Household Air Pollution and Health in Laos

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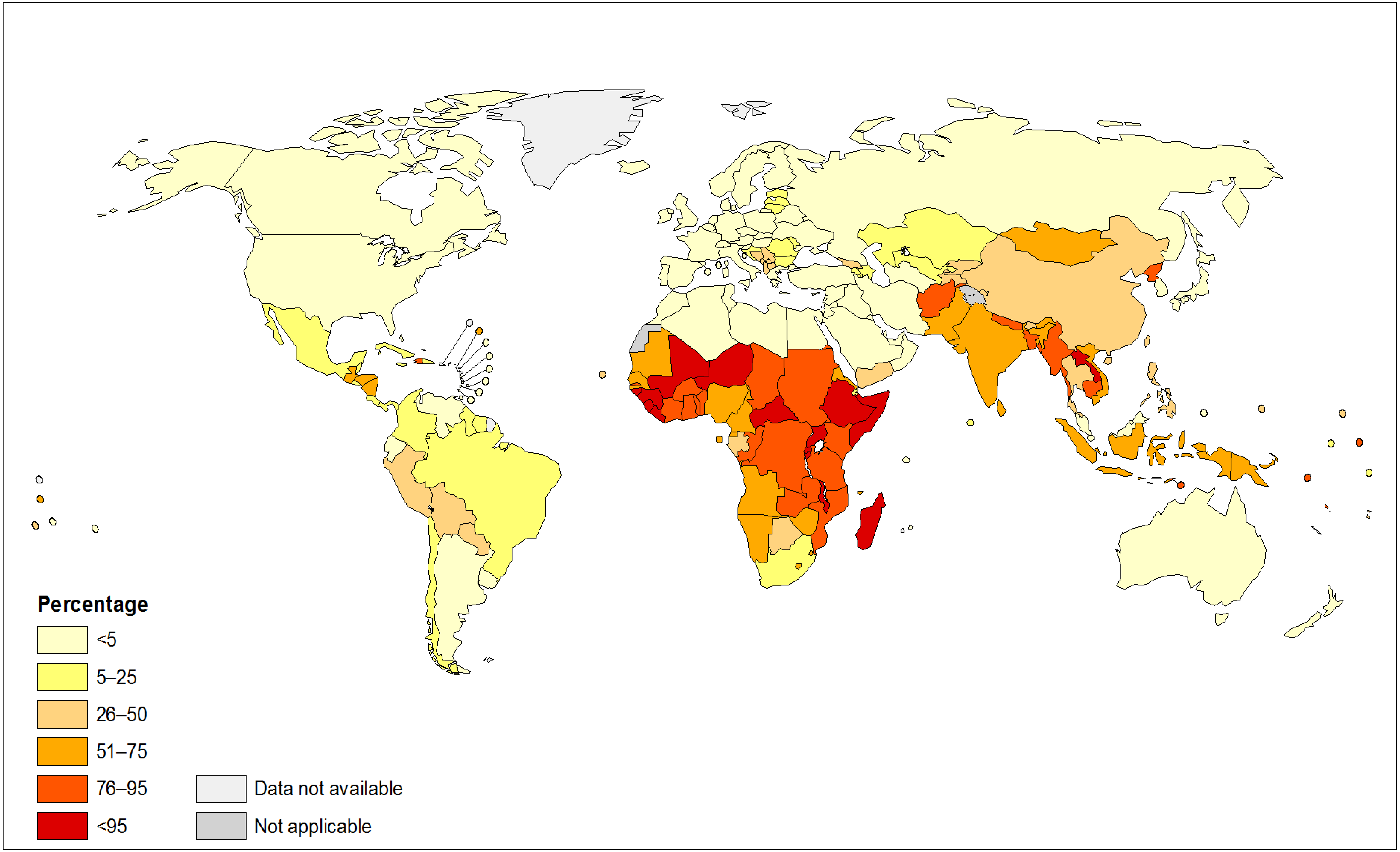
Joint Energy and Health Sector Workshop on Innovative Health Impacts
Result-based Financing to Promote Clean Cookstoves
World Bank, Washington DC

Feb 10, 2014


The three major solid fuels

Population Cooking with Solid Fuels in 2010 (%)



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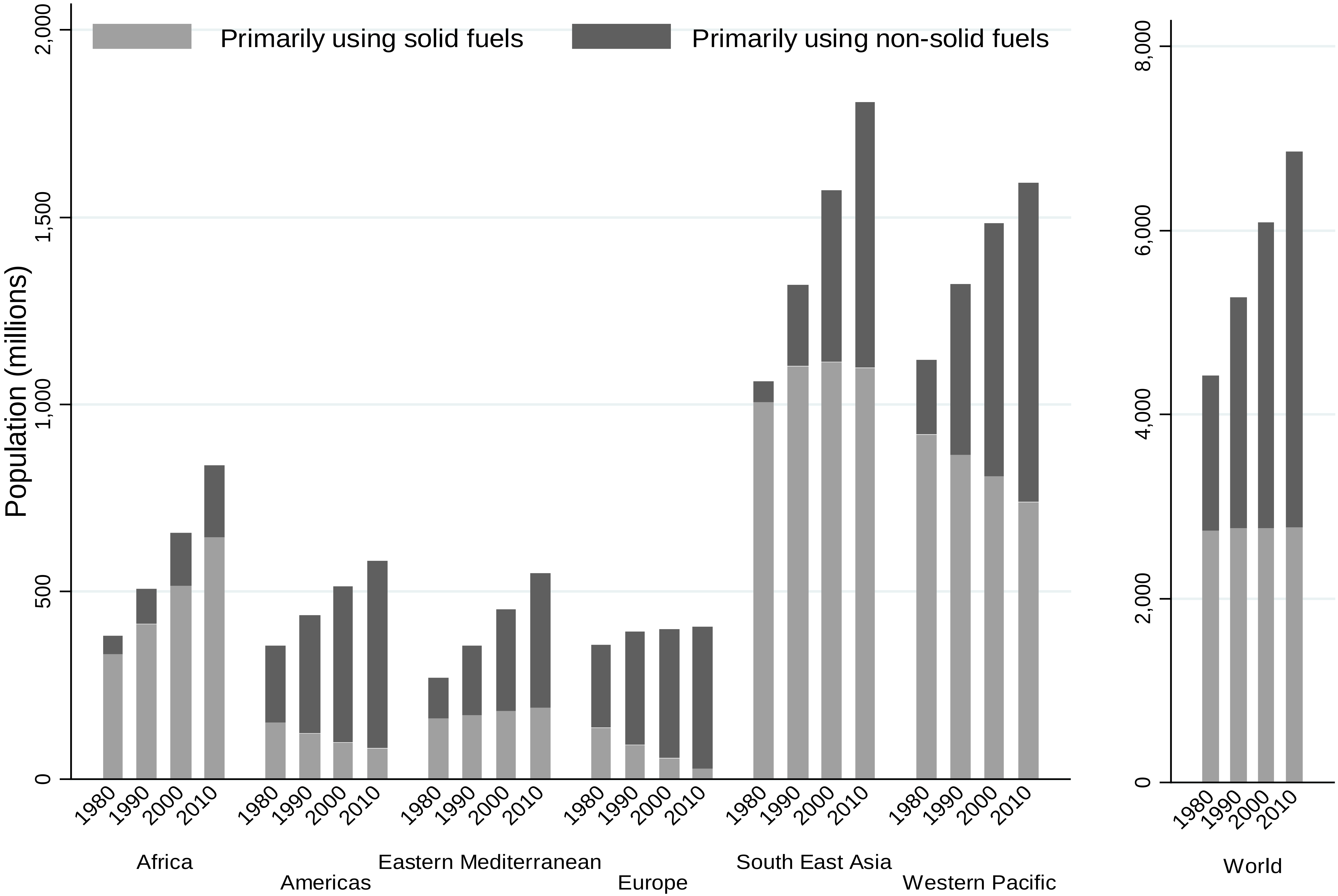
Data Source: World Health Organization
Map Production: Public Health Information and Geographic Information Systems (GIS)
World Health Organization

