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Supplemental Material

Assessing Exposure to Household Air Pollution: A Systematic Review and Pooled Analysis of Carbon Monoxide as a Surrogate Measure of Particulate Matter

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References

Table S1. Characteristics of study population represented by paired measurements of personal exposure to $PM_{2.5}$ and CO

Author/Publication Year (setting)	Study Population with Description of Stoves Used
Armendáriz-Arnez et al. 2008 (rural Mexico)	60 non-smoking women from Comachuen (indigenous agricultural community) who burn wood in traditional, unvented stoves (*fogon*)
Balakrishnan et al. 2015 (rural India)	45 observations among non-smoking women who burned dung and wood; 35 paired measurements during use of traditional unvented stoves and 10 paired measurements during use of unvented gasifier stoves (Philips)
Commodore et al. 2013 (rural Peru)	20 non-smoking mothers or childcare providers who used biomass and were participating in a community randomized-control trial; 11 control households using open fires, vented, unvented, or gas and 9 intervention households with vented stoves (OPTIMA)
Dionisio et al. 2012 (peri-urban The Gambia)	48 children recruited who were younger than 61 months and older than 15 months at the time of measurement (mean: 34 ± 9 months); 29 complete paired personal $PM_{2.5}$ and CO exposure measurements; households burned biomass in open fires
Ellegard and Egneus 1993 (urban Zambia)	268 low-income, non-smoking women >15 years old who undertook primary cooking activities and burned biomass in traditional, unvented open fires or traditional *mbaulas* charcoal stoves; some households reported using electricity in addition to solid fuels
Hartinger et al. 2013 (rural Peru)	93 non-smoking mothers or childcare-providers from households enrolled in a home-based environmental intervention study; 48 participants burned biomass in open fires and unvented stoves and 43 burned biomass in vented intervention stoves (OPTIMA), 2 households belonged to near-by village with a different vented stove
Fitzgerald et al. 2012 (rural Peru)	64 non-smoking women aged 18-45 years old who undertook primary cooking activities and burned wood in indoor open fires; paired measurements pre- and post-intervention were made in households using open fires and vented intervention stoves, respectively
McCracken et al. 2013 (rural Guatemala)	116 non-smoking women who undertook primary cooking activities and burned wood in indoor open fires or vented woodstoves; 40 with one paired measurement, 52 with two paired measurements, and 24 with three paired measurements for a total of 216 observations
Mukhopadhyay et al. 2012 (rural India)	32 non-smoking women who undertook primary cooking activities and burned wood and/or cow dung using unvented stoves; 71% of cooking locations were outdoors, of which 82% were completely uncovered; personal $PM_{2.5}$ measurements made only during cooking
Naeher et al. 2000 (rural and semi-urban Guatemala)	3 mother-child pairs (child <15 months) monitored under each of the following stove/fuel combinations separately: gas stove, traditional vented

	stove, and open fire; personal monitoring for $PM_{2.5}$ and CO conducted for 10-12-h period during the day (primary cooking hours); results reported for only one mother-child pair
Ni et al. (under review) (rural China)	22 non-smoking women who undertook primary cooking activities and burned wood in vented woodstoves; 4 paired measurements conducted in summer; 18 paired measurements conducted in winter
Peel et al. *unpub*. (rural Honduras)	105 cross-sectional observations among non-smoking women who burned wood in traditional chimney stoves or improved-combustion chimney stoves (*Justa*)
St. Helen et al. 2015 (peri-urban Peru)	106 non-smoking women recruited during their first trimester of pregnancy; women undertook primary cooking activities and among those who participated fully, 17 burned wood, 33 burned LPG, 13 burned coal briquettes, 5 burned kerosene, and 30 burned a combination of fuels that included electricity
Wylie et al. 2016 (urban Tanzania)	239 non-smoking, pregnant women > 15 years old were recruited into a prospective observational cohort study; 118 successful paired personal $PM_{2.5}$ and CO exposure measurements

