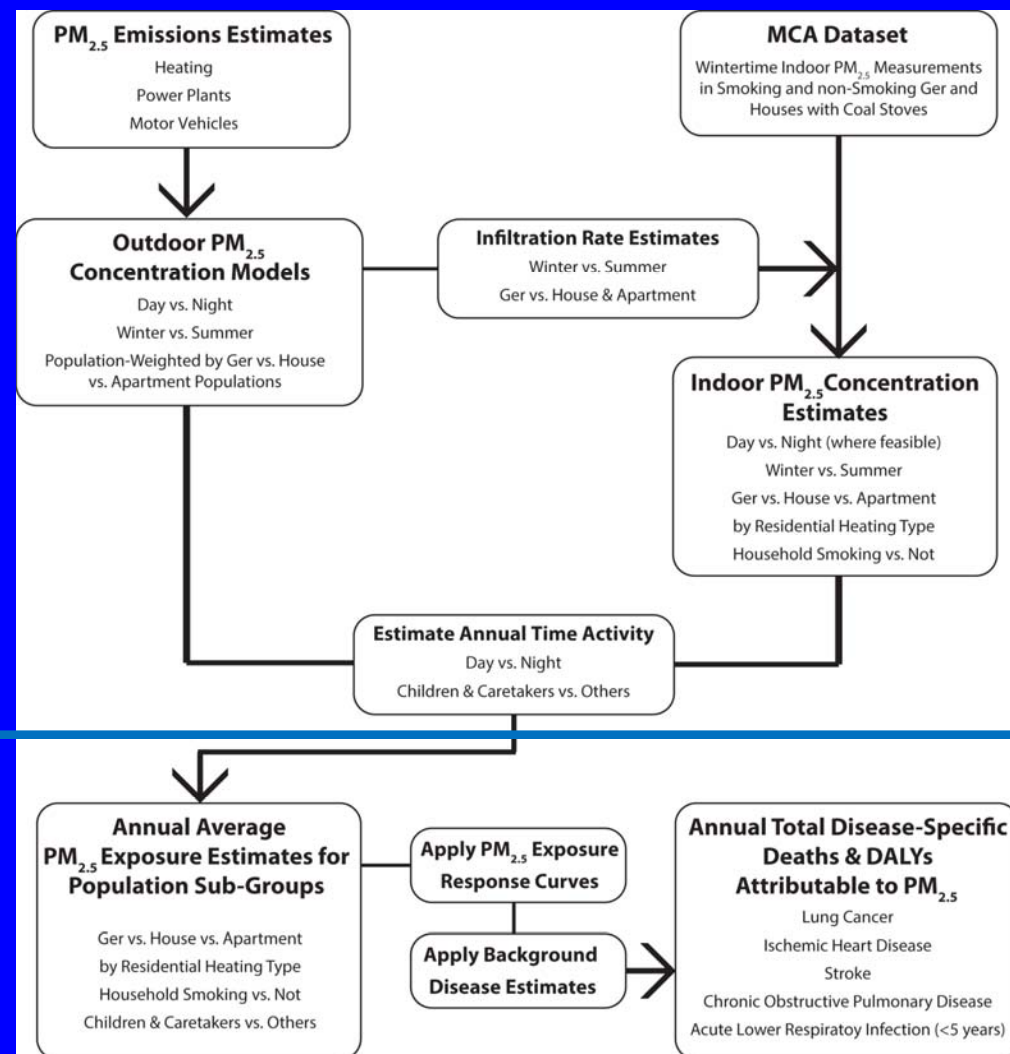
Combined:

- Modeled outdoor concentrations
- Indoor concentrations estimated by:
  - Home type
  - Home heating type
  - Presence of tobacco smoke (SHS)
- Estimated time activity values

Produced estimates of seasonal and annual average $PM_{2.5}$ exposures in UB

Findings from Hill et al 2017

Fig 1, Hill et al 2017. High-level flow chart of the general exposure and disease analysis approach.