World Health Organization



Total Population Cooking with Solid Fuels

Bonjour et al., CRA-2010

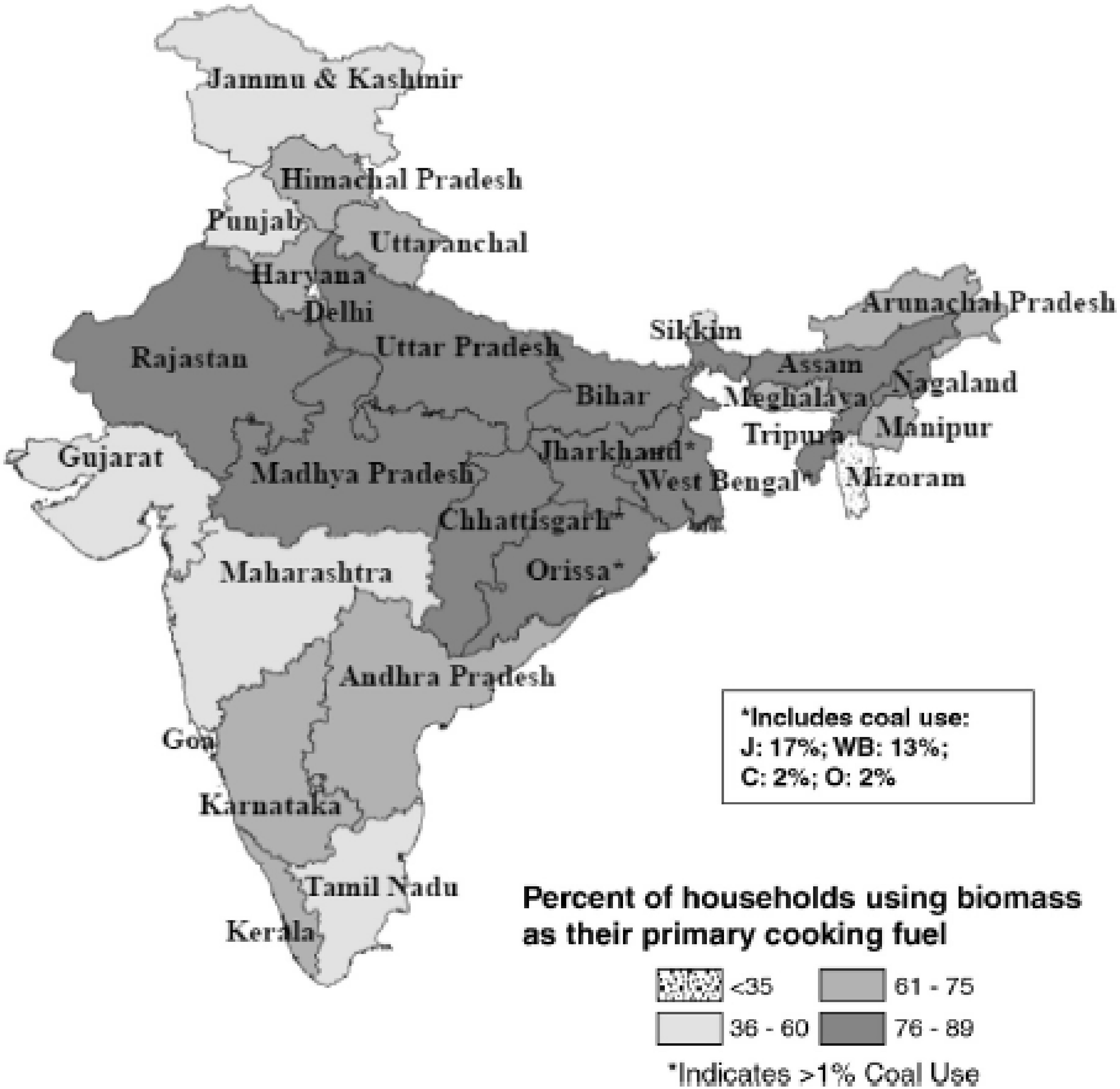


Fig. 1. Distribution by state of households using biomass or coal as their main cooking fuel in 2005. From (IIPS, 2007).

1990:
85%: 700 million people using solid fuels

2010:
60%: 700 million people

~1980
700 million people in entire country

Laos

	Total Pop - million	Percent solid fuel	Solid fuel users
1990	4.2	96%	4.0
2000	5.3	95%	5.0
2010	6.2	94%	5.8

Woodsmoke is natural – how can it hurt you?

Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn't it just change to CO_2 and H_2O when it is combined with oxygen (burned)?

Reason: the combustion efficiency is far less than 100%

Energy flows in a well-operating traditional wood-fired cookstove

A Toxic Waste Factory!!

Typical biomass cookstoves convert 6-20% of the fuel carbon to toxic substances

Into Pot	In PIC	Waste Heat
2.8 MJ	1.2 MJ	11.3 MJ
18%	8%	74%

PIC = products of incomplete combustion = CO, HC, C, etc.

Source: Smith, et al., 2000

Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

- Small particles, CO, NO_2
- Hydrocarbons
  - –
  - – *adiene*
  - – *ne*
  - – *ene*
- Oxy
  - 20+ aldehydes including *formaldehyde* & *acrolein*
  - 25+ alcohols and acids such as *methanol*
  - 33+ phenols such as *catechol* & *cresol*
  - Many quinones such as *hydroquinone*
  - Semi-quinone-type and other radicals
- Chlorinated organics such as *methylene chloride* and *dioxin*

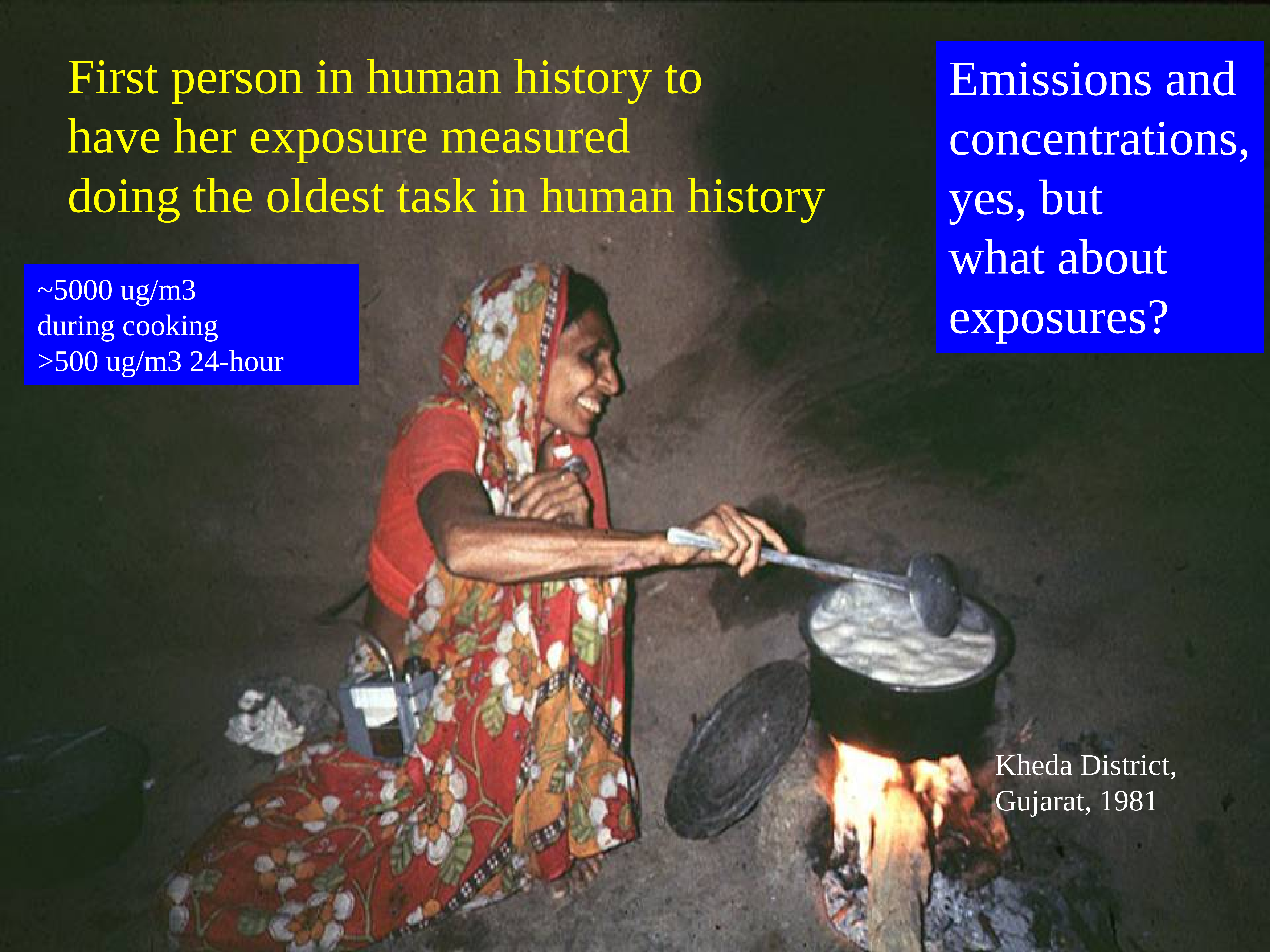
Typical chullah releases 400 cigarettes per hour worth of smoke

Source: Naeher et al, *J Inhal Tox*, 2007

First person in human history to have her exposure measured doing the oldest task in human history

Emissions and concentrations, yes, but what about exposures?

~5000 ug/m3
during cooking
>500 ug/m3 24-hour



Kheda District, Gujarat, 1981

How much PM2.5 is unhealthy?

- WHO Air Quality Guidelines
  - 10 ug/m3 annual average
  - No public microenvironment, indoor or outdoor, should be more than 35 ug/m3
- National standards – annual outdoors
  - USA: 12 ug/m3
  - China: 35 ug/m3
  - India: 40 ug/m3

A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010

Stephen S Lim‡, Theo Vos, Abraham D Flaxman, Goodarz Danaei, Kenji Shibuya, Heather Adair-Rohani, Markus Amann*, H Ross Anderson*, Kathryn G Andrews*, Martin Aryee*, Charles Atkinson*, Loraine J Bacchus*, Adil N Bahalim*, Kalpana Balakrishnan*, John Balmes*, Suzanne Barker-Collo*, Amanda Baxter*, Michelle L Bell*, Jed D Blore*, Fiona Blyth*, Carissa Bonner*, Guilherme Borges*, Rupert Bourne*, Michel Boussinesq*, Michael Brauer*, Peter Brooks*, Nigel G Bruce*, Bert Brunekreef*, Claire Bryan-Hancock*, Chiara Bucello*, Rachelle Buchbinder*, Fiona Bull*, Richard T Burnett*, Tim E Byers*, Bianca Calabria*, Jonathan Carapetis*, Emily Carnahan*, Zoe Chafe*, Fiona Charlson*, Honglei Chen*, Jian Shen Chen*, Andrew Tai-Ann Cheng*, Jennifer Christine Child*, Aaron Cohen*, K Ellicott Colson*, Benjamin C Cowie*, Sarah Darby*, Susan Darling*, Adrian Davis*, Louisa Degenhardt*, Frank Dentener*, Don C Des Jarlais*, Karen Devries*, Mukesh Dherani*, Eric L Ding*, E Ray Dorsey*, Tim Driscoll*, Karen Edmond*, Suad Eltahir Ali*, Rebecca E Engell*, Patricia J Erwin*, Saman Fahimi*, Gail Falder*, Farshad Farzadfar*,*

