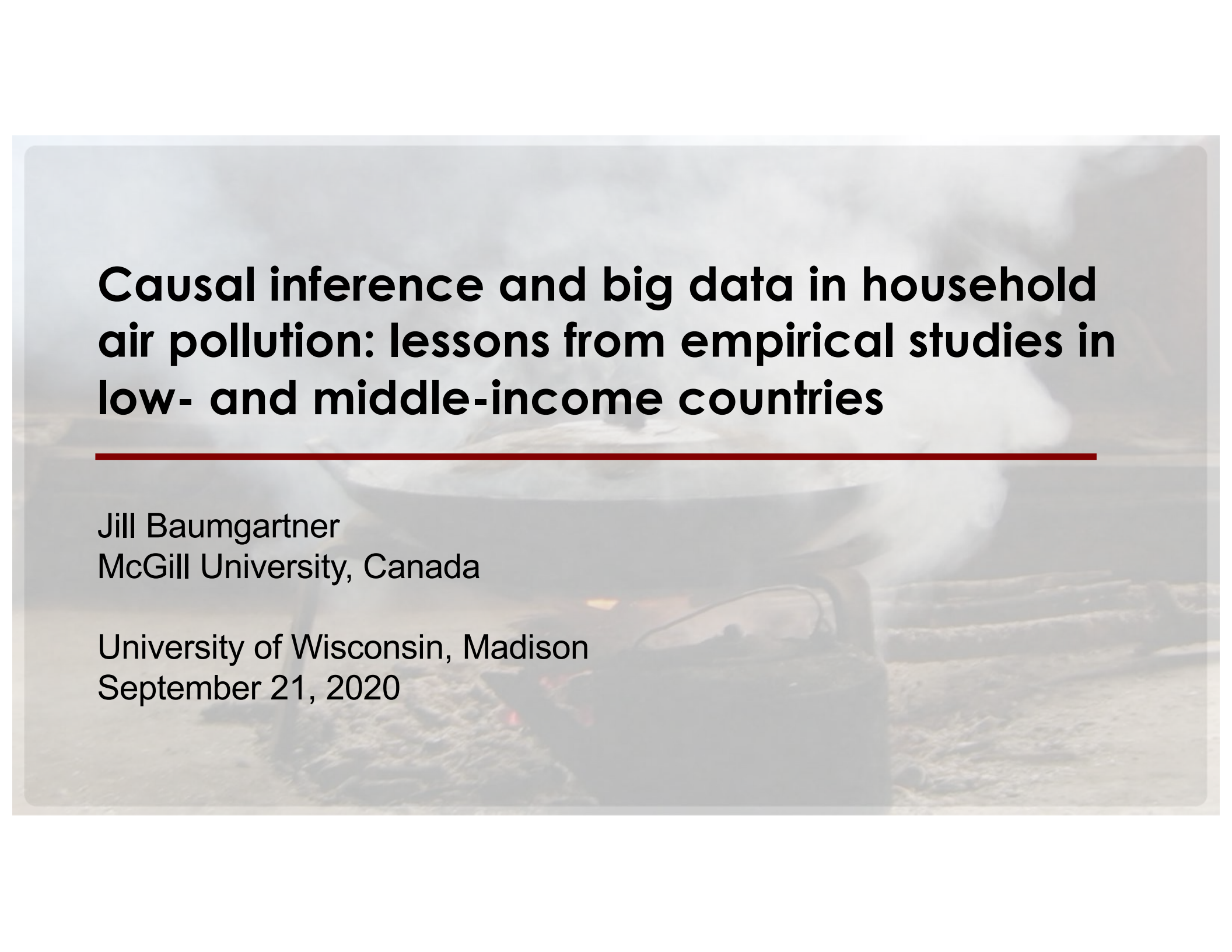




Causal inference and big data in household air pollution: lessons from empirical studies in low- and middle-income countries

Jill Baumgartner
McGill University, Canada

University of Wisconsin, Madison
September 21, 2020

Perspectives from settings of household air pollution

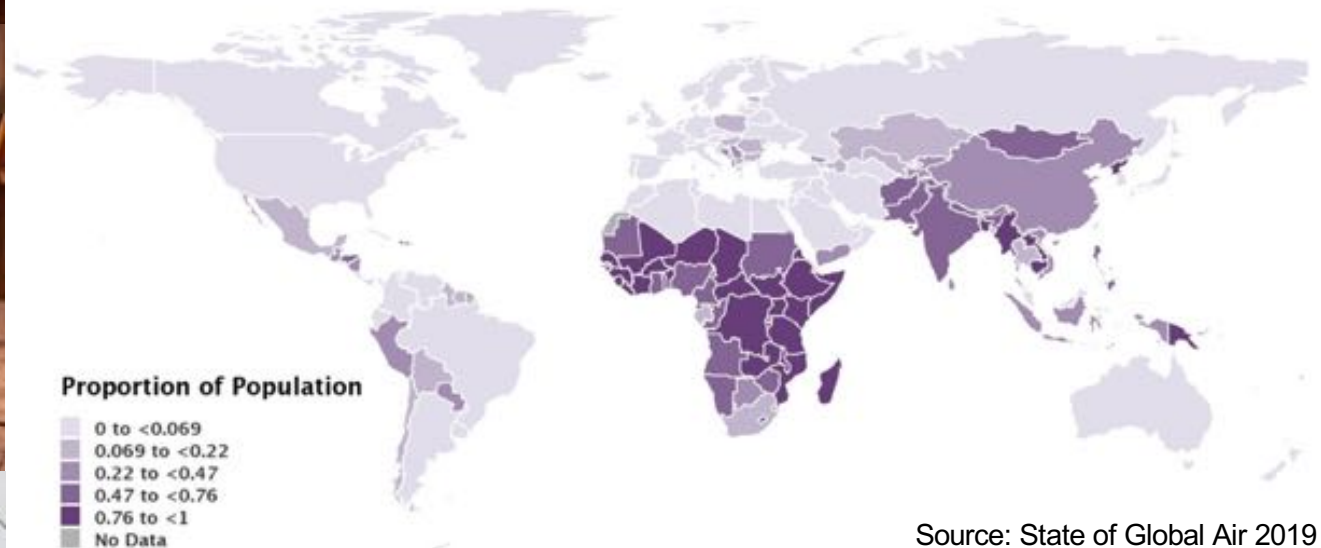
 What is household air pollution?

- Causal inference methods in household air pollution
- Role of big data in household air pollution and health



Photos: GACC, 2017; HEI 2018

Proportion of population primarily cooking with biomass or coal (solid fuel) stoves in 2017*



Source: State of Global Air 2019

***These do not account for secondary fuel use or for solid fuel stoves used for purposes other than cooking**

Solid fuel burning generates large amounts of pollutants

Formaldehyde

Methane

VOCs

Benzene

Benzo(e)pyrene

Toluene

SO_x

NO_x

Particulate matter (PM)