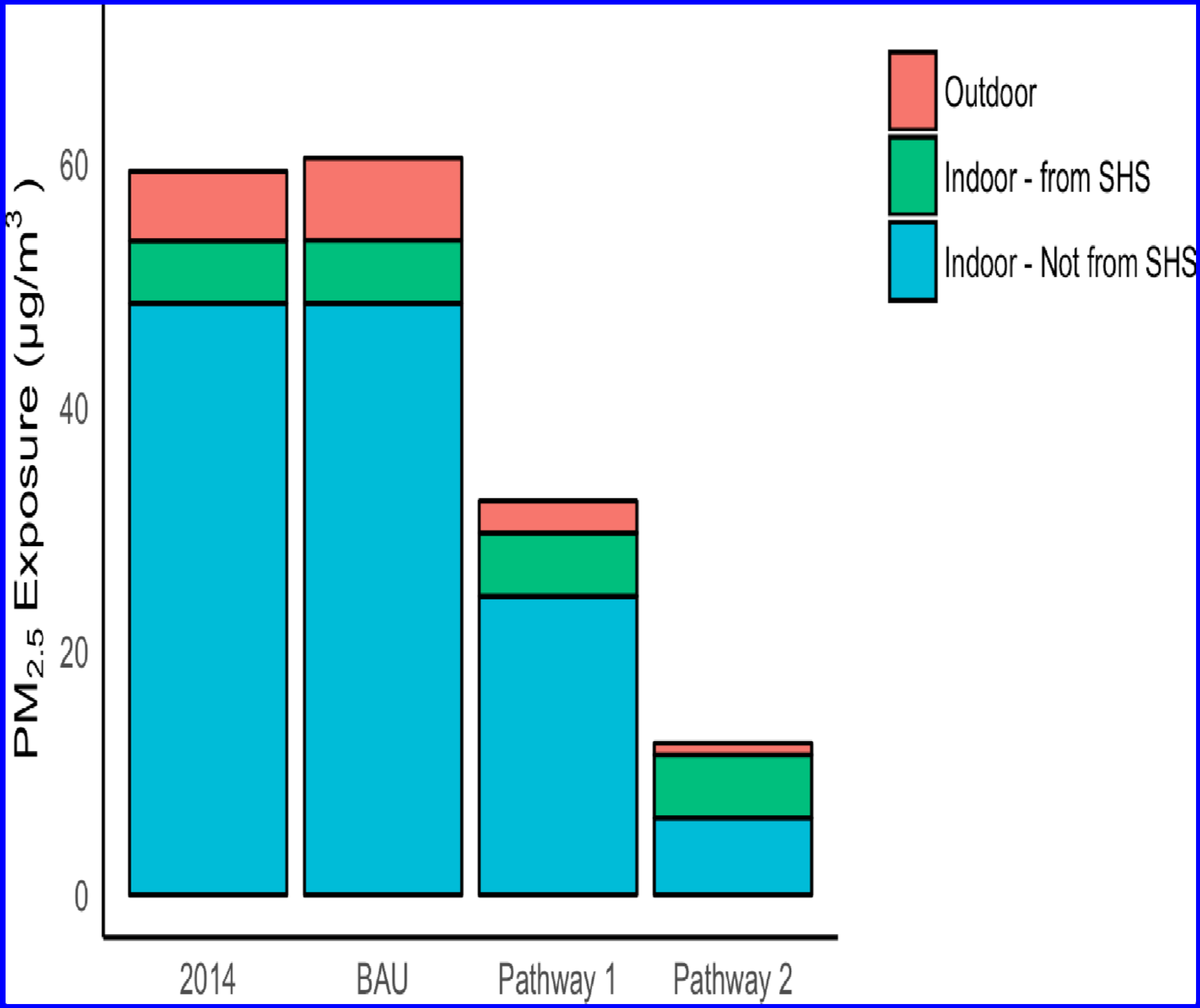


# Annual average $PM_{2.5}$ exposures in UB

**2014:** 59 µg/m³

**2024:**

- BAU: 60 µg/m³
- Pathway 1: 32 µg/m³
- Pathway 2: 12 µg/m³




Findings from Hill et al 2017

# Summary of $PM_{2.5}$- attributable health impact estimates

Findings from Hill et al 2017

# Metrics

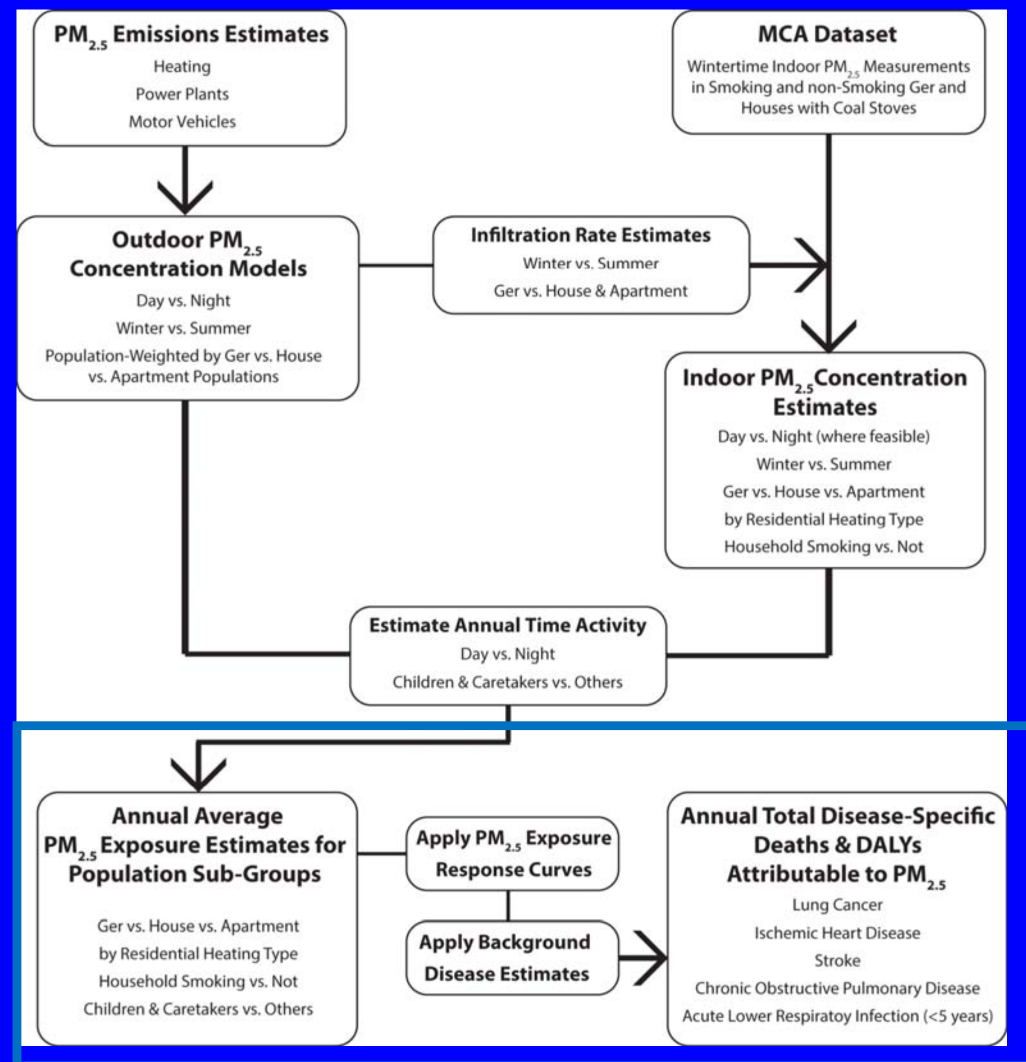
- Premature deaths due to air pollution caused diseases

- Disability Adjusted Life Years lost – DALYs
  - This metric is adjusted to account for the age of death and the severity of the illness even if not fatal
  - Important when adding together child and adult outcomes

# $PM_{2.5}$ attributable deaths and DALYs estimated from:

- Annual avg. UB exposure estimates
- $PM_{2.5}$ exposure-response curves used in the 2010 Global Burden of Disease study (Burnett et al 2014, Lim et al 2012)
  - Counterfactual (i.e. relative risk = 1) of **12.0 µg/m$^3$**
- Projected demographics and background total mortality for 5 diseases
- Disease-specific Death/DALY ratios for Mongolia in 2010 (Lim et al 2012)

Fig 1, Hill et al 2017. High-level flow chart of the general exposure and disease analysis approach.



