Presentation to

CONSULTATIVE MEETING ON GLOBAL ACTION PLAN FOR PREVENTION AND CONTROL OF PNEUMONIA (GAPP)

UNICEF/WHO

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Exposure to indoor air pollution from solid fuels and risk of childhood pneumonia:

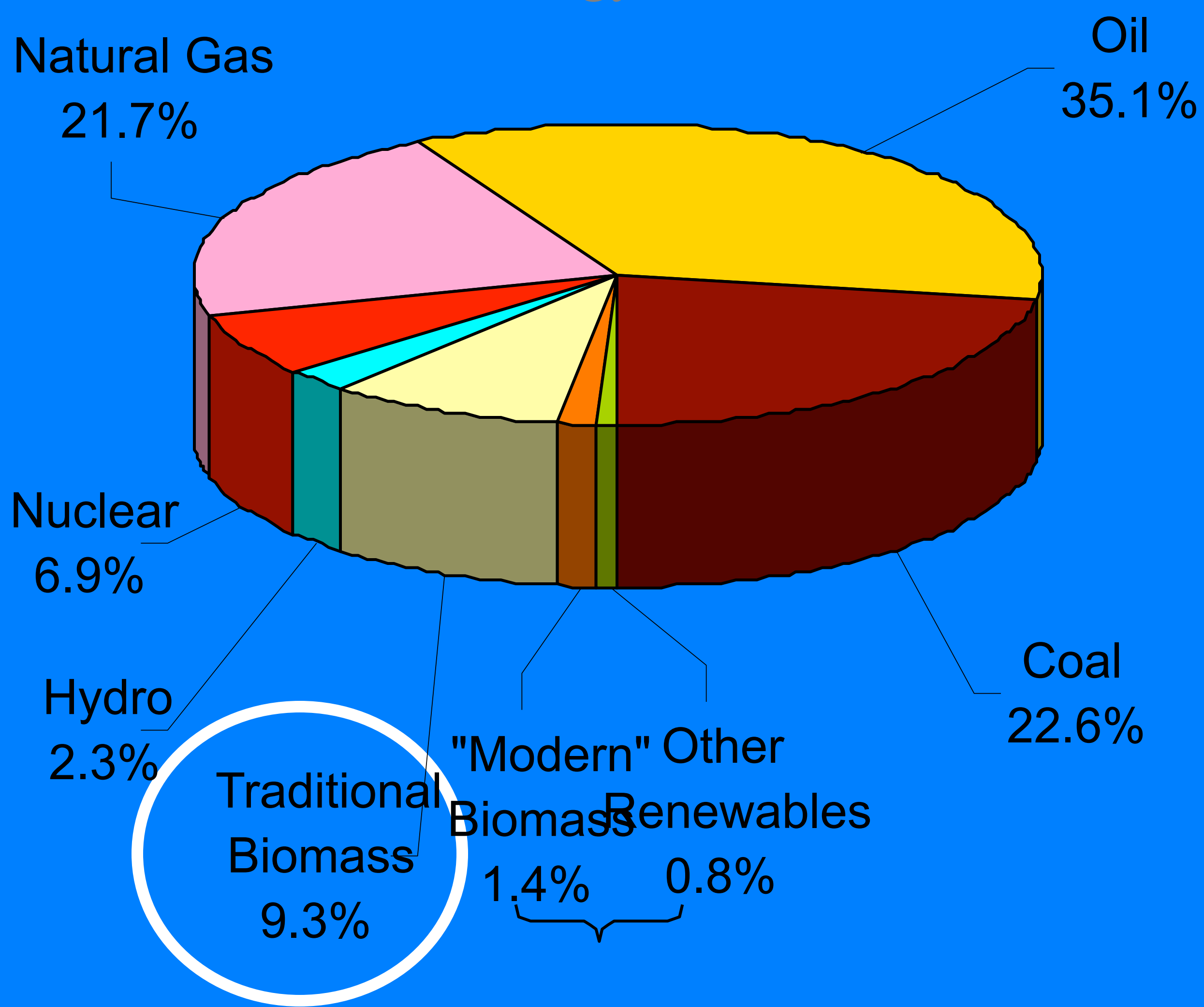
Background and review of evidence

Kirk R. Smith and Nigel Bruce

Overview

- Sources of IAP
- Pollutants and known health risks
- Geographic and socio-economic patterns of solid fuel use and burden of exposure
- Levels of pollution and exposure
- Systematic review and meta-analysis of risk for childhood ALRI
- Other recent studies
- Burden of disease estimates (ALRI)
- Discussion and conclusions
- Rationale for doing Randomized Control Trial

World Energy - 2001



6.1 billion people

World Energy Assessment – 2004

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 Indian cooking stove

Wood: 1 kg

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

Indoor Air Pollution from Cooking and Heating with Solid Fuels

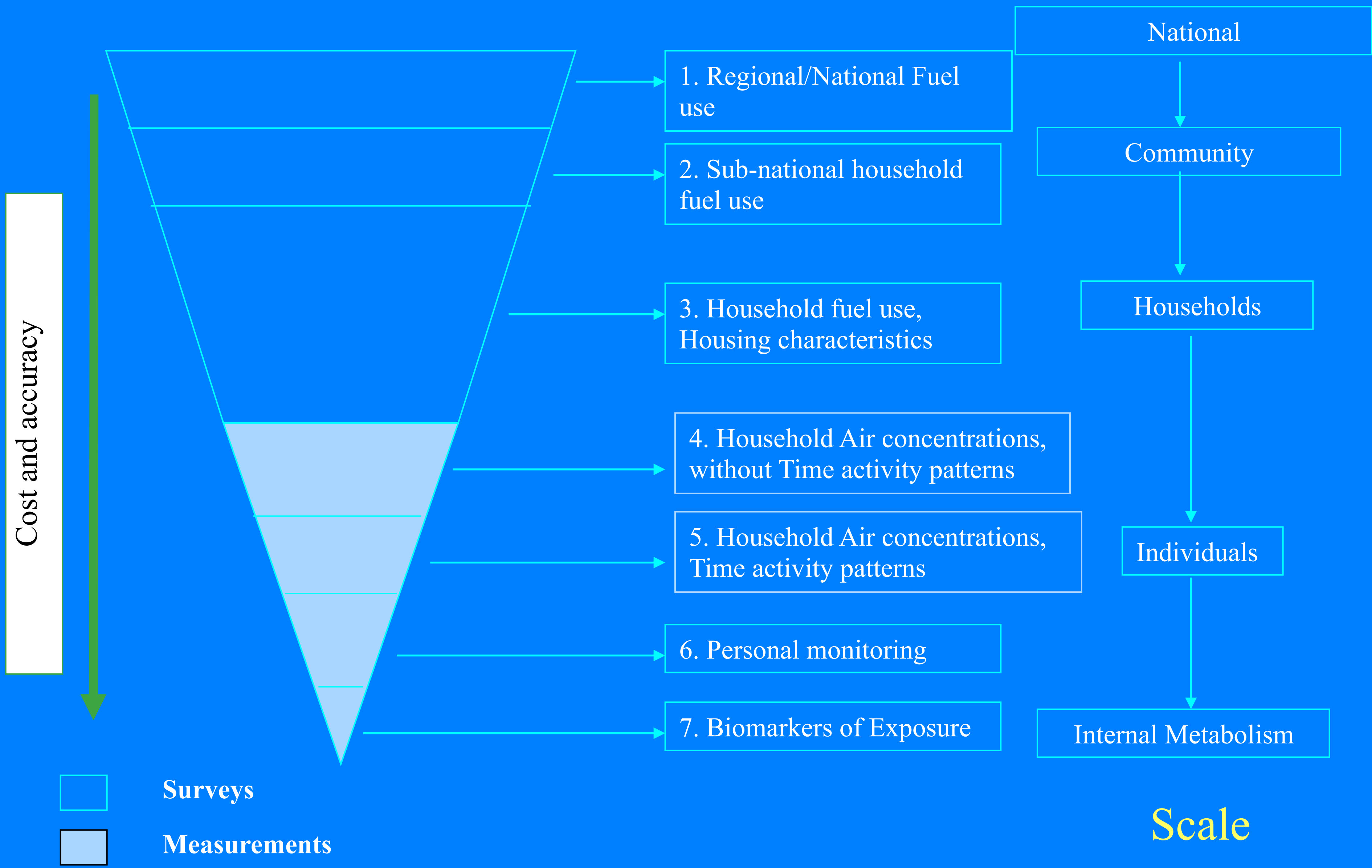
- Solid fuels: dung, wood, agricultural residues, charcoal, coal
- Largest traditional source of indoor air pollution (over half the world)