CRA published along with the other
GBD papers on Dec 14, 2012
in *The Lancet*

Millions Dead: How Do We Know and What Does It Mean? Methods Used in the Comparative Risk Assessment of Household Air Pollution

Kirk R. Smith,[1,*] Nigel Bruce,[2,*]
Kalpana Balakrishnan,[3] Heather Adair-Rohani,[1]
John Balmes,[1,4] Zöe Chafe,[1,5] Mukesh Dherani,[2]
H. Dean Hosgood,[6] Sumi Mehta,[7] Daniel Pope,[2]
Eva Rehfuess,[8] and others in the HAP CRA Risk
Expert Group[1]

Annual Review of Public Health,
vol 35, 2014, to be published in March

Definitions

- **Global Burden of Disease (GBD)**
- Envelope of death, illness, and injury by age, sex, and region.
- Coherent – no overlap – one death has one cause

- **Comparative Risk Assessment (CRA)**
- The amount of the GBD due to a particular risk factor, e.g. smoking
- Not coherent – deaths can be prevented by several means

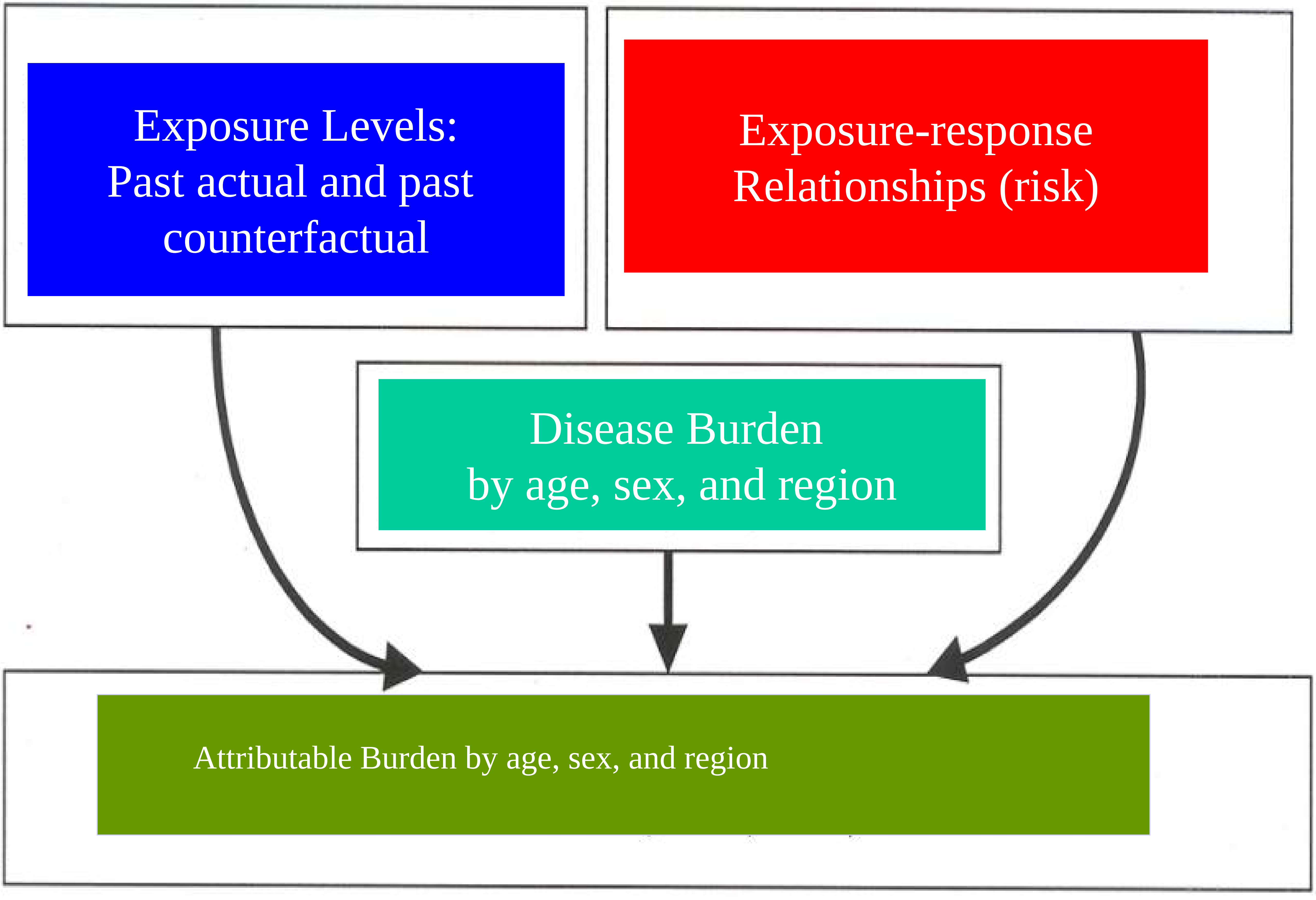
Metrics

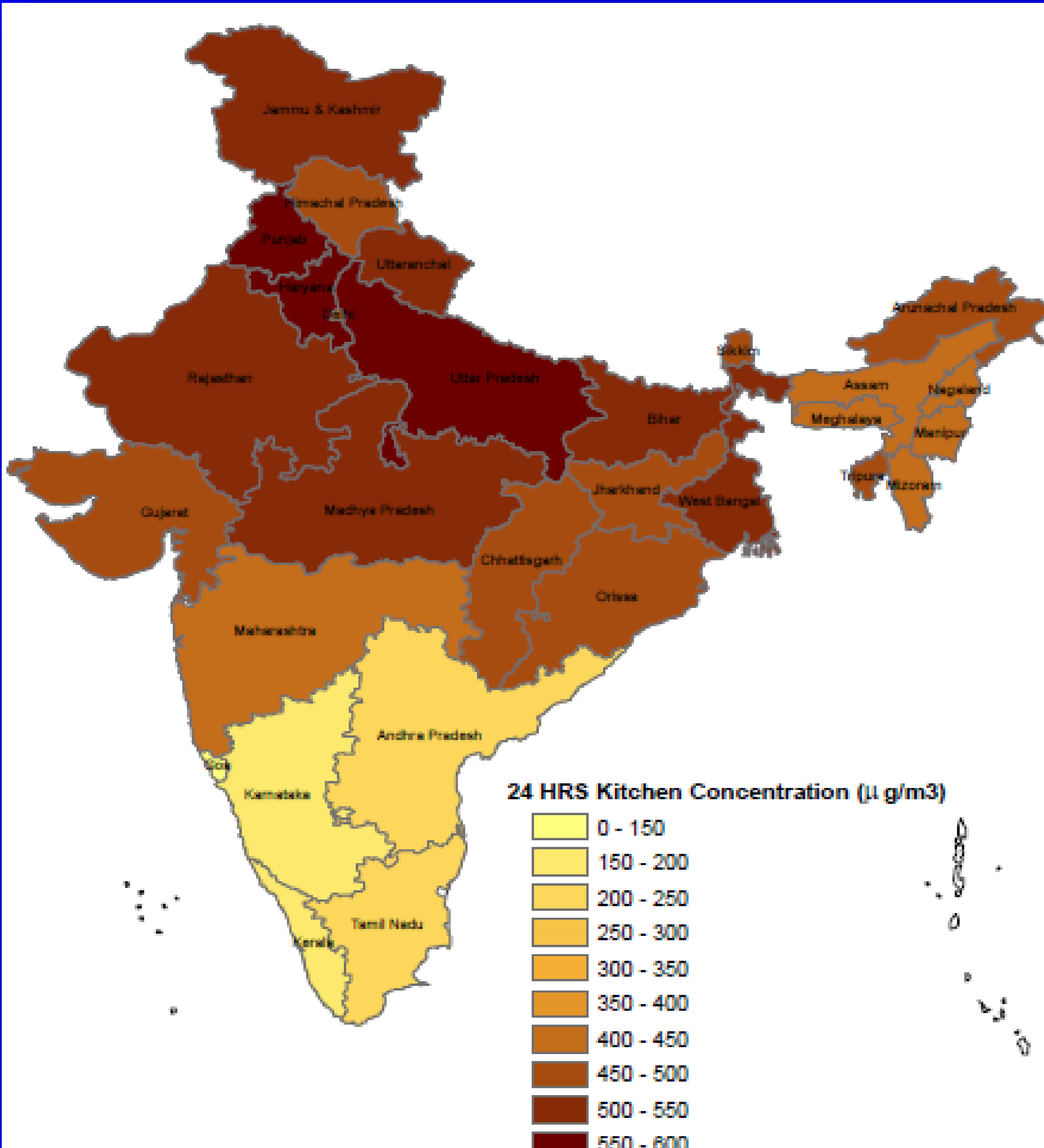
- Mortality – important, but can be misleading as it does not take age into account or years of illness/injury
  - Death at 88 years counts same as at 18, which is not appropriate
- Disability-adjusted Life Years (DALYs) lost do account for age and illness.
- GBD 2010 compares deaths against best life expectancy in world – 86 years