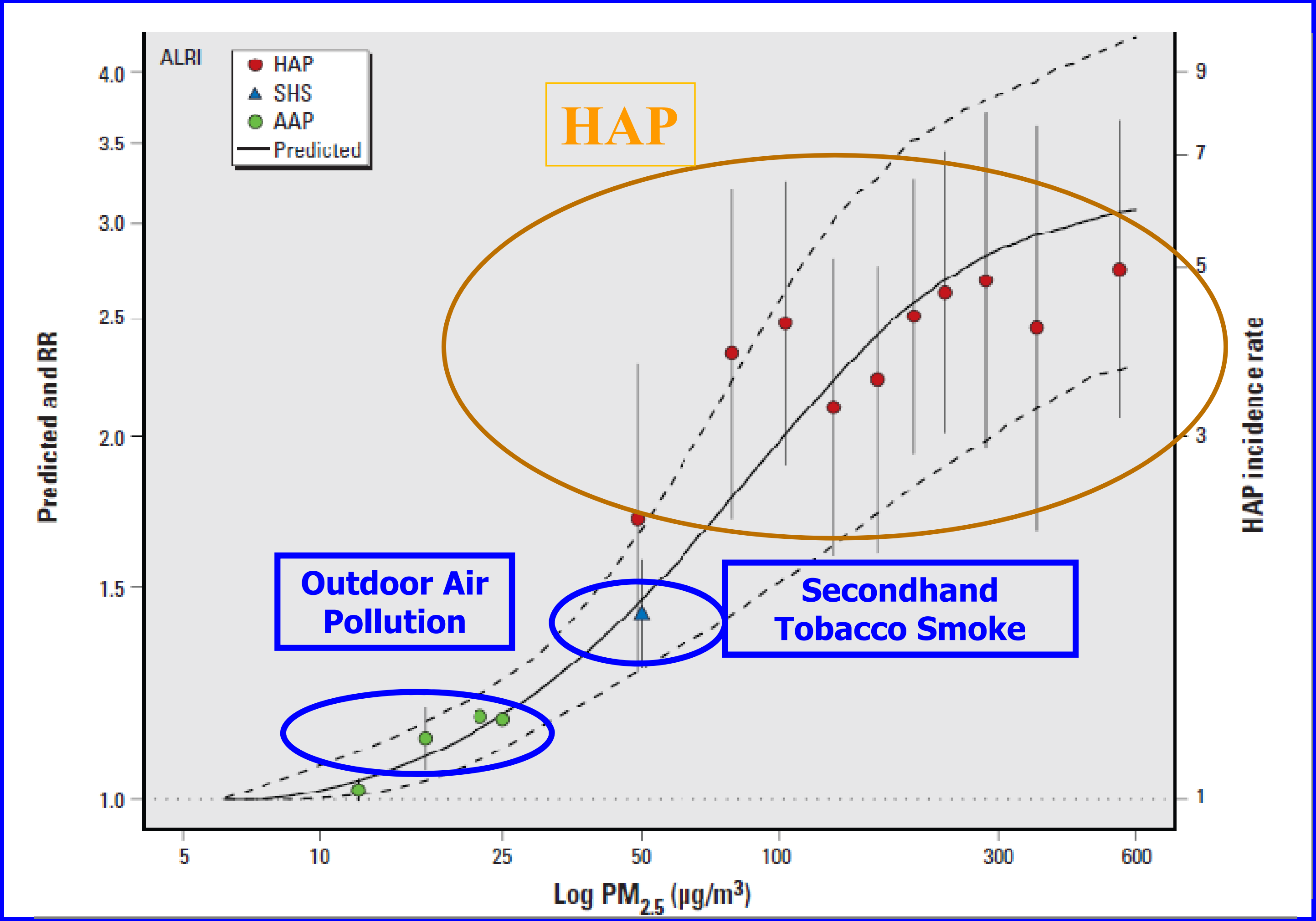

Findings from Hill et al 2017

Global Health Metrics

# Global, regional, and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016

GBD 2016 Risk Factors Collaborators*

*the Lancet*, Sep 16, 2017

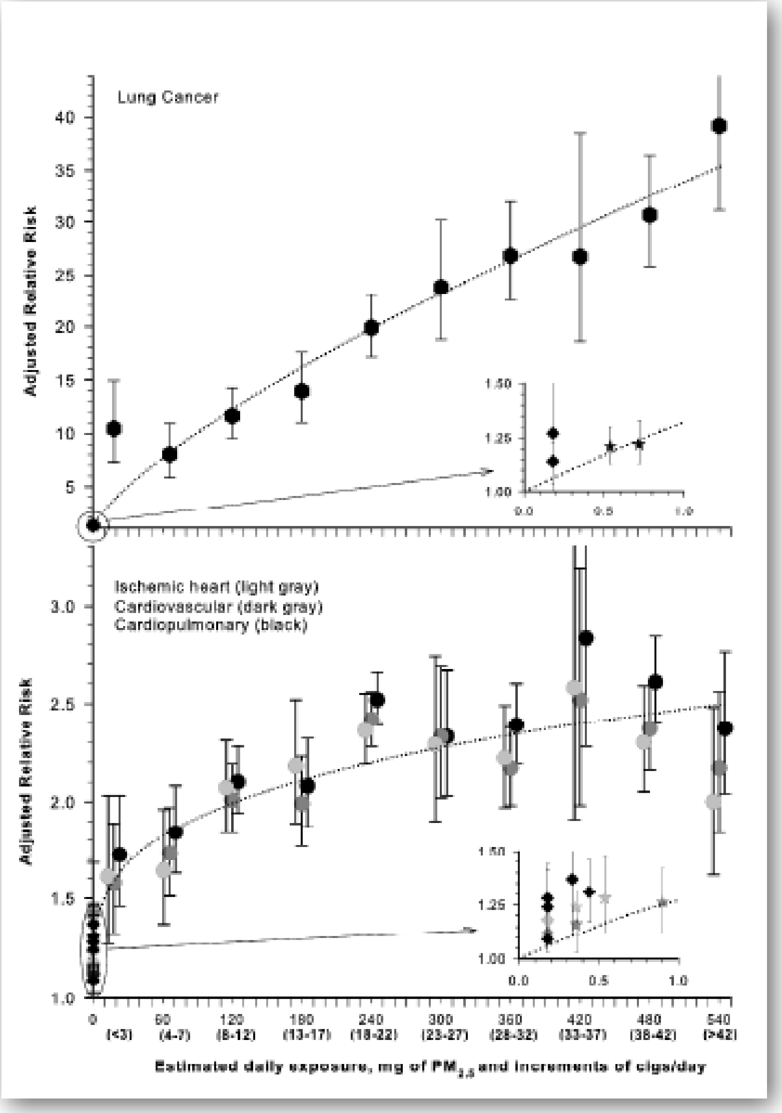



Burnett et al., EHP. 2014, Integrated Exposure-Response Functions

Table 2. Adjusted relative risk estimates[a] for various increments of exposure from cigarette smoking (versus never smokers), second hand cigarette smoke, and ambient air pollution from the present analysis and selected comparison studies.

| Source of risk estimate | Increments of Exposure | Adjusted RR (95% CI) | | | | Estimated Daily Dose $PM_{2.5}$ (mg)[b] |
|---|---|---|---|---|---|---|
| | | Lung Cancer | IHD | CVD | CPD | |
| ACS- present analysis | ≤3 (1.5) cigs/day | 10.44 (7.30-14.94) | 1.61 (1.27-2.03) | 1.58 (1.32-1.89) | 1.72 (1.46-2.03) | 18 |
| ACS- present analysis | 4-7 (5.5) cigs/day | 8.03 (5.89-10.96) | 1.64 (1.37-1.96) | 1.73 (1.51-1.97) | 1.84 (1.63-2.08) | 66 |
| ACS- present analysis | 8-12 (10) cigs/day | 11.63 (9.51-14.24) | 2.07 (1.84-2.31) | 2.01 (1.84-2.19) | 2.10 (1.94-2.28) | 120 |
| ACS- present analysis | 13-17 (15) cigs/day | 13.93 (11.04-17.58) | 2.18 (1.89-2.52) | 1.99 (1.77-2.23) | 2.08 (1.87-2.32) | 180 |
| ACS- present analysis | 18-22 (20) cigs/day | 19.88 (17.14-23.06) | 2.36 (2.19-2.55) | 2.42 (2.28-2.56) | 2.52 (2.39-2.66) | 240 |
| ACS- present analysis | 23-27 (25) cigs/day | 23.82 (18.80-30.18) | 2.29 (1.91-2.75) | 2.33 (2.02-2.69) | 2.33 (2.03-2.67) | 300 |
| ACS- present analysis | 28-32 (30) cigs/day | 26.82 (22.54-31.91) | 2.22 (1.97-2.49) | 2.17 (1.98-2.38) | 2.39 (2.19-2.60) | 360 |
| ACS- present analysis | 33-37 (35) cigs/day | 26.72 (18.58-38.44) | 2.58 (1.91-3.47) | 2.52 (1.98-3.19) | 2.83 (2.28-3.52) | 420 |
| ACS- present analysis | 38-42 (40) cigs/day | 30.63 (25.79-36.38) | 2.30 (2.05-2.59) | 2.37 (2.16-2.59) | 2.61 (2.40-2.84) | 480 |
| ACS- present analysis | 43+ (45) cigs/day | 39.16 (31.13-49.26) | 2.00 (1.62-2.48) | 2.17 (1.84-2.56) | 2.37 (2.04-2.76) | 540 |
| ACS-air pol. original | 24.5 $\mu g/m^3$ ambient $PM_{2.5}$ | ----- | ----- | ----- | 1.31(1.17-1.46) | 0.44 |
| ACS-air pol. extend. | 10 $\mu g/m^3$ ambient $PM_{2.5}$ | 1.14(1.04-1.23) | 1.18(1.14-1.23) | 1.12(1.08-1.15) | 1.09(1.03-1.16) | 0.18 |
| HSC-air pol. original | 18.6 $\mu g/m^3$ ambient $PM_{2.5}$ | ----- | ----- | ----- | 1.37(1.11-1.68) | 0.33 |
| HSC-air pol. extend. | 10 $\mu g/m^3$ ambient $PM_{2.5}$ | 1.21(0.92-1.69) | ----- | 1.28(1.13-1.44) | ----- | 0.18 |
| WHI-air pol. | 10 $\mu g/m^3$ ambient $PM_{2.5}$ | ----- | ----- | 1.24(1.09-1.41)[c] | ----- | 0.18 |
| SGR-SHS | Low- moderate SHS exp. | ----- | ----- | 1.16(1.03-1.32) | ----- | 0.36 |
| SGR-SHS | Moderate-high SHS exp | ----- | ----- | 1.26(1.12-1.42) | ----- | 0.90 |
| SGR-SHS | Live with smoking spouse | 1.21(1.13-1.30) | ----- | ----- | ----- | 0.54 |
| SGR-SHS | Work with SHS exposure | 1.22(1.13-1.33) | ----- | ----- | ----- | 0.72 |
| INTERHEART | 1-7 hrs/wk SHS exp. | ----- | 1.24(1.17-1.32)[d] | ----- | ----- | 0.36 |
| INTERHEART | Live with smoking spouse | ----- | 1.28(1.12-1.47)[d] | ----- | ----- | 0.54 |