Solid fuels + poor ventilation / inefficient stoves
→ high concentrations of a complex mix of health damaging pollutants, including PM, CO, R-CH, NO_X

- Women and young children, who spend most time indoors at home, experience largest exposure burdens

First person in human history to have her exposure measured doing one of the oldest tasks in human history

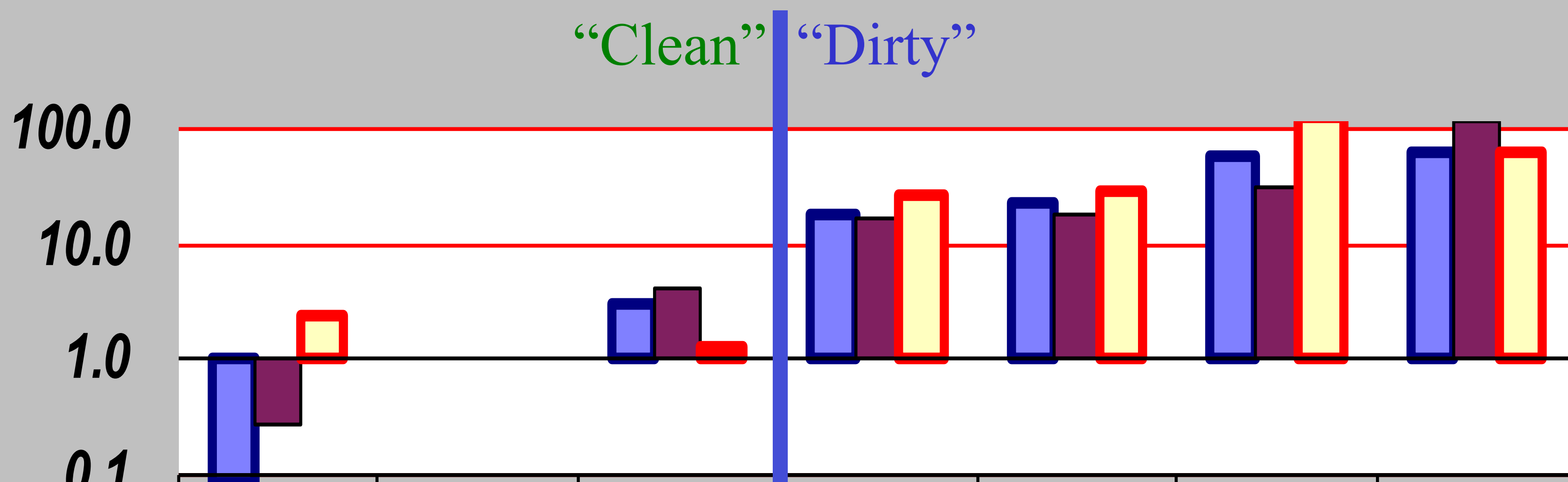
Exposure Pyramid: Example of Indoor Air Pollution from Solid Fuel Use



Health Effects of Indoor Air Pollution From Solid Fuel Use

- Relative risk estimates based on crude exposure classifications of exposure (whether solid fuels used for cooking or heating)
- Strong evidence: ALRI, COPD (women), lung cancer (coal)
- Moderate evidence: lung cancer (biomass), COPD (men), asthma, blindness (cataract), tuberculosis
- Limited evidence: adverse pregnancy outcomes, cardiovascular disease, trachoma

The Energy Ladder: Relative Pollutant Emissions Per Meal

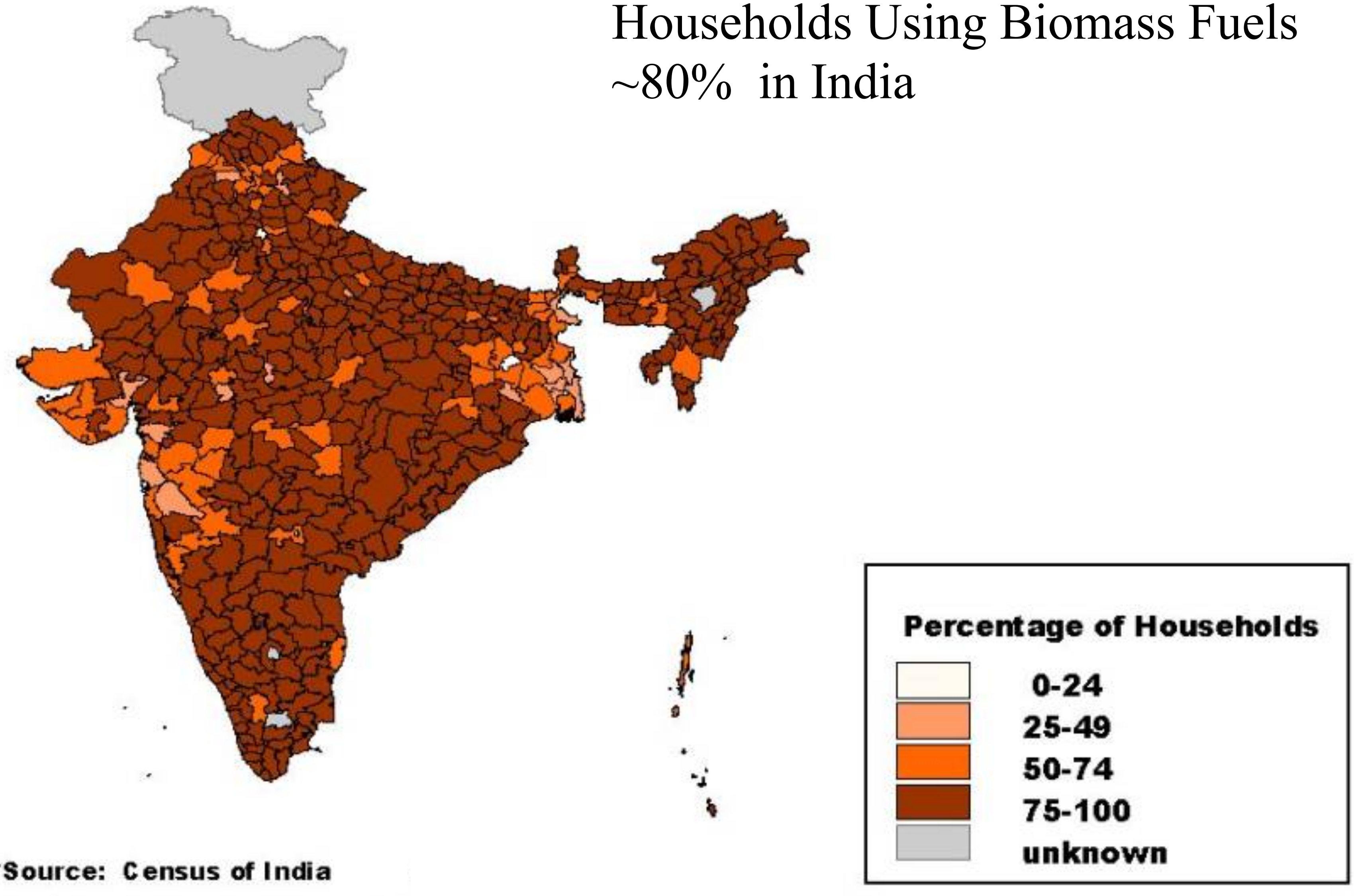


	Biogas	LPG	Kerosene	Wood	Roots	Crop Residues	Dung
CO	0.1	1.0	3	19	22	60	64
Hydrocarbons	0.3	1.0	4.2	17	18	32	115
PM	2.5	1.0	1.3	26	30	124	63