PAHs

1,3-Butadiene

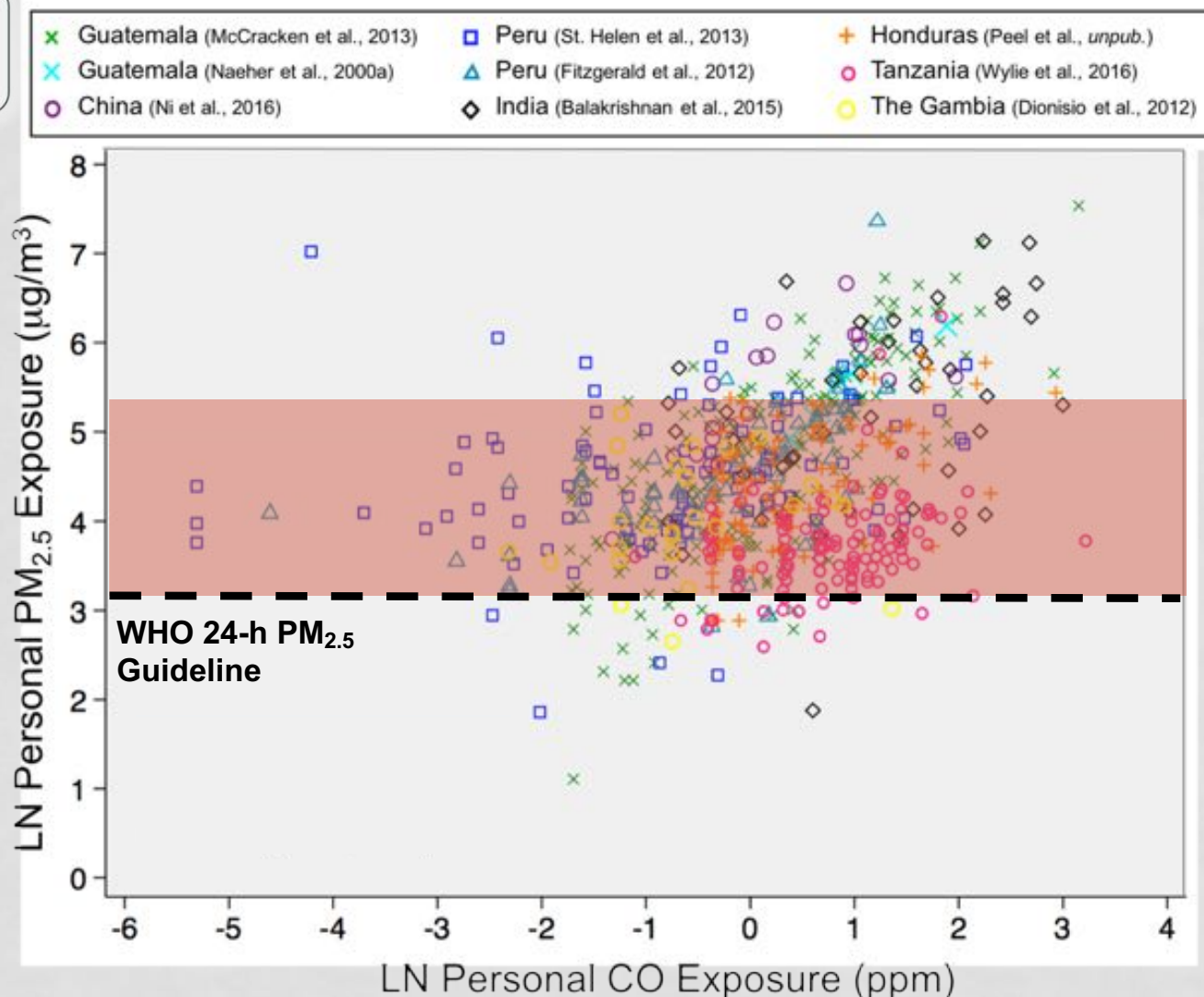
Carbon
monoxide

Acetic Acid

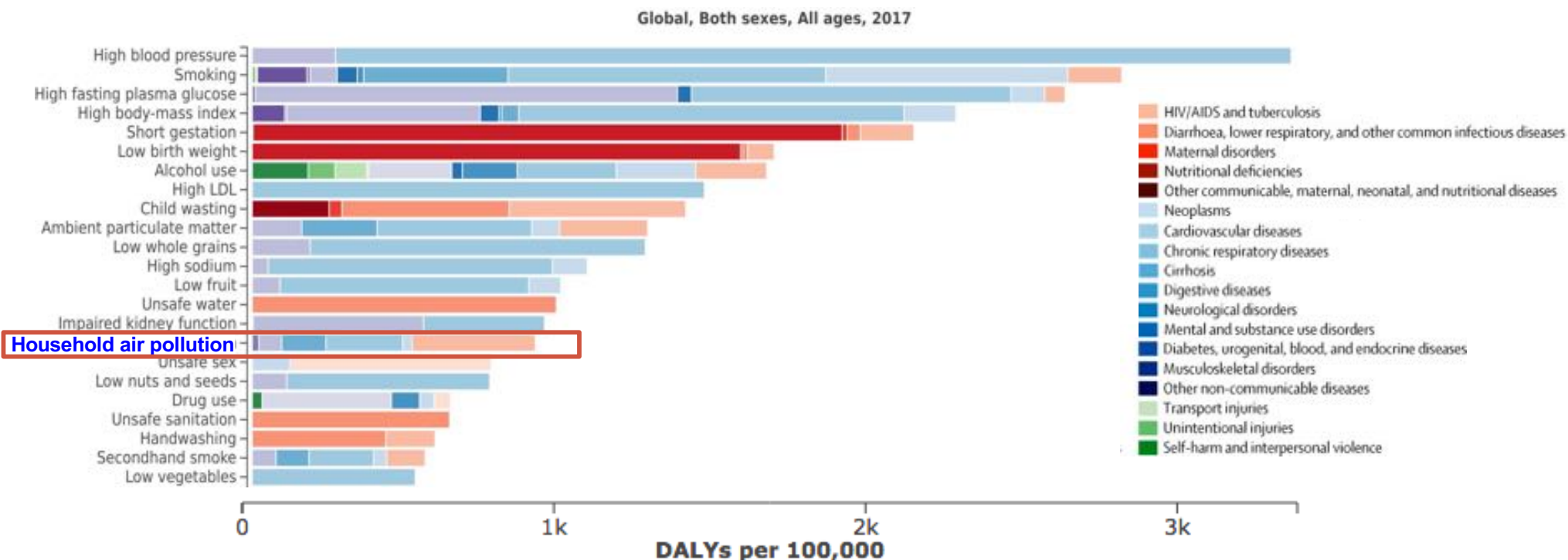
Outdoor & household ranges overlap

Range of exposures to $\text{PM}_{2.5}$ in settings of **household air pollution** (n=15 studies):
40-186 $\mu\text{g}/\text{m}^3$

Range of average yearly **outdoor $\text{PM}_{2.5}$** in the world's 500 most polluted cities:
27-173 $\mu\text{g}/\text{m}^3$



Disease burden attributable to household air pollution, 2017



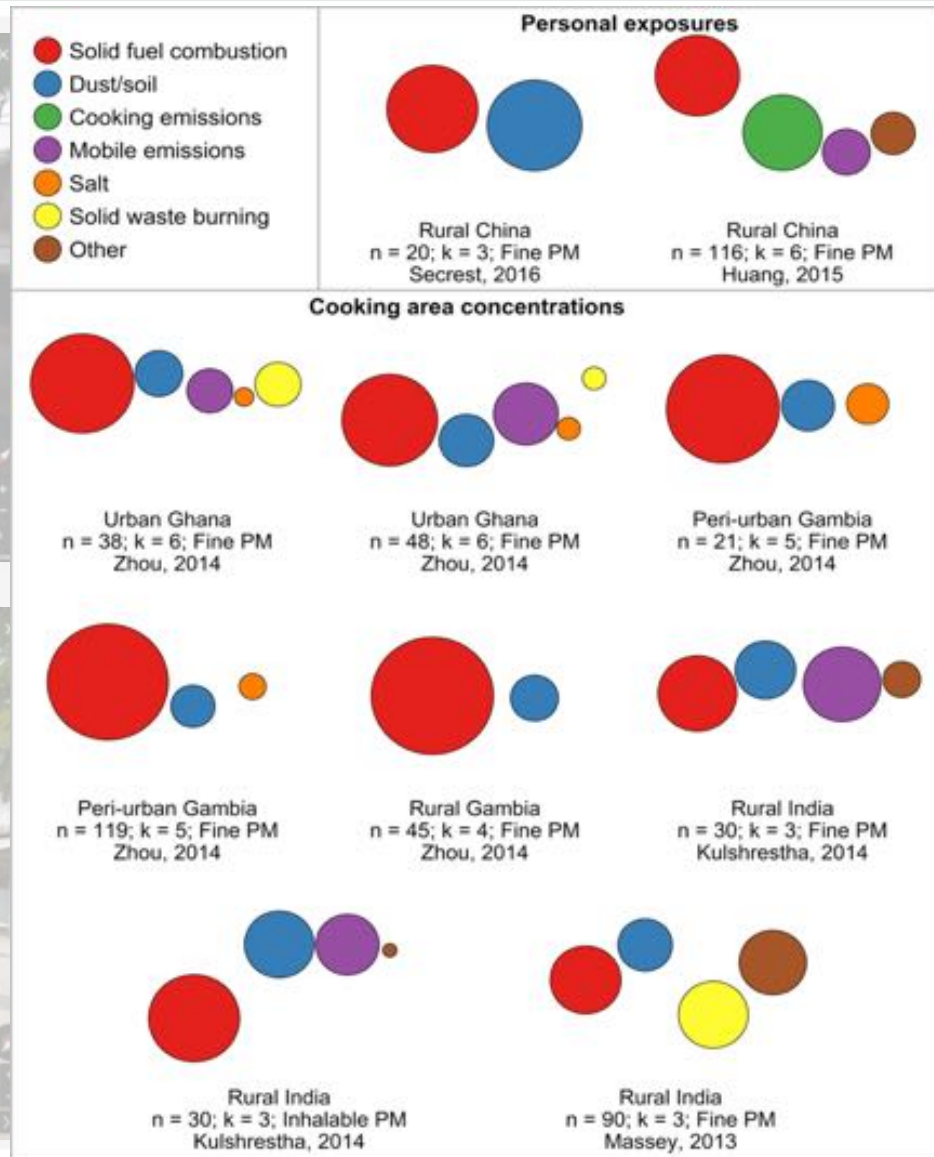
Household air pollution responsible for an estimated **1.6 million deaths** in 2017

