Health impacts of Ulaanbaatar air pollution, policy recommendations, and projections

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National Conference on Air Pollution and Health – 2019

Mongolia National University of Medical Sciences

Ulaanbaatar, March 28, 2019

Road Map

- Study of future health impacts of air pollution policy in UB under different policy options
- New diseases not included in burden of disease studies to date
- Pilot study of advanced electric heat pumps in UB
- Unique opportunities for air pollution control in UB

An International Collaboration

Mongolia National University of Medical Sciences
University of California, Berkeley
University of California, Irvine
Washington University in St. Louis
US National Science Foundation
Desert Research Institute

Funded by the Ministry of Environment and Green Development

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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

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Check for updates

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.

Findings from Hill et al 2017

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 in each year, 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 deaths and DALYs attributable to $PM_{2.5}$ exposure in UB

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

Table 4. Estimated annual $PM_{2.5}$ emissions from major sources (tons/yr).

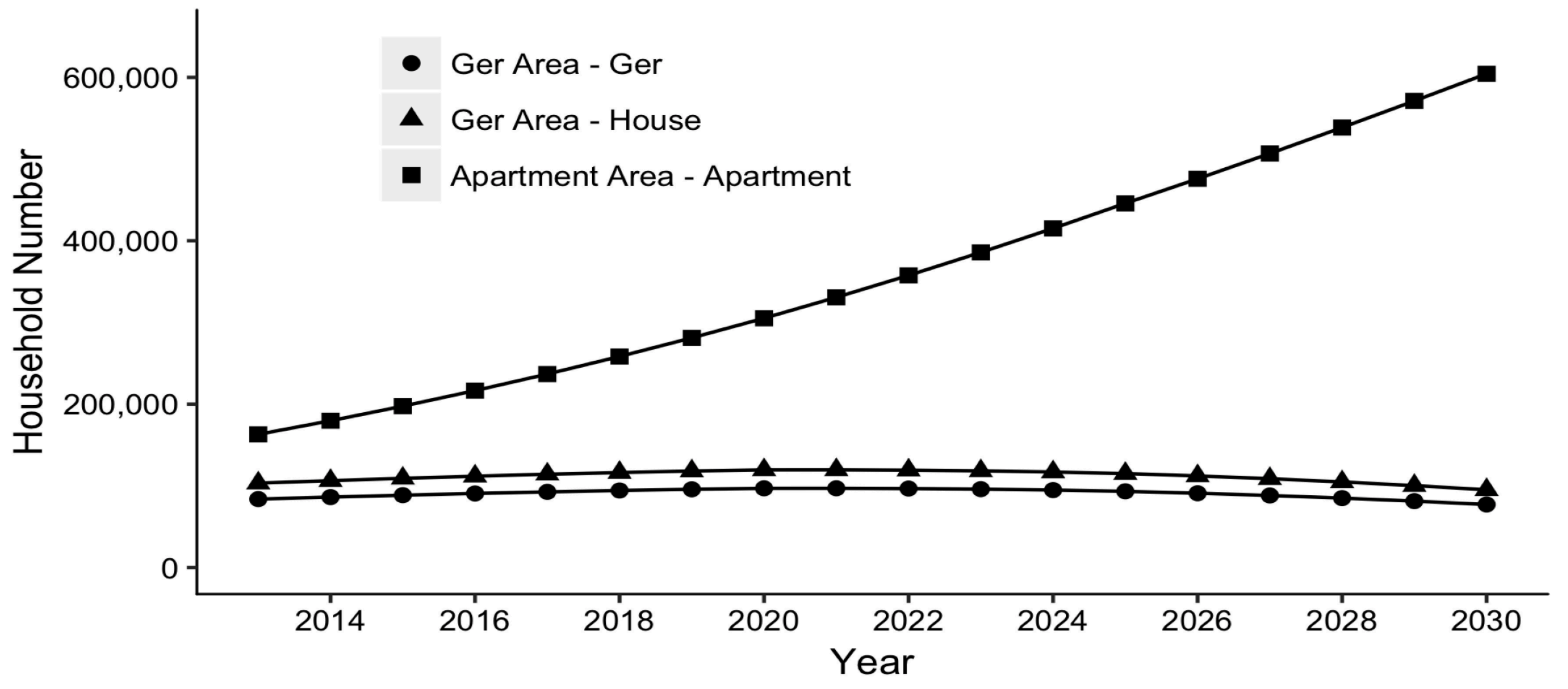
Pathway	Vehicles	Power Plants	Heat Only Boilers	Household Stoves & LPB
2014 Baseline	384	11,500	1,300	1,700
2024 BAU	500	12,000	1,300	1,900
2024 Pathway 1	96	1,900	390	640
2024 Pathway 2	48	1,830	0	0

https://doi.org/10.1371/journal.pone.0186834.t004

Estimates of demographics and background disease trends

Anticipate major growth in total population and household number

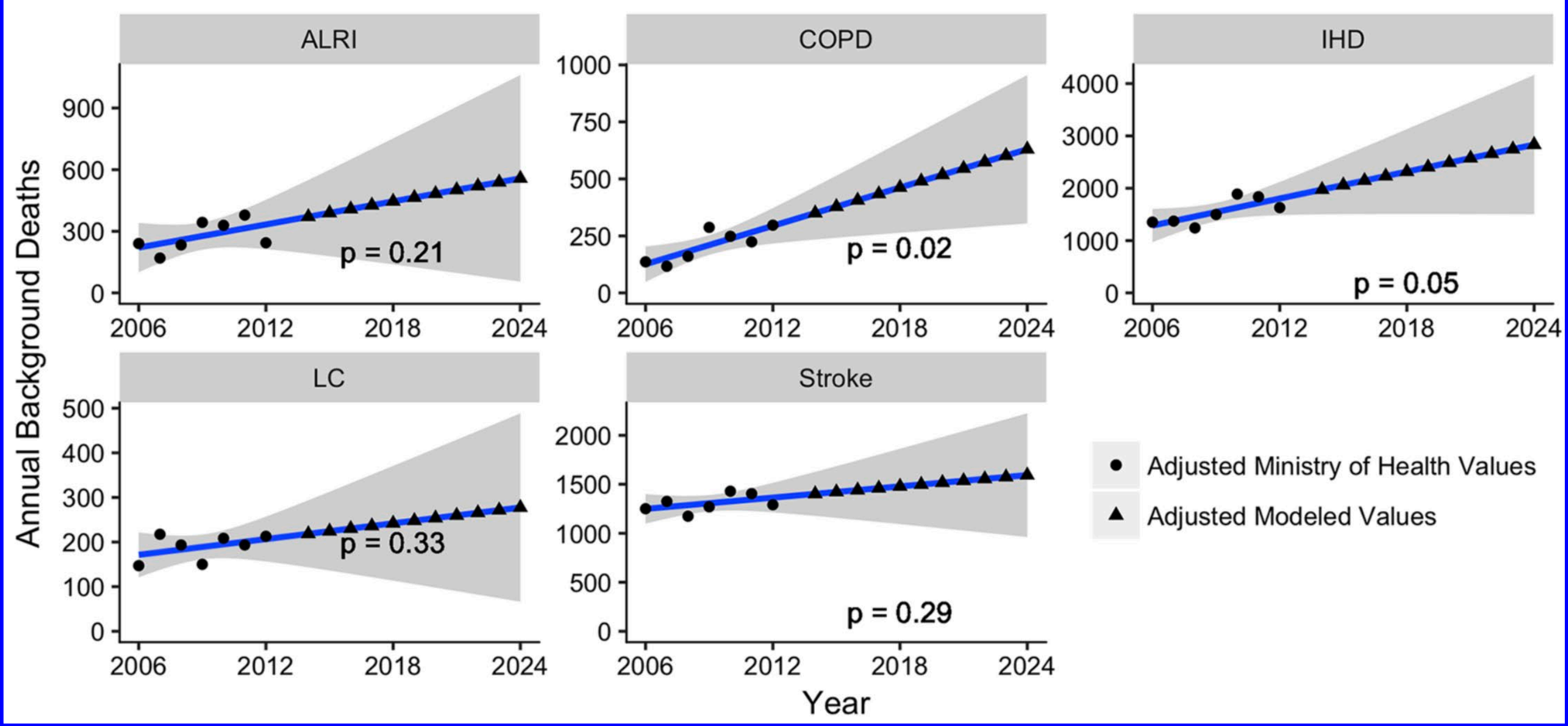
Expect increase in % population living in Apartments



see manuscript for methods, data sources, assumptions

Findings from Hill et al 2017

Projected annual background mortality in UB for 5 diseases in GBD health effects for air pollution



Findings from Hill et al 2017

Table 3. Estimates of age-specific city-wide population and household number by home type, and estimated household size.

Year	Population [1]		Number of Households [2]			Pop. per
-	Total Pop.	Pop. 0–4 Years	Ger	House	Apartment	Household [2]
2014	1,355,176	148,219	86,246	106,353	179,718	3.64
2015	1,407,196	155,551	88,547	109,191	197,539	3.56
2016	1,459,516	158,438	90,684	111,826	216,586	3.48
2017	1,511,836	161,325	92,616	114,209	236,854	3.41
2018	1,564,157	164,212	94,323	116,313	258,369	3.34
2019	1,616,477	167,099	95,781	118,112	281,152	3.27
2020	1,668,797	169,986	96,967	119,574	305,219	3.20
2021	1,715,748	168,427	96,997	119,611	330,782	3.13
2022	1,762,700	166,869	96,667	119,204	357,645	3.07
2023	1,809,651	165,310	95,954	118,324	385,792	3.02
2024	1,856,603	163,752	94,834	116,943	415,195	2.96

1.Interpolated from five-year "medium growth" (version 1b) projections identified in the 2010 Population and Housing Census of Mongolia Report [18].

2.Estimated using the techniques and sources described in S1 Text.