CO **Hydrocarbons** **PM**

Smith, et al., 2005

Households Using Biomass Fuels ~80% in India



*Source: Census of India

Final Fuel Prediction Model

- Parameters:

	Standardized Coefficients			95% Confidence Interval for B	
	Beta	t	Sig.	Lower	Upper
(Constant)		3.1926	0.0025	0.4135	1.8223
RURAL	0.3527	3.0938	0.0033	0.2312	1.0908
EMR	-0.2838	-3.4968	0.0010	-0.3904	-0.1053
LNGNP	-0.2646	-2.5648	0.0136	-0.1852	-0.0224
per capita Petroleum Use	-0.2244	-2.5454	0.0143	-0.0006	-0.0001

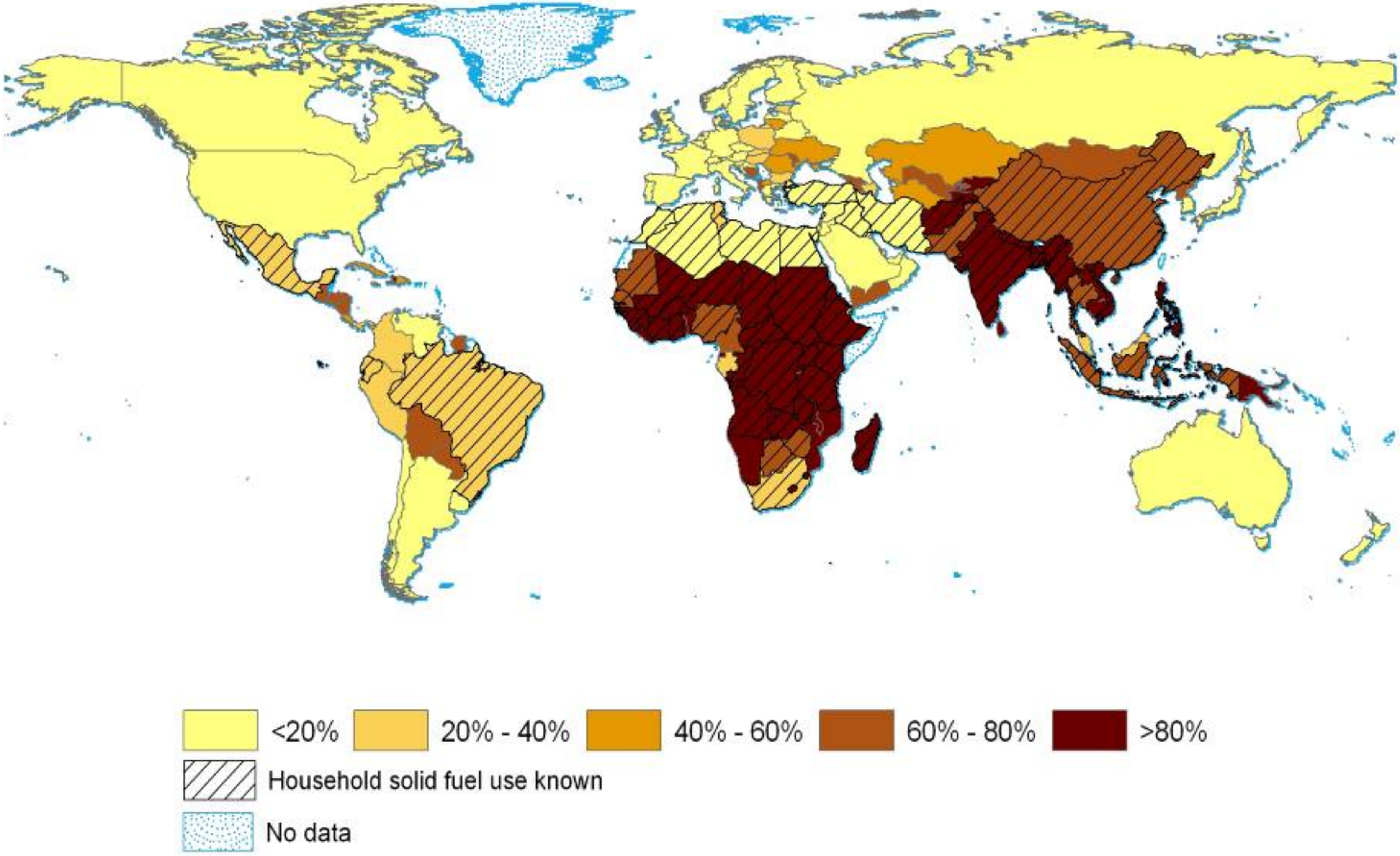
- Model Summary:
  - R: 0.8637
  - R^2: 0.7460
  - Adjusted R^2: 0.7244
  - Standard Error of the Estimate: 0.1891
- Model meets assumptions of norma variance.
- Collinearity and Tolerance also assessed.

ln GNP/cap
Percent Rural
Petroleum use
Eastern Mediter.

Sample Model Results: Solid Fuel Use by WHO Region

Region	Population	Solid Fuel Use
Africa – Poor	300 million	73%
Africa – V Poor	338	84
Americas - Rich	321	1.5
Americas - Mid	431	25
Americas - Poor	71	53
Near East - Mid	140	6.1
Near East - Poor	357	54

National Household Solid Fuel Use, 2000



Indoor Air Pollution and ALRI

- We cannot determine the risk associated with specific pollutants or concentrations of pollutants
  - Binary exposure categories → no exposure-response curve
  - Misclassification of exposure is differential (misclassification of unexposed) → bias towards the null
- Practical application of the result: used to quantify the risk-factor disease relationship in CRA for indoor air pollution

Identification of Studies

- Systematic literature search: review articles, MEDLINE, bibliographies of retrieved articles, personal communication
- Eligibility criteria:
  - Primary studies, not re-analyses or reviews
  - Examine either ARI, ALRI, or death due to ARI or ALRI in children under five years of age as outcome
  - Examine some proxy for exposure to indoor smoke from the use of solid fuels for cooking and/or heating purposes
  - Report an odds ratio and its variance or sufficient data to estimate them
  - Written or abstracted in English.