Source: IHME, 2019; HEI State of Global Air 2019

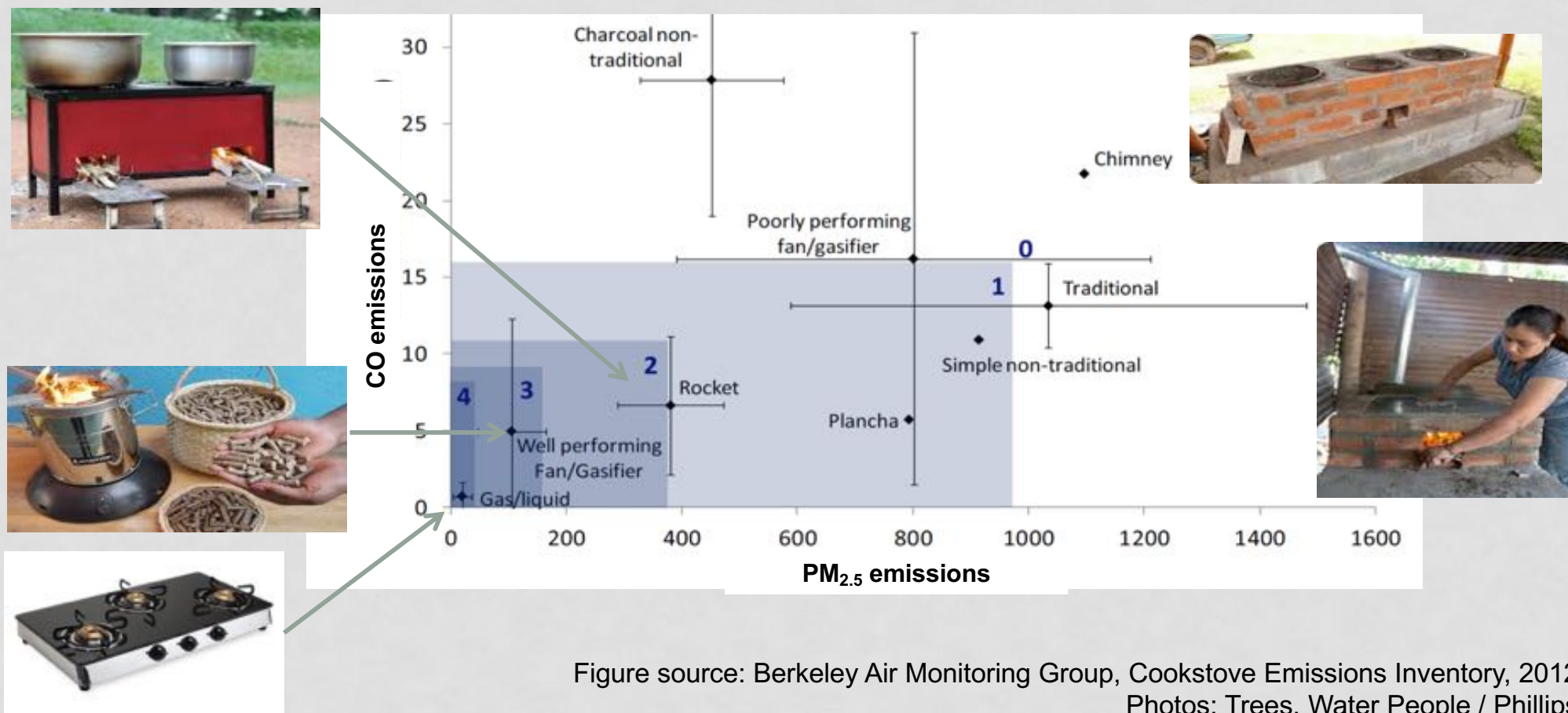
**Biomass and coal
stoves are a major
source contributor to
indoor PM_{2.5} &
exposures...**

**...but not the only
source or even the
largest one.**

Secrest et al, *Indoor Air*, 2017

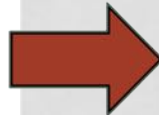


Decades of developing 'interventions' with different emissions performance



Perspectives from settings of household air pollution

- What is household air pollution?

 Causal inference methods in household air pollution

- Role of big data in household air pollution and health

Two directions for causal inference in household air pollution

(1) Observational research with personal exposure measurement

(+) Characterize exposure-response relationships to determine pollution reductions needed to achieve health benefit

Exposure-response associations for household air pollution

Health outcomes with 1+ exposure-response study

Lower respiratory infections (4+)

Blood pressure (4+ studies)

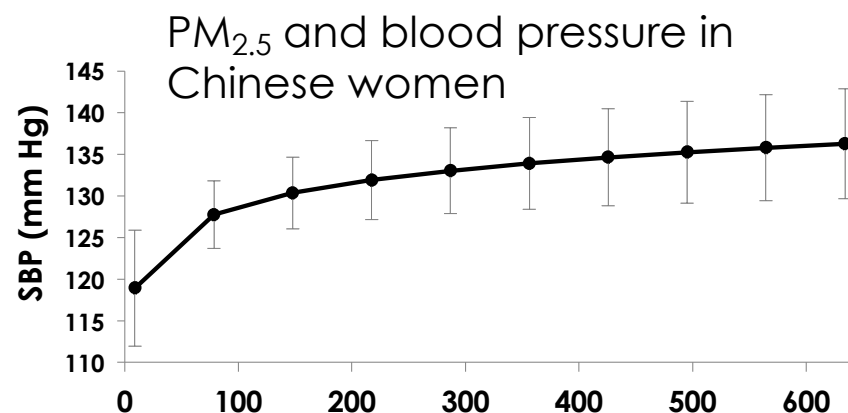
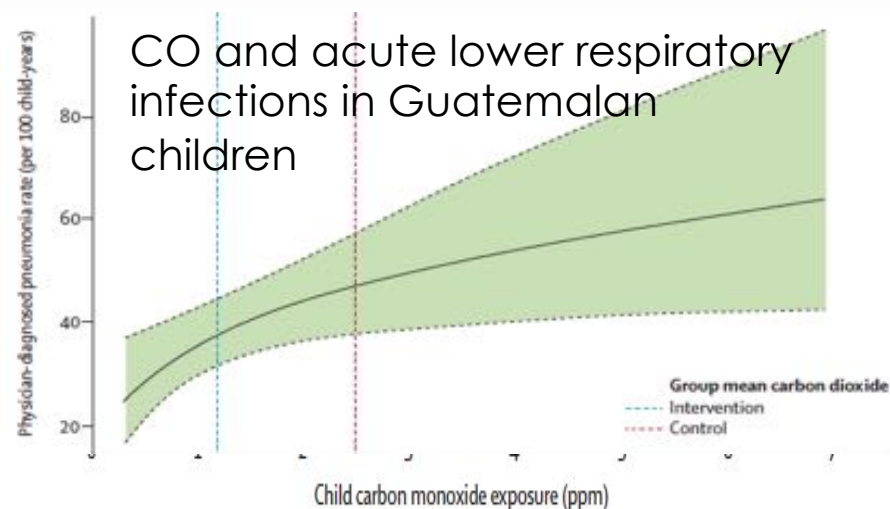
COPD (3+ studies)

Lung cancer (2+ studies)

Diabetes (1 study)

Blood/DNA biomarkers (2 studies)

All cause & cardiovascular mortality (1; abstract only)