https://doi.org/10.1371/journal.pone.0186834.t003

Key aspects of the exposure assessment

Findings from Hill et al 2017

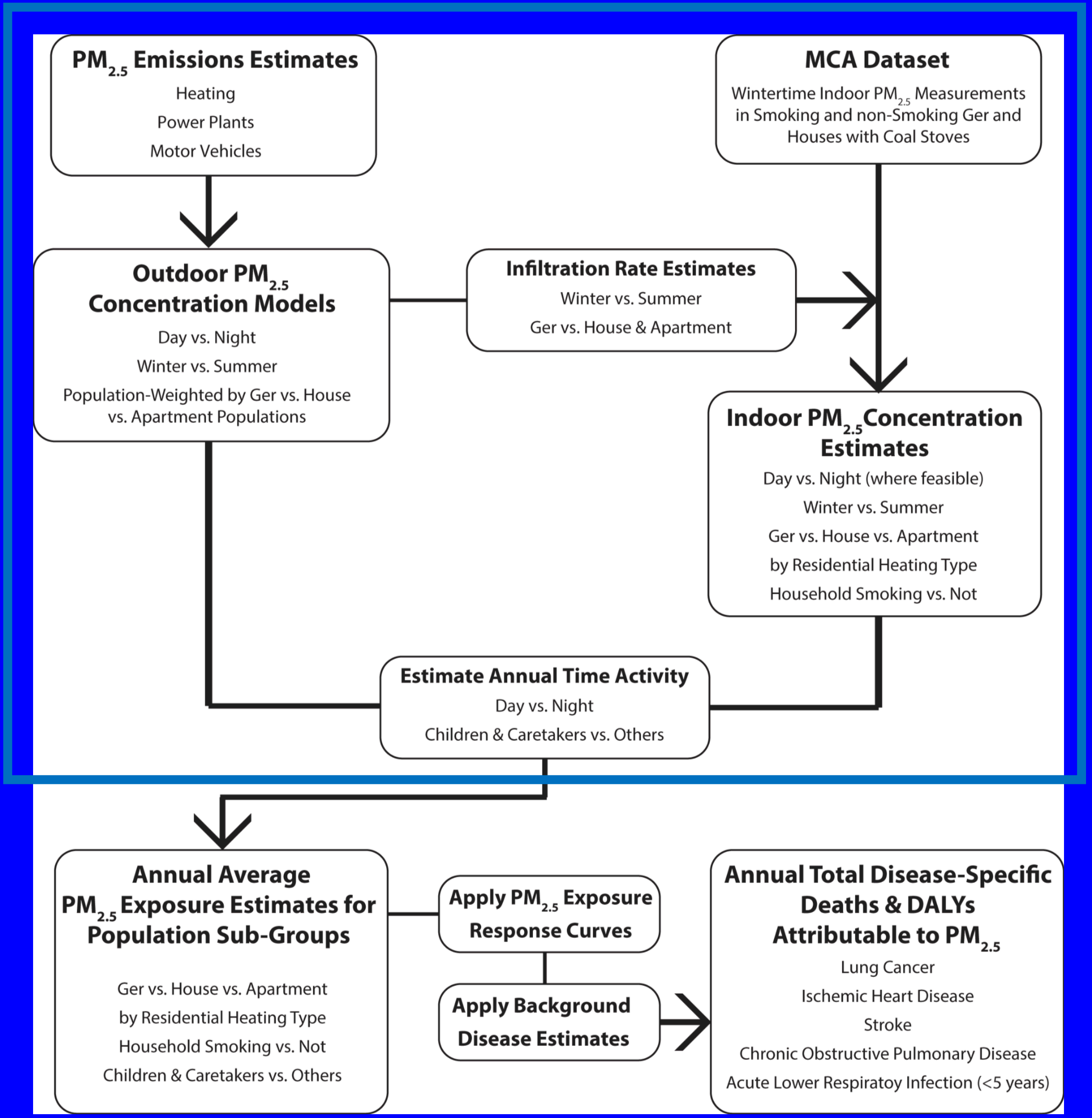
Total exposure approach

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

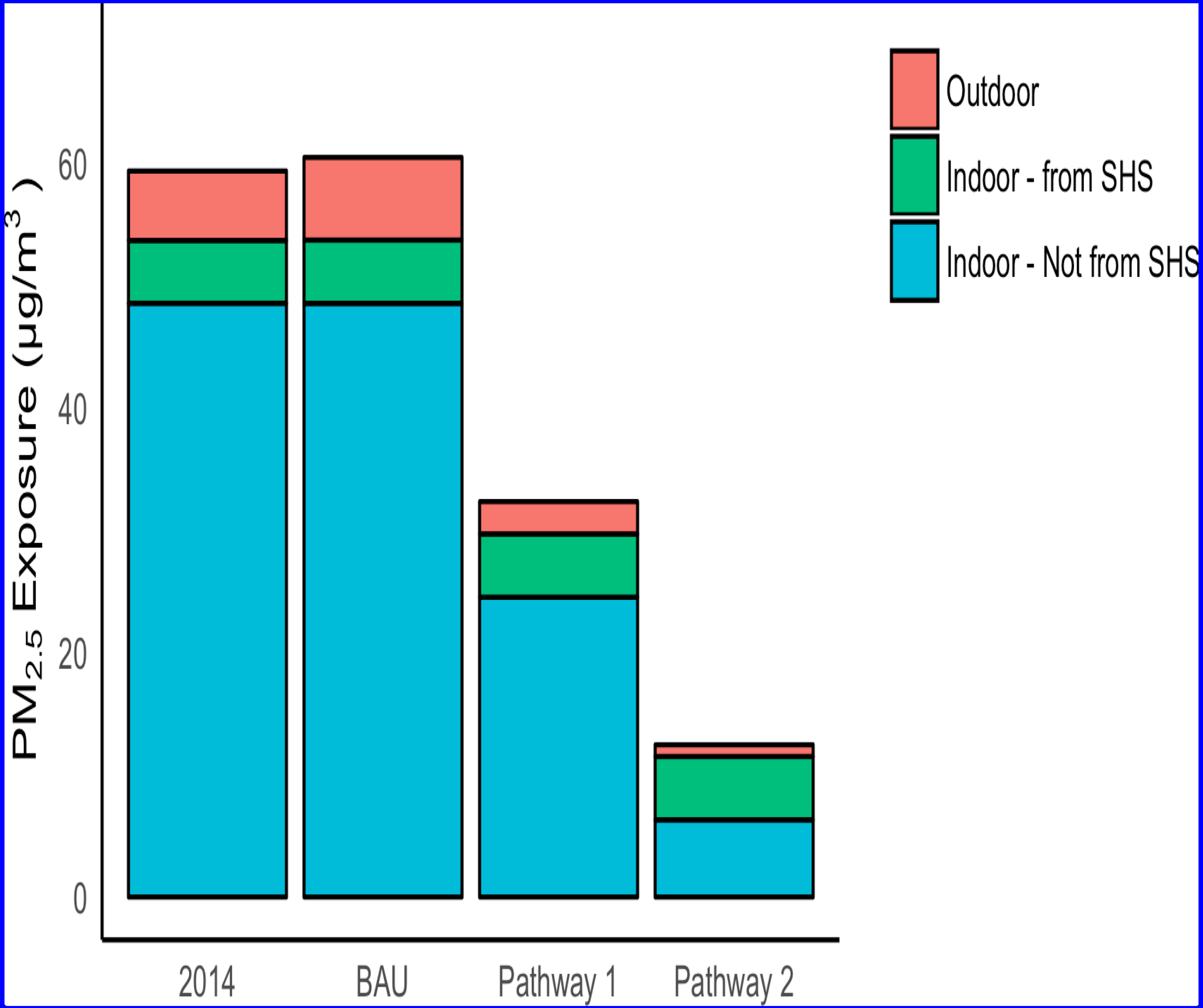
Fig 1, Hill et al 2017. High-level flow chart of the general exposure and disease analysis approach.



Annual average $PM_{2.5}$ exposures in UB

2014: 59 µg/m^3

2024:
- BAU: 60 µg/m^3
- Pathway 1: 32 µg/m^3
- Pathway 2: 12 µg/m^3



Findings from Hill et al 2017

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

Findings from Hill et al 2017

Metrics

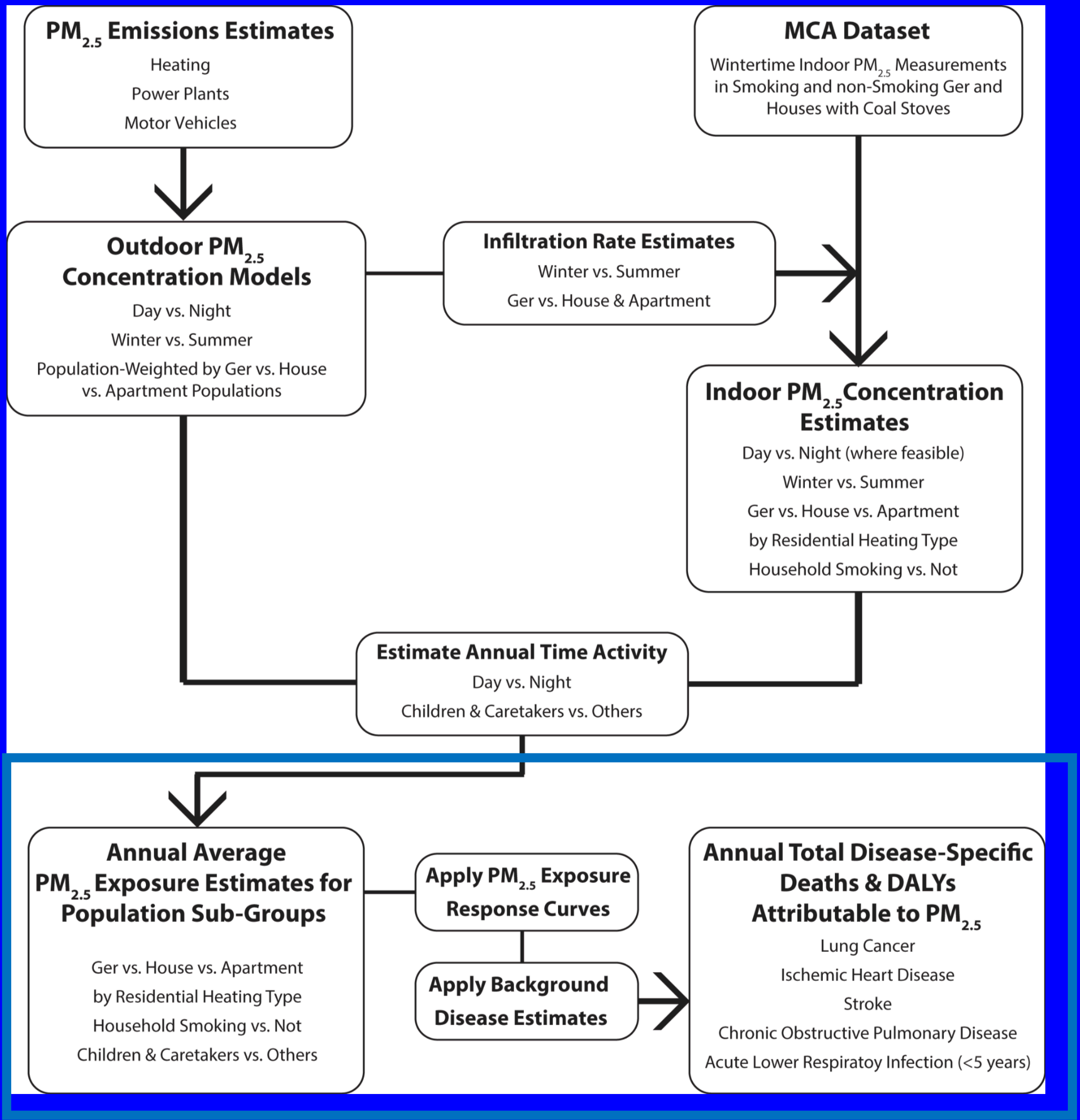
- Premature deaths due to air pollution caused diseases

- 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/m³**
- 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.



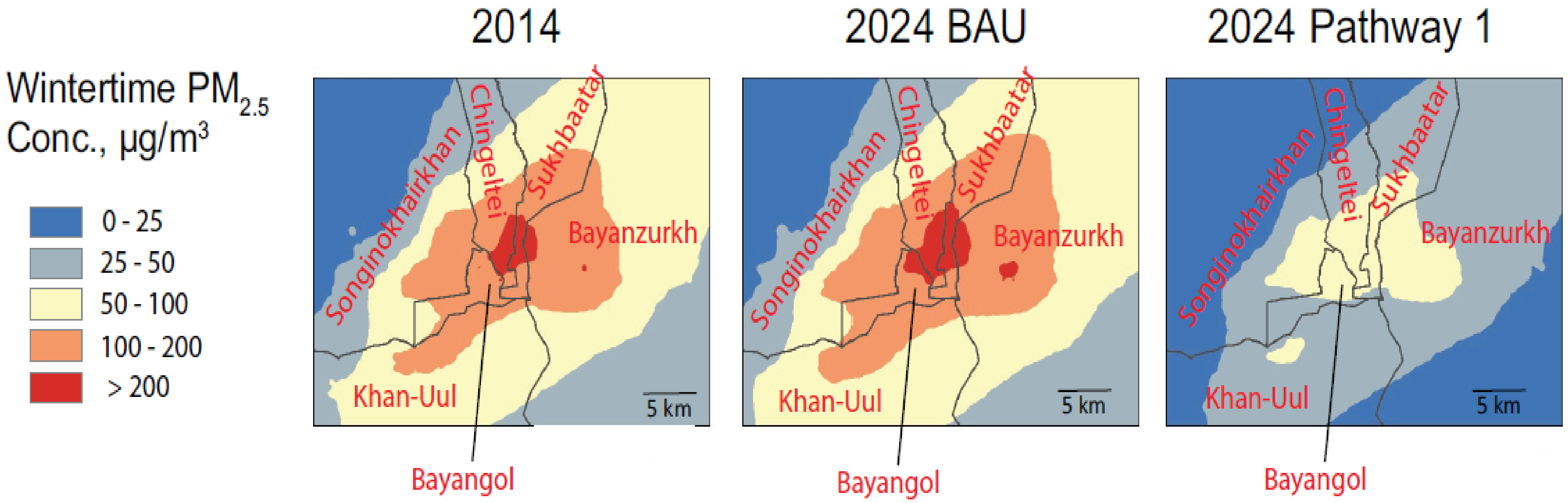


Fig 3. Winter average outdoor $PM_{2.5}$ concentrations for baseline and 2024 under BAU and Pathway 1.