Identification of Studies

Results of search: 567 references

- 143 were considered
- 15 studies met initial criteria for inclusion
- 8 studies included in the analysis

Some characteristics of excluded studies

- Extremely low prevalence of exposure (6% in one study)
- Inappropriate exposure classification (households with ineffective improved stoves classified as unexposed)
- One study classified exposures to cooking fuels, but did not address exposures to charcoal heating in the population
- Cause-specific deaths not reported for pneumonias

IAP and Childhood ALRI: Studies included in Meta-Analysis

- **9 Case-control:** South Africa, Zimbabwe, *Nigeria, Tanzania, Gambia, *Brazil, *India, Argentina 6 adjusted for confounders; *n* = 4311; Odds Ratios = 2.2-9.9
- **3 Cohort:** Nepal, Gambia 2 adjusted for confounders; *n* = 910; Odds Ratios = 2.2-6.0
- **1 Case-fatality:** Nigeria Hospitalized patients; *n* = 103; Odds Ratio = 8.2
- **2 US Case-control**; *n* = 206 Adjusted for confounders. Odds Ratios = 4.8

Included Studies

- 2 cohort, 6 case-control
- 6 from developing countries (Gambia, Zimbabwe, Nigeria, Nepal)
- 2 from Native American populations
  - Concern: these studies most likely to differ in their socio-economic characteristics
  - Overall odds ratio did not change substantially when these studies excluded
    - Including studies: OR= 2.0 (95% CI: 1.7, 2.4)
    - Excluding studies OR= 2.0 (95% CI: 1.7, 2.3)
  - Subsequent analysis performed including these studies

Systematic review: studies (1):

Country, yr, author	Design	Number and population	Exposure	Outcome	Adj	OR (95%CI)
Argentina 90 (Cerquiero)	Case-control	616, 669 Children <5yr	Questions on fuel type	ALRI last 12 days, clinic	No	9.9 (1.8, 31.4)
Brazil 94 (Victora)	Case-control	510, 510 Children <2yr	Question on indoor smoke	Hospital ALRI, clinical, CXR	Yes	1.1 (0.6, 2.0)
Gambia 91 (Armstrong)	Cohort	500 Children <5yr	Child on back while cooking	ALRI at weekly home visits	Yes	M: 0.5 (0.2, 1.2) F: 1.9 (1.0, 3.9)
Gambia 89 (Campbell)	Cohort	271 Children <1yr	Child on back while cooking	ALRI at weekly home visits	Yes	2.8 (1.3, 6.1)
Gambia 93 (de Francisco)	Case-control	129, 270 Children <2yr	Child on back while cooking	Death from ALRI by VA	Yes	5.2 (1.7, 15.9)
Gambia 96 (O' Dempsey)	Case-control	80, 159 Children <5yr	Child on back while cooking	Hospital ALRI, clinical, CXR, laboratory	Yes	2.5 (1.0, 6.6)
India 94 (Shah)	Case-control	400 Children ≤5yr	Stove produces smoke	Severe ARI hospital cases	Yes	1.2 (0.7, 2.3)

[yellow box] = included in meta-analysis

Systematic review: studies (2)

Country	Design	Number and population	Exposure	Outcome	Adj	OR (95%CI)
Kenya 01 (Ezzati)	Cohort	93 Children <5yr	Daily PM_{10} exposure	Weeks with ALRI criteria	Yes	2.93 (1.34, 6.39)
Nepal 89 (Pandey)	Cohort	280 Children <2yr	Time near fireplace	ARI by bi-weekly home visits	No	2.3 (1,8, 2.9)
Nigeria 92 (Johnson)	Case-control	103, 103 Children <5yr	Type of fuel used	Hospital ALRI, clinical, CXR, lab	No	0.8 (0.4, 1.7)
S Africa 82 (Kossove)	Case-control	132, 18 Children $\leq$1yr	Child stays in smoke	Hospital ALRI, clinical, CXR	No	4.8 (1.7, 13.6)
Tanzania 92, (Mtango)	Case-control	456, 1160 Children <5yr	Child sleeps in cooking room	Death all causes by VA and MD	Yes	2.8 (1.8, 4.3)
USA 90 (Morris)	Case-control	58, 58 Children <2yr	Main source: heating, cook	Hospital ALRI, clinical, CXR	Yes	4.9 (1.7, 12.9)
USA 96 (Robin)	Case-control	45, 45 Children <2yr	Use wood for cooking	Hospital ALRI	Yes	5.0 (0.6, 42.8)
Zimbabwe 90 (Collings)	Case-control	244, 500 Children <3yr	Open wood fire to cook	Hospital ALRI, clinical, CXR	Yes	2.2 (1.4, 3.3)

Meta-analyses

- Followed general principles of Greenland
- Heterogeneous exposure measurements and diverse analytical strategies used by investigators (especially control of confounding)

→ A single statistical analysis not appropriate
  - Several meta-analyses conducted for different sub-groupings of studies
  - Results remarkably consistent, with pooled relative risk estimates increasing with increased precision of exposure

Sub-analysis: Exposure assessment

1. Carrying child on the back during cooking (more specific)
2. Use of solid fuels for cooking or heating

	OR (f)	95% CI	OR (r)	95% CI
Carrying the child on the back	3.1	1.8, 5.3	3.1	1.8, 5.3
Use of solid fuels for cooking or heating	2.0	1.4, 2.8	2.1	1.0, 4.7

OR (f): Odds ratio from fixed effects model
OR (r)> Odds ratio from random effects model

Sub-analysis: *Age*

- Almost all studies adjusted for age
- Results of sub-analysis suggest a stronger effect in younger children

	OR (f)	95% CI	OR (r)	95% CI
Age < 24 months	2.5	2.0, 3.0	2.6	2.0, 3.5
Age 0-59 months	1.8	1.3, 2.5	1.7	0.8, 3.2

OR (f): Odds ratio from fixed effects model
OR (r)> Odds ratio from random effects model

Sub-analysis: Nutritional Status

- Malnutrition is a major risk factor for ARI
- Three studies adjusted for nutritional status
- Studies that did not adjust for nutritional status may overestimate the association between indoor air pollution and ARI.
- Studies that adjusted for nutritional status had the most precise exposure measure (carriage on the mother's back)

	OR (f)	95% CI	OR (r)	95% CI
Adjusted for nutritional status	3.1	1.8, 5.3	3.1	1.8, 5.3
Not adjusted for nutritional status	2.2	1.8, 2.6	2.1	1.4, 3.2

OR (f): Odds ratio from fixed effects model
OR (r)> Odds ratio from random effects model

Summary of Sub-analyses

	OR (f)	95% CI	OR (r)	95% CI
All studies	2.3	1.9, 2,7	2.3	1.7, 3.2
Carrying the child on the back	3.1	1.8, 5.3	3.1	1.8, 5.3
Use of solid fuels for cooking or heating	2.0	1.4, 2.8	2.1	1.0, 4.7
Adjusted for nutritional status	3.1	1.8, 5.3	3.1	1.8, 5.3
Not adjusted for nutritional status	2.2	1.8, 2.6	2.1	1.4, 3.2
Age < 24 months	2.5	2.0, 3.0	2.6	2.0, 3.5
Age 0-59 months	1.8	1.3, 2.5	1.7	0.8, 3.2

OR (f): Odds ratio from fixed effects model
OR (r)> Odds ratio from random effects model

Practical Application to CRA

- As we could not separate better exposure measures from adjustment for nutritional status, we used the combined odds ratios from all eight studies in the CRA.
- This is consistent with:
  - Difference between exposure measures (less vs. more precise)
  - Differences between age groups (GBD does not differentiate within the 0-5 age group). Note that around 2/3 of ARI in the final model occurs in <24 month age group, similar to age distribution of ARI in many areas.