Lao Burden of Disease

Rank and disorder 1990	Rank and disorder 2010	(% of total)
1 Lower respiratory infections	1 Lower respiratory infections	223 (11.9%)
2 Diarrheal diseases	2 Ischemic heart disease	108 (5.8%)
3 Congenital anomalies	3 Diarrheal diseases	114 (6.0%)
4 Preterm birth complications	4 Congenital anomalies	102 (5.4%)
5 Tetanus	5 Stroke	97 (5.2%)
6 Tuberculosis	6 Preterm birth complications	93 (4.9%)
7 Measles	7 Tuberculosis	72 (3.8%)
8 Malaria	8 Road injury	56 (3.0%)
9 Protein-energy malnutrition	9 Neonatal encephalopathy	51 (2.7%)
10 Ischemic heart disease	10 Meningitis	30 (1.6%)
11 Stroke	11 Asthma	31 (1.6%)
12 Meningitis	12 Self-harm	29 (1.5%)
13 Neonatal encephalopathy	13 Interpersonal violence	28 (1.5%)
14 Maternal disorders	14 Cirrhosis	26 (1.4%)
15 Asthma	15 Drowning	26 (1.4%)
16 Mechanical forces	16 COPD	25 (1.3%)
17 COPD	17 Protein-energy malnutrition	26 (1.4%)
18 Rabies	18 Diabetes	24 (1.3%)
19 Drowning	19 Maternal disorders	23 (1.2%)
20 Road injury	20 Dengue	81 (4.0%)

Comparative Risk Assessment Method





State-wise estimates of 24-h kitchen concentrations of PM2.5 in India

Solid-fuel using households

Balakrishnan et al. 2013 (SRU group)

Environ. Sci. Technol. **2011**, *45*, 882–889

Pollutant Concentrations within Households in Lao PDR and Association with Housing Characteristics and Occupants' Activities

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H. WANG,† F. TAYPHASAVANH,‡
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conducted in oth
of different const
impossible. One
indoor pollution
for which hardly
the Lao People's
landlocked tropi
Southeast Asian
covering approxi
the country is co
far the dominant
during winter (bu
heating is nowhe
colder climates).
where people do
and poor health a
the country. Life

"12 h mean PM10 concentrations 1275 (=/-98 μg m-3 and 1183 (=/-99 μg m-3 in Vientiane and Bolikhamxay provinces, respectively.

However, no significant differences in pollutant concentrations were observed as a function of cooking location."

Diseases for which we have epidemiological studies

ALRI/
Pneumonia

COPD

Lung cancer (coal)

Lung cancer (biomass)

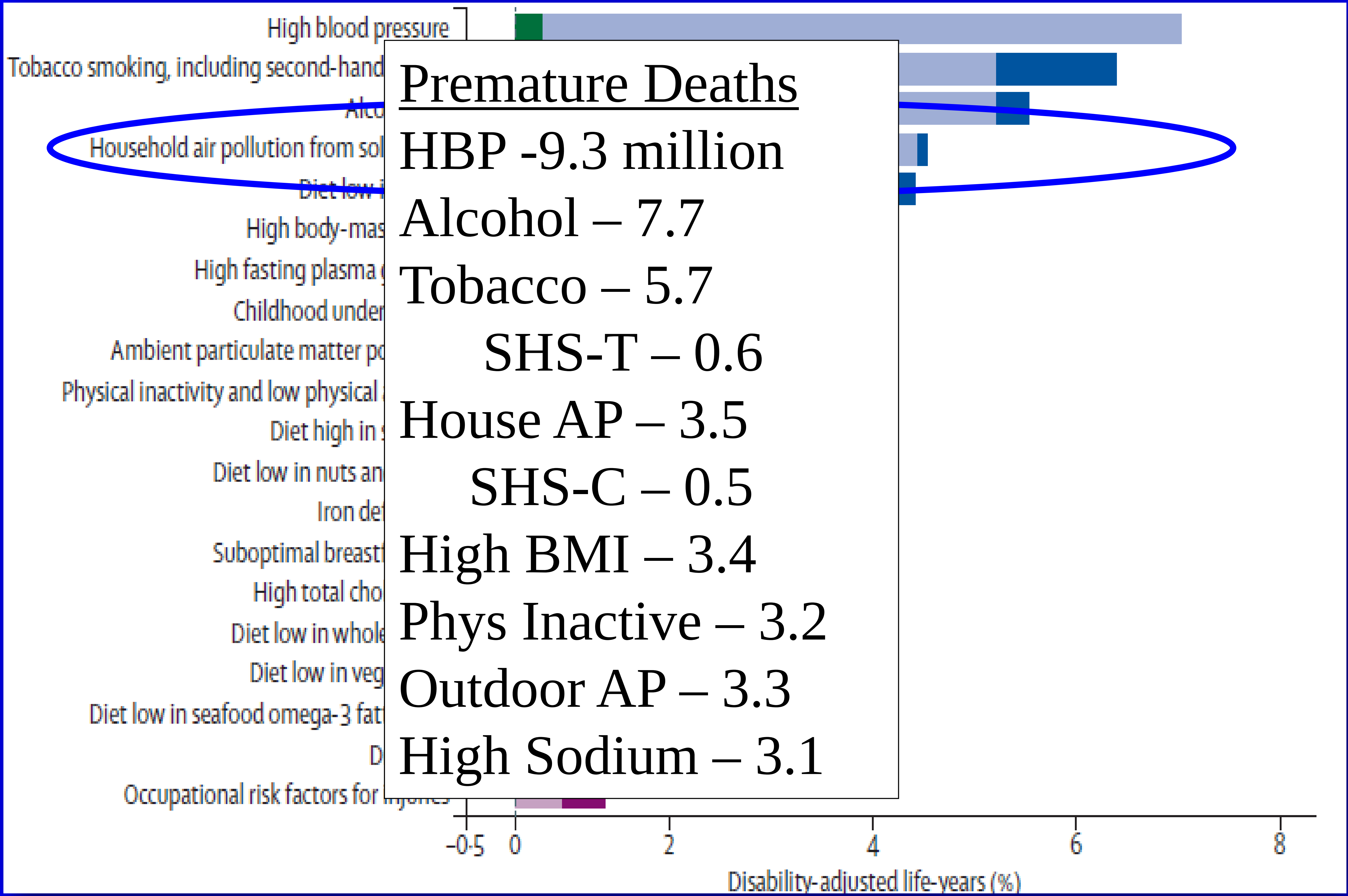
Cataracts

Ischemic heart disease

Stroke

These diseases are included in the
2010 Comparative Risk Assessment (released in 2012)