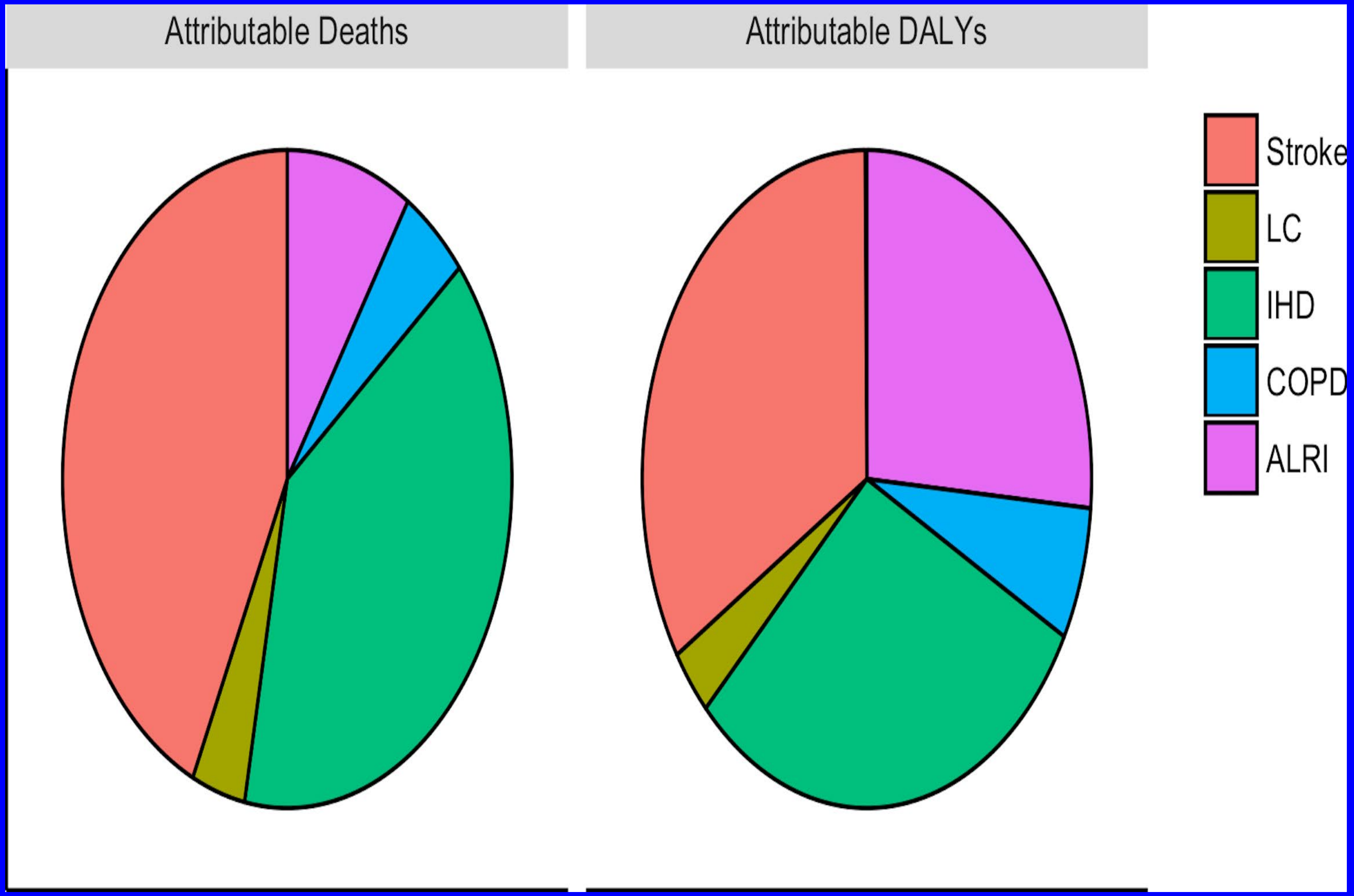
https://doi.org/10.1371/journal.pone.0186834.g003

Estimated $PM_{2.5}$ health impacts

At baseline, 2014
- 1,400 deaths
- 40,000 DALYs

Deaths accrued, 2014 - 2024
- BAU: 18,000
- Pathway 1: 14,000
- Pathway 2: 9,800

DALYs accrued, 2014 - 2024
- BAU: 530,000
- Pathway 1: 420,000
- Pathway 2: 290,000

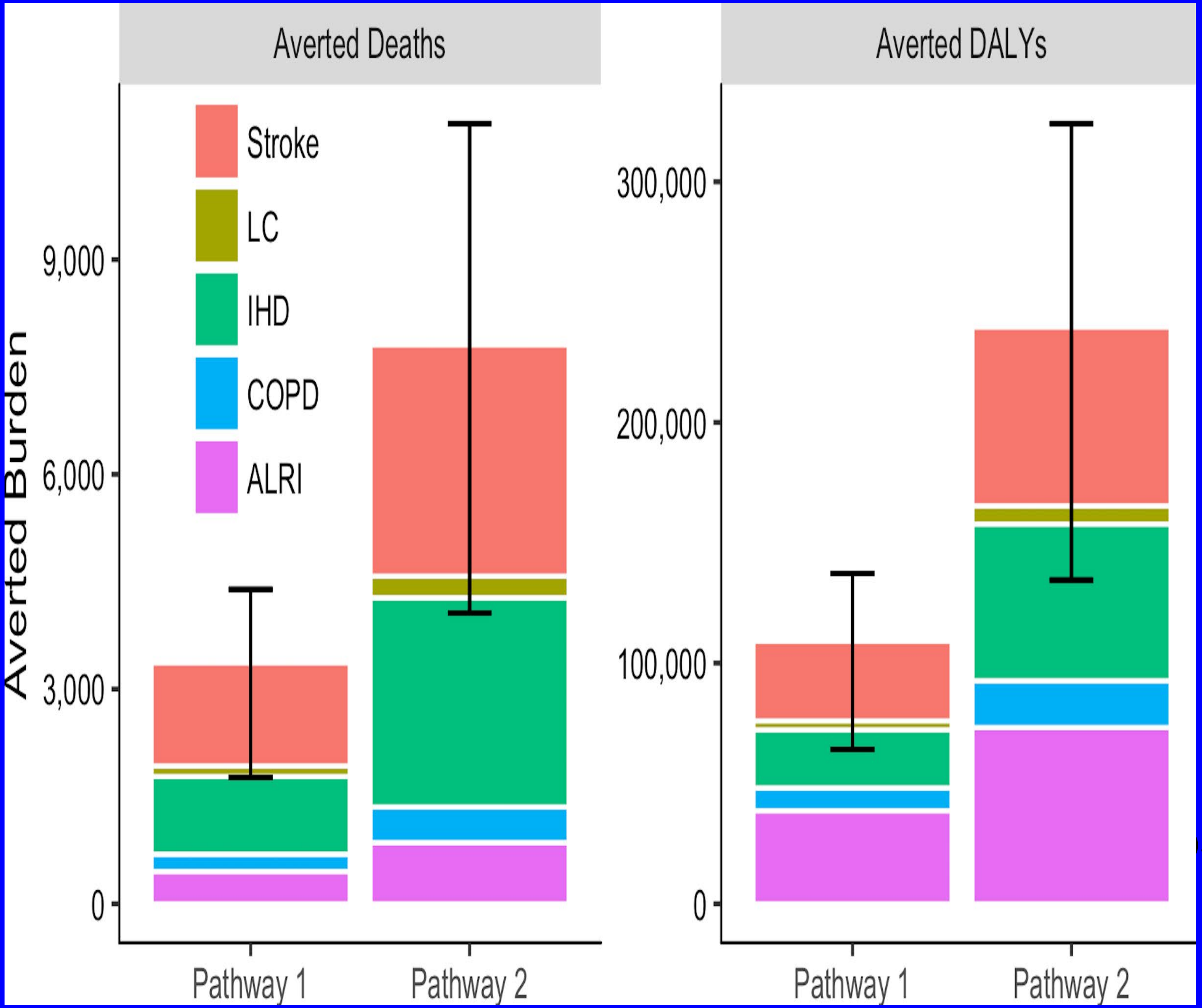


Findings from Hill et al 2017

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

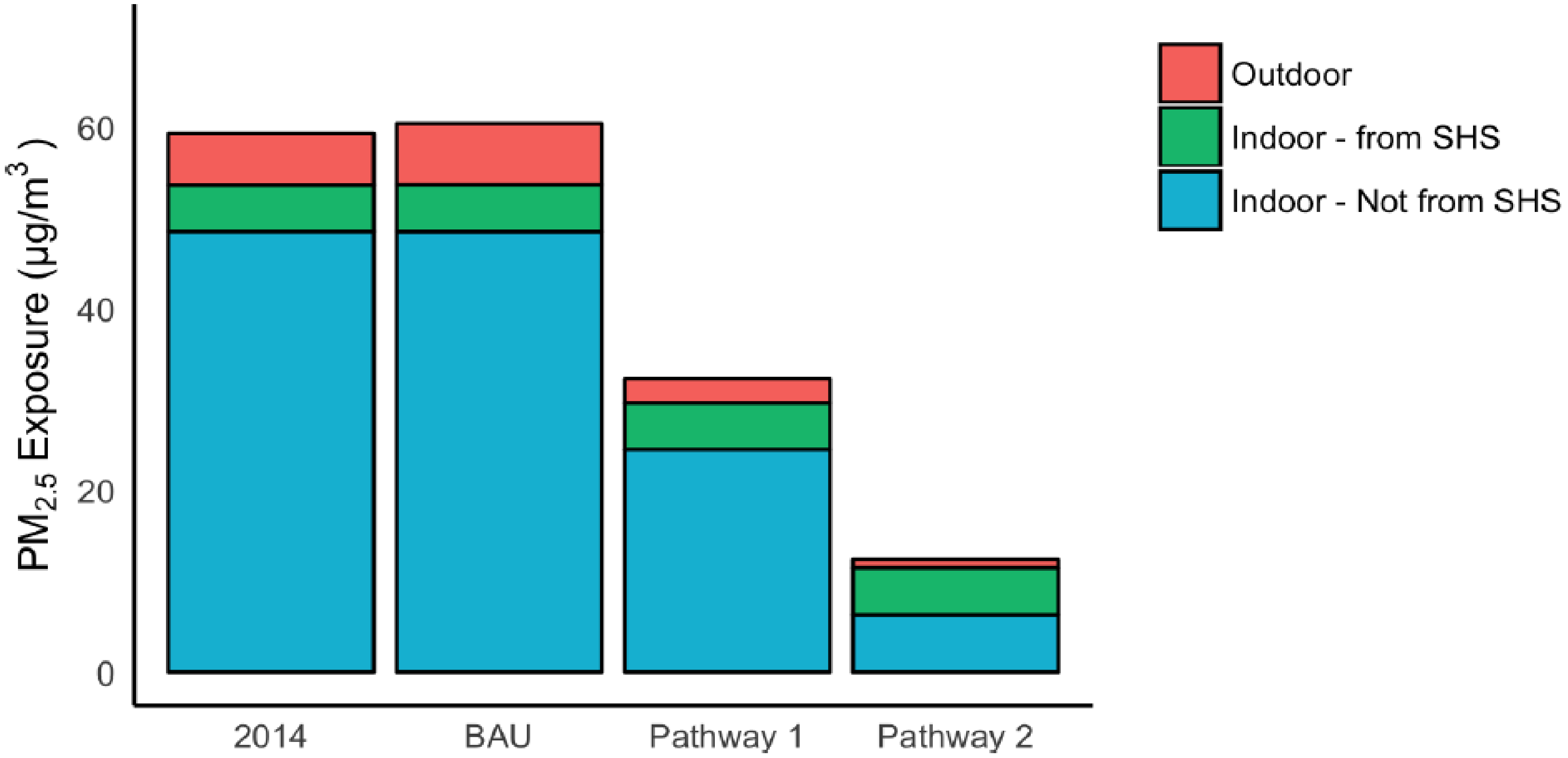


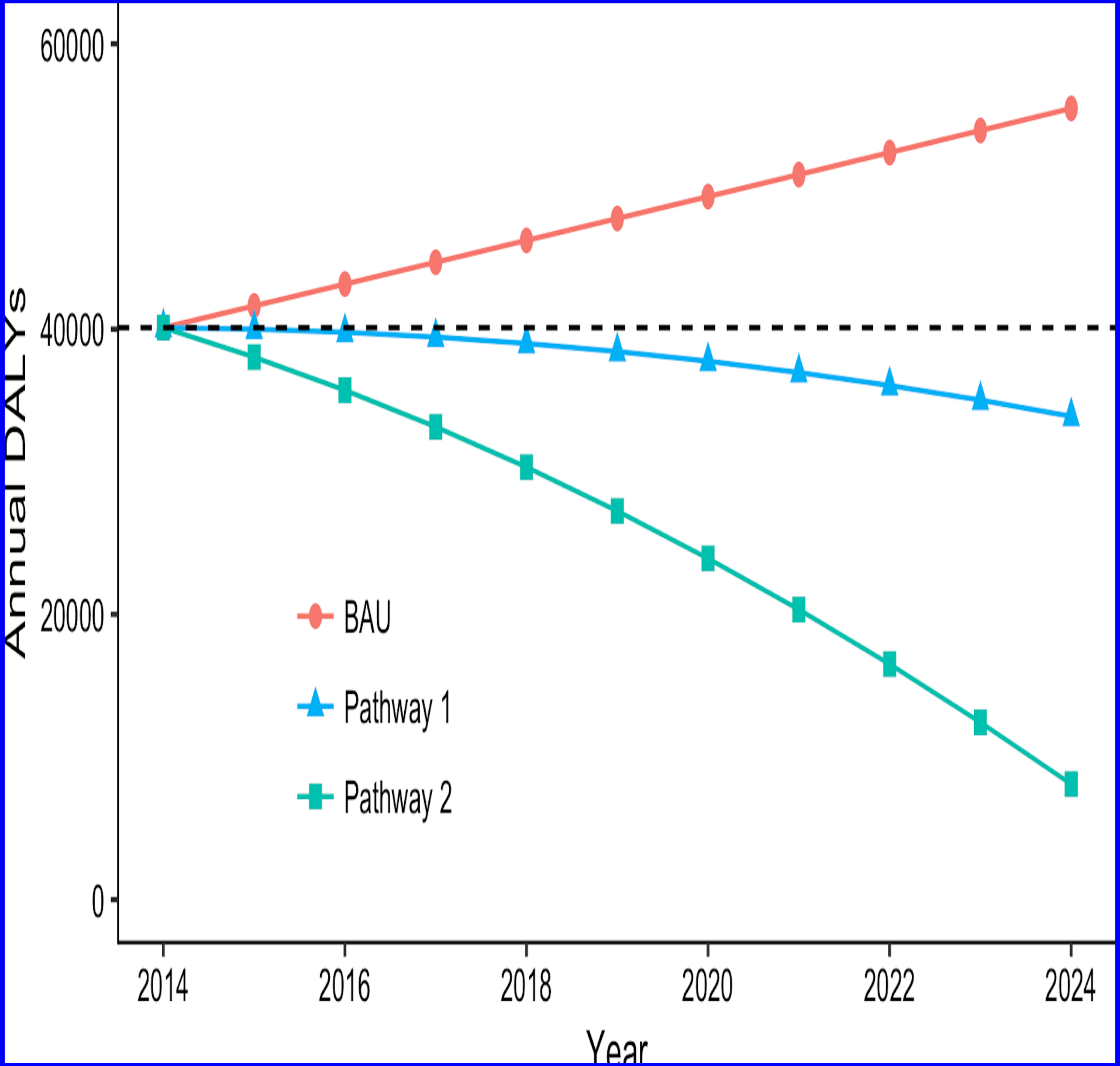
Fig 5. Exposures in 2014 and 2024 under BAU and alternative policy pathways, by environment. Indoor exposures are stratified by SHS and non-SHS environments. The difference between indoor and outdoor contribution to total exposure is primarily from the disproportionately high fraction of time spent indoors.