Burden of disease from biomass fuel (ALRI)

Subregion	Deaths (000s)	DALYs (000s)
AFR - D	**153**	**5221**
AFR - E	**198**	**6746**
AMR - A	0	1
AMR - D	6	291
AMR - D	9	314
EMR – B	2	59
EMR – D	**94**	**3306**
EUR – A	0	0
EUR - B	12	417
EUR – C	1	22
SEAR – B	19	761
SEAR – D	**355**	**12506**
WPR – A	0	0
WPR - B	**62**	**2275**
World	**910**	**31919**

Global Burden from Indoor Air Pollution

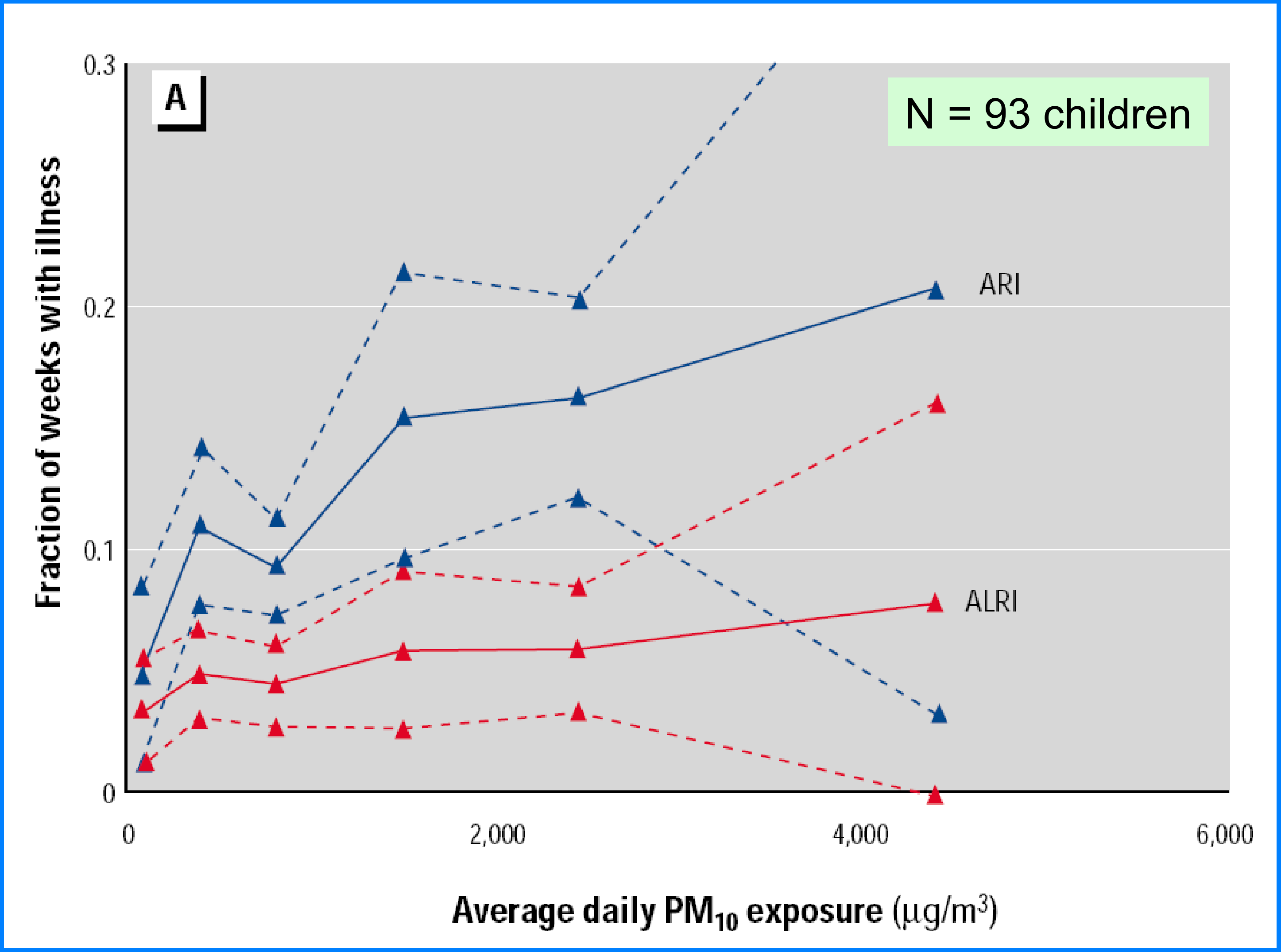
	AF (%)	Deaths (thousands)	YLLs /death
ALRI (<5 y)	36	1020	30.0
COPD	22	588	6.5
Lung Cancer	1	12	8.8
Total-indoor	--	1620	21.6
Total-outdoor	--	804	8.0

Other recent studies

- Not included in meta-analysis, hence did not contribute to risk estimates for CRA
  - India: Broor et al. 2001
  - Kenya: Ezzati et al. 2001
  - Zimbabwe: Mishra 2003
  - India: Mahalanabis et al. 2003
  - India: Mishra et al. 2005
  - Other?
- All showed significant effects, with no large differences from MA results.

Kenya (cohort study)

Unadjusted exposure-response (ages 0-4 years)



Ezzati M and Kammen D (2001)

Zimbabwe – DHS

- Demographic and Health Survey
- Zimbabwe (1999)
- Analysis of 3559 children aged 0-59 months
- ALRI: respondent recall of cough with short, rapid breathing in prior 2 weeks
- Exposure: type of fuel (biomass vs. clean fuel)
- Multivariate logistic regression: OR = 2.20 (95% CI: 1.16, 4.19)
- Potential limitations of study design and ALRI definition (2-week prevalence of 15.8% is high for true ALRI)

Mishra 2003

How Does This Compare to the Largest Modern Source of IAP?

Environmental tobacco smoke (ETS)

Similarities between the sources:

- Both are result of incomplete combustion of biomass in inadequately ventilated households
- Similar chemical and physical characteristics and potential intervention approaches
- Both address exposure to "smoke" rather than a specific agent→ studies included in the meta-analyses rely on proxies for exposure
- In most cases, subjects are classified as exposed or unexposed based on binary categories of exposure

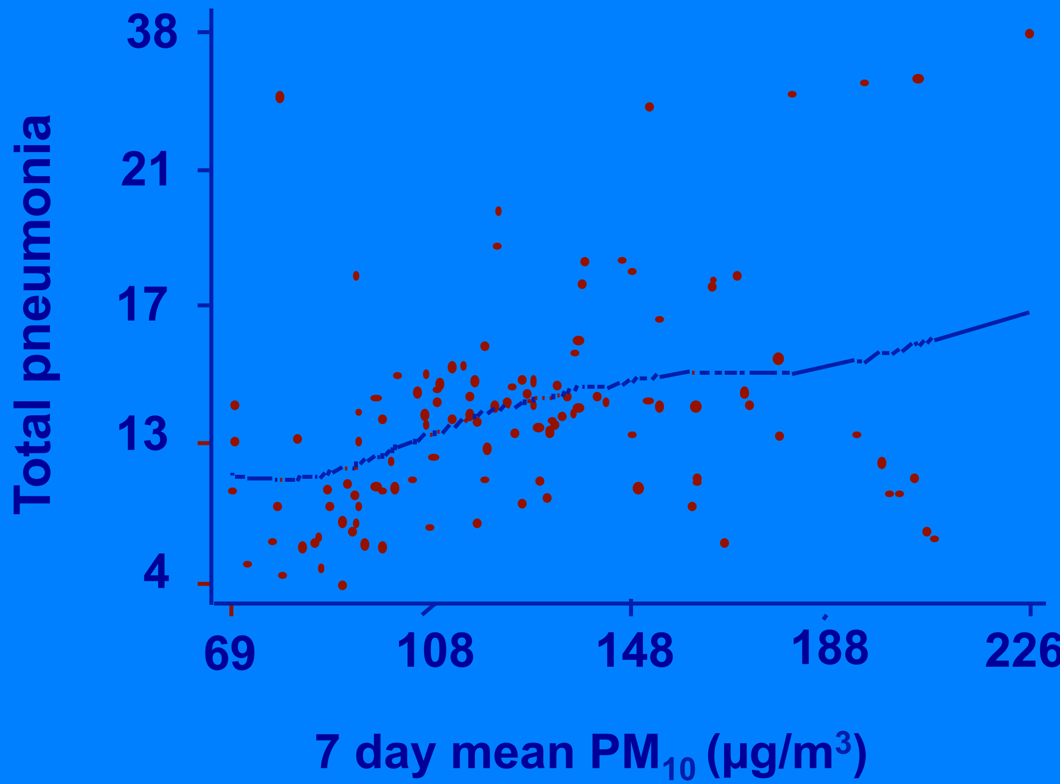
Solid Fuel Use vs. ETS

Exposure Intensity	Solid Fuel Use		Environmental Tobacco Smoke	
	Exposure Proxy	OR (95% CI)	Exposure Proxy	OR (95% CI)
Low	Use of solid fuels for cooking or heating (4 studies)	2.0 (1.4, 2.8)	Paternal smoking (4 studies)	1.3 (1.2, 1.5)
Intermediate	Child remains indoors during cooking (studies with this proxy excluded for methodological reasons	Not applicable	Parental smoking (11 studies)	1.5 (1.4, 1.6)
High	Carriage on mother's back during cooking (3 studies)	3.1 (1.8, 5.3)	Maternal smoking (7 studies)	1.6 (1.4, 1.7)