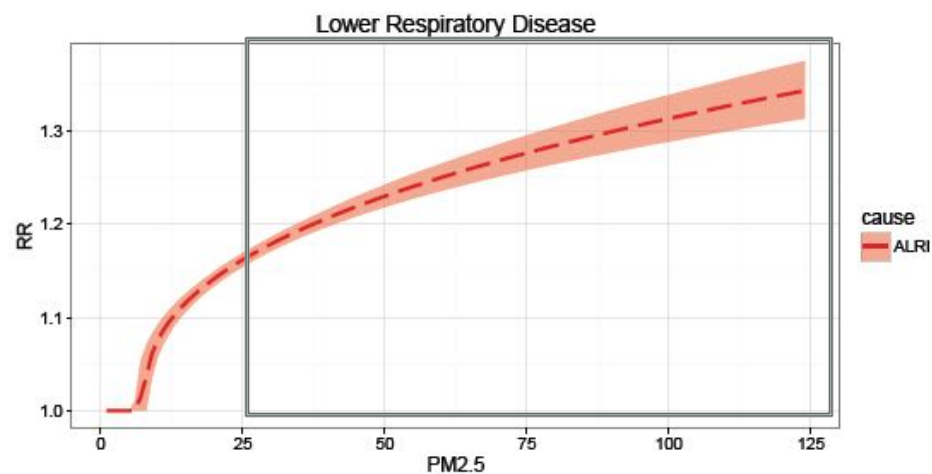
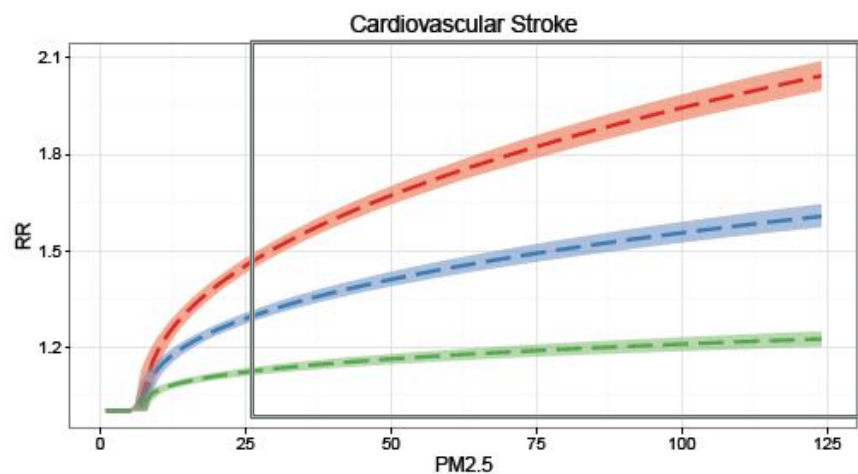
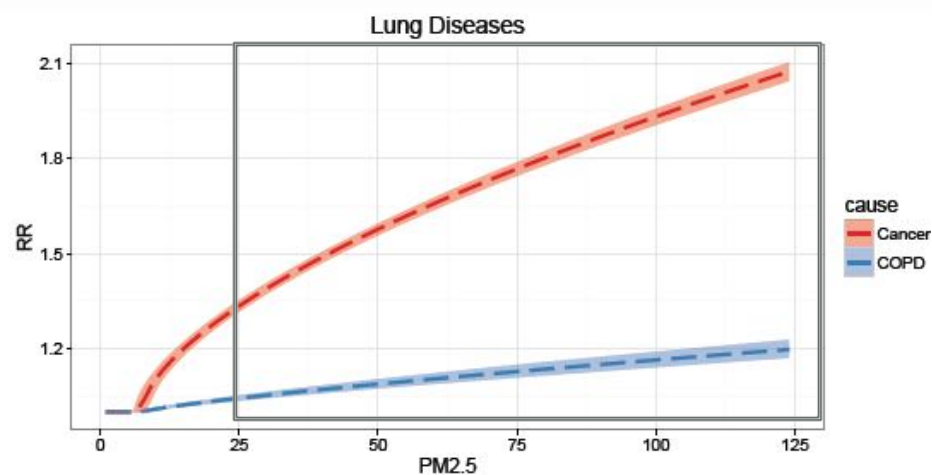
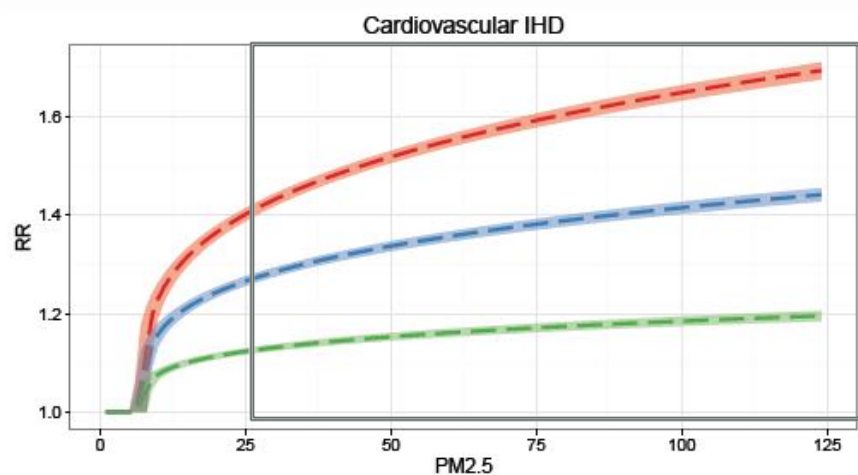
Sources: WHO-IAQ Guidelines, Smith, 2011; Baumgartner, 2011

Measuring exposure to PM_{2.5} is challenging

- Air monitors are expensive, bulky, limited by battery life, and not robust to field conditions; issues of electricity and logistics
- Household (indoor) measurements poorly correlate with exposure in many settings; outdoor monitors fail to capture indoor sources
- Biomarker research is limited and unconvincing



Integrated exposure-response curves for air pollution (PM_{2.5}) and health



Sources: Forouzanfar et al. 2015; Burnett et al. 2014

Measurement of confounding variables

Special Theme – Environment and Health

Indoor air pollution in developing countries: a major environmental and public health challenge

Nigel Bruce,¹ Rogelio Perez-Padilla,² & Rachel Albalak³

Around 50% of people, almost all in developing countries, rely on coal and biomass in the form of wood, dung and crop residues for domestic energy. These materials are typically burnt in simple stoves with very incomplete combustion. Consequently, women and young children are exposed to high levels of indoor air pollution every day.

There is consistent evidence that indoor air pollution increases the risk of chronic obstructive pulmonary disease and of acute respiratory infections in childhood, the most important cause of death among children under 5 years of age in developing countries. Evidence also exists of associations with low birth weight, increased infant and perinatal mortality, pulmonary tuberculosis, nasopharyngeal and laryngeal cancer, cataract, and, specifically in respect of the use of coal, with lung cancer. Conflicting evidence exists with regard to asthma. All studies are observational and very few have measured exposure directly, while a substantial proportion have not dealt with confounding. As a result, risk estimates are poorly quantified and may be biased. Exposure to indoor air pollution may be responsible for nearly 2 million excess deaths in developing countries and for some 4% of the global burden of disease.

Indoor air pollution is a major global public health threat requiring greatly increased efforts in the areas of research and policy-making. Research on its health effects should be strengthened, particularly in relation to tuberculosis and acute lower respiratory infections. A more systematic approach to the development and evaluation of interventions is desirable, with clearer recognition of the interrelationships between poverty and dependence on polluting fuels.

Keywords: air pollution, indoor – adverse effects; fossil fuels – toxicity; lung diseases; smoke inhalation injury; cataract; developing countries.

”All studies were observational and very few have measured exposure directly, while a substantial proportion had not dealt with confounding”

Two directions for causal inference in household air pollution

(1) Observational research with personal exposure measurement

(+) Characterize exposure-response relationships to determine pollution reductions needed to achieve health benefit

(-) *Personal exposure assessment is challenging*

(-) *Confounders can be hard to measure well or at all*

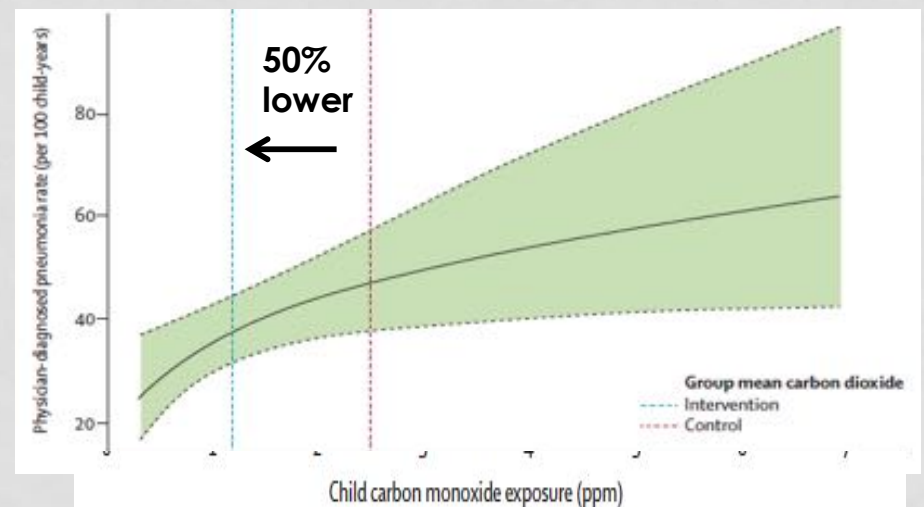
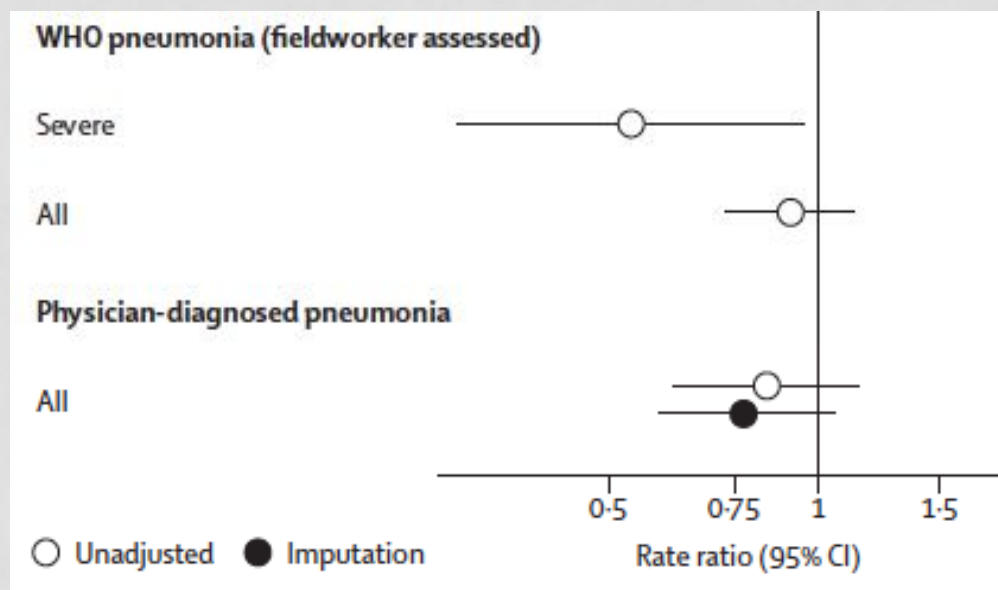
(2) Randomized controlled trials