Table S2. Categorization of covariates

Covariate	Category 1 (reference)	Category 2
Fuel use	‘exclusive use of unprocessed biomass’, which included wood, agricultural residues, cow dung	‘non-exclusive use of biomass’
Level of urbanicity	‘rural’ setting	‘peri-urban or urban’ setting
Season of data collection	‘non-heating’ season (summer or dry)	‘heating’ season (winter or rainy)
Other local air pollution sources	‘absent’ if none were reported	‘present’ if environmental tobacco smoke, traffic, and/or other local sources of air pollution were specified
CO measurement	‘colorimetric’ measurement based on passive diffusion of CO through dositubes	‘sensor’ measurement based on electrochemical or photoelectric response to CO by sensor
PM measurement	‘gravimetric’	‘light-scattering’

Table S3. Personal $PM_{2.5}$ exposure measurement methods and quality assurance and quality control protocols

Author/Publication Year (setting)	PM Measurement Method (duration, instruments, and interval)	Reported Quality Assurance and Quality Control Protocols for PM Measurements
Armendáriz-Arnez et al. 2008 (rural China)	24-h; UCB particle monitor logged $PM_{2.5}$ concentration every 1-min	--adjustment for inter-instrument variability observed in controlled combustion chamber experiments --nephelometer sensitivity adjustment using co-located $PM_{2.5}$ gravimetric measurements
Balakrishnan et al., *unpub*. (rural India)	24-h; gravimetric; pump (1.5 L/min) + cyclone + 37-mm PTFE filter backed with cellulose support	--pump flow rates measured pre-/ post- measurement --filters weighed on microbalance with ±1 μg sensitivity after 24-h conditioning in T/RH controlled room --field blanks collected every 1 in 5 measurements
Commodore et al. 2013 (rural Peru)	Variable: 2.8 – 13.1 h; SidePak AM510 (TSI Inc) logged $PM_{2.5}$ concentration every 30-s	--zero-calibrated with HEPA filter before each use -- $PM_{2.5}$ concentration adjusted with correction factor of 0.77 according to Jiang et al. (2011)
Dionisio et al. 2012 (peri-urban The Gambia)	48-h; gravimetric; pump (1.8 L/min) + personal exposure monitor (Harvard-PEM) + 37-mm PTFE filter backed with Whatman drain disc	--pump flow rates measured pre-/ post- measurement using a calibrated rotameter or digital mass flowmeter --measurement excluded if <80% of target 48-h --filters weighed on microbalance with ±1 μg sensitivity after 24-h conditioning in T/RH controlled room --limit of detection (LOD) for filter weights calculated as 3 times the standard deviation of the mean absolute difference of blanks = 11.6 μg --31 filter field blanks; mean absolute difference = 4.6 μg --10 duplicate filter measurements; mean difference = 0.8% and mean absolute difference = 6.8%
Ellegard and Egneus 1993 (urban Zambia)	Variable: ~4 – 5 h; gravimetric; pump (flow rate not specified) + cyclone + 37-mm Millipore SCWP filters	--none reported --monitoring occurred for 4 – 5 hours during mid-day meal --measured respirable fraction of particulate matter (aerodynamic diameter < 7.1 μm)