Pope et al.
Environmental Health Perspectives
2011,

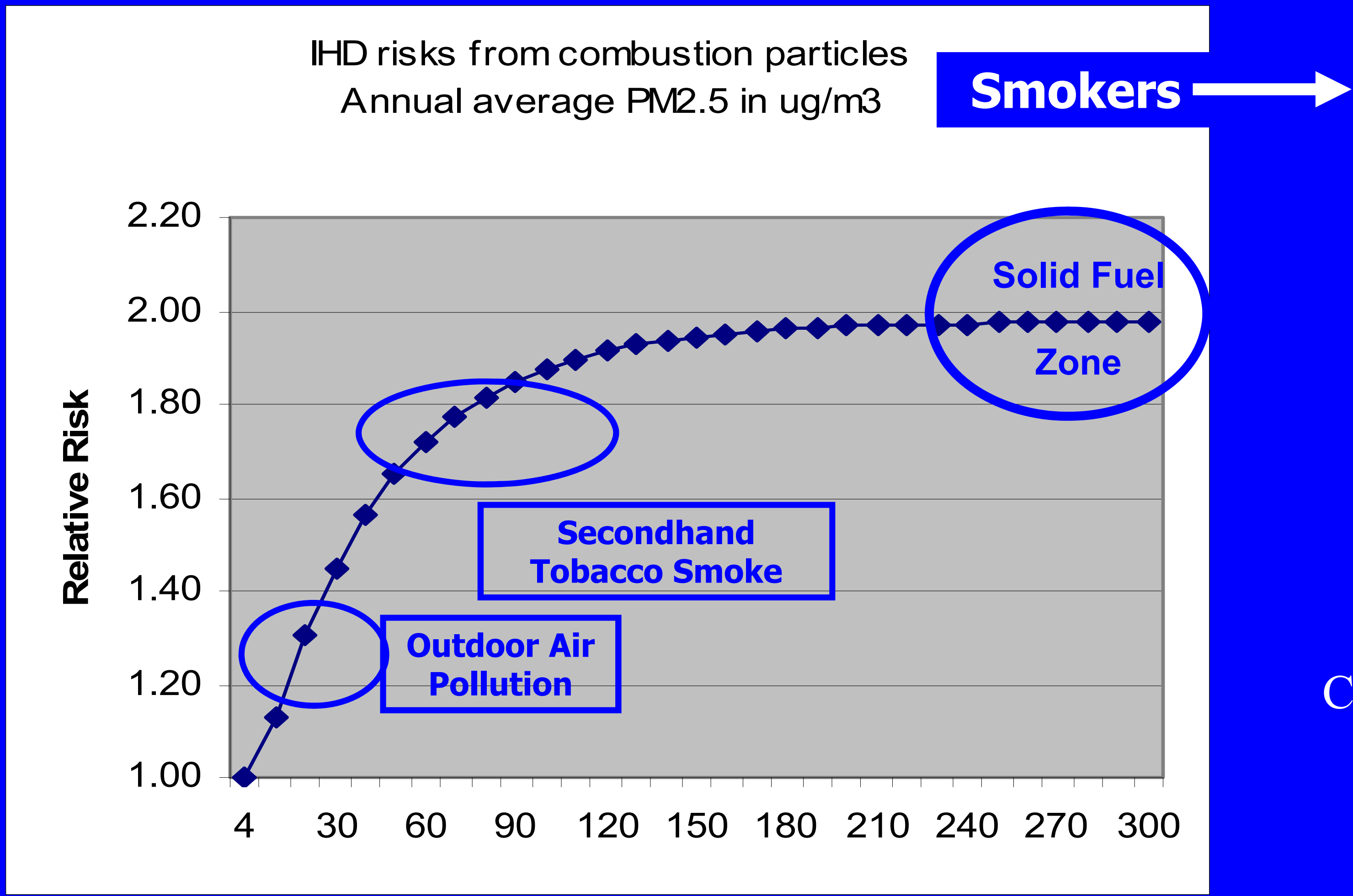



Lung Cancer

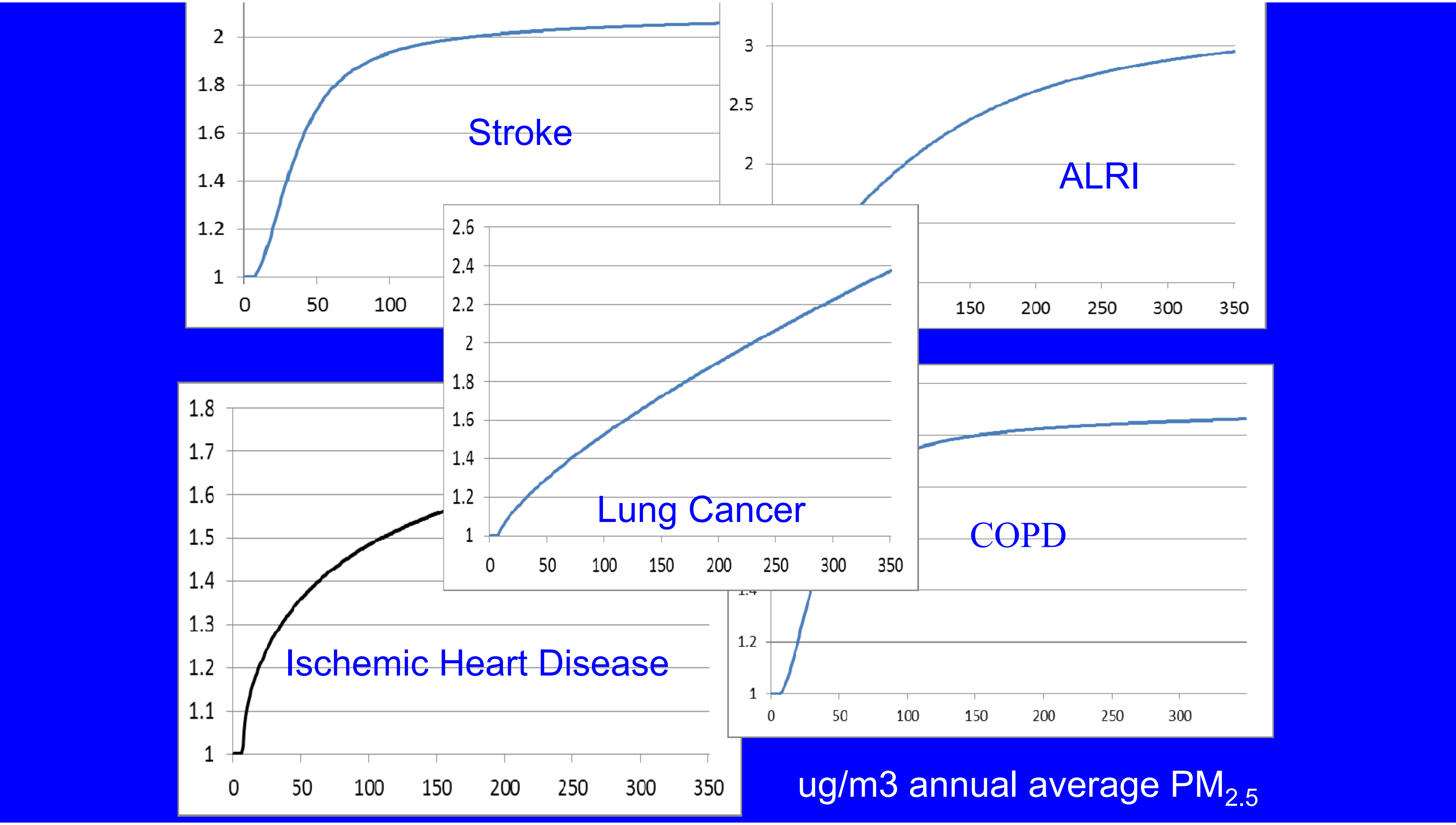
Heart Disease

Pope et al. Environmental Health Perspectives 2011,

# Generalized Exposure-Response: Outdoor Air, SHS, and Smoking




CRA/GBD


Stroke
ALRI
Lung Cancer
COPD
Ischemic Heart Disease
ug/m3 annual average PM2.5