https://doi.org/10.1371/journal.pone.0186834.g005

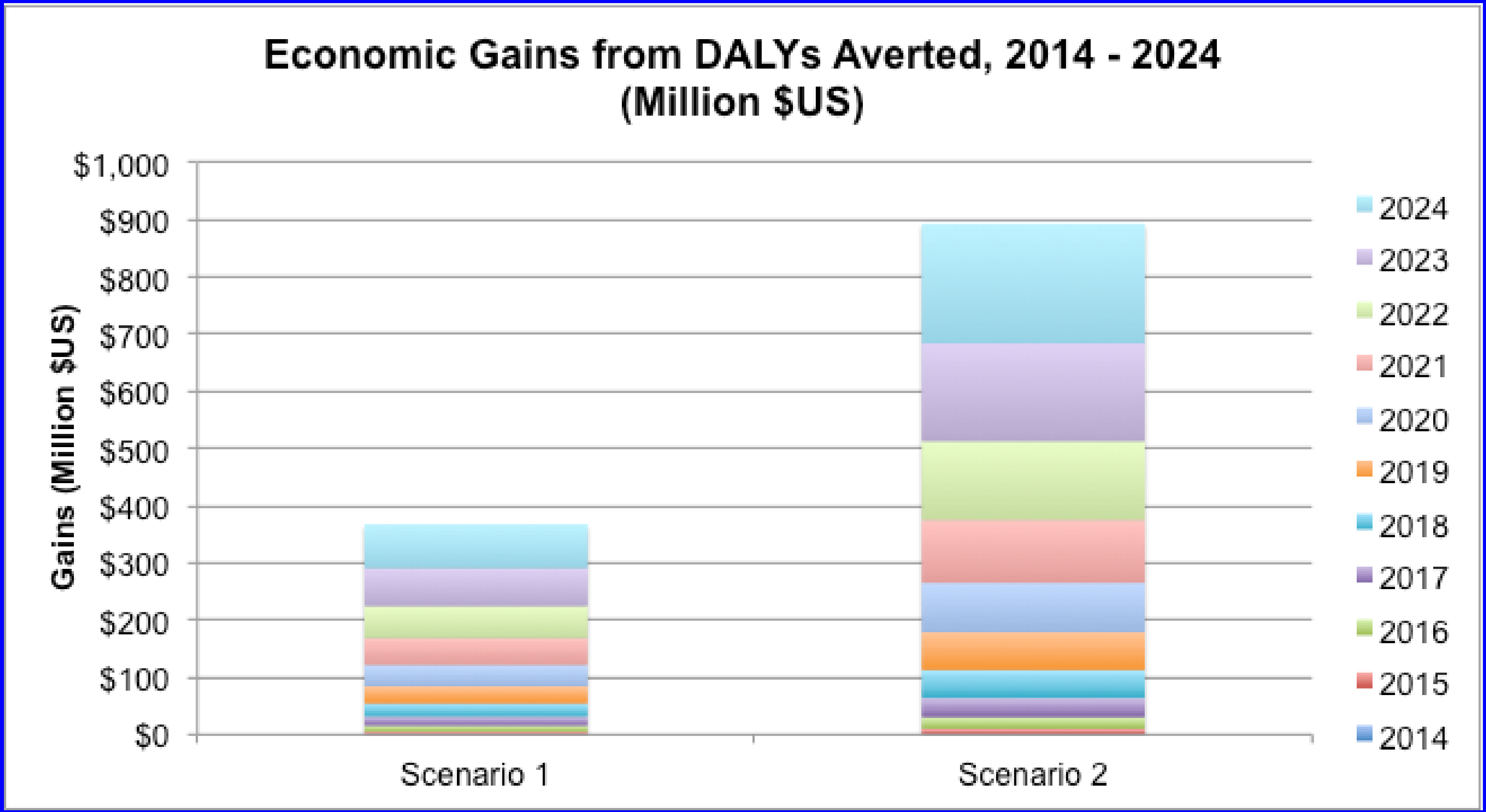
Total DALYs from $PM_{2.5}$ increase by 2024

- 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

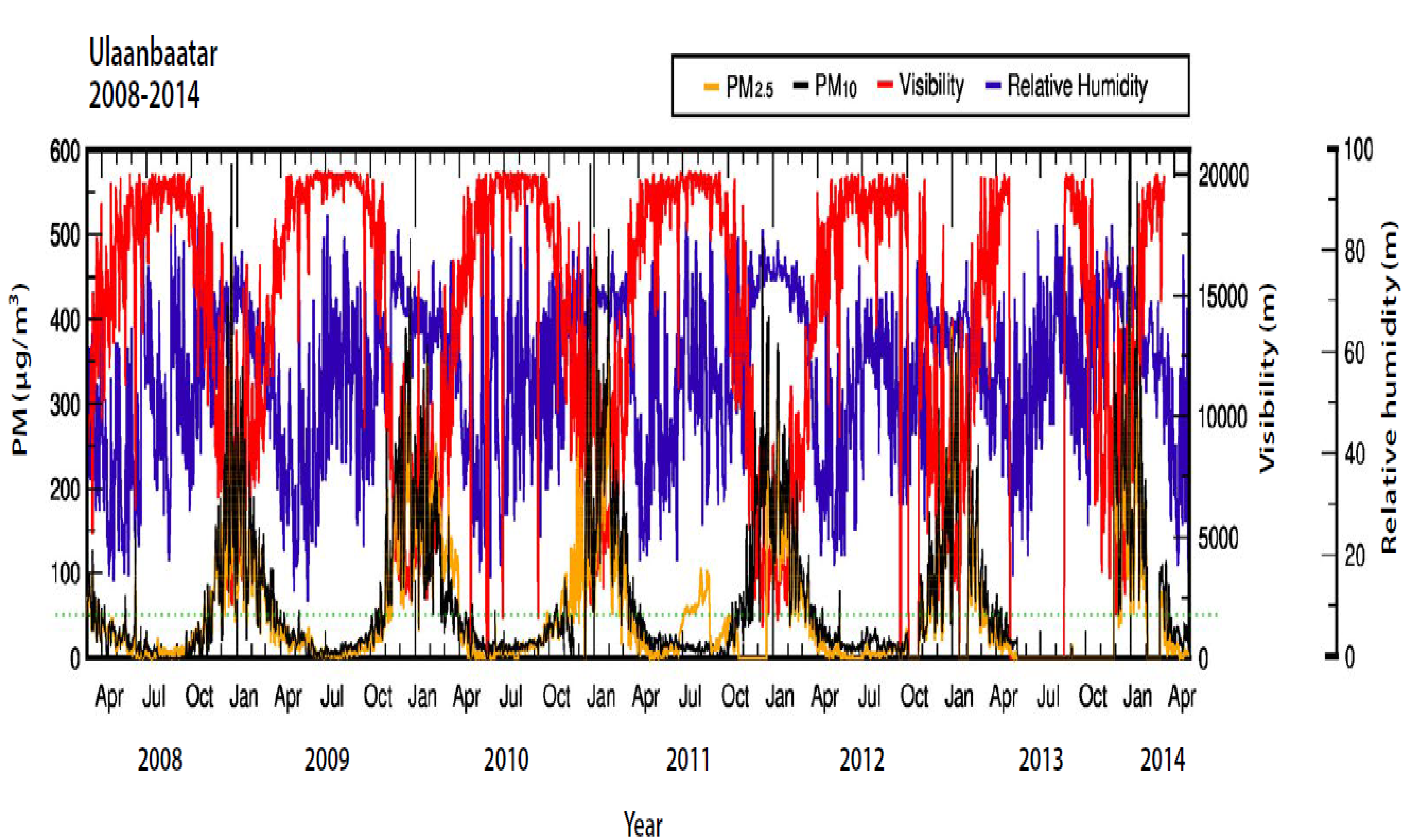


Findings from Hill et al 2017



Estimates are based on the 2012 GDP per Capita, $5374 per Year

Economic gains from avoided DALYs are substantial in both Scenarios 1 and 2. Gains accrue at nearly three times the rate in Scenario 2, and ultimately account for nearly $900 million in economic gains over the entire period.



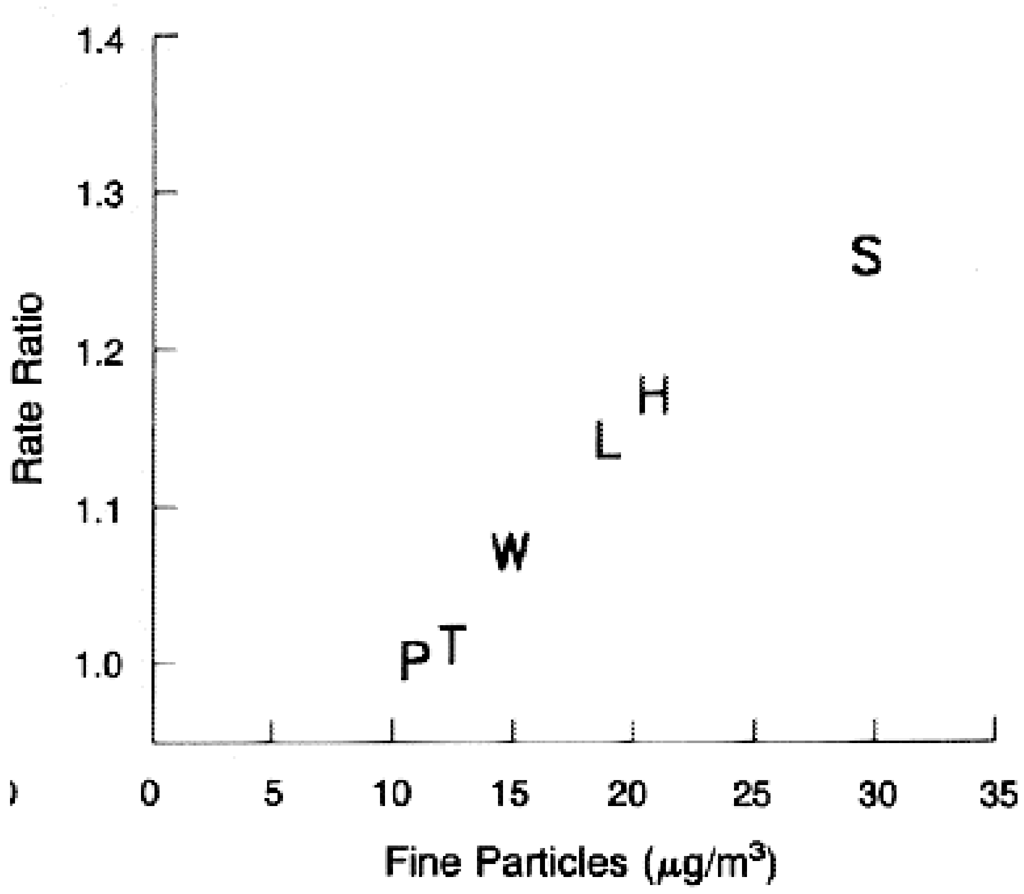
Wang et al., AJAE, 2018

Table 1. Monthly mean temperature inversion (ΔT), temperature inversion layer thickness (Δh), and temperature inversion intensity between the ground level and height at 800 hPa (500-600 m) $\left(\frac{\Delta T_{800}}{\Delta h_{800}}\right)$ $PM_{2.5}$, PM_{10}, and visibility by month from September to April, 2008-2016.