(+) Free of confounding to measure the pure intervention effects

Results from RCTs of clean stove interventions

	Stove provided a benefit to PRIMARY OUTCOME(S) of the trial	Stove provided a benefit to SECONDARY OUTCOME(S) of the trial
Smith, 2011 Guatemala (biomass stove)	Acute lower respiratory infections	Blood pressure, neurocognitive impacts in children, severe pneumonia, biomarkers
Tielsch, abstract Nepal (biomass stove)	Acute lower respiratory infections and birth weight	
Olopade, 2017; 2018 Nigeria (fuel gel-gas)	Birth weight	Blood pressure, birth weight and birth outcomes, markers of inflammation
Mortimer, 2017 Malawi (biomass stove)	Acute lower respiratory infections	Air pollution
Wylie, abstract Ghana (LPG and gasifier)	Birth weight and pneumonia	
Rosa, 2018 Rwanda (biomass stove)	Respiratory Infection, Pneumonia	Child and maternal mortality
Romieu, 2009 Mexico (biomass stove)	Acute lower respiratory infections and respiratory signs/symptoms in adults	Biological markers of inflammation
Hanna, 2016 India (biomass stove)	Lung function, pneumonia	Air pollution, respiratory symptoms, headaches, burning eyes

Incidence of pneumonia in children in the first randomised controlled trial of a (wood chimney) cookstove in Guatemala



Incidence of severe pneumonia in children from a cluster randomised controlled trial of a biomass cookstove in Malawi



	Intervention (n=5297)		Control (n=5246)		Incidence rate ratio (95% CI)	P-value
	# Cases	Incidence rate	# Cases	Incidence rate		
Severe pneumonia	186	2.33 (2.00-2.67)	145	1.80 (1.51-2.09)	1.30 (0.99-1.71)	0.06
Air pollution	?	?	?	?	?	

Intervention stoves were used for 0.34 cooking events per day by year 2 of follow-up.

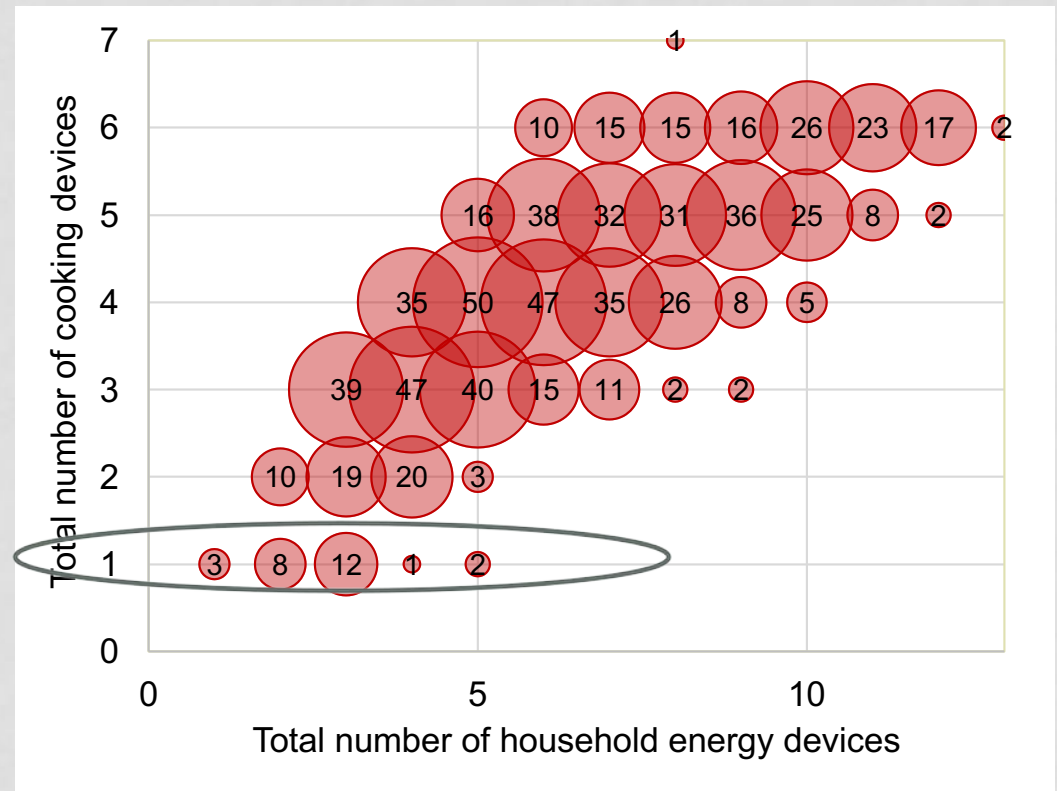
Each intervention stove was replaced or repaired 3.1 times over 2 years, on average.

Mortimer et al, Lancet, 2017

Can a single stove realistically meet the complexity of household energy use demands?

Ownership of household energy devices in rural Chinese homes

3 of 856 homes (0.4%) had 1 household energy device



Two directions for causal inference in household air pollution

Observational research with personal exposure measurement

(+) Characterize exposure-response relationships to determine pollution reductions needed to achieve health benefit

(-) *Personal exposure assessment is challenging*

(-) *Confounders can be hard to measure well or at all*

Randomized controlled trials

(+) Free of confounding to measure the pure intervention effects

Two directions for causal inference in household air pollution

Observational research with personal exposure measurement

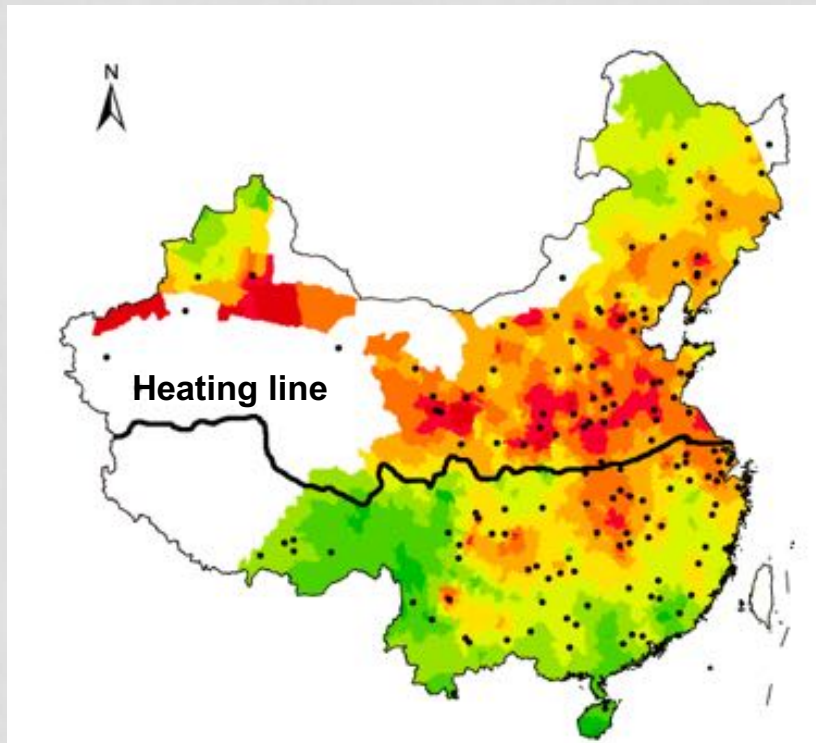
- (+) Characterize exposure-response relationships to determine pollution reductions needed to achieve health benefit
- (-) *Personal exposure assessment is challenging*
- (-) *Confounders can be hard to measure well or at all*