# Estimated $PM_{2.5}$ health impacts

**At baseline, 2014**

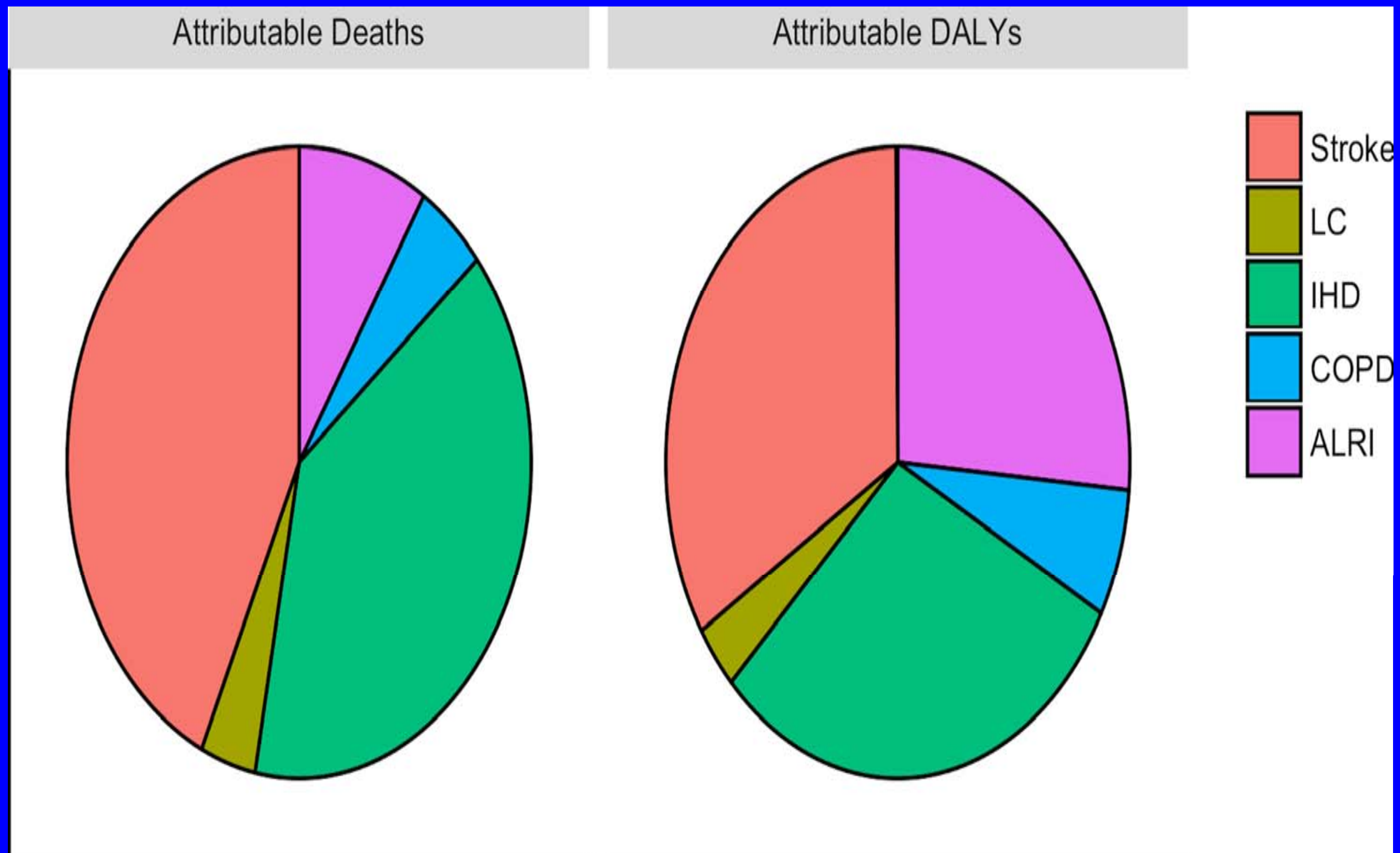
- 1,400 deaths
- 40,000 DALYs

**Deaths accrued, 2014 -24**

- BAU: 18,000
- Pathway 1: 14,000
- Pathway 2: 9,800

**DALYs accrued, 2014-24**

- BAU: 530,000
- Pathway 1: 420,000
- Pathway 2: 290,000

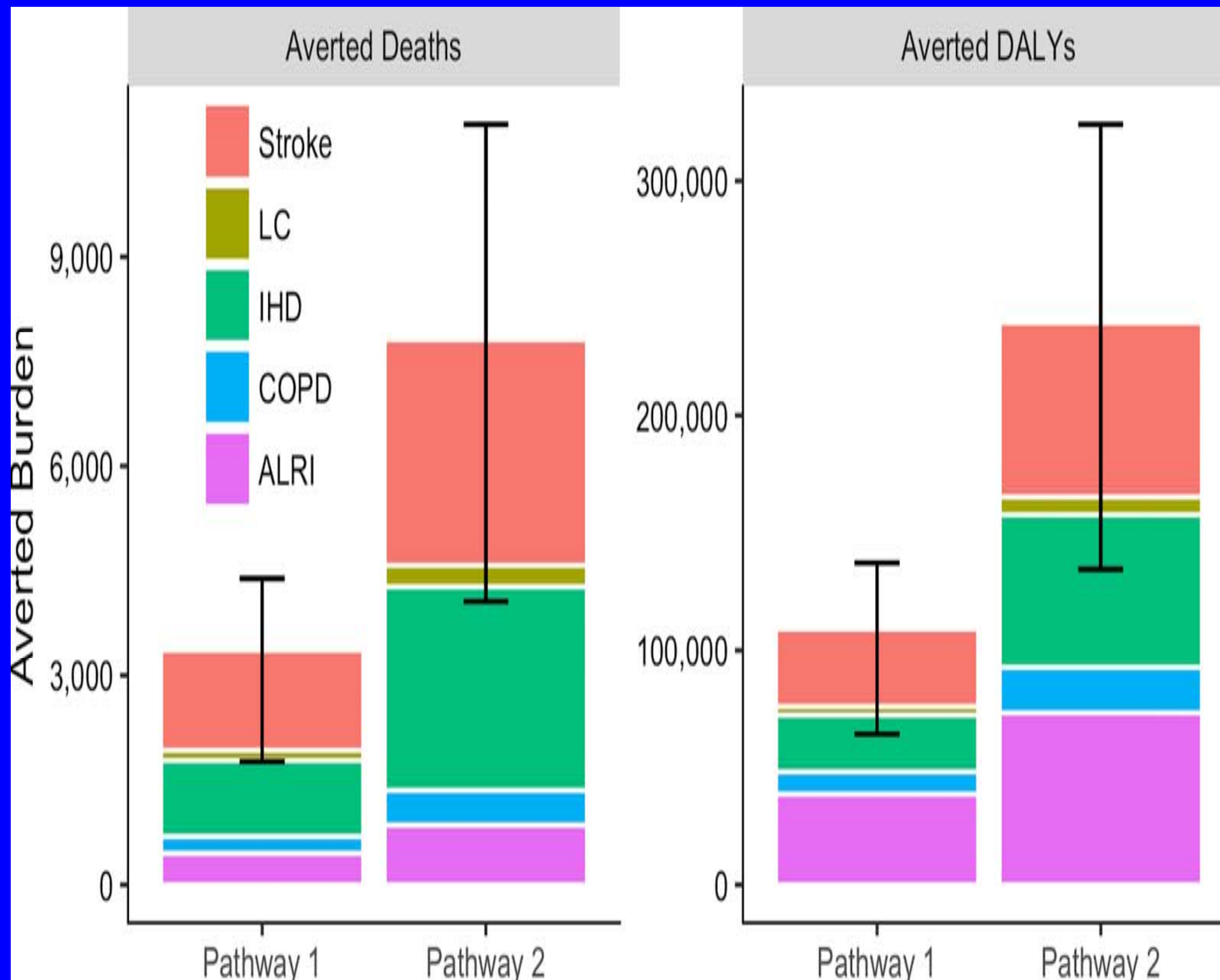



Findings from Hill et al 2017

Pathways 1 & 2 avert thousands of deaths and many more DALYS otherwise accrued under BAU