Hartinger et al. 2013 (rural Peru)	48-h; gravimetric; pump (1.5 L/min) + cyclone + filter (type not specified)	--pump flow rates measured pre-/ post- measurement using a calibrated rotameter or digital mass flowmeter --measurement excluded if <36-h --filters weighed in duplicate on microbalance with ±1 μg sensitivity after 48-h T/RH controlled conditioning (21 ± 0.1 °C; 40.9 ± 1.5% RH) -- 2 laboratory blanks; 28 field blanks (0.013 ± 0.002 mg); 16 open blanks (0.004 ± 0.001 mg) --US EPA QA Guidance Document cited (US EPA 2005)
Fitzgerald et al. 2011 (rural Peru)	48-h; gravimetric; pump (1.5 L/min) + cyclone + 37-mm PTFE filter	--pump flow rates measured pre-/ post- measurement using a calibrated rotameter or digital mass flowmeter --measurement excluded if <36-h --filters weighed in duplicate on microbalance with ±1 μg sensitivity after 48-h T/RH controlled conditioning (20.6 ± 1.4 °C; 31 ± 13% RH) -- 30 field blanks; average mass equivalent to 0.88 μg/m^3 for 48-h measurement period --US EPA QA Guidance Document cited (US EPA 1998)
McCracken et al. 2013 (rural Guatemala)	24-h; gravimetric; pump (1.5 L/min) + cyclone + 37-mm PTFE filter with drain disc support	--pump flow rates measured pre-/ post- measurement using a soap bubble flow meter --filters weighed with microbalance under atmosphere controlled conditions
Mukhopadhyay et al. 2012 (rural India)	Variable: during cooking period (duration not reported); gravimetric; pump (1.5 L/min) + cyclone + 37-mm PTFE filter with cellulose support	--pump flow rates measured pre-/ post- measurement using a calibrated rotameter --filters weighed with Mettler balance (sensitivity not reported) after 24-h T/RH-controlled conditioning
Naeher et al. 2000 (rural and semi-urban Guatemala)	Variable: ~10 – 12 h; gravimetric; pump (3.5 L/min) + cyclone + 37-mm PTFE-coated glass fiber filter with cellulose support	--pump flow rates measured every two days using a soap bubble flow meter --filters weighed after 48-h T/RH-controlled conditioning --12 field blanks collected
Ni et al. 2016 (rural China)	48-h; gravimetric; pump (1.8 L/min) + personal exposure monitor (Harvard-PEM) + 37-mm PTFE filter backed	--pump flow rates measured pre-/ post- measurement using a calibrated rotameter --measurement excluded if <80% of target 48-h --filters stored at -30 °C

	with metal screen	--filters weighed on microbalance with ±1 μg sensitivity after 24-h conditioning in T/RH controlled room (72.1 ± 0.9 °F; 31.2 ± 1.8% RH) --approx. 40 filter field blanks; mean pre-/post- mass difference = 24.7 μg
Peel et al. *unpub*. (rural Honduras)	24-h; gravimetric; pump (1.5 L/min, SKC AirChek XR5000) + cyclone (Triplex Cyclone) + 37-mm Fiberfilm filters (T60A20, Pall)	--pump flow rates pre-calibrated daily using a Bios International DryCal DC-Lite --all pumps were programmed to run for 24 hours before automatically turning off --measurements excluded if <75% of target time (n=4, no pumps ran between 75-100%) --filters stored at -20 °C in Honduras and -80 °C in Colorado --filters pre and post-weighed after 24-h equilibration in a T/RH-controlled room --one measurement blank collected every 2 weeks (n=7, mean = 0.029 mg, SD = 0.008 mg); LOD for filter weights calculated as 3 times the SD of the mean absolute difference of blanks = 0.054 mg; values < LOD replaced with LOD/(square root of 2) --final time-weighted average values were blank-corrected and used the average of the pre- and post-flow rates (flow fault flags were created if the post flow was <1.35 L/min)
St. Helen et al. 2015 (peri-urban Peru)	48-h; gravimetric; pump (1.5 L/min) + cyclone + 37-mm PTFE filter	--filters stored at -30 °C --filters weighed in duplicate on microbalance with ±1 μg sensitivity after 48-h T/RH controlled conditioning (70.0 ± 4.0 °F; 35 ± 4% RH) -- 48-h $PM_{2.5}$ concentrations were field-blank-corrected --US EPA QA Guidance Document cited (US EPA 1998)
Wylie et al. 2016 (peri-urban Tanzania)	48-h; gravimetric; pump (3.5 L/min) + cyclone + 37-mm PTFE filter	--filters weighed in duplicate on microbalance with ±1 μg sensitivity after 24-h T/RH controlled conditioning (20.5 ± 0.2 °C; 39 ± 2% RH) -- 48-h $PM_{2.5}$ concentrations were field-blank-corrected --US EPA QA Guidance Document cited (US EPA 1998)

Table S4. Personal CO exposure measurement methods and quality assurance and quality control protocols