Global DALYs 2010: Top 20 Risk Factors



<u>Premature Deaths</u>

HBP -9.3 million

Alcohol – 7.7

Tobacco – 5.7

SHS-T – 0.6

House AP – 3.5

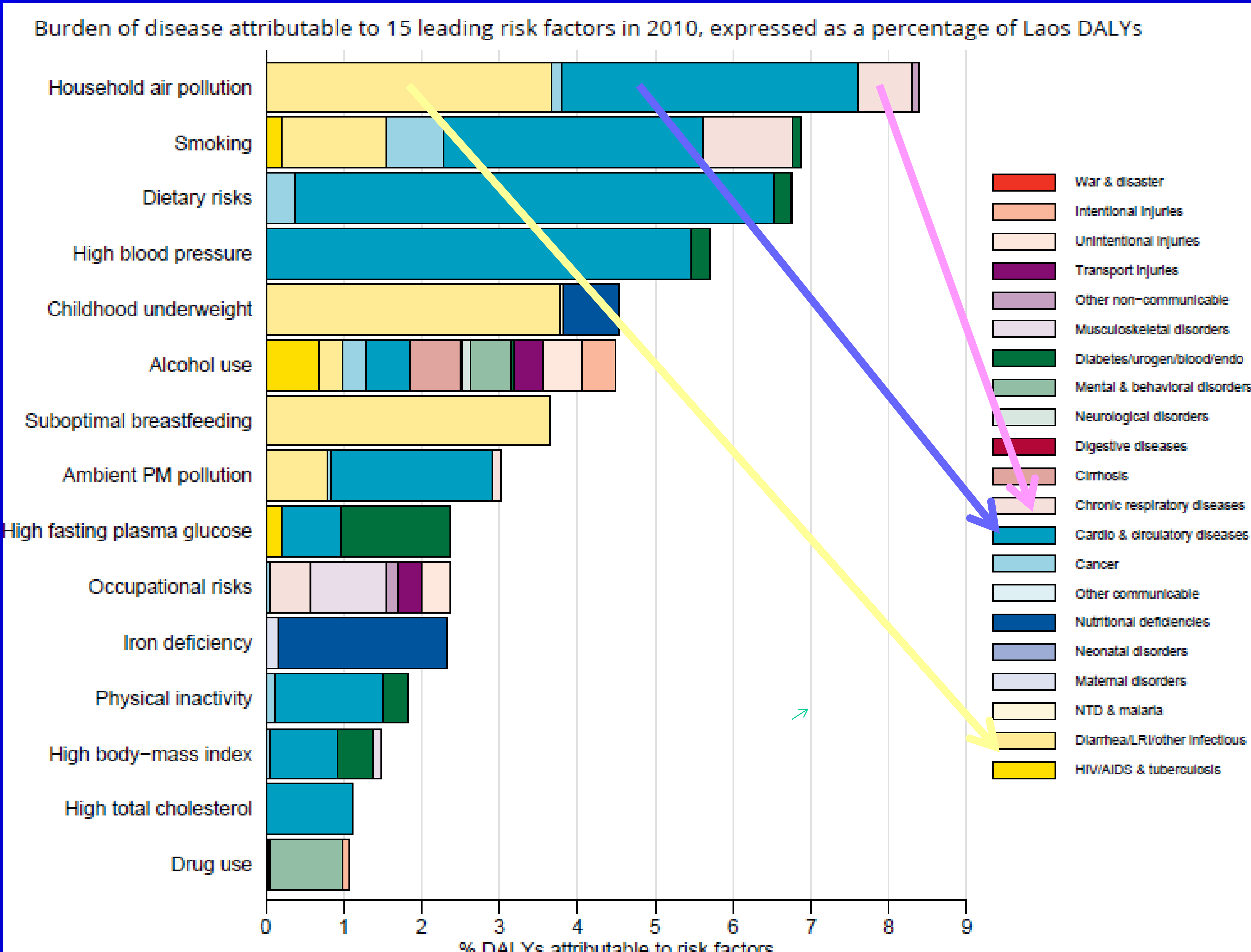
SHS-C – 0.5

High BMI – 3.4

Phys Inactive – 3.2

Outdoor AP – 3.3

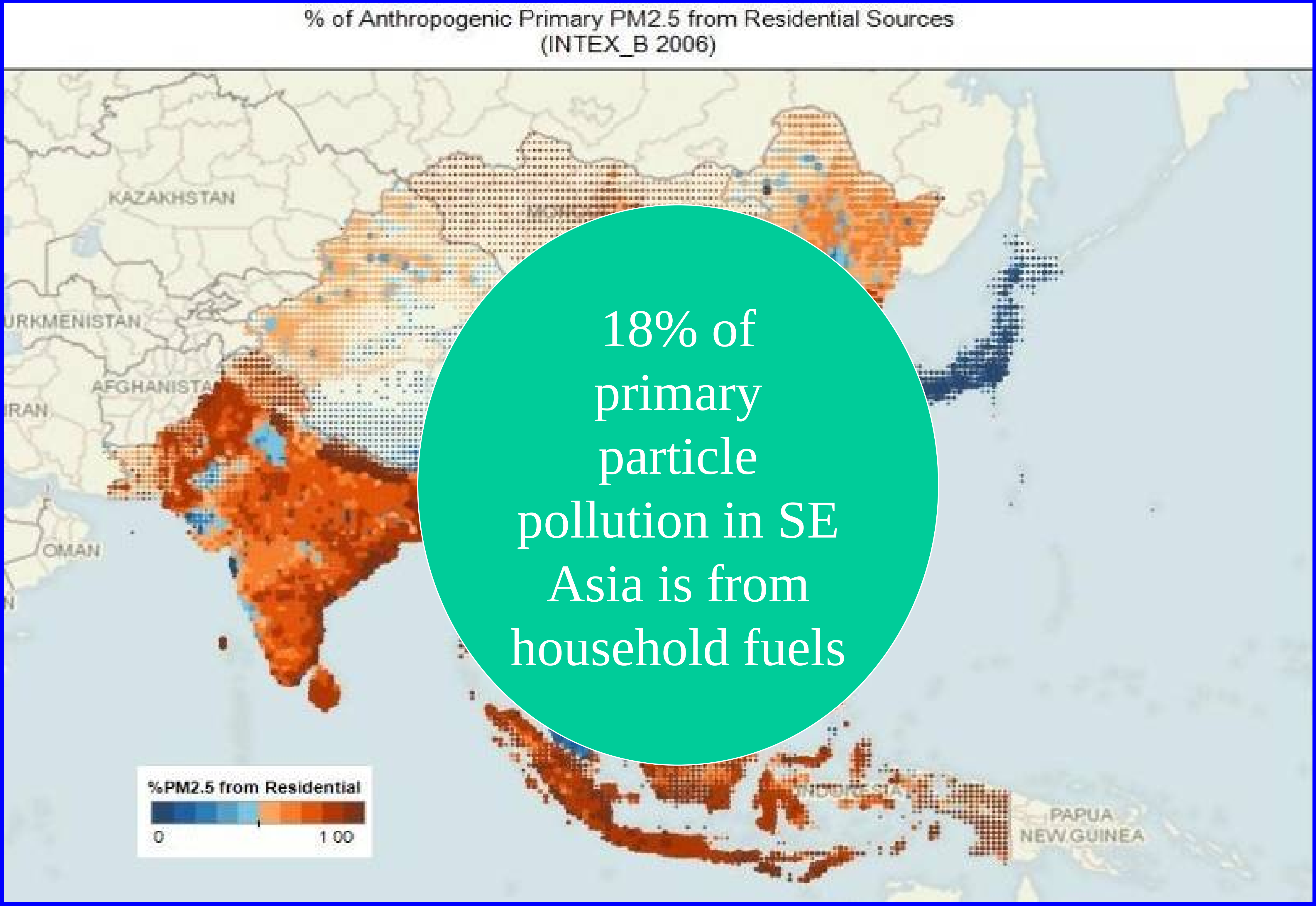
High Sodium – 3.1


Burden of disease attributable to 15 leading risk factors in 2010, expressed as a percentage of Laos DALYs
Household air pollution
Smoking
Dietary risks
High blood pressure
Childhood underweight
Alcohol use
Suboptimal breastfeeding
Ambient PM pollution
High fasting plasma glucose
Occupational risks
Iron deficiency
Physical inactivity
High body-mass index
High total cholesterol
Drug use
0
1
2
3
4
5
6
7
8
9
% DALYs attributable to risk factors
War & disaster
Intentional injuries
Unintentional injuries
Transport injuries
Other non-communicable
Musculoskeletal disorders
Diabetes/urogen/blood/endo
Mental & behavioral disorders
Neurological disorders
Digestive diseases
Cirrhosis
Chronic respiratory diseases
Cardio & circulatory diseases
Cancer
Other communicable
Nutritional deficiencies
Neonatal disorders
Maternal disorders
NTD & malaria
Diarrhea/LRI/other infectious
HIV/AIDS & tuberculosis

Framing, cont.

- Not called “indoor” because stove smoke enters atmosphere to become part of general outdoor air pollution (OAP)
- HAP contributes about 12% to OAP globally, but much more in some countries
- ~25% in India
- Thus, part of the burden of disease due to OAP is attributable to cooking fuels in households   ~150,000 premature deaths in India.

%$PM_{2.5}$ from "Residential" Emissions from INTEX_B



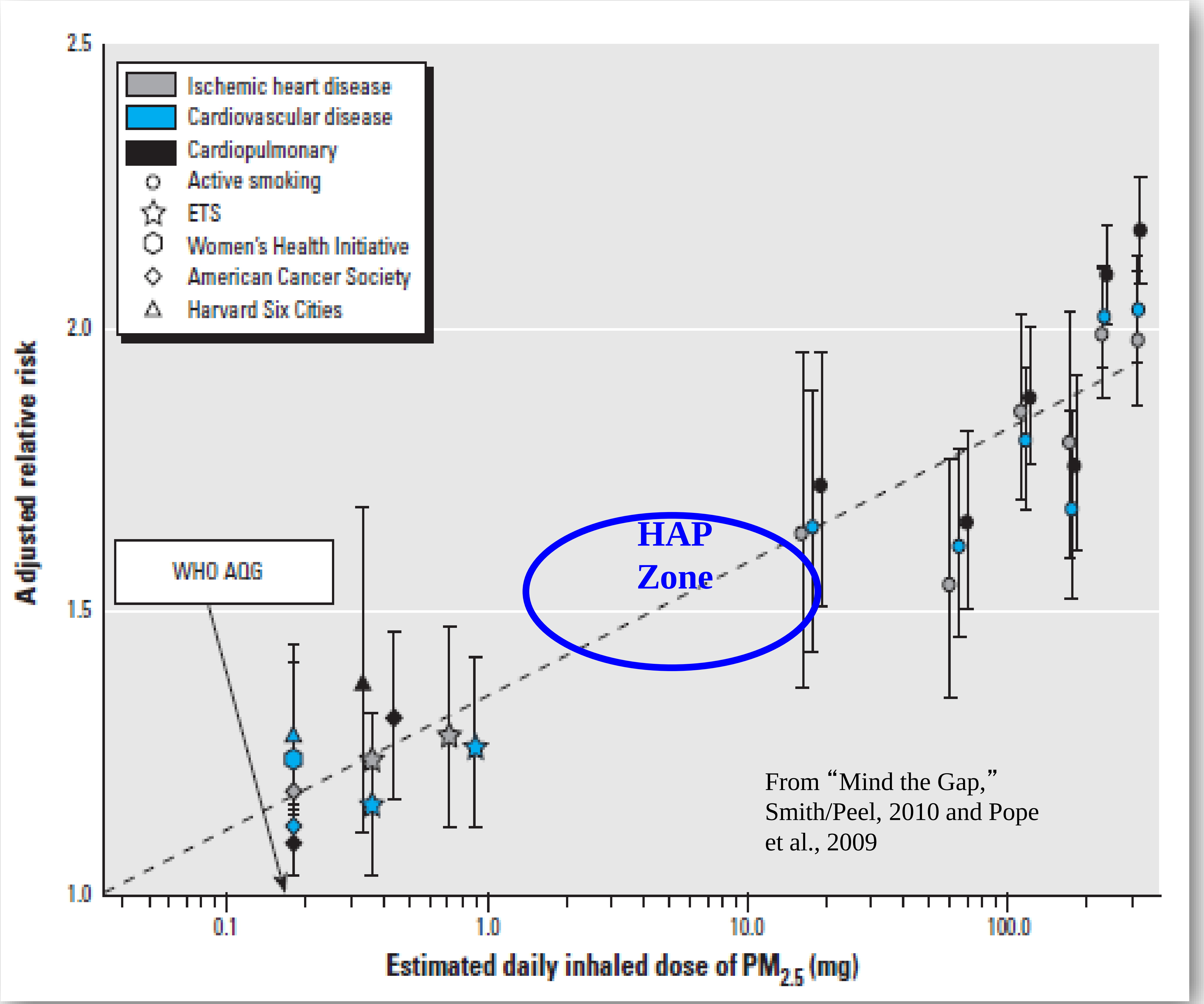
18% of primary particle pollution in SE Asia is from household fuels