Child disease (ALRI) accounts for many of the averted DALYs

**Substantially more burden averted by Pathway 2 than Pathway 1**

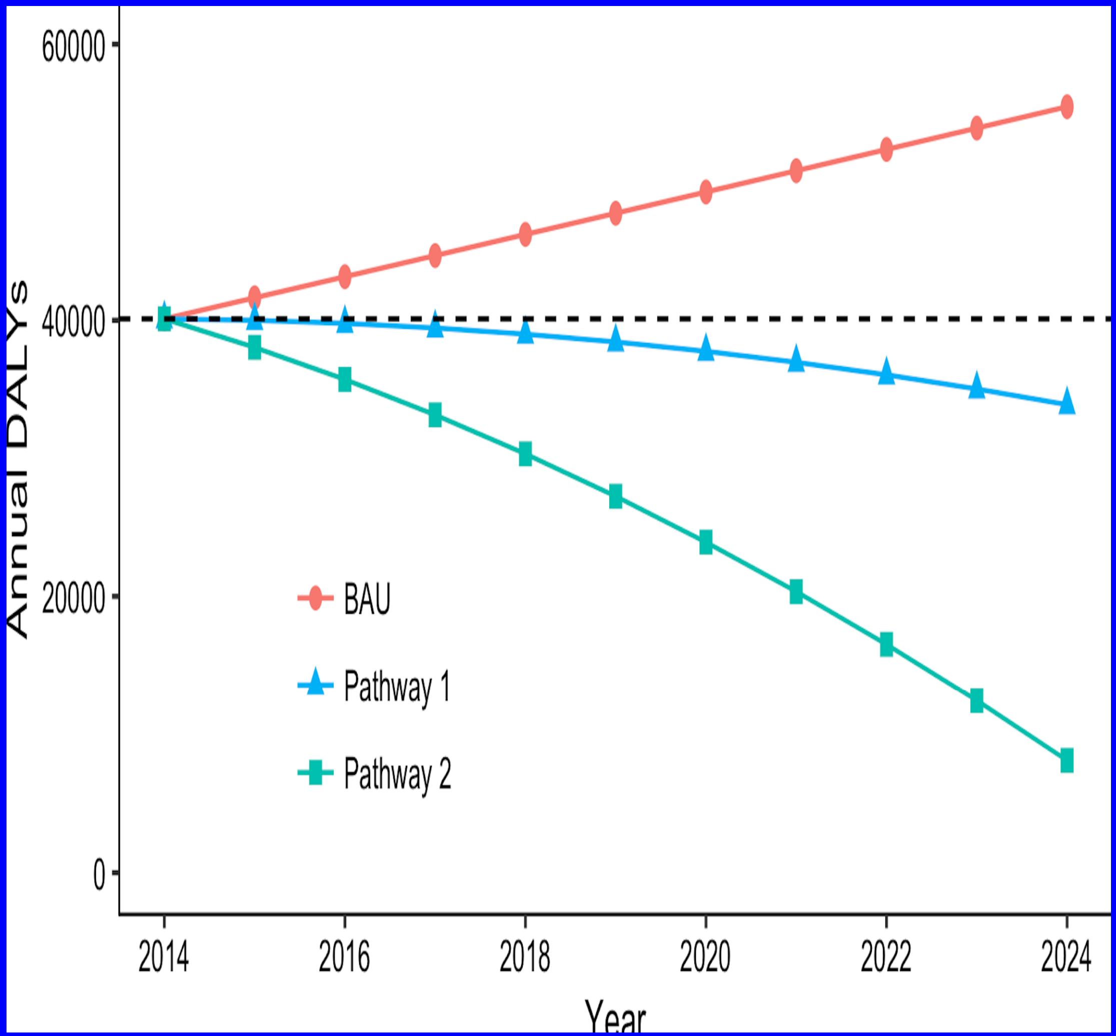



Findings from Hill et al 2017

Total DALYs from $PM_{2.5}$ increase by 2024

- Due in part to population growth

Large reductions in *total* annual DALYs from $PM_{2.5}$ are achieved under the major emissions reduction policy pathway




Findings from Hill et al 2017

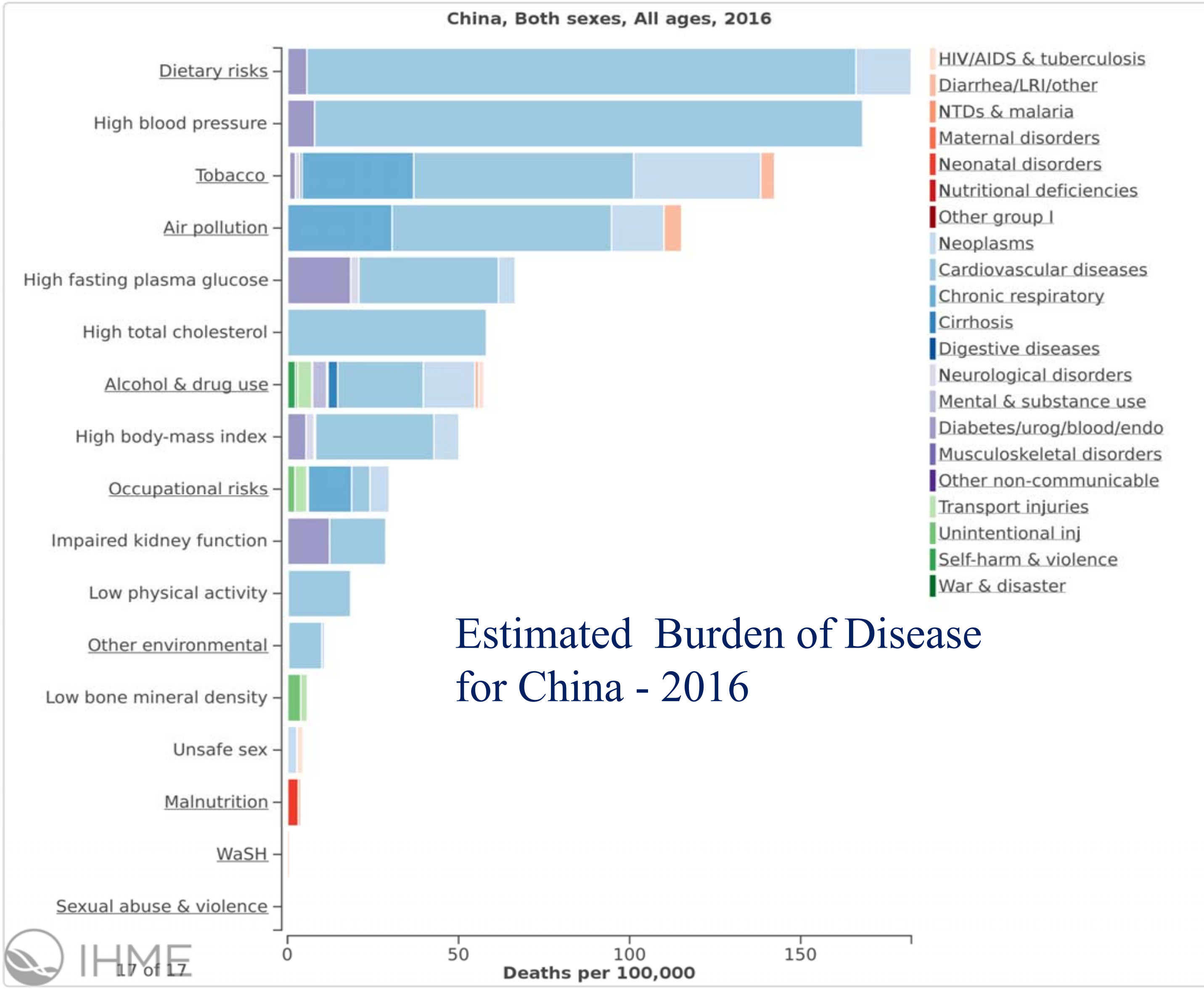
# Caveats

- Does not include every source of pollution ; only the major ones
- Tobacco smoke, which begins to be important late in the  period, may come down as anti-tobacco policies are implemented
- Not all air pollution health effects included, only the five in the Global Burden of Disease studies
- There is growing evidence of other effects, however, including
  - Other cancers
  - Adverse pregnancy outcomes
  - TB, adult pneumonia, and flu
  - Diabetes
  - Etc.