	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	Avg.
ΔT (°C)	3.6	4.4	5.5	8.0	7.9	6.1	4.9	3.2	5.4
Δh (m)	371	476	525	593	580	479	477	411	489
$\frac{\Delta T_{800}}{\Delta h_{800}}$ (°C/m)	0.008	0.009	0.011	0.012	0.013	0.012	0.011	0.007	0.011
$PM_{2.5}$ (μg/m^3)	15	56	123	187	175	110	60	19	93
PM_{10} (μg/m^3)	17	71	135	213	209	133	69	28	110
Visibility (km)	19.1	16.7	10.2	8.6	7.6	10.3	14.5	17.6	13.1

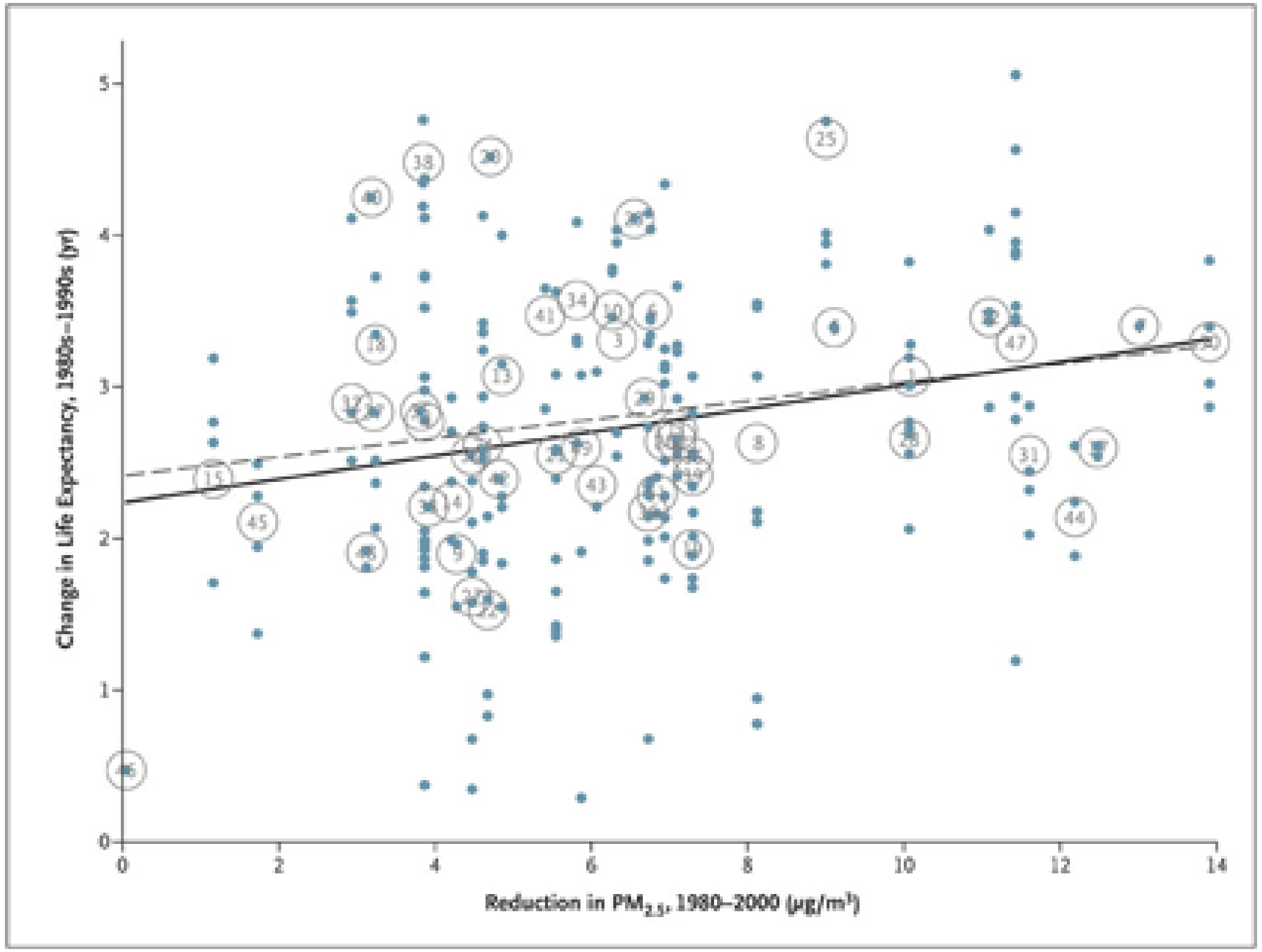
Wang et al., AJAE, 2018

An Association between Air Pollution and Mortality in Six U.S. Cities



Dockery et al. N Engl J Med 1993;329:1753-1759

Fine-Particulate Air Pollution and Life Expectancy in the United States



Pope et al. N Engl J Med 2009;360:376-386.

PM and Stroke

- Short-term exposure was associated with risk of ischemic stroke in the Greater Boston area
- Onset of stroke was most strongly associated with PM exposures 12-14 hrs before the event

Wellenius et al. Arch Intern Med 2012;172(3):229-234

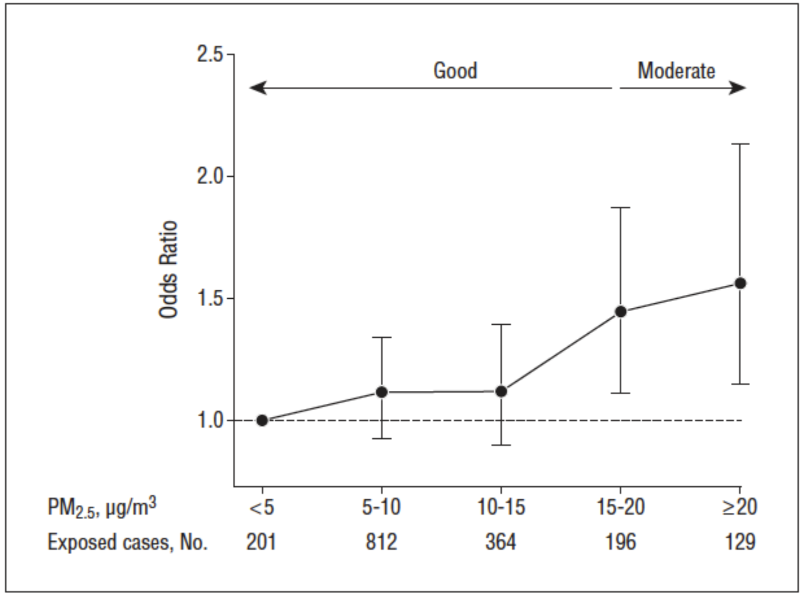


Table 2. Odds Ratio of Ischemic Stroke Onset Comparing the 75th to 25th Percentile (Interquartile Range) of Each Pollutant in the 24 Hours Preceding Stroke Onset

Pollutant	IQR	Odds Ratio (95% CI)	*P* Value
$PM_{2.5}$[a]	6.4 μg/m^3	1.11 (1.03-1.20)	.006
Black carbon[a]	0.5 μg/m^3	1.10 (1.02-1.19)	.02
Estimated residential black carbon[b]	0.6 μg/m^3	1.08 (1.01-1.16)	.02

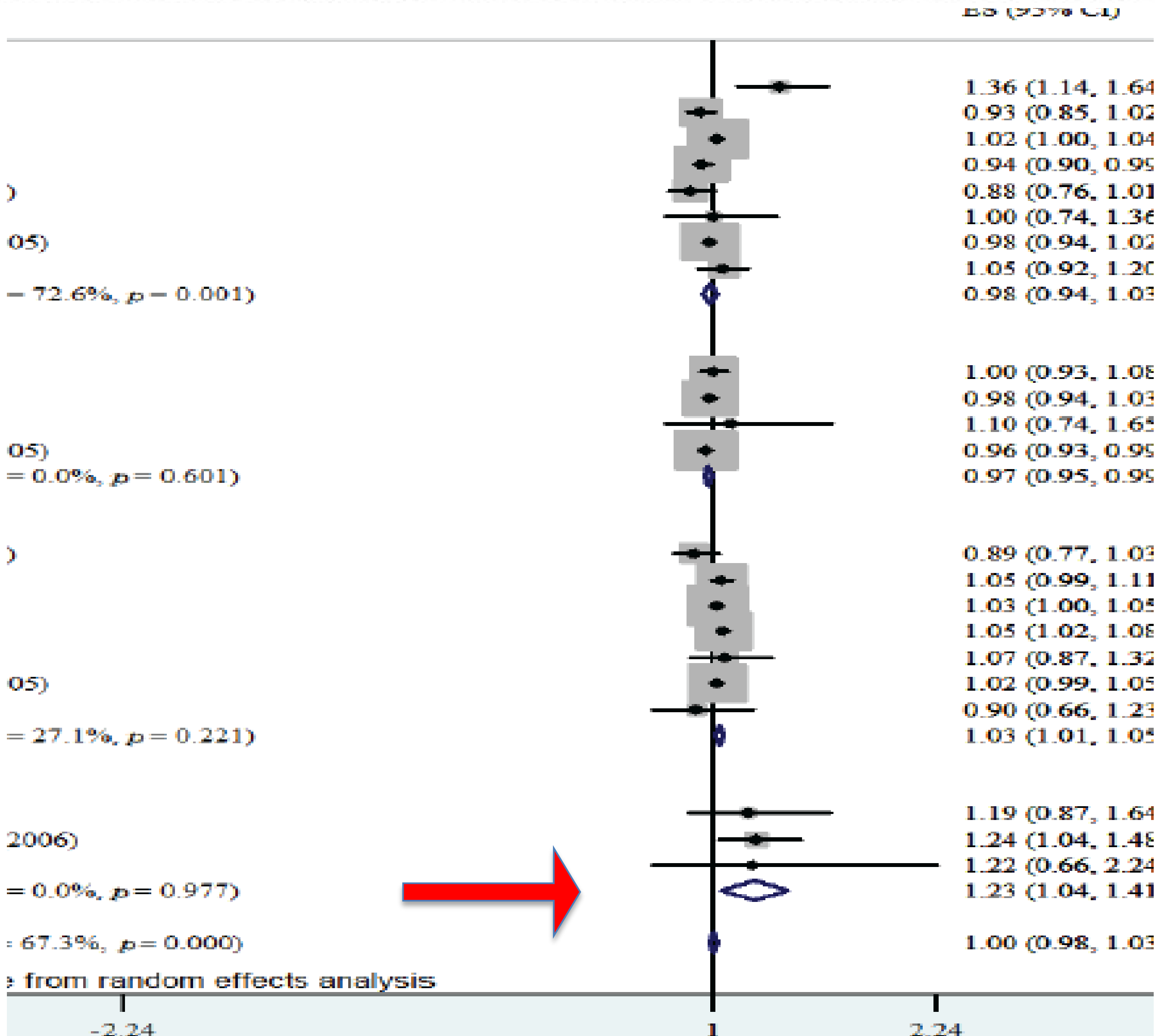
New Health Effects

- Adverse birth outcomes
- Metabolic effects/Diabetes
- Neurological effects

A meta-analysis of exposure to particulate matter and adverse birth outcomes

Dirga Kumar Lamichhane[1], Jong-Han Leem[2], Ji-Young Lee[1], Hwan-Cheol Kim[2]