Source: Asian Emission Inventory for NASA INTEX_B 2006 (accessed 2010) Chafe, 2010

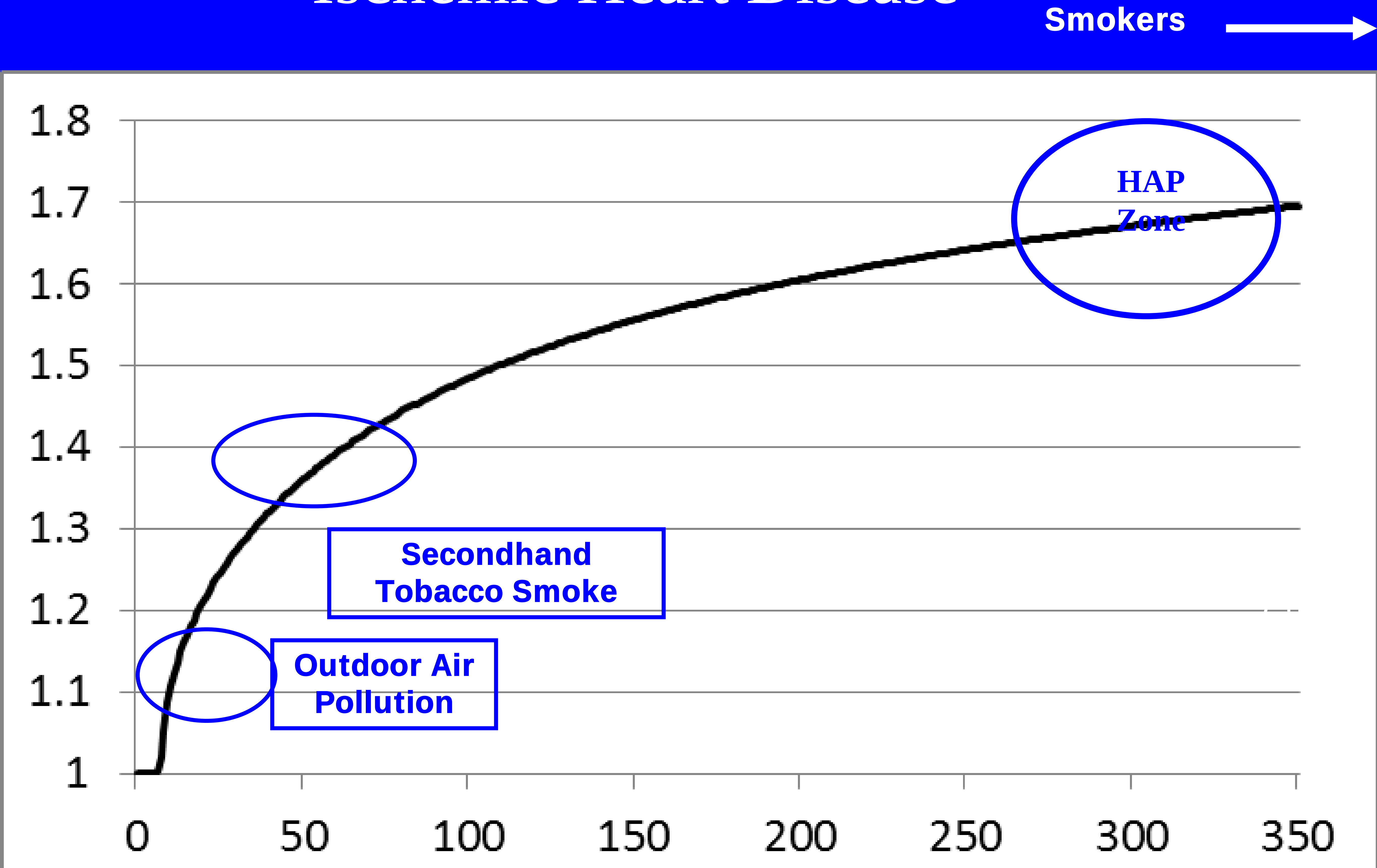
New Category of Evidence for CVD

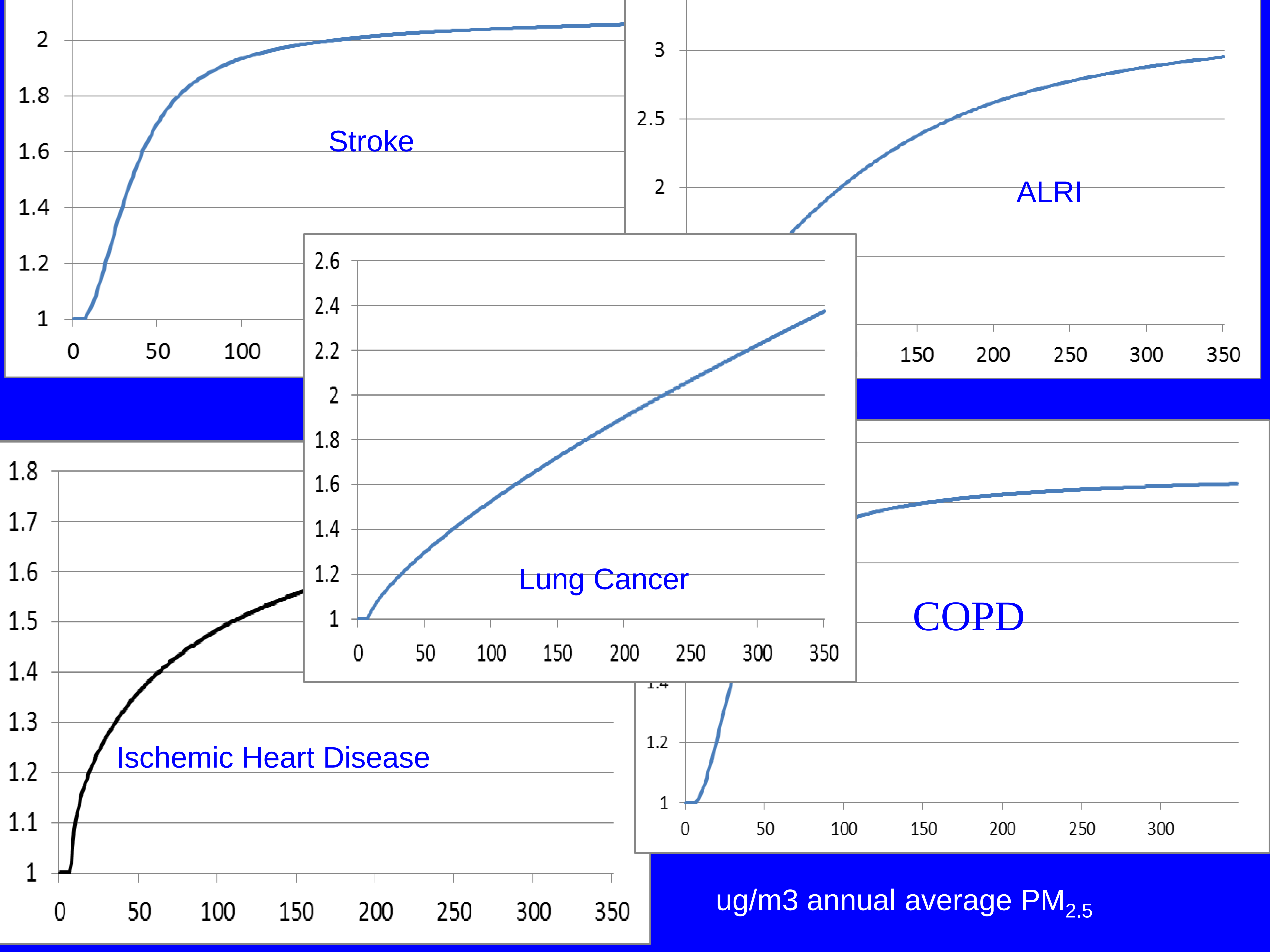
- No direct studies of CVD and HAP, yet
  - But studies showing effects on blood pressure and ST-segment, important disease signs
- Epidemiologic evidence shows clear, consistent evidence of increasing risk across exposures to combustion particles
  - at higher exposures – Active smoking
  - and lower exposures – Outdoor air pollution and secondhand tobacco smoke

Heart Disease and Combustion Particle Doses



Integrated Exposure-Response: Ischemic Heart Disease




Stroke
ALRI
Lung Cancer
COPD
Ischemic Heart Disease
ug/m3 annual average $PM_{2.5}$