Randomized controlled trials

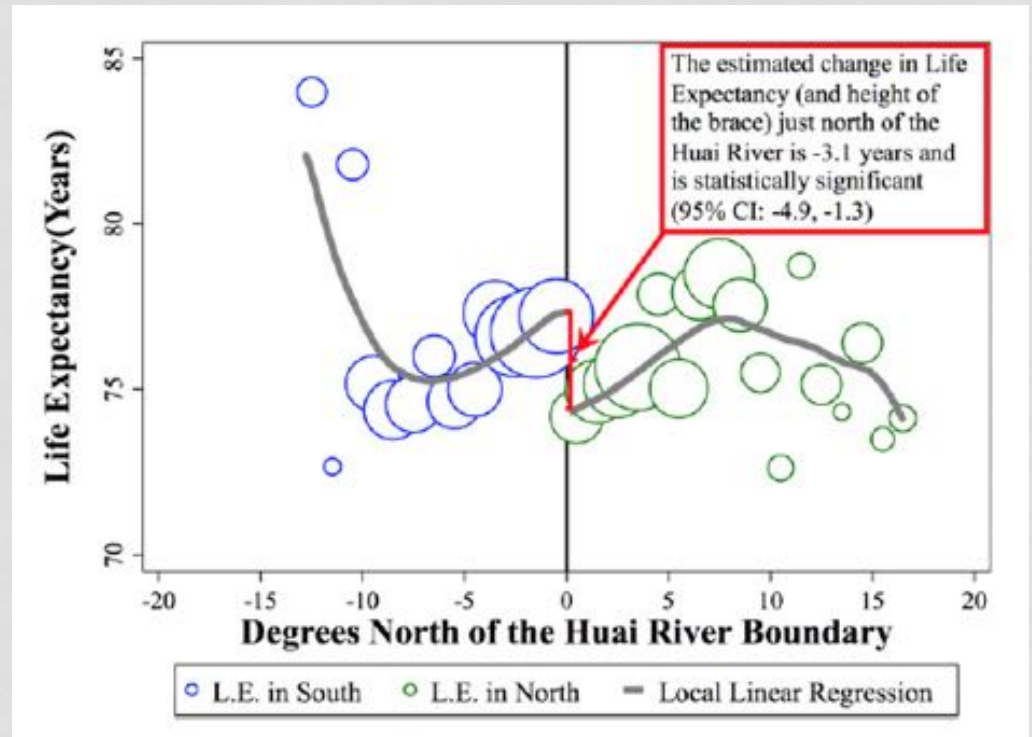
- (+) Free of confounding to measure the pure intervention effects
- (-) *Not feasible for many health endpoints*
- (-) *Often plagued by low stove adoption, continued use of old stoves, and non-cooking sources*
- (-) *Limited external validity*
- (-) *Policy is already moving ahead*

Quasi-experimental approaches

Natural experiment: The effect of the Huai River winter heating policy on air pollution and life expectancy

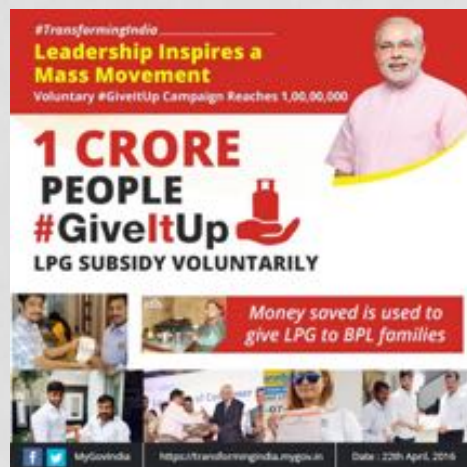
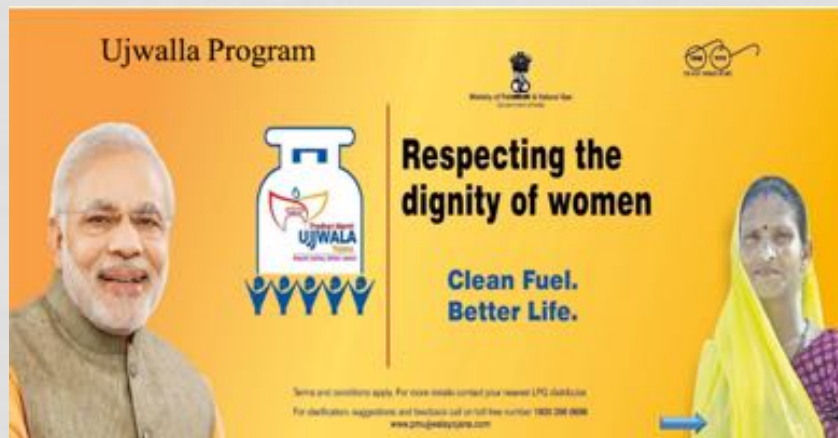


Heat map of PM10 concentrations (red=high)

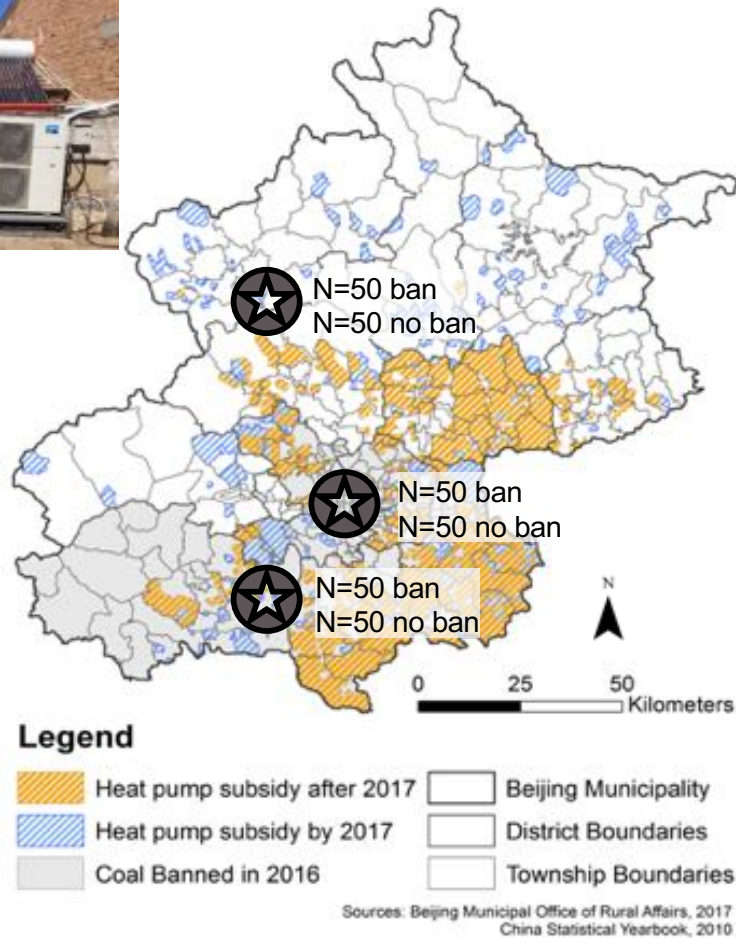


Fitted values from regression of life expectancy and distance from the Huai river

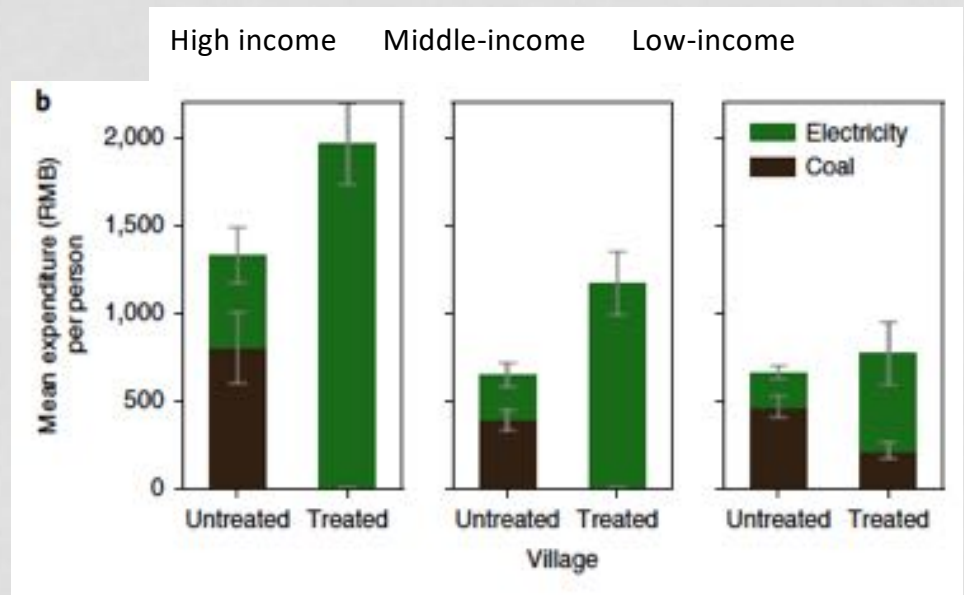
Large-scale intervention programs provide opportunity for evaluation