Preterm Birth

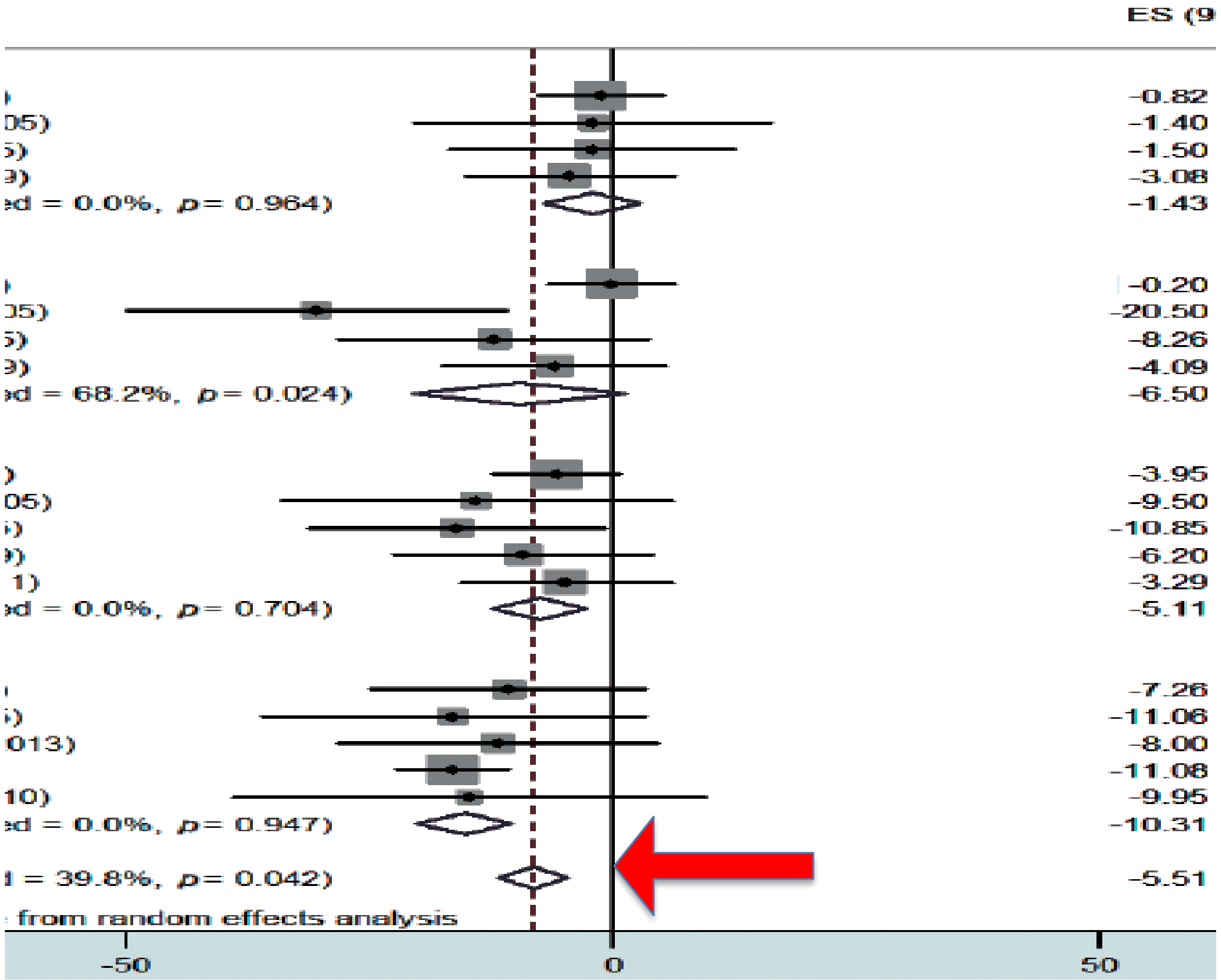


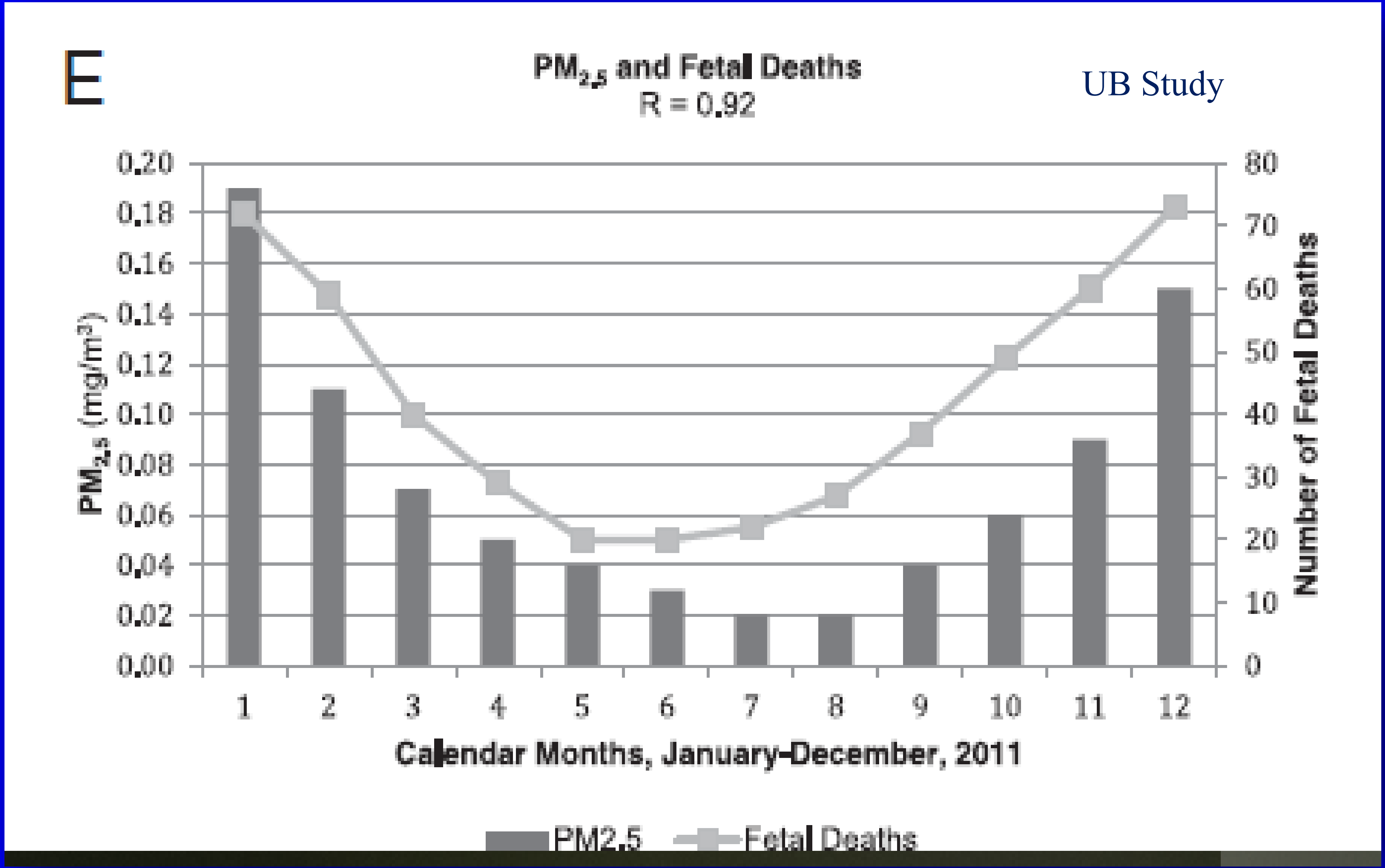
A meta-analysis of exposure to particulate matter and adverse birth outcomes

Dirga Kumar Lamichhane[1], Jong-Han Leem[2], Ji-Young Lee[1], Hwan-Cheol Kim[2]

Environ Health Toxicol 2015;30:e2015011.

Birth Weight





Enkhmaa, et al, BMC Pregnancy, 2014

Risk of Incident Diabetes in Relation to Long-term Exposure to Fine Particulate Matter in Ontario, Canada

Hong Chen,[1,2] Richard T. Burnett,[3] Jeffrey C. Kwong,[1,4,5] Paul J. Villeneuve,[2,3] Mark S. Goldberg,[6,7] Robert D. Brook,[8] Aaron van Donkelaar,[9] Michael Jerrett,[10] Randall V. Martin,[9,11] Jeffrey R. Brook,[12] and Ray Copes[1,2]

Table 2. HRs (95% CIs) for the association between incident diabetes and a 10-μg/m^3 increase in $PM_{2.5}$.

	HR (95% CI)
Adjusting for sex and stratified by age, survey year, and region	1.08 (0.99, 1.17)
+ All individual-level covariates[a]	1.11 (1.02, 1.21)
+ All neighborhood-level covariates[b]	1.11 (1.02, 1.21)
+ All other comorbidities[c]	1.11 (1.02, 1.21)

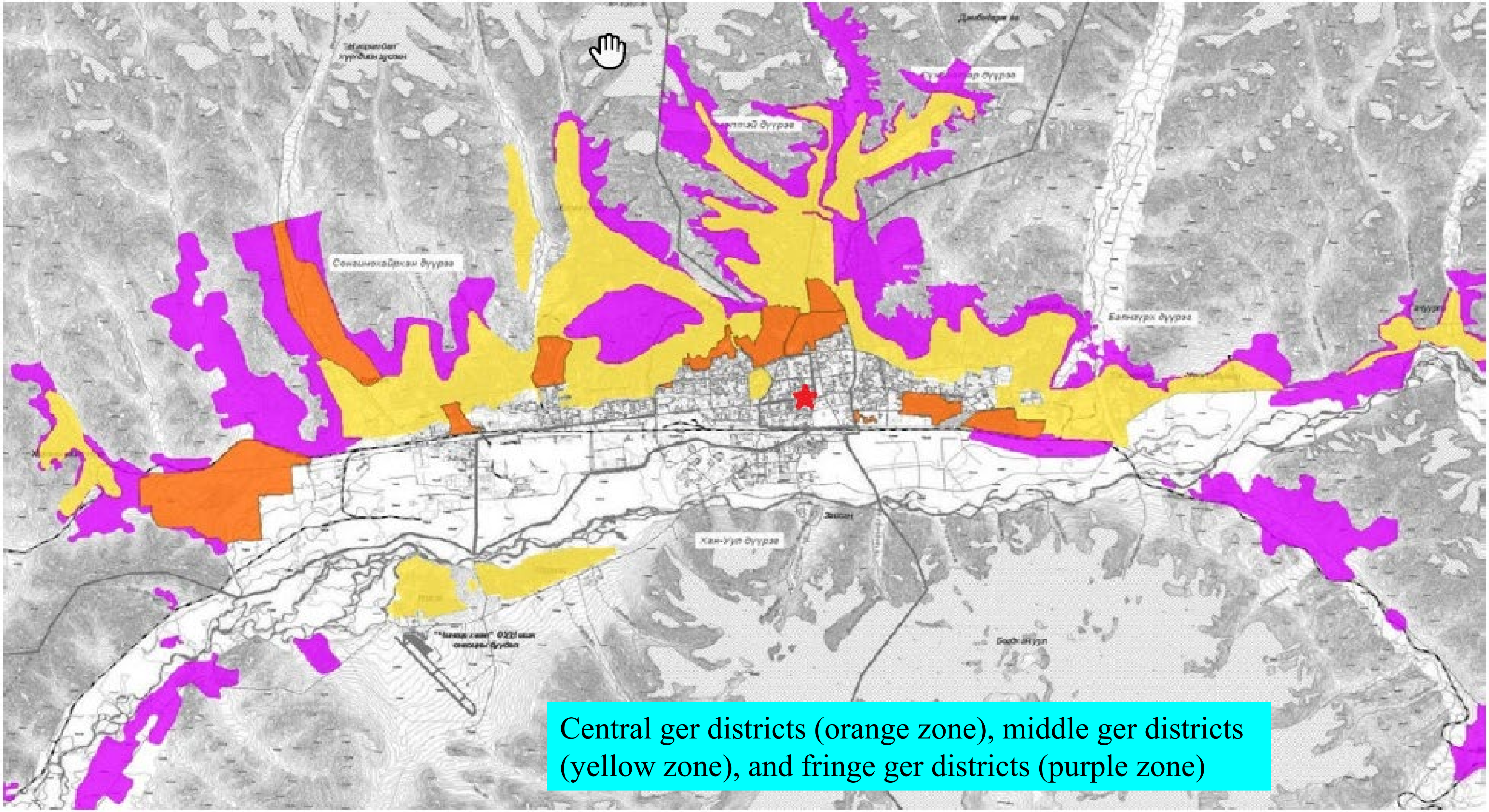
[a]Adjusted for sex, marital status, education, household income adequacy, BMI, physical activity, smoking, alcohol consumption, diet, race, hypertension, and urban residency. [b]Also adjusted for neighborhood-level unemployment rate, education, and household income. [c]Also adjusted for COPD, asthma, congestive heart failure, and acute myocardial infarction.

Chen et al. Environ Health Perspect 2013;121:804-810

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

What might be done about household heating?