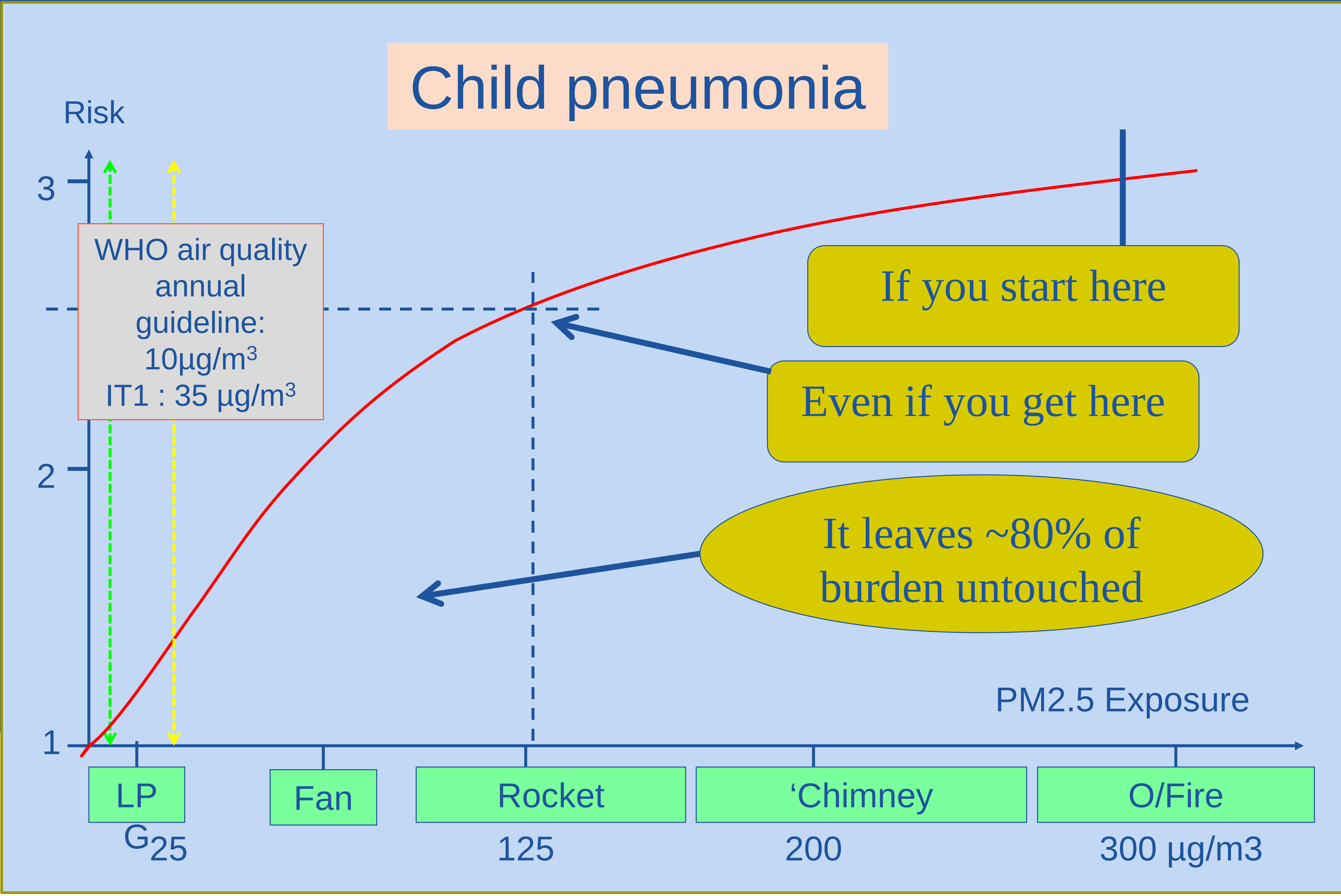
Summary

- One of the top risk factors in the world for ill-health.
- Biggest impact in adults --3 million premature deaths (two-thirds the DALYs)
- Still important for children ~500,000 deaths (one-third the DALYs)
- Important source of outdoor air pollution
- Impact going down slowly because background health conditions improving
- Actual number of people affected is not going down globally or in Laos

Bottom line #1

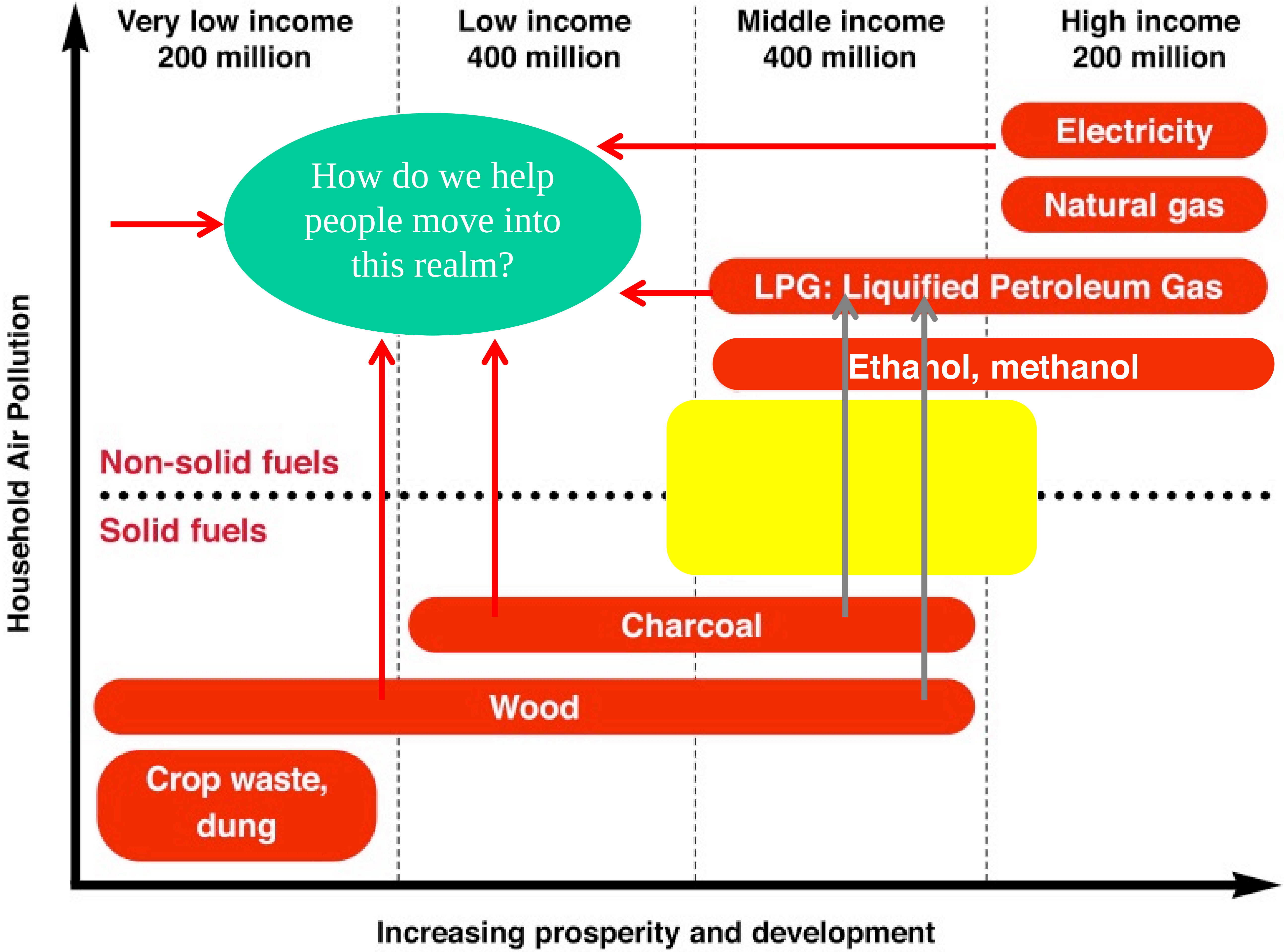
- Implied health benefit from HAP reduction only potentially achieved by shifting to clean completely cooking.
- No biomass stove in the world yet clean enough to obtain all these benefits - much more effort needed
- Including matching with people's needs and enhancing usage/adoption

Exposure-response relationship



Bottom Line #2

- Clean cooking now only achievable with gas and/or electric cooking
- High priority needs to be given to expanding gas and electricity to all households
- Usage/adoption still issues, but not emissions


Very low income
200 million
Low income
400 million
Middle income
400 million
High income
200 million
Electricity
Natural gas
How do we help people move into this realm?
LPG: Liquified Petroleum Gas
Ethanol, methanol
Non-solid fuels
Solid fuels
Charcoal
Wood
Crop waste, dung
Household Air Pollution
Increasing prosperity and development