| 2014 | 2024 | | |
|---|---|---|---|
| Baseline | Business as Usual (BAU) | Pathway 1 | Pathway 2 |
| • "Clean indoor" heat in apartments<br>  • assumes no indoor emissions<br>• Some heat-only boilers (HOB)<br>• Houses & ger heat with "improved" MCA stove or similar (e.g. low pressure boiler, [LPB])<br>• 4 combined heat & power plants (CHP)<br>• Nearly 100% growth in traffic from 2010 values | • Not much change from home heating schema of 2014<br>• Add 1 CHP, meets US standards (NSPS)<br>• 2.5% traffic growth per year from 2014, Euro III emissions standards | • "Clean indoor" heat in many houses, all apartments<br>• 50% HOB retired, others retrofitted<br>• New "Future Tech" improved coal stove in many houses, all ger<br>• LPB still in some houses<br>• 4 CHP retrofitted<br>• Add 1 CHP at US NSPS<br>• Same traffic growth as BAU, Euro V standards | • **"Clean indoor" heat in all homes**<br>• All HOB retired<br>• 3 original CHP retrofitted<br>• Add 1 CHP at US NSPS<br>• 1 CHP replaced by renewables and/or imports<br>• 50% reduction in traffic emissions from Pathway 1 |

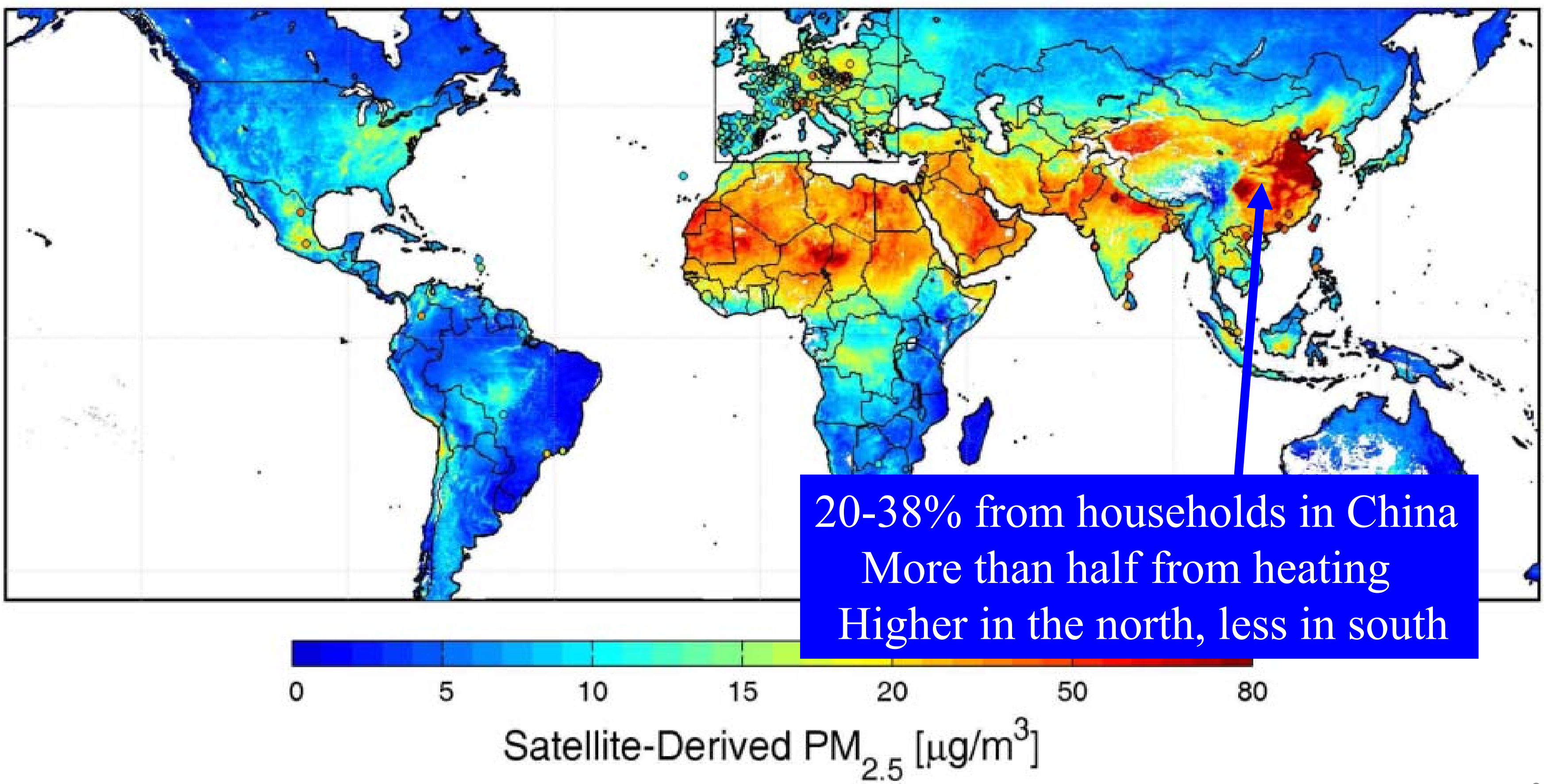
# What might be done?

- Better coal stoves: Not clean enough, not reliable enough
- LPG: Requires imports
- Natural Gas: Requires imports plus pipelines
- Synthetic NG or LPG from coal? Requires synfuel industry and pipelines
- Electric heating: Most households electrified, but conventional heaters too inefficient