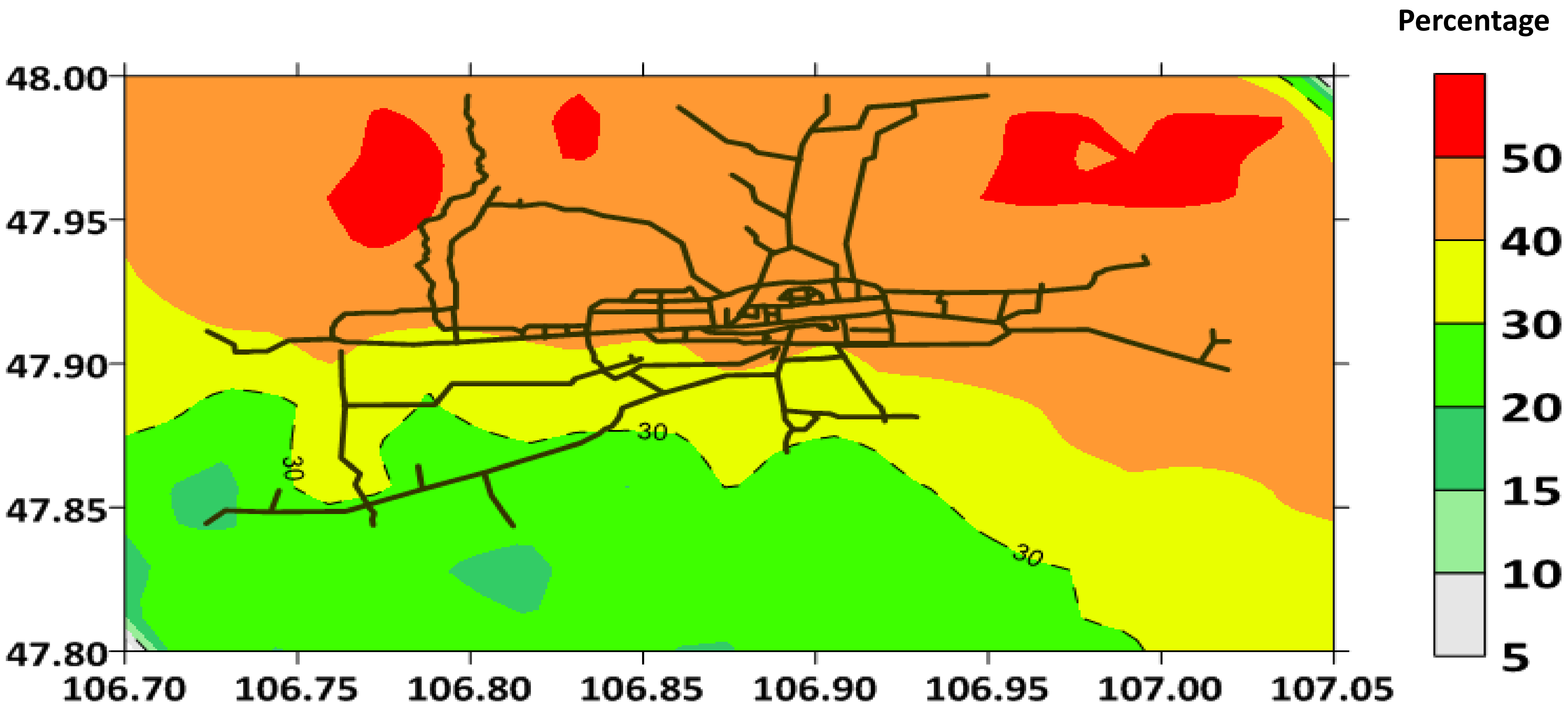
- Better coal stoves: Not clean enough, not reliable enough
- LPG: Requires imports
- Natural Gas: Also requires imports plus pipelines
- Synthetic NG or LPG from coal? Requires synfuel industry
- Electric heating: Most households electrified, but conventional heaters too inefficient



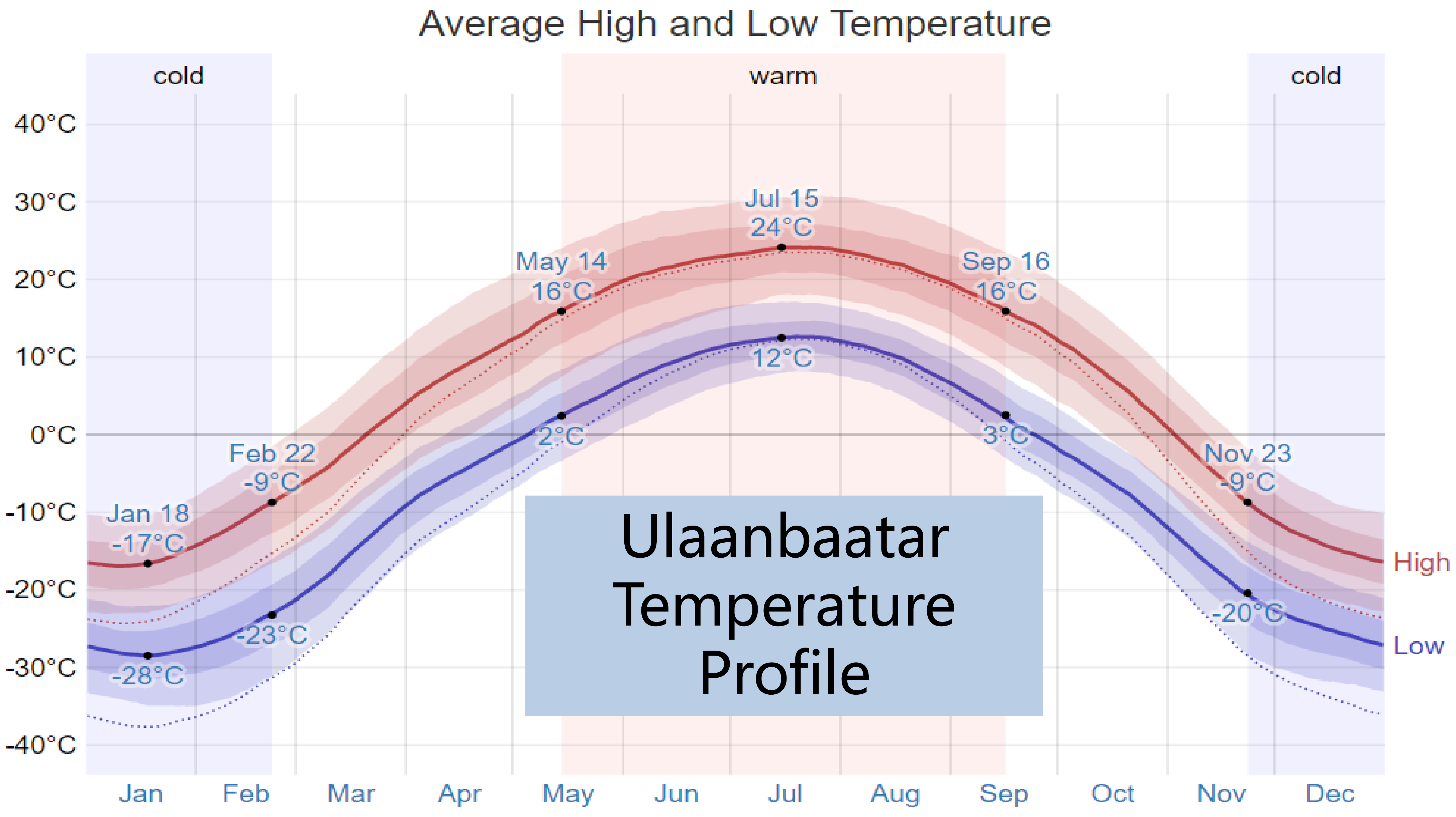
Central ger districts (orange zone), middle ger districts (yellow zone), and fringe ger districts (purple zone)

Wang et al., AJAE, 2018

Modelled Stove Contributions Winter Months: Ulaanbaatar



Guttikunda, 2014



The daily average high (red line) and low (blue line) temperature, with 25th to 75th and 10th to 90th percentile bands. The thin dotted lines are the corresponding average perceived temperatures.

Environmental Research xxx (xxxx) xxx-xxx

Contents lists available at ScienceDirect

Environmental Research

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Short communication

Advanced household heat pumps for air pollution control: A pilot field study in Ulaanbaatar, the coldest capital city in the world

Ajay Pillarisetti [a,*], Rongjiang Ma [b], Munkhbayar Buyan [c], Boldkhuu Nanzad [d], Yuma Argo [a], Xudong Yang [b], Kirk R. Smith [a]

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[b] *Department of Building Science, Tsinghua University, Beijing 100084, China*
[c] *Department of Environmental Engineering, Mongolian University of Science and Technology, Mongolia*
[d] *Mongolian Ministry of Energy, Ulaanbaatar, Mongolia*

March 2019

Improvement by changing compressor

Traditional single stage compressor (one cylinder)

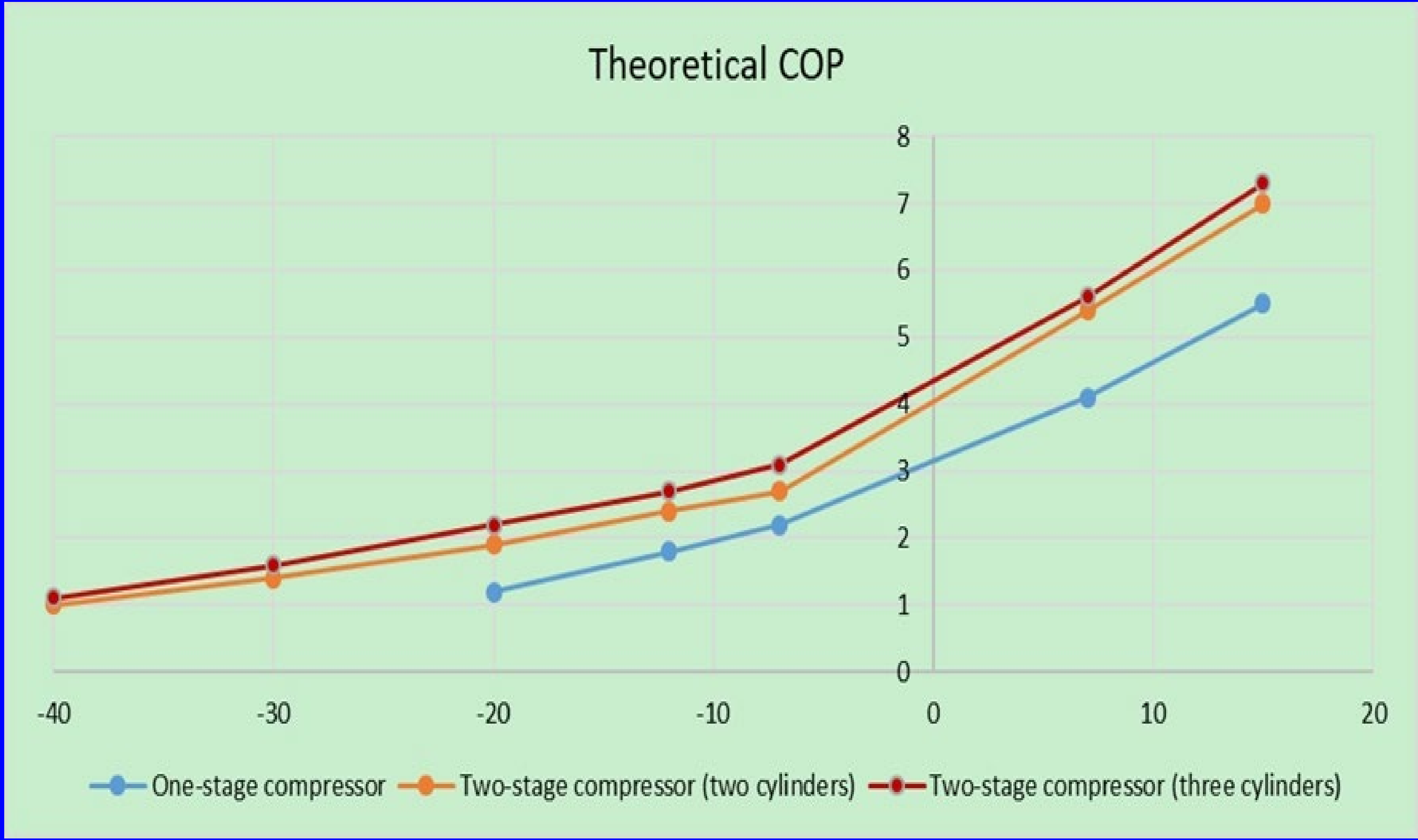
Improved double stage enthalpy-added compressor

(Two cylinders)

(Three cylinders)

- Enhanced capacity in cold ambient Improved conditions
- COP is up to 2.0+ at the outdoor temperature of -20℃
- Can running normally at the outdoor temperature of -35℃
- Includes automatic defrost
- Working fluid is R-32 , Difluoromethane, also called HFC-32.

Benefits of Double Compression

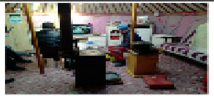
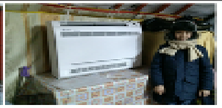
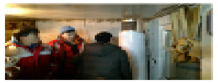
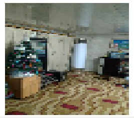
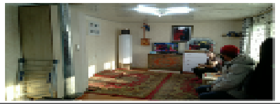
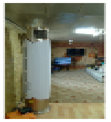
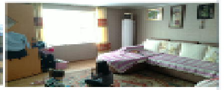




GREE

1. Detail information about the installation of experimental prototypes

Seven sets of experimental prototypes, including 2 sets of warm air blower which heating capacity is 4000W and 5 sets of packaged unit which heating capacity is 8500W, are installed in different zone, the detail information are as below.