ETS: Strachan and Cook, 1997

Outdoor Air Pollution

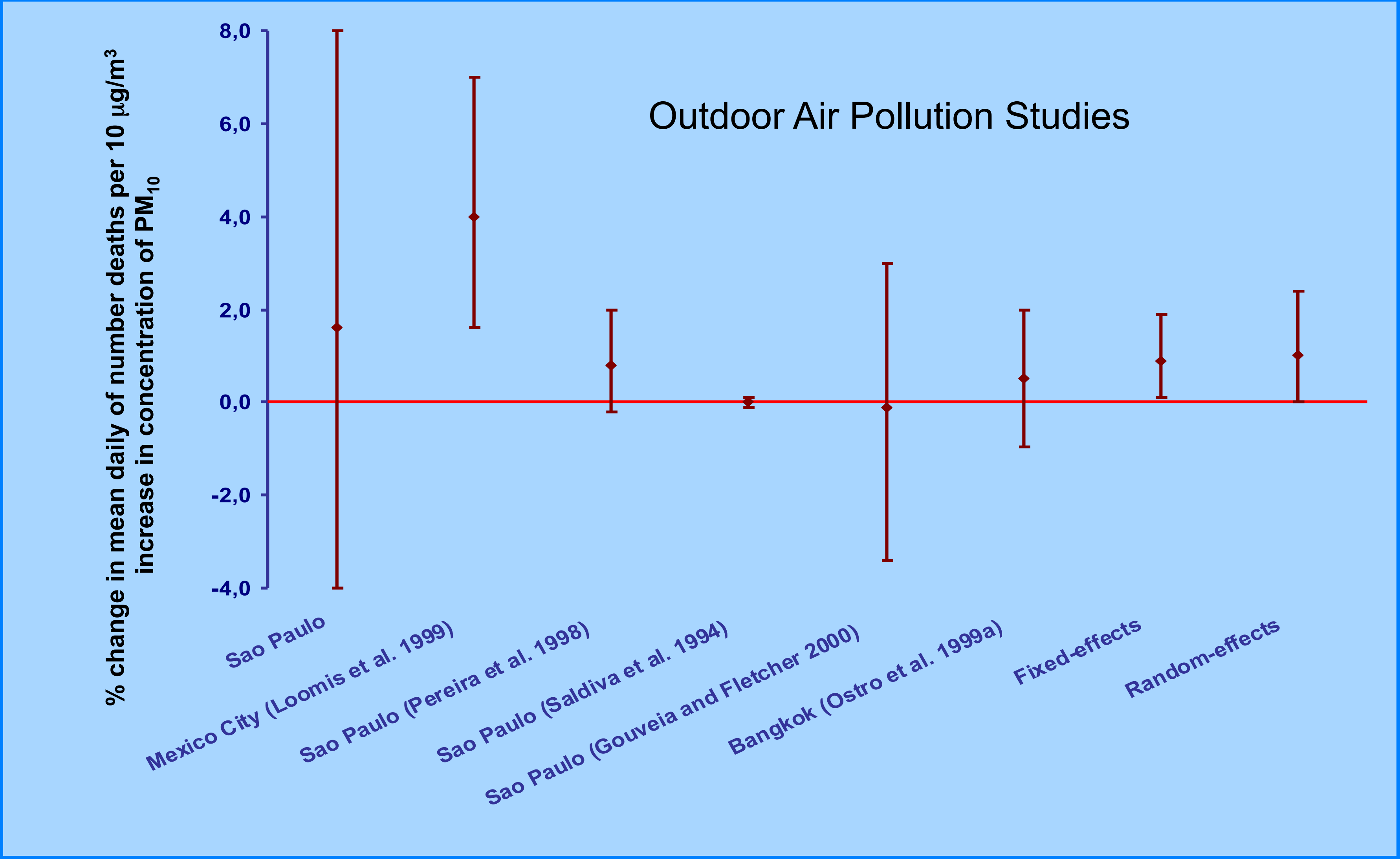
Number of daily emergency visits for child pneumonia, Santiago, Chile



Adjusted for time (time)^2, (time)^3, (time)^4, week-day/weekend, minimum temperature, (mintemp)^2, relative humidity, months, epidemic

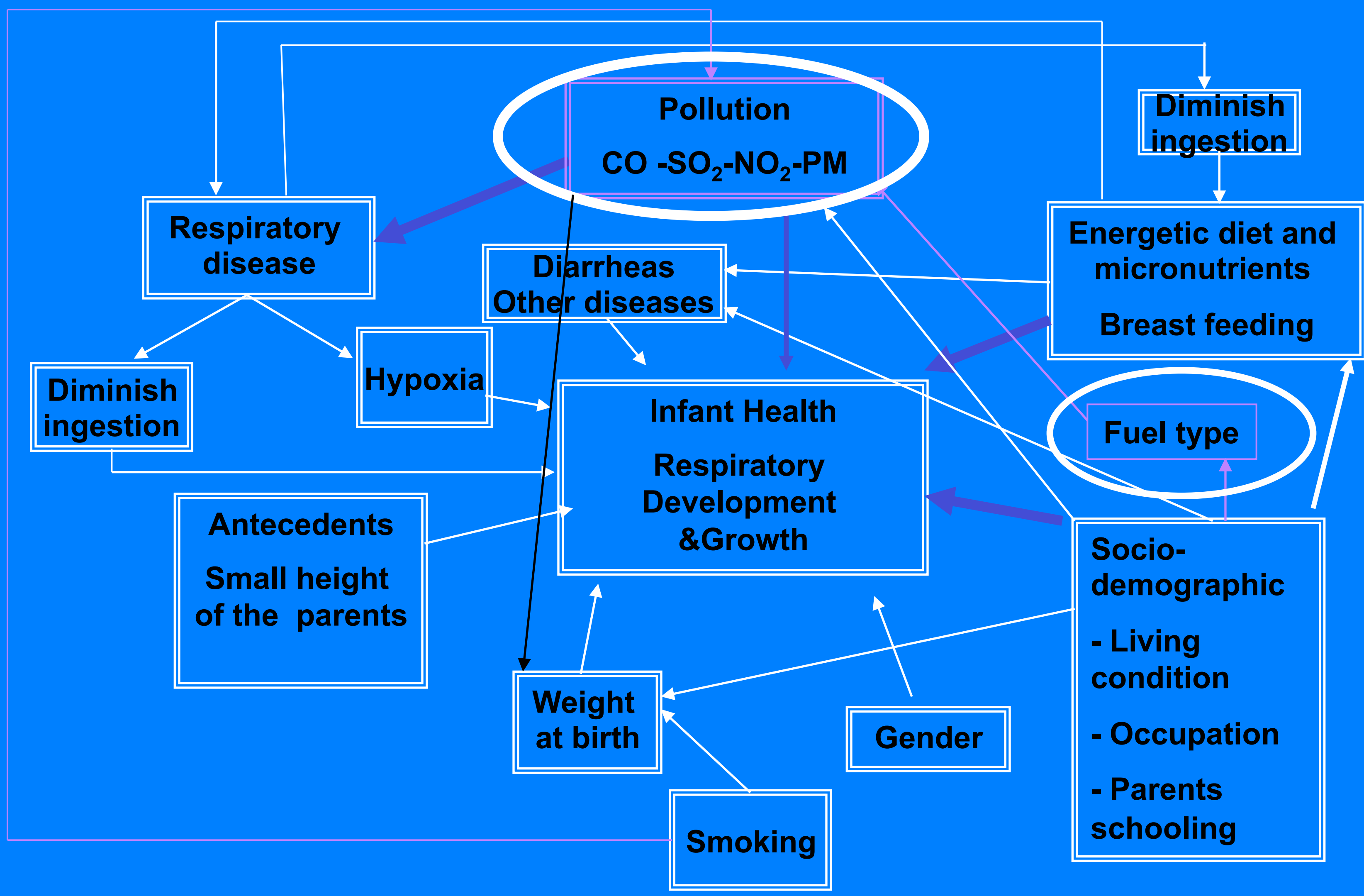
Ilabaca et al., JAWMA, 1999

Percentage change in non-accidental deaths, in children, per 10 $\mu g/m^3$ increase in outdoor PM_{10}