Author/Publication Year (setting)	CO Measurement Method (duration, measurement devices, and interval)	Reported Quality Assurance and Quality Control Protocols for CO Measurements
Armendáriz-Arnez et al. 2008 (rural China)	24-h; CO monitor not specified for personal exposure, but assumed to be same as was used for stationary CO measurements—HOBO CO monitor logged CO concentration every 1-min	--calibration with NIST traceable gas (5, 10, 25, 60 ppm) before measurement season --adjustment to calibration made for inter-instrument variability observed in controlled combustion chamber experiments
Balakrishnan et al., unpublished (rural India)	24-h; Drager Pac 7000 instrument logged CO concentration every 1-min	--span gas calibration per manufacturer specifications (concentrations unspecified)
Commodore et al. 2013 (rural Peru)	48-h; Drager Pac III logged CO concentration every 30-s	--calibration before measurement campaign with 0 ppm (pure N_2) and 50 ppm levels
Dionisio et al. 2012 (peri-urban The Gambia)	72-h; Drager CO 50/a-D diffusion tubes, detection range 50-600 ppm-hr	-- three replicate readings of color stain length recorded by a field worker --independent color stain length verification by lab staff performed weekly with sealed, refrigerated tubes --20% of tubes randomly selected for second set of replicate readings by all field workers to account for inter- and intra-observer variability
Ellegard and Egneus1993 (urban Zambia)	Variable: ~4 – 5 h; Drager CO diffusion tubes	--none reported
Hartinger et al. 2013 (rural Peru)	48-h; Drager Pac III logged CO concentration every 30-s	--none reported
Fitzgerald et al. 2011 (rural Peru)	48-h; Drager Pac III logged CO concentration every 30-s	--calibration before measurement campaign with 0 ppm (pure N_2) and 50 ppm levels --reading range: 0 – 2000 ppm; resolution: 1 ppm

McCracken et al. 2013 (rural Guatemala)	24-h; HOBO passive electrochemical datalogger	–span gas calibration (no indication of timing or frequency)
Mukhopadhyay et al. 2012 (rural India)	24-h; Drager Pac 7000 instrument logged CO concentration every 1-min	--none reported
Naeher et al. 2000 (rural and semi-urban Guatemala)	10 – 12-h; Drager CO diffusion tubes	--color stain length recorded on-site immediately following measurement period or on the same day at the field base (sealed during transport from household to field base) --Draeger continuous CO monitors were calibrated every two weeks at the field base using 100 and 250 ppm CO calibration gas
Ni et al. 2016 (rural China)	48-h; Drager CO 50/a-D diffusion tubes, detection range 50-600 ppm-hr	-- two replicate readings of color stain length recorded independently by three field workers --calibration with third order polynomial fit to the millimeter measurements corresponding to preprinted ppm-h markings on each batch of CO dositubes
Peel et al. *unpub*. (rural Honduras)	24-hr; Drager Pac 7000 logged CO maximum every 1-min	--instruments calibrated with 100 pppm CO gas in the lab prior to the field session --LOD for the instrument is 1 ppm; all values <LOD were substituted with LOD/(square root of 2)
St. Helen et al. 2015 (peri-urban Peru)	48-h; Drager Pac III logged CO concentration every 30-s	--calibration before/after measurement campaign with 0 ppm (pure N_2) and 50 ppm --pre-/post- calibration agreement within 5%
Wylie et al. 2016 (peri-urban Tanzania)	72 or 48-h; Drager CO 50/a-D diffusion tubes, detection range 50-600 ppm-hr	-- three replicate readings of color stain length recorded every 24-h by field staff --calibration with third order polynomial fit to the millimeter measurements corresponding to preprinted ppm-h markings on each batch of CO dositubes

Table S5. Characteristics of studies with paired measurements of cooking area PM$_{2.5}$ and CO concentrations