Cross-sectional evaluation of the Beijing coal ban



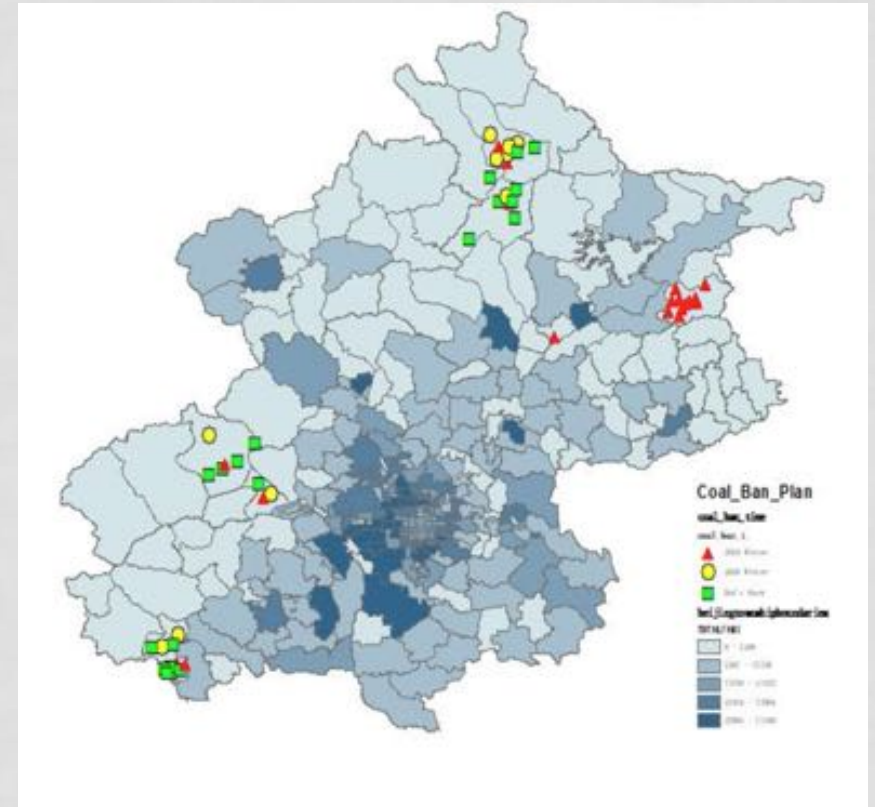
- Beijing designated “coal restricted areas” and subsidized electric heat pumps
- 2017: 2 million households into the program
- Stepped implementation from 2016-2021 in northern China (>63 million households)



Barrington-Leigh et al, *Nature Energy* 2019

Ongoing prospective evaluation of the Beijing coal ban

- ~1200 households in 50 villages with measurements from 2018-2021
- Repeated measures of sociodemographics, stove and electricity use, air quality (outdoor, indoor, exposure), health, and wellbeing



Perspectives from settings of household air pollution

- What is household air pollution?
- Causal inference methods in household air pollution

 Role of big data in household air pollution and health

Leveraging fuel data to evaluate space-time trends in fuel and health

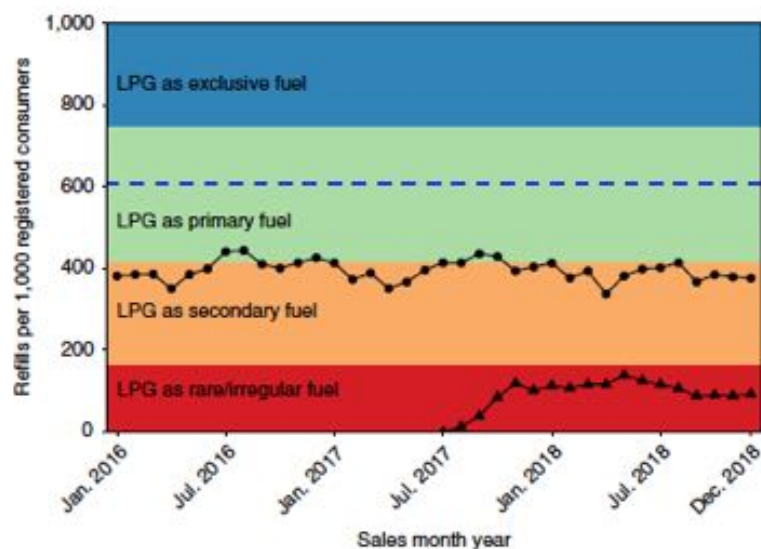
nature
energy

ANALYSIS

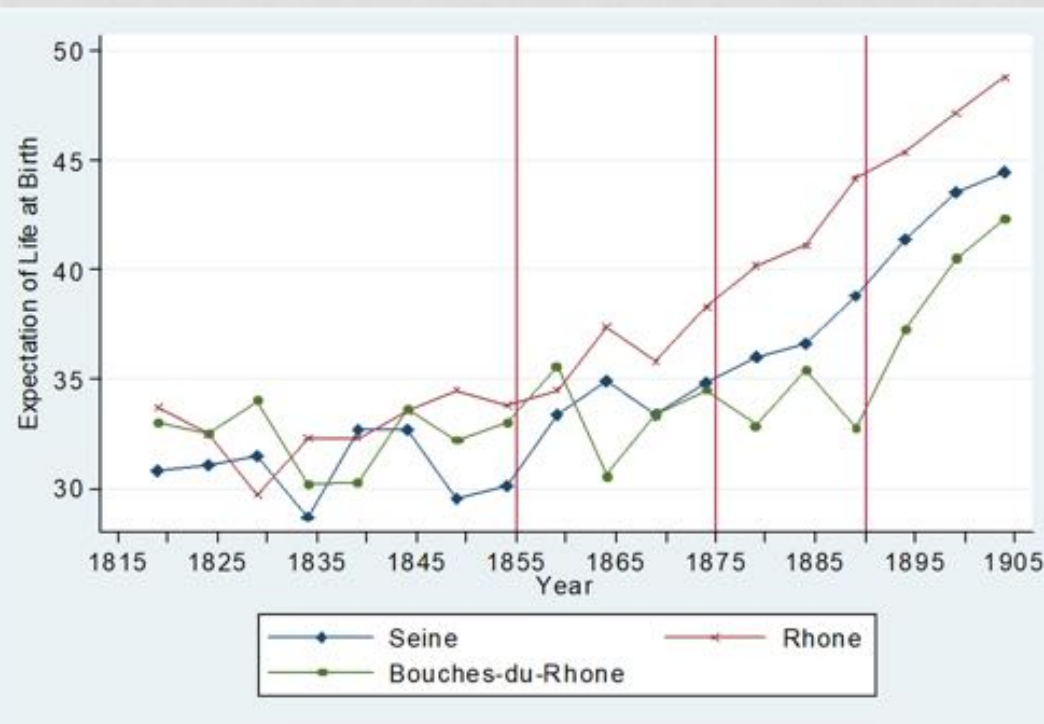
<https://doi.org/10.1038/s41560-019-0429-8>

Using sales data to assess cooking gas adoption and the impact of India's *Ujjwala* programme in rural Karnataka