Cohen et al in WHO, Comparative quantification of health risks, 2004

Biological model for infant health



Rationale for RCT

- Evidence to date observational:
  - Problem of (residual) confounding
  - ‘Competing’ with RCT evidence
- ALRI definition and case-finding:
  - Varies from WHO pneumonia (sensitive) to clinical with CXR (specific)
  - Few (none) used highly specific case definition with community case-finding
- No direct exposure measurement
- No studies have measured the health impact of a feasible intervention

Acute Respiratory Infections in the World – 2002
In Children 0-5 years

Acute Lower Respiratory Infections (ALRI) +
Acute Upper Respiratory Infections (AURI)

Incidence/100,000	ALRI	AURI	ALRI/AURI
World	41,000	536,000	0.08
OECD	3,000	450,000	0.01
India	45,000	700,000	0.06
Ratio Poor/Rich	15	1.6	

In India, if an ALRI assessment method is 82% sensitive and 88% specific,* then only 31% of the ALRI found by the method is actually ALRI

The rest is probably AURI or nothing!

*Average of three best studies

WHO, Global Burden of Disease Database

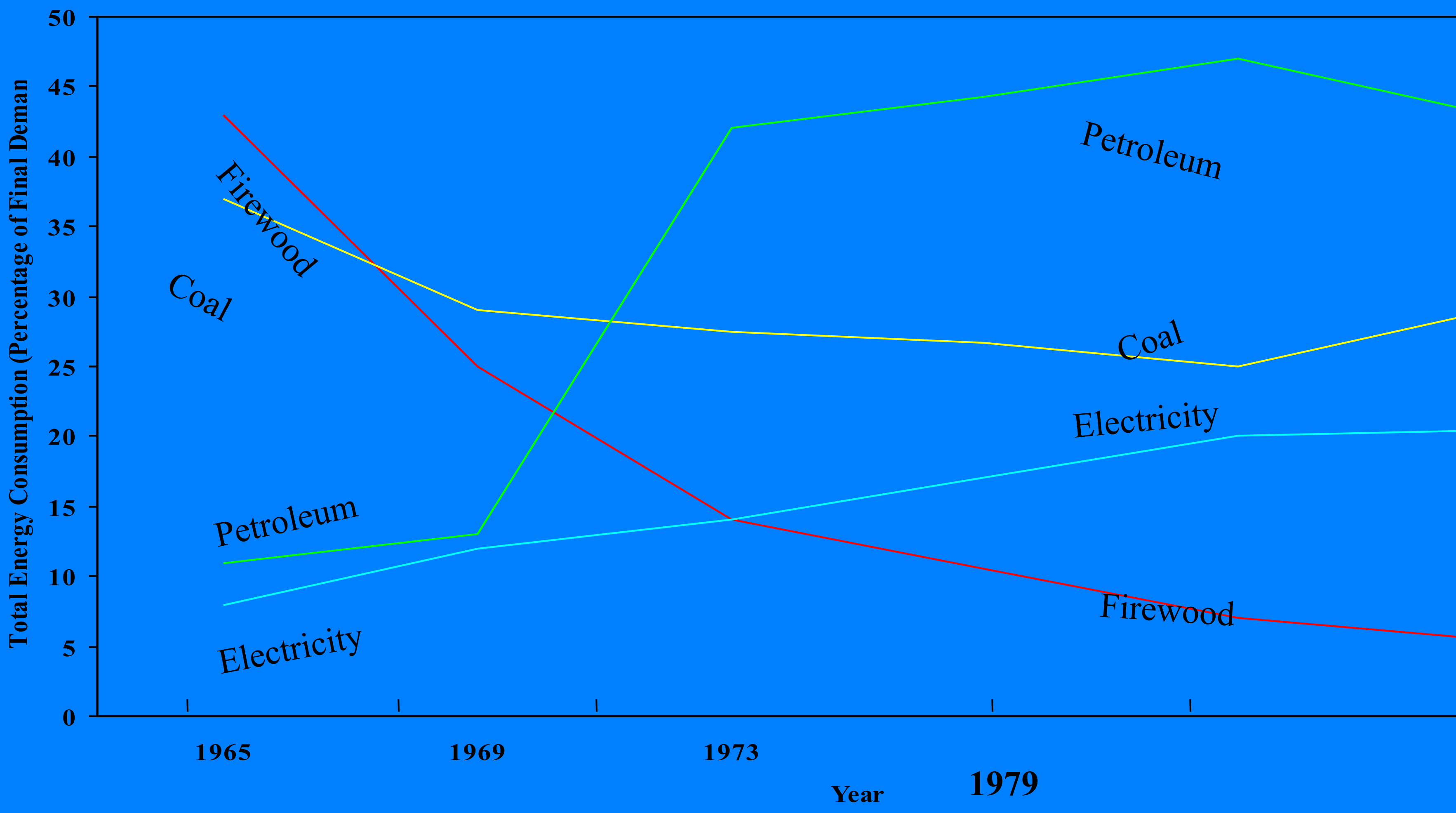
History of the RCT

- ~1980: early accounts of health effects in Nepal and elsewhere
- 1981: first measurements of pollution levels in India
- 1984: international meeting to decide on needed research
  - Chose randomized control trial (RCT) of ALRI
- 1986-89: unfunded proposals to do RCT in Nepal
- 1990: WHO establishes committee to find best sites
- 1992: Guatemala chosen
- 1991-1999: Pilot studies to establish data needed for proposal
- 1996-1999: unfunded proposals
- 2001: NIH funds first randomized control trial for air pollution in highland Guatemala
- 2002-2006: fieldwork completed
- 2007: first results being published
- 23 years from deciding to conduct RCT to results!