Author/Year	**Country**	**Fuel(s)**	**Other Local Air Pollution Sources**	**CO/PM Method**		**PM$_{2.5}$-CO Correlation** **Spearman *r* unless otherwise noted; * if Pearson *r***
				CO S[a]/D[b]	PM G[c]/LS[d]	
Alnes et al. 2014	China	biomass, coal, biogas	ETS[e] (minimal)	D	LS	0.53 (n=179) 0.83 (n=55) open fires 0.42 (n=40) biomass stoves
Armendáriz-Arnez et al. 2008	Mexico	wood	ETS (minimal)	S	LS	0.71 (n=60) * before intervention 0.80 (n=60) * after intervention
Balakrishnan et al. 2015	India	wood, dung		S	G	0.48 (n=26)
Balakrishnan et al. 2013	India	wood, dung		S	G	0.10 (n=350)
Bruce et al. 2004	Guatemala	wood, LPG[f]	ETS (minimal)	D	G	0.73 (n=24) for log(CO)-PM
Chengappa et al. 2007	India	wood, dung		S	LS	0.86 (n=36) *
Chowdhury et al. 2012	Bangladesh	wood, rice husks, dung, leaves	ETS (minimal)	S	LS	0.79 (n=31) *
Chowdhury et al. 2013	China	wood		S	LS	0.73 (n=56) * 0.86 (n=21) * open fires 0.85 (n=17) * biomass 0.87 (n=18) * w/ chimney
Clark et al. 2007	Guatemala	wood		S	G	0.95 (n=10) *
Clark et al. 2010	Honduras	wood		S	G	0.61 to 0.69 (n=54)
Clark et al. 2011	Nicaragua	wood	ETS (minimal)	S	LS	0.76 (n=124)
Clark et al. 2013	Nicaragua	wood	ETS (minimal)	S	LS	NR[g] (n = 25)
Cleary et al. 1968	New Guinea	wood		D	G	0.72/0.87 (n=9) site 1/site 2
Dasgupta et al. 2015	Madagascar	wood, charcoal	ETS (minimal)	S	LS	NR (n=338)
de la Sota et al. 2014	Senegal, The Gambia, Guinea	wood		S	LS	NR (n=149) before intervention NR (n=175) after intervention

Dionisio et al. 2008	The Gambia	wood, charcoal		D	LS	0.85 (n=13) * 24-h 0.80 (n=13) * 48-h
Dionisio et al. 2012	The Gambia	wood, charcoal		D	G	0.87 (n=213) * 0.83 (n=208) for CO 0 – 21 ppm 0.41 (n=41) for CO <1.3 ppm
Dutta et al. 2007	India	wood, dung		S	LS	0.78 (n=37) *
Edwards et al. 2007	China	wood, crop residue, coal, LPG, biogas	ETS	D	G	0.27 (n=171) * 0.78 (n=20) wood, crop, coal 0.50 (n=21) crop residue
Ezzati et al. 2000	Kenya	wood, charcoal		S	LS[h]	0.48 (n=139) * burn 0.33 (n=131) * smolder 0.50 (n=115) * burn wood 0.35 (n=114) * smolder wood
Fischer and Koshland 2007	China	wood, LPG, coal, electricity	ETS	S D	LS	0.50 (n=39) * sensor CO 0.45 (n=34) * colorimetric CO
Fitzgerald et al., 2012	Peru	wood		S	G	0.80 (n=74)
Hankey et al., 2014	Uganda	wood		S	LS	0.40 (n=25) before intervention 0.32 (n=23) after intervention
Hartinger et al. 2013	Peru	wood	ETS	S	G	0.63 (n=61) 0.65 (n=32) open fires/non-OPTIMA 0.70 (n=40) OPTIMA stoves
He et al., 2005	China	coal, biomass	ETS	D	G	0.48 (n=128)
Henkle et al., 2010	Honduras	wood	ETS	S	G[i]	0.14 (n=25)
Huboyo et al. 2014	Indonesia	wood, LPG	ETS	S	LS	0.76 (n=18) * site 1 0.96 (n=14) * site 2
Klasen et al. 2015	Peru, Nepal, Kenya	biomass, LPG, kerosene		S	LS	0.59 Peru, 1-min $PM_{2.5}$ and CO 0.61 Nepal, 1-min $PM_{2.5}$ and CO 0.83 Kenya, 1-min $PM_{2.5}$ and CO
Leavey et al. 2015	India	biomass, dung	ETS (minimal)	S	LS	0.71 (n=54[j]) Pearson
Li et al. 2011	Peru	wood		S	G	NR (n=57)
Li et al. 2012	Tibetan	dung	ETS	S	LS	0.94 (n=20) hourly $PM_{2.5}$ and CO