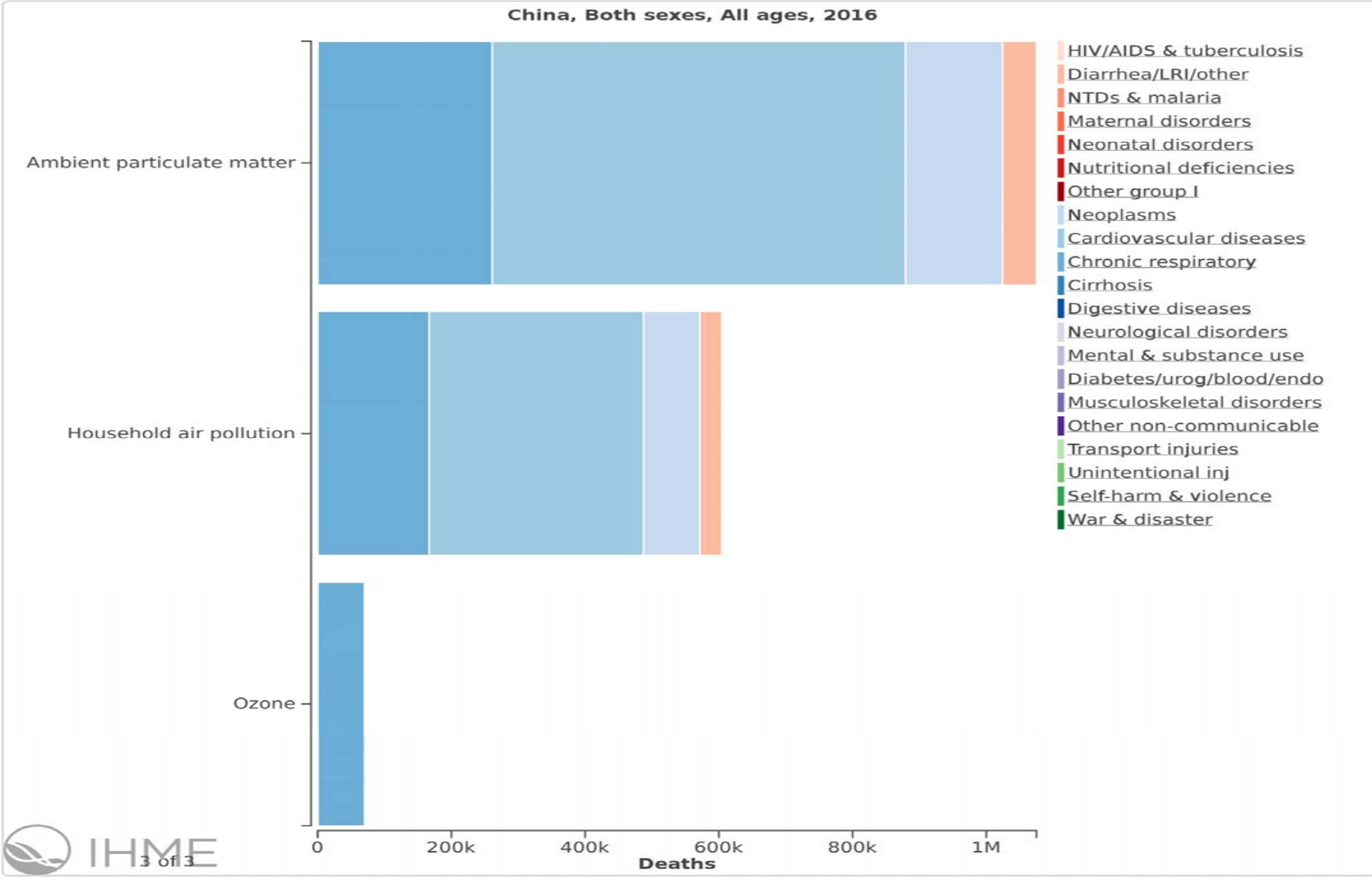

Estimated Burden of Disease for China - 2016

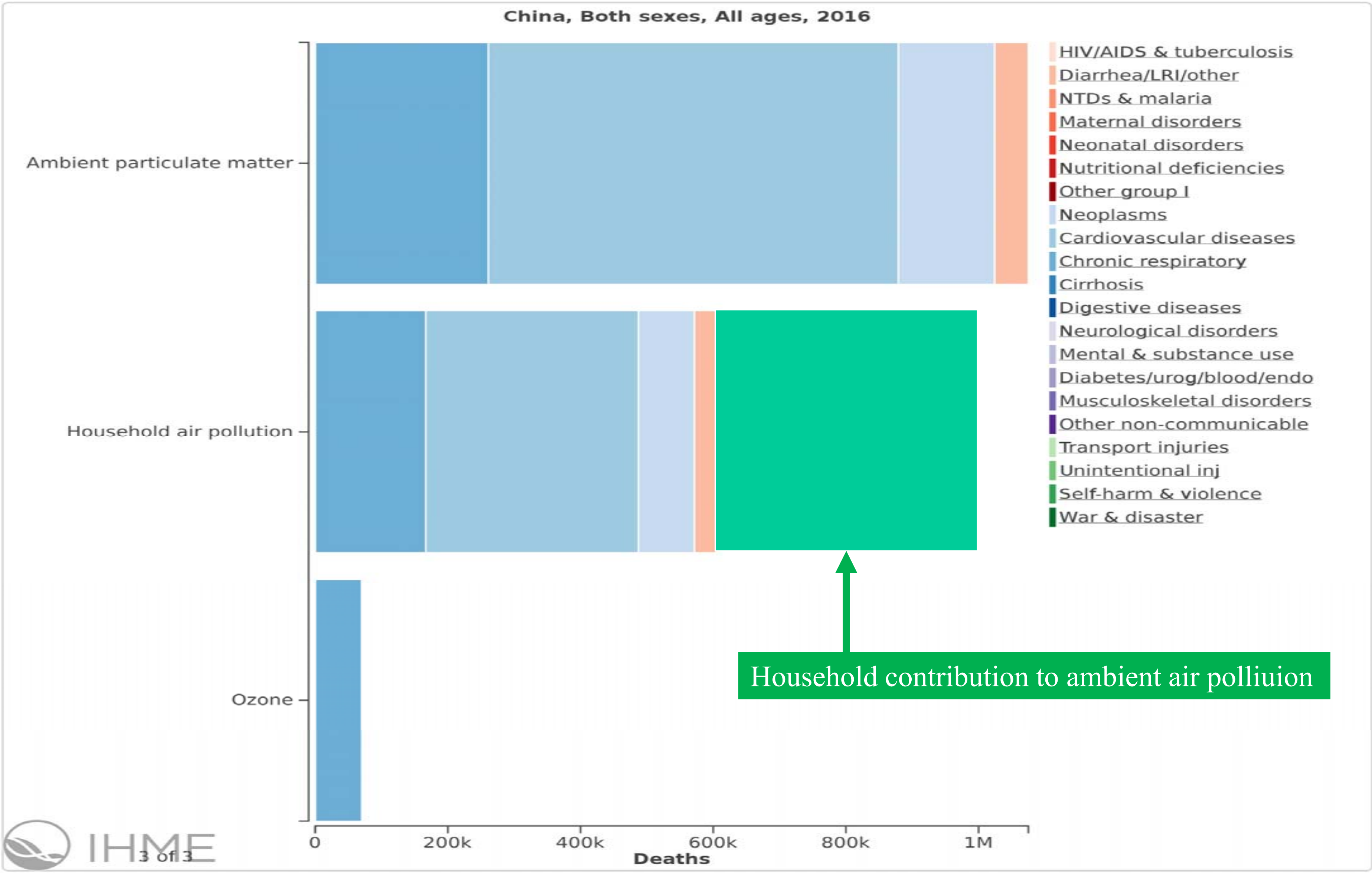
# Satellite-based ambient $PM_{2.5}$






van Donkelaar et al, EHP 2010


China, Both sexes, All ages, 2016
Ambient particulate matter
Household air pollution
Ozone
0
200k
400k
600k
800k
1M
Deaths
HIV/AIDS & tuberculosis
Diarrhea/LRI/other
NTDs & malaria
Maternal disorders
Neonatal disorders
Nutritional deficiencies
Other group I
Neoplasms
Cardiovascular diseases
Chronic respiratory
Cirrhosis
Digestive diseases
Neurological disorders
Mental & substance use
Diabetes/urog/blood/endo
Musculoskeletal disorders
Other non-communicable
Transport injuries
Unintentional inj
Self-harm & violence
War & disaster
IHME
3 of 3


China, Both sexes, All ages, 2016
Ambient particulate matter
Household air pollution
Ozone
HIV/AIDS & tuberculosis
Diarrhea/LRI/other
NTDs & malaria
Maternal disorders
Neonatal disorders
Nutritional deficiencies
Other group I
Neoplasms
Cardiovascular diseases
Chronic respiratory
Cirrhosis
Digestive diseases
Neurological disorders
Mental & substance use
Diabetes/urog/blood/endo
Musculoskeletal disorders
Other non-communicable
Transport injuries
Unintentional inj
Self-harm & violence
War & disaster
Household contribution to ambient air polliuion
0
200k
400k
600k
800k
1M
Deaths
IHME
3 of 3

https://hapit.shinyapps.io ×

Secure | https://hapit.shinyapps.io/HAPIT/

# Household Air Pollution Intervention Tool

## Welcome to HAPIT!

HAPIT estimates and compares health benefits attributable to stove and/or fuel programs that reduce exposure to household air pollution (H countries. HAPIT allows users to customize two scenarios based on locally gathered information relevant to their intervention, which is the r work at the dissemination site to demonstrate pollution exposures before and after the intervention in a representative sample of househol conservative default values for four broad classes of household energy interventions based on the available literature -- liquid fuels, chimne country's health and HAP situation is different, HAPIT currently contains the background data necessary to conduct the analysis in 55 count cooking and China, which has a lower percentage of households using solid fuels for cooking, but a high number in absolute terms. See the

HAPIT also estimates program cost-effectiveness in US dollars per averted DALY (disability-adjusted life year) based on the World Health Org

GLOBAL ALLIANCE FOR CLEAN COOKSTOVES

HOUSEHOLD ENERGY, CLIMATE, & HEALTH RESEARCH
UNIVERSITY OF CALIFORNIA, BERKELEY

HAPIT 2.0 was created by Ajay Pillarisetti and Kirk R. Smith of the Household Energy, Climate, and Health at the University of California, Berkeley and supported by the Global Alliance for Clean Cookst

# Thank you

Publications and presentations on website: Just Google “Kirk R. Smith