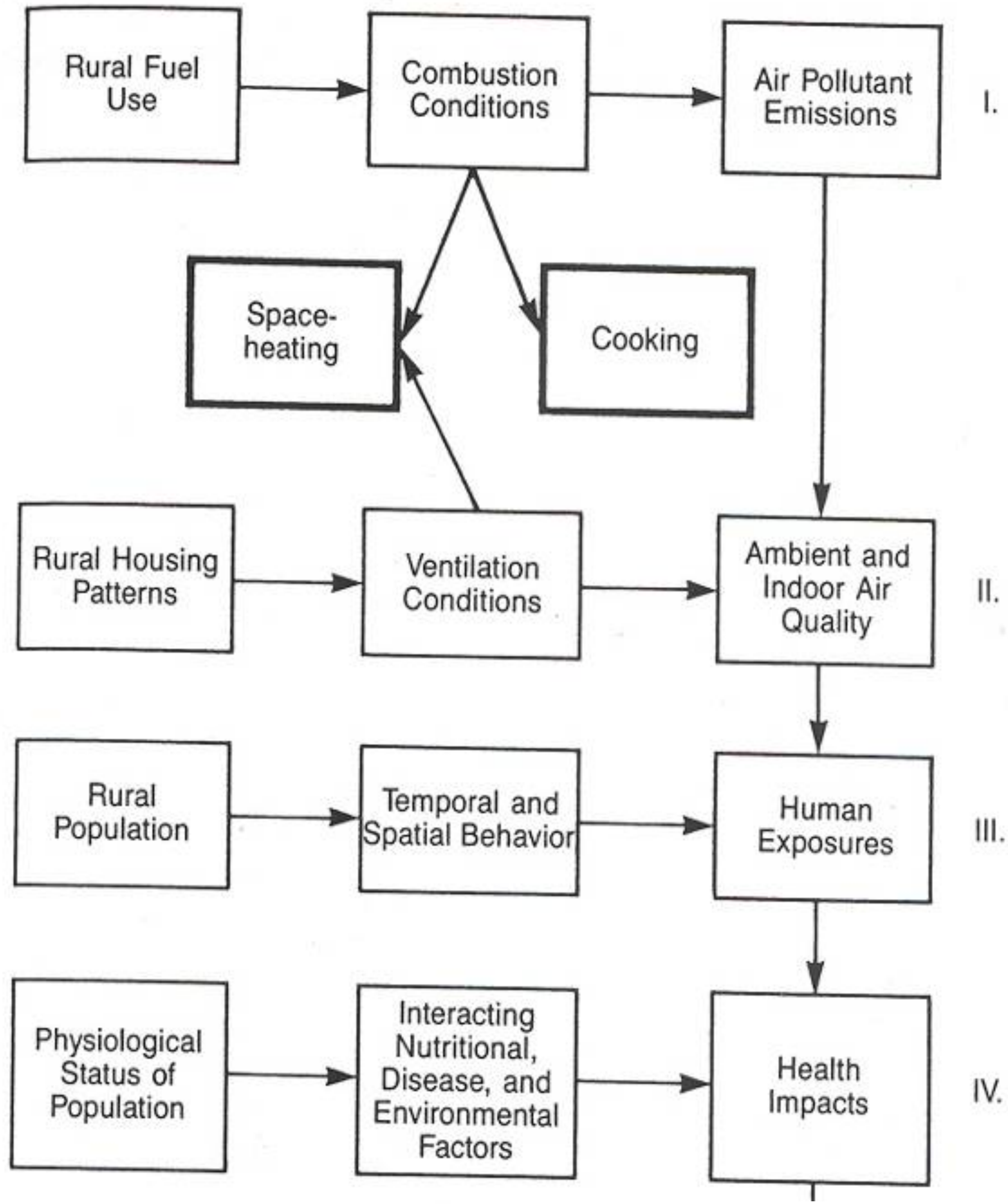
What Can be Done?

- Poverty is the problem, but poverty-alleviation may not be the best answer:
  - It is too slow -- it will take many decades at least
  - It is too inefficient – it is possible to target improvements in improving household ventilation and fuel quality just as it is possible to target improvement in household sanitation and water quality
  - Healthy people needed to propel economic growth as well as end in themselves

Energy Ladder Transition in the Republic of Korea, 1965-1980



What Can be Done?



Improved Stove in Shanxi

Technical Solutions

- Better Ventilation
  - Windows
  - Chimneys
  - Hoods
- Better Stoves
  - Fuel efficiency
  - Combustion efficiency
- Better Fuels
  - Clean solids (?)
  - Gases and liquids

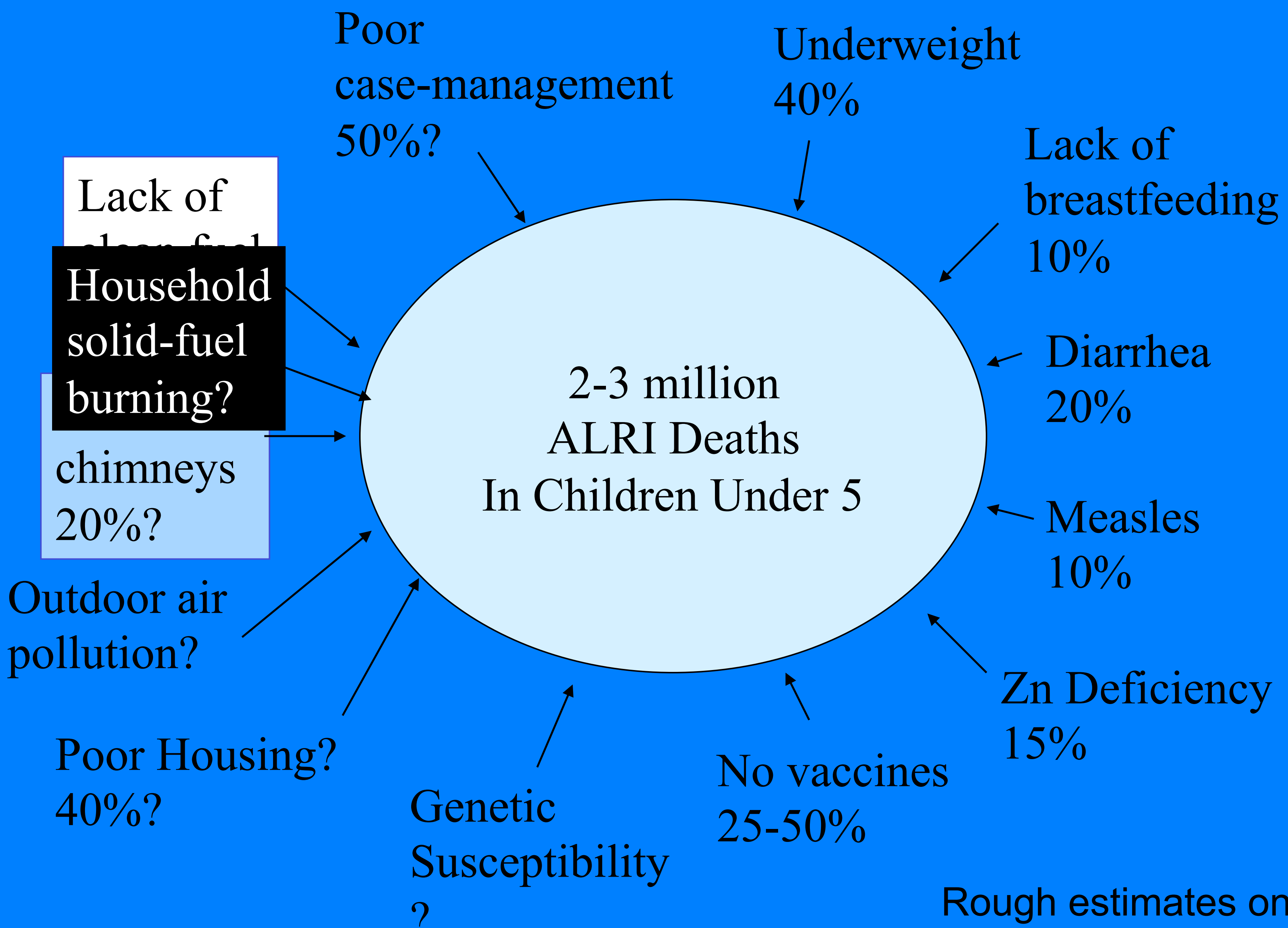
Short Term

Long Term

As an environmental intervention,

- Often not cost-effective in narrow disease context, i.e., for pneumonia, compared to vaccines, etc.
- But has other health benefits
  - Protects entire family
  - Multiple diseases
  - Hygiene, safety, ergonomics
- Important non-health benefits
  - Economic benefits
    - Fuel savings
    - Energy security
  - Social benefits, e.g., time savings (think of clean water)
  - Environmental protection benefits
    - Local biodiversity
    - Climate change

Attributable Fractions do not add to 100%



Rough estimates only

Thank you