Abhishek Kar^{1*}, Shonali Pachauri², Rob Bailis³ and Hisham Zerriffi⁴

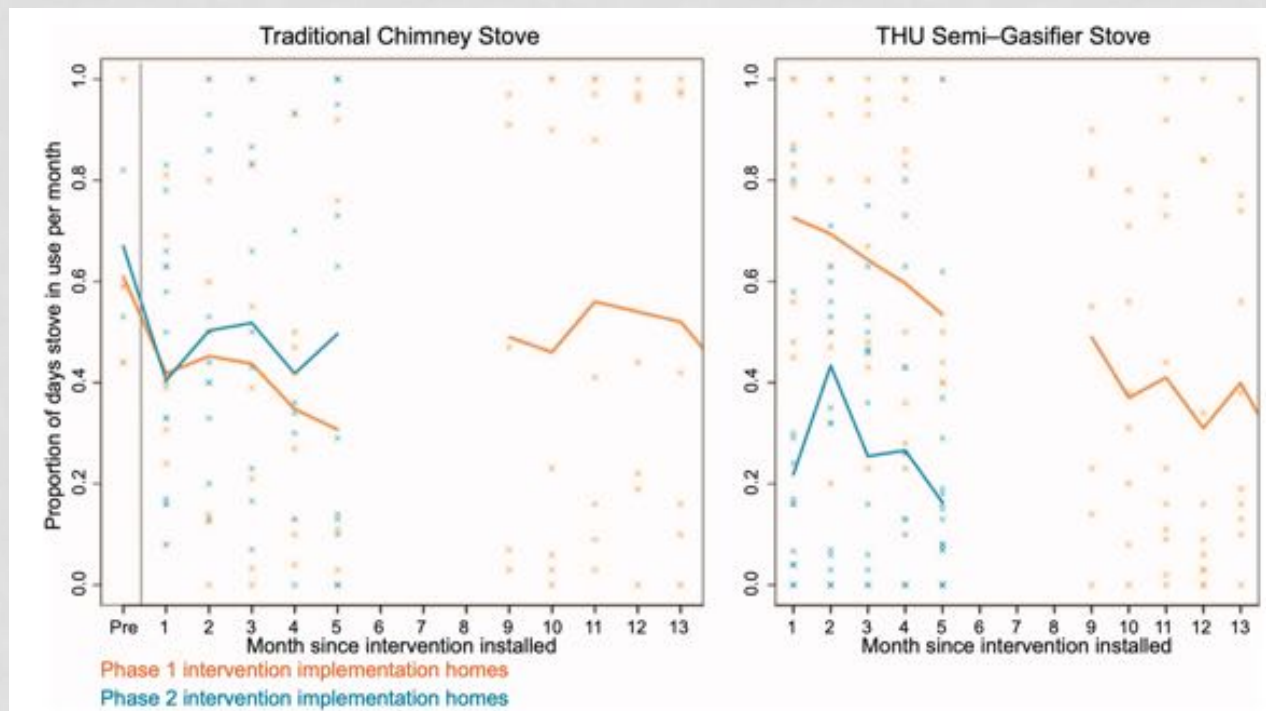


Introduction of safe water and life expectancy in cities in France



Source: Preston and van de Walle (1978)

Use of sensors to assess use of LPG and traditional biomass stoves



Use of machine learning techniques to develop algorithms that detect rises in surface temperature associated with stove use events

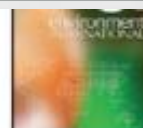


Low-cost air pollution sensors for large-scale long-term monitoring



Environment International

journal homepage: www.elsevier.com/locate/envint



Full length article

Can commercial low-cost sensor platforms contribute to air quality monitoring and exposure estimates?



Nuria Castell^{a,*}, Franck R. Dauge^a,
David Broday^b, Alena Bartonova^a

^a NILU – Norwegian Institute for Air Research, Kjeller, Norway
^b Faculty of Civil and Environmental Engineering, Technion –



Environmental Research

journal homepage: www.elsevier.com/locate/envres



Validating novel air pollution sensors to improve exposure estimates for epidemiological analyses and citizen science

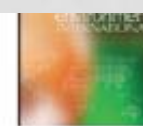


Michael Jerrett^{a,*}, David Broday^b, Ronald C. Cohen^d, Estel
Tom Cole-Hunter^b, Mary



Environment International

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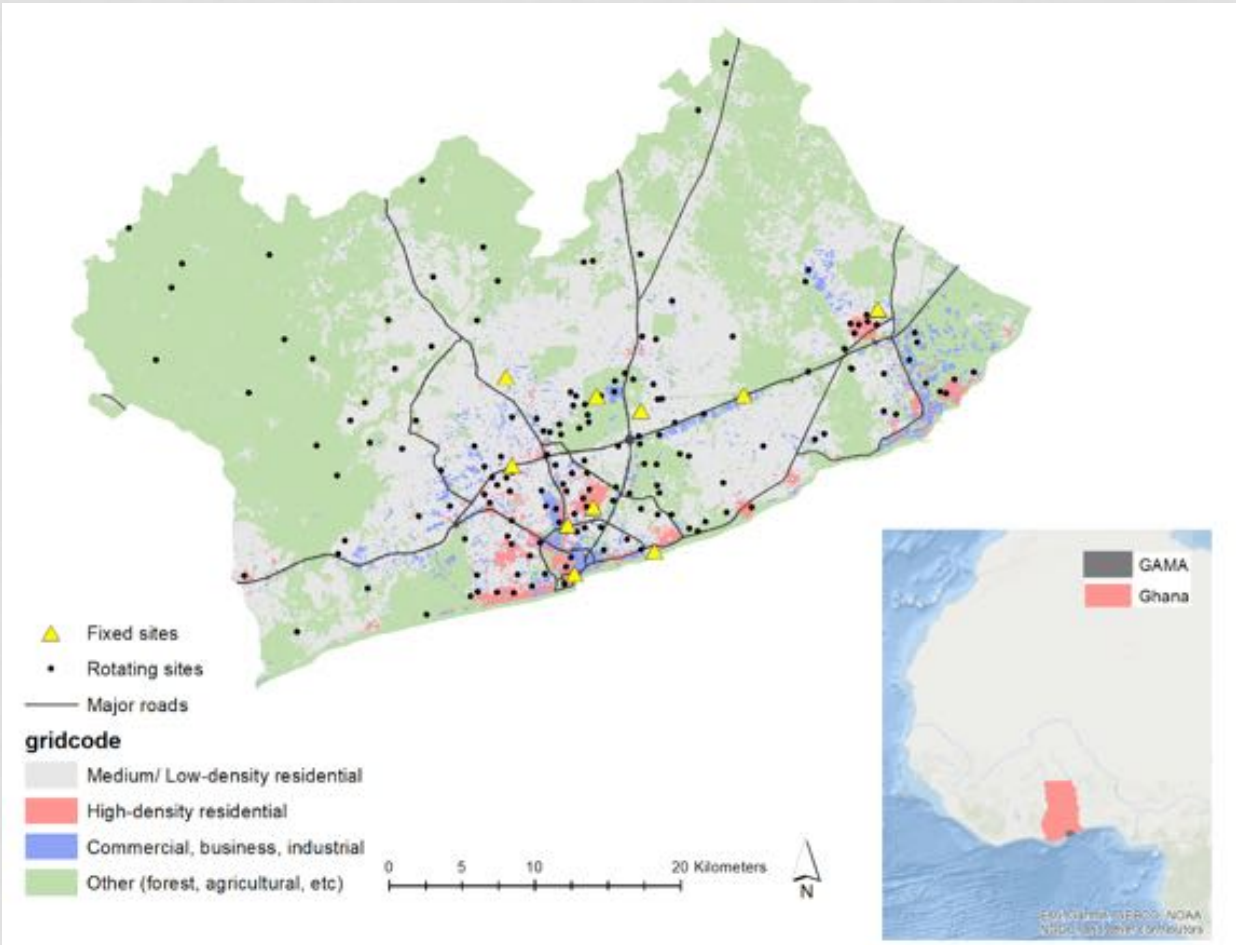
Review

The rise of low-cost sensing for managing air pollution in cities

Prashant Kumar^{a,b,*}, Lidia Morawska^c, Claudio Martani^d, George Biskos^{e,f,g}, Marina Neophytou^h,
Silvana Di Sabatinoⁱ, Margaret Bell^j, Leslie Norford^k, Rex Britter^l



High-resolution spatiotemporal air pollution in Sub-Saharan Africa



Clark et al., BMC Open 2020

Predicting within-city spatial variation in air pollution in Bucaramanga, Colombia using images



Unpublished results removed

Use of imagery and satellite data for exposure estimation



Small scale industry, traffic, road dust, biomass burning, diesel-powered equipment: rural Ghana

Traffic, roadside cooking with biomass, dust, other urban sources: peri-urban Dhaka



Policy and research implications

- Actions to reduce household air pollution are warranted, not least because exposures are very high
- Leveraging natural experiments and policy evaluation can move focus beyond single stove interventions to assess more complex, contextualised, and realistic energy interventions
- Evaluation of whether clean energy programs policies achieve intended benefits and avoid harm, and whether benefits reach the most vulnerable, remains a need
- Big data still in its infancy in household air pollution; data availability and logistics in low-resource settings are a challenge

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U.S. Environmental Protection Agency
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Health Effects Institute

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