	Plateau					
Lodhi and Zain-al-Abdin 1999	Malaysia	wood, LPG	ETS	S	LS[i]	NR (n=NR)
Marshall et al. (*unpub.*)	India	wood		S	G	0.65 (n=59)
Morawska et al. 2011	Lao PDR	wood, electricity	ETS	D	G[i]	0.01 (n=NR) open fires site 1 0.19 (n=NR) open fires site 2
Mukhopadhyay et al. 2012	India	wood, dung, LPG[i]		S	G	NR (n=5)
Muralidharan et al. 2015	India	wood, dung		S	LS	0.82 (n=72[j])
Naeher et al. 2000a	Guatemala	wood, LPG		D	G	NR (n=27)
Naeher et al. 2000b	Guatemala	wood, gas		S	LS	0.81 (n=290)
Naeher et al. 2001	Guatemala	wood, LPG		D	G	0.94 (n=40) 0.70 (n=15) open fire 0.89 (n=25) stove w/chimney
Ni et al. 2016	China	wood	ETS	D	G	0.71 (n=98)
Northcross et al. 2010	Guatemala	wood	ETS (minimal)	S/D	LS/G	0.87 (n=232) * 0.83 (n=122) * open fires 0.88 (n=110) * stove w/chimney
Park et al. 2003	Costa Rica	wood		S	G	0.71 (n=21)
Pearce et al. 2009	Peru	wood, dung, gas, kerosene		S	LS	0.57 (n=237[j]) partial correlation (adjust for fuel, location, time of day)
Peel et al. (*unpub.*)	Honduras	wood		S	G	0.86 (n=105)
Pennise et al. 2009	Ghana, Ethiopia	wood, ethanol	ETS (minimal)	S	LS	NR (n=69)
Pollard et al. 2014	Peru	wood, dung, crop residue, LPG		S	G	0.07 (n=32) * urban 0.67 (n=72) * rural 0.54 (n=34) * rural w/ chimney 0.79 (n=38) * rural, no chimney
Reid et al., 1986	Nepal	wood		S	G[j]	NR ("positive relationship between kitchen CO and TSP")

Rollin et al. 2004	South Africa	wood, biomass, kerosene	ETS	D	G[h]	NR ("no evidence of relationship between CO and RSP")
Saatkamp et al., 2000	Mexico	wood		S	G[h]	NR (n=230)
Saksena et al. 1992	India	wood		S	G[i]	0.66 (n=124[j])
Saksena et al. 2003	India	wood	ETS (minimal)	S	G[i]	0.96 (n=40) *
Saksena et al. 2007	Phillippines	wood		S	G[m]	0.49 (n=19)
Sambandam et al. 2014	India	wood, crop residue, dung		S	G	0.80 (n=167)
Shrestha and Shrestha 2005	Nepal	biomass		D	LS[k]	NR (n=87)
Siddiqui et al. 2009	Pakistan	wood, natural gas		S	LS	0.72 (n=51) wood 0.37 (n=44) natural gas
St. Helen et al. 2015	Peru	wood, LPG, coal, kerosene		S	G	0.51 (n=90)
Yamamoto et al. 2014	Burkina Faso	wood, charcoal		D	LS[m]	0.65 (n=119)

[a]sensor-based, [b]colorimetric/diffusion-based, [c]gravimetric, [d]light-scattering, [e]environmental tobacco smoke, [f]not reported, [g]liquefied petroleum gas, [h]respirable PM, [i]total suspended particles, [j]cooking session duration only, [k]PM$_{10}$ measured, [m]PM$_{4}$ measured.