Sequence NO.	Type	Model	Prototype No.	Installation Location	Building Type	Indoor Area（m²）	Photos about Installation Location
1	warm air blower	GN-40DZW/(40549)FNhAa-1	1#	See the Attachment No .1	ger	28.26	  
2		GN-40DZW/(40549)FNhAa-1	2#			28.26	 
3	Packaged unit	KFR-72LW/(72518)FNhAb-A1	3#		household	19.78	  
4		KFR-72LW/(72518)FNhAb-A1	4#			39	  
5		KFR-72LW/(72518)FNhAb-A1	5#			28	 
6		KFR-72LW/(72518)FNhAb-A1	6#			27	 
7		KFR-72LW/(72518)FNhAb-A1	7#			42	  

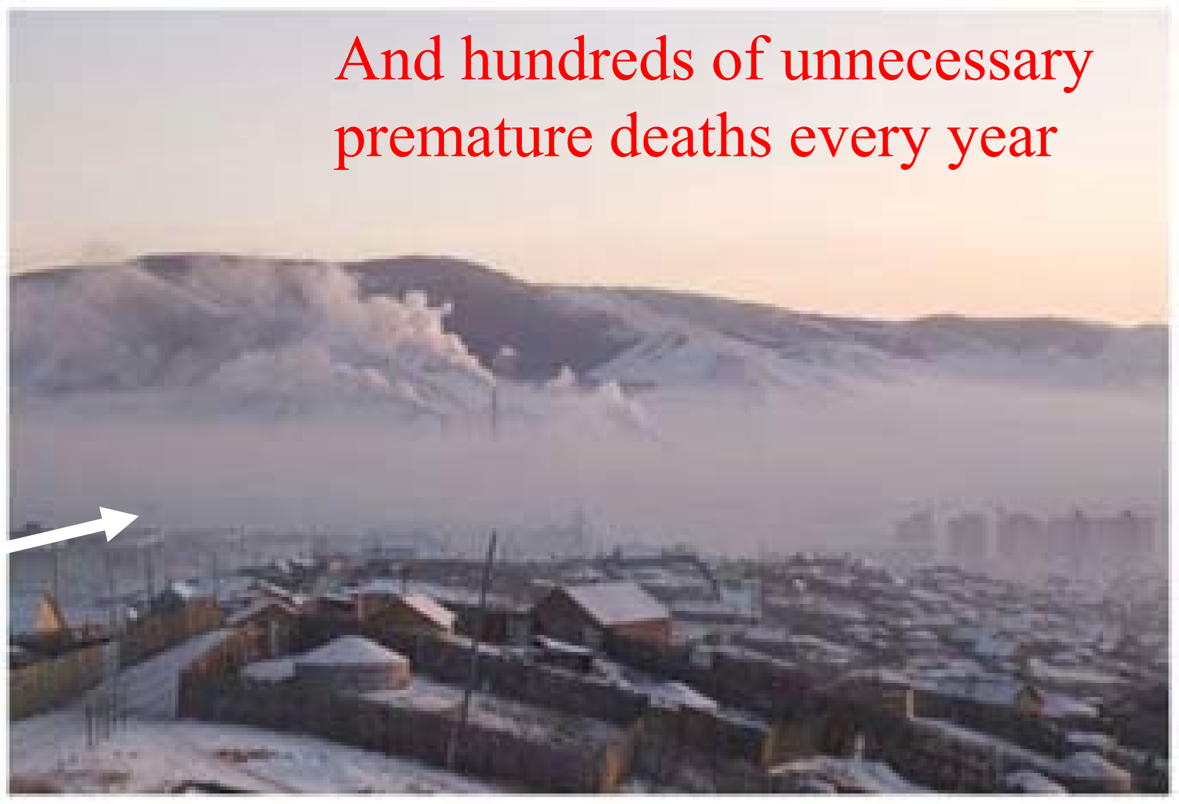
Attachment No .1, detail information about installation lacation:

	Consumption	Tariff	Total (USD)	$/m2
Coal	3.5 tons[a]	71 USD/ton[b]	248.5	8.88
Direct Heating	12,960 kWh[a]	0.0375 USD / kWh[c]	486	17.36
Heat Pumps (this study)	4634 kWh[d]	0.0375 USD / kWh[c]	173.8	6.21
Heat Pumps (conservative)[e]	6524 kWh	0.043 USD / kWh	280.5	10.02

Mongolia in the Old Days

A few solid fuel stoves
spread across the
countryside
were not a problem

Half of Mongolia today



And hundreds of unnecessary premature deaths every year

100’s of thousands of coal stoves now lead to this

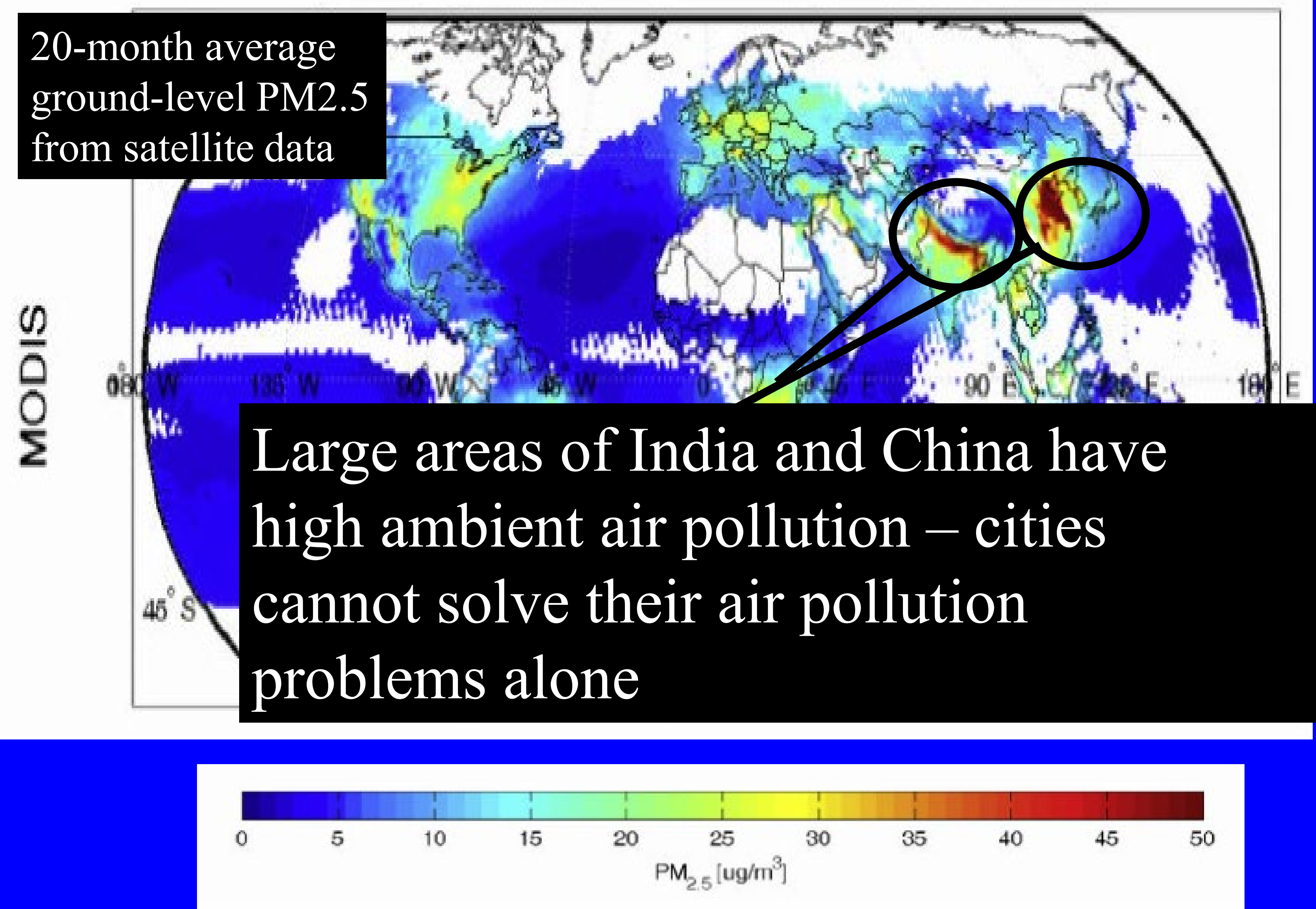
Conclusion

- If aggressive action is taken, as in Scenario 2,
- An average of one premature death per day can be prevented every day for the next 10 years
- Leaving UB as one of the cleanest large cities in Asia
- This is easier in UB that other places.

Heat Pumps in UB

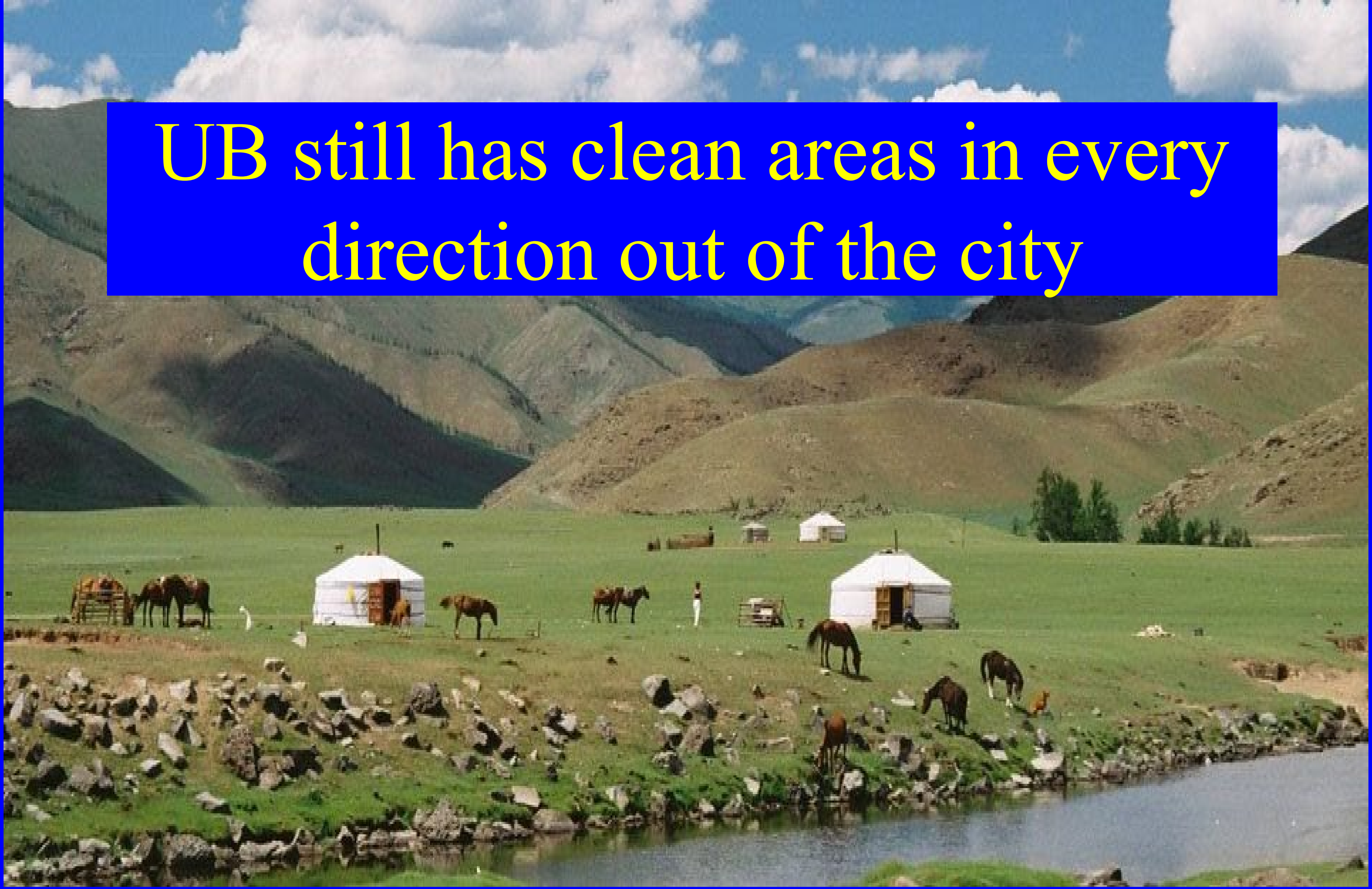
- Need fuller demonstration studies
- Combined with efforts to improve house insulation
- Household behavior is critical
- Impact on power system needs to evaluated
- Possible demand management
- Implications for fuel demand in country
- Possibility of bringing forward in time the energy transition for Mongolia

20-month average ground-level PM2.5 from satellite data



Large areas of India and China have high ambient air pollution – cities cannot solve their air pollution problems alone

UB still has clean areas in every direction out of the city



Mongolia is the least densely populated country in the world

Unlike Beijing, Delhi, and other polluted cities in Asia,

Ulaanbaatar

holds its destiny in

its own hands.

Thank you

Publications on website: Just Google "Kirk R. Smith