Household Air Pollution and Health in Laos

Kirk R. Smith and Ajay Pillarisetti
Household Energy, Climate, and Health Program
School of Public Health
University of California, Berkeley

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
Total Population Cooking with Solid Fuels

Bonjour et al., CRA-2010
1990:
85%: 700 million people using solid fuels

2010:
60%: 700 million people

~1980
700 million people in entire country
<table>
<thead>
<tr>
<th>Year</th>
<th>Total Pop - million</th>
<th>Percent solid fuel</th>
<th>Solid fuel users</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>4.2</td>
<td>96%</td>
<td>4.0</td>
</tr>
<tr>
<td>2000</td>
<td>5.3</td>
<td>95%</td>
<td>5.0</td>
</tr>
<tr>
<td>2010</td>
<td>6.2</td>
<td>94%</td>
<td>5.8</td>
</tr>
</tbody>
</table>
Woodsmoke is natural – how can it hurt you?

Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn’t it just change to CO₂ and H₂O 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
2.8 MJ
18%

In PIC
1.2 MJ
8%

Waste Heat
11.3 MJ
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, NO₂
- Hydrocarbons
  - 25+ saturated hydrocarbons such as n-hexane
  - 40+ unsaturated hydrocarbons such as 1,3 butadiene
  - 28+ mono-aromatics such as benzene & styrene
  - 20+ polycyclic aromatics such as benzo(α)pyrene
- Oxygenated organics
  - 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

Source: Naehler et al, J Inhal Tox, 2007

Typical chullah releases 400 cigarettes per hour worth of smoke
First person in human history to have her exposure measured doing the oldest task in human history

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

Emissions and concentrations, yes, but what about exposures?

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

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 Zœe 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 Group¹

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

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

Note: The table compares the leading causes of burden in 1990 and 2010 for Laos, listing the top 20 causes with their respective rankings and percentages of the total burden.
Comparative Risk Assessment Method

Exposure Levels:
Past actual and past counterfactual

Exposure-response Relationships (risk)

Disease Burden
by age, sex, and region

Attributable Burden by age, sex, and region
State-wise estimates of 24-h kitchen concentrations of PM2.5 in India

Solid-fuel using households

Balakrishnan et al. 2013 (SRU group)
“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

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

- ALRI/Pneumonia
- COPD
- Lung cancer (coal)
- Lung cancer (biomass)
- Cataracts
- Ischemic heart disease
- Stroke
Global DALYs 2010: Top 20 Risk Factors

Premature Deaths
- 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
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.
18% of primary particle pollution in SE Asia is from household fuels.

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

From “Mind the Gap,” Smith/Peel, 2010 and Pope et al., 2009
Integrated Exposure-Response: Ischemic Heart Disease

Smokers

Outdoor Air Pollution

Secondhand Tobacco Smoke

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

Child pneumonia

WHO air quality annual guideline: 10 µg/m³
IT1: 35 µg/m³

Risk

If you start here
Even if you get here
It leaves ~80% of burden untouched

PM2.5 Exposure

LP
G25
Fan
Rocket
‘Chimney
O/Fire

125
200
300 µg/m³
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
How do we help people move into this realm?
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
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
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.
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

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 + PAFS

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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.

\[
AF = \frac{\text{Fraction Exposed} \times (\text{RR}-1)}{\text{Fraction Exposed} \times (\text{RR}-1) + 1}
\]

\[
\text{Fraction Exposed} = \% \text{ Solid Fuel Users}
\]

Attributable burden = \( AF \times (\text{DALYs or Deaths}) \)

Repeat for both post-intervention and pre-intervention PM levels. Subtract post-intervention burden from pre-intervention burden to determine averted burden.
Advanced Cookstove
Introduction
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
# Cookstove Intervention

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Exposure Reduction</th>
<th>Yearly Cost (USD)</th>
<th>Intervention Use</th>
<th>Averted Annual DALYs</th>
<th>Remaining Annual DALYs</th>
<th>% DALYs remaining</th>
<th>$ / DALY</th>
<th>WHO-CHOICE CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>44%</td>
<td>66,667</td>
<td>50%</td>
<td>232</td>
<td>4070</td>
<td>95%</td>
<td>287</td>
<td>VCE</td>
</tr>
<tr>
<td>150 ug/m3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>81%</td>
<td>333,333</td>
<td>100%</td>
<td>987</td>
<td>3315</td>
<td>77%</td>
<td>143</td>
<td>VCE</td>
</tr>
<tr>
<td>50 ug/m3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>89%</td>
<td>500,000</td>
<td>50%</td>
<td>1401</td>
<td>2901</td>
<td>67%</td>
<td>357</td>
<td>VCE</td>
</tr>
<tr>
<td>30 ug/m3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>178</td>
<td></td>
</tr>
</tbody>
</table>

**Notes:**
- The table compares three scenarios for a cookstove intervention, with different exposure levels and associated metrics such as exposure reduction, yearly cost, intervention use, averted DALYs, remaining DALYs, percentage of DALYs remaining, and cost per DALY.
- The WHO-CHOICE CE column indicates the cost-effectiveness classification, with VCE typically indicating value for money.
Thank you for more information on HAPIT

Ajay Pillarisetti
ajaypillarisetti@gmail.com

Kirk R. Smith
krksmith@berkeley.edu
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
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