Bottom lines, restated

– In addition to continuing to try to

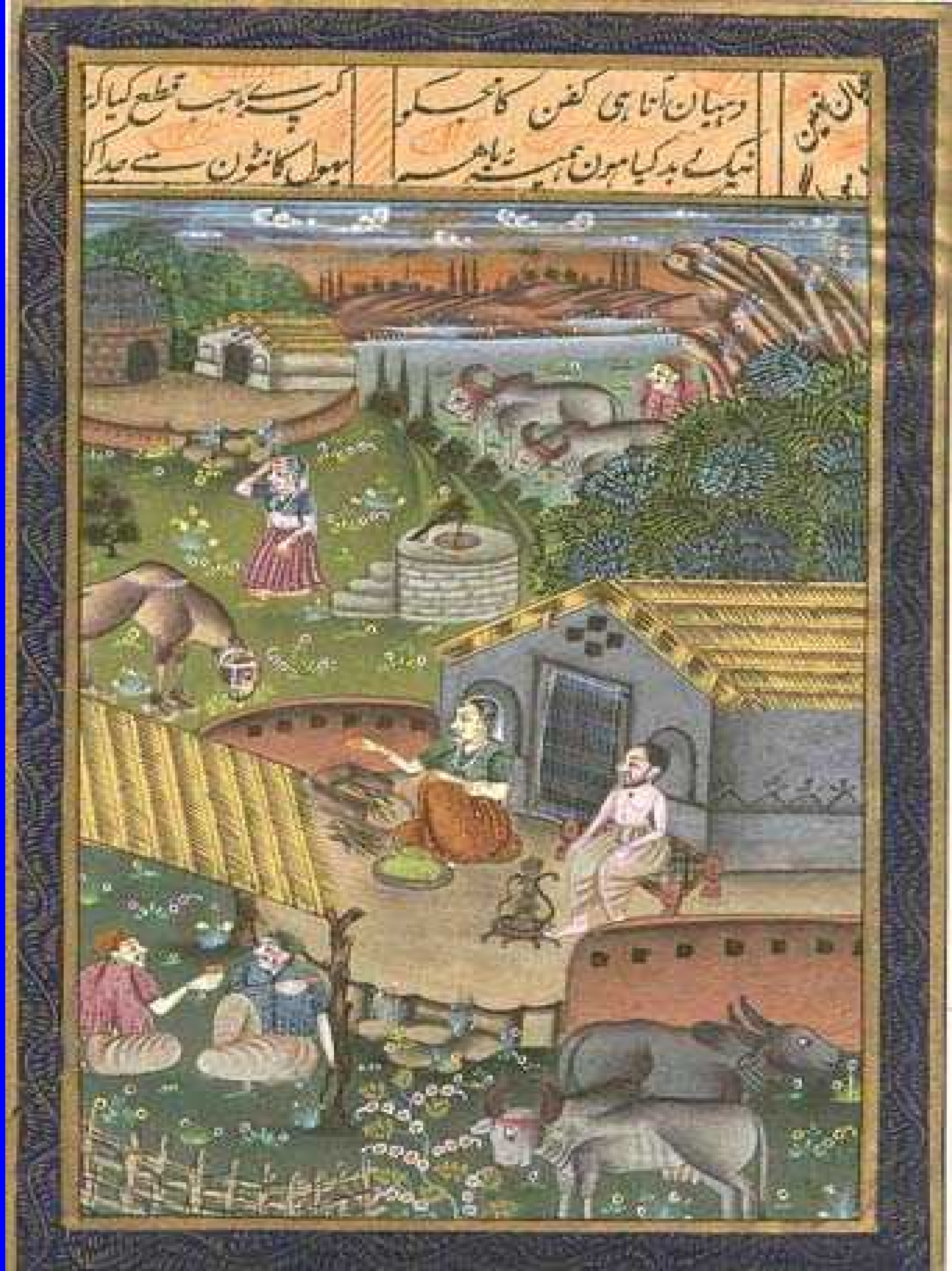
Make the available clean

– Shouldn't we also try to

Make the clean available?

Many thanks

Publications and presentations on website – easiest to just "google" Kirk R. Smith



Magnitude and Cost-Effectiveness of Health Benefits from Stove Interventions in Laos

An analysis using the
Household Air Pollution Intervention Tool (HAPIT)

Ajay Pillarisetti and Kirk R. Smith

10 February 2014

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

HAPIT Overview

Advanced Cookstoves in Laos

HAPIT Overview & Motivations

An easy-to-use & accessible software tool to calculate the health benefits of household energy interventions

Requires knowledge of

- – average $PM_{2.5}$ exposures before intervention
- – average $PM_{2.5}$ exposures after intervention
- – expected usage fraction of intervention
- – number of households receiving intervention
- – number of individuals per household

HAPIT users are encouraged to conduct feasibility studies in advance of investments to obtain local field evidence on

- – usage patterns of the proposed intervention
- – pre- and post-intervention exposures to PM2.5

HAPIT Overview & Motivations

An optional module calculates cost-effectiveness based on WHO CHOICE criteria in international dollars per DALY

- Very Cost Effective: less than GDP per capita / DALY (2374 Int’l $)
- Cost Effective: more than one but less than 3 x GDP per capita / DALY (2374 – 7122 Int’l $)
- Not Cost Effective: more than 3 x GDP per capita / DALY (>7122 Int’l $)

Cost effectiveness analysis accounts for national program costs and health benefits. It does not

- consider costs or savings at the household level (payment for fuel or intervention)
- consider costs or savings at the societal scale (saved health costs, CAP reductions)
- discount or consider the time value of funds

Program costs can be altered to incorporate household scale benefits

BETA

HAPIT Overview & Motivations

Calculations are based on an attributable burden calculation parallel to that used in the GBD-2010:

– $PM_{2.5}$ annual avg. exposures used as the indicator of risk

– Integrated Exposure-Response relationships distilled from the world epidemiology literature by disease

– Low counterfactual (~7.3 ug/m^3) used by GBD and HAPIT equivalent to gas cooking with no other sources present

– Population attributable fraction (PAF) metrics by disease

– Background national or regional disease conditions

– EPA cessation lag for chronic diseases; 80% of benefits by year 5 applied here as a 0.80 multiplier for simplicity.

BETA

Background Data

2010 Background Disease Data – Deaths & DALYs
GBD Compare 2013

2010 Population Data
US Census Int'l Bureau

2010 Solid Fuel Use
Bonjour et al 2013

GDP per capita (Int'l $)
IHME 2013

Average HH Size
GACC 2013 • UNPD

User Inputs

Pre-Intervention & Post-Intervention PM Exposures

# of Target HH, Fraction Receiving, Fraction Using

Intervention & Maintenance Costs

Years to deploy & intervention life

Relative Risks + PAFS

Calculate relative risks for each disease at each user-input exposure level using mathematical functions fit to exposure-response data.

Calculate population attributable fractions for each disease at each exposure level.

Attributable Burden

Calculate attributable burdens for each exposure scenario.

Averted Burden

Subtract post-intervention deaths and DALYs from pre-intervention values to determine the health benefits of the intervention

BETA

Relative Risks + PAFS

Calculate relative risks for each disease at each user-input exposure level using mathematical functions fit to exposure-response data.

Calculate population attributable fractions for each disease at each exposure level.

↓

Attributable Burden

Calculate attributable burdens for each exposure scenario.

↓

Averted Burden

Subtract post-intervention deaths and DALYs from pre-intervention values to determine the health benefits of the intervention

Relative risks are derived from equations fit to the Integrated exposure response curves.

$$AF = \frac{\text{Fraction Exposed} * (RR-1)}{\text{Fraction Exposed} * (RR-1) + 1}$$

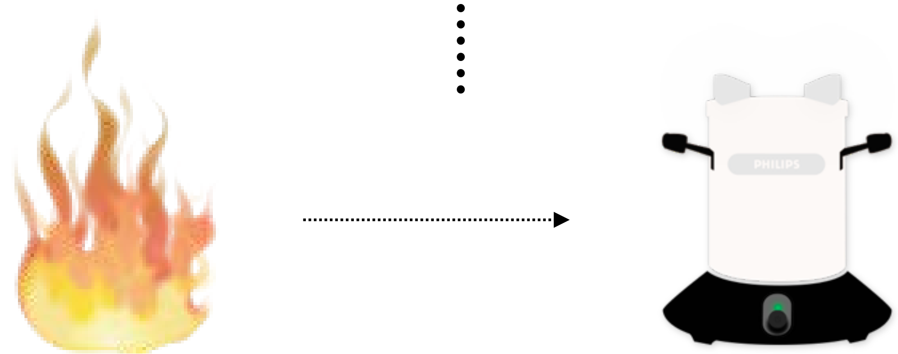
Fraction Exposed = % Solid Fuel Users

Attributable burden = AF × (DALYs or Deaths)

Repeat for both post-intervention and pre-intervention PM levels. Subtract post-intervention burden from pre-intervention burden to determine averted burden.

BETA

Advanced Cookstove Introduction



HAPIT BETA

Cookstove Intervention

Pre-intervention exposure: 266 ug/m3

Targeted households: 25,000

People per household: 5

Annual Maintenance Costs: 10% of first year cost

100% of targeted households receive intervention

Six Scenarios

1.Chimney Stove - Post-intervention exposure: 150 ug/m3 – 10 USD / stove

2.Advanced Stove - Post-intervention exposure: 50 ug/m3 – 50 USD / stove

3.Advanced Stove - Post-intervention exposure: 30 ug/m3 – 75 USD / stove

Each first with 100% usage and then with 50% usage

BETA

Cookstove Intervention

	Scenario I		Scenario 2		Scenario 3	
	150 ug/m3		50 ug/m3		30 ug/m3	
Exposure Reduction	44%		81%		89%	
Yearly Cost (USD)	66,667		333,333		500,000	
Intervention Use	50%	100%	50%	100%	50%	100%
Averted Annual DALYs	232	465	987	1975	1401	2803
Remaining Annual DALYs	4070	3837	3315	2327	2901	1499
% DALYs remaining	95%	89%	77%	54%	67%	35%
$ / DALY	287	143	338	169	357	178
WHO-CHOICE CE	VCE	VCE	VCE	VCE	VCE	VCE

BETA

Thank you

for more information on HAPIT

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HAPIT 2

Online version of HAPIT built using the following:

– R, the open-source, free stats programming environment

– Shiny, an R package and web framework allowing creation of interactive data processors and visualizers

– jQuery, an open-source and free javascript library

Focuses on allowing comparison of multiple user-defined interventions

– Contains a number of default intervention scenarios (for LPG, rocket stoves, chimney stoves, etc)

– Users can add and remove interventions easily

Any analysis or function that can be implemented in R can be presented and manipulated in a web browser

Runs locally on a laptop or over the internet

HAPIT

caveats & next steps

Provide additional versions

- sub-national regions (geographic, state boundaries, etc)
- by poverty/income quintiles

Leverage GBD data from IHME to propagate uncertainty throughout estimates

Include all GBD countries

Dynamic linking to GBD country data (any updates reflected instantly in HAPIT / R-HAPIT)

Differentiate potential benefits by sex

Explore ways to include disease categories not currently included in GBD assessment – including cataract, tuberculosis, low birth weight, and others

BETA

HAPIT

caveats & next steps

Build in more sophisticated lag models to better and more accurately describe ‘achieved’ health benefits

Consider optional, commercial modules in Excel to allow for Monte Carlo analysis

Prepare for GBD 2013 updates