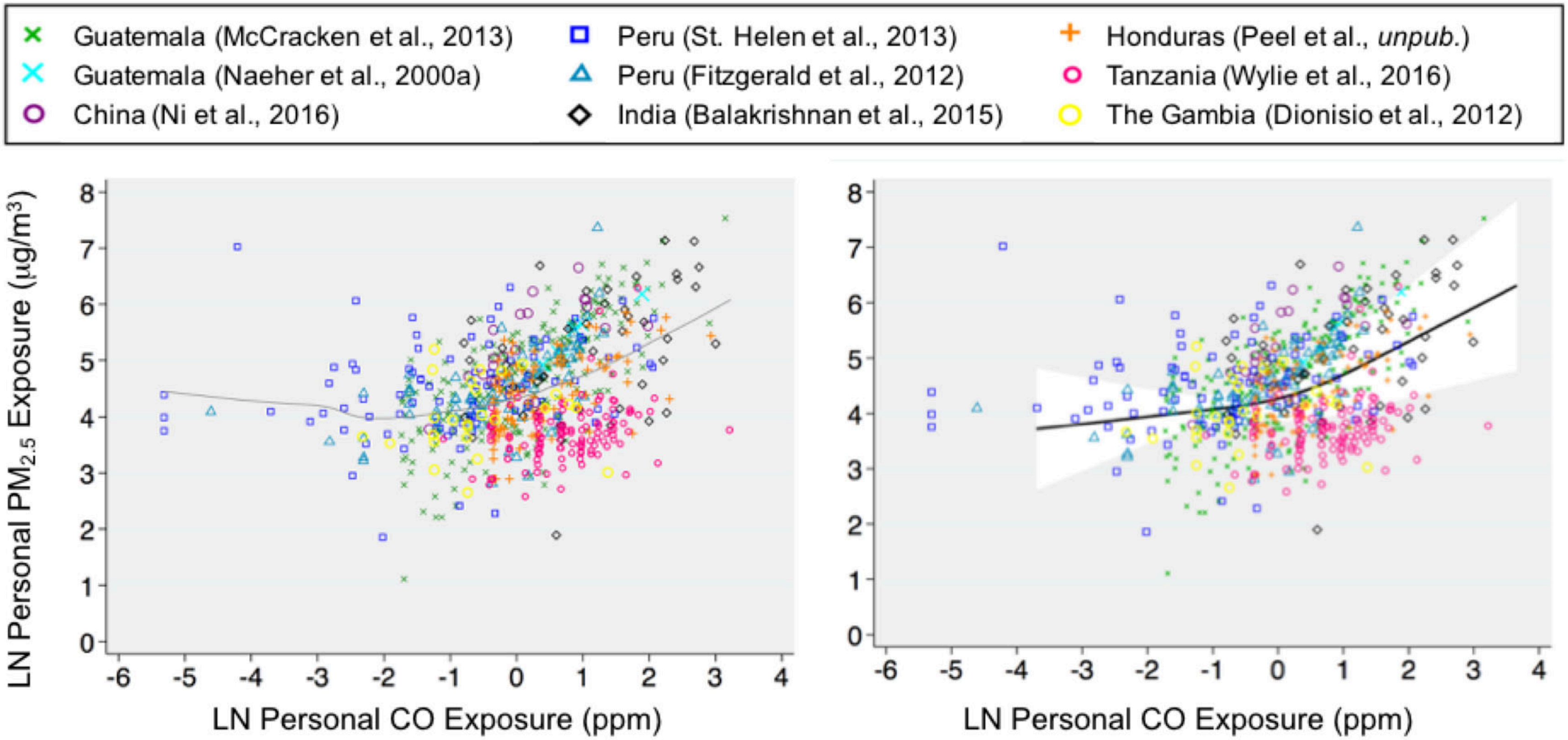


Figure S1a. Locally weighted scatterplot smoothing line shown for natural log-transformed $PM_{2.5}$ personal exposures versus natural log-transformed CO personal exposures plotted for nine unique studies.

Figure S1b. Natural cubic spline model (3 knots) $\ln(PM_{2.5})$ versus ln(CO), including fuel, urbanicity, season, CO measurement type, and study covariates in the model (n = 703 pairs).

Table S6. Arithmetic and geometric (GM) means (95% confidence intervals (CI)) and ranges for nine studies with paired measurements of personal exposure to $PM_{2.5}$ and CO.

$PM_{2.5}$ (μg/m^3)	**N**	**Mean (95% CI[a])**	**GM (95% CI)**	**Range**	**IQR[b]**
Guatemala (Naeher et al., 2000)	6	245 (109, 381)	221 (134, 366)	136-481	149-279
China (Ni et al., 2016)	22	241 (161, 322)	186 (133, 260)	44-770	103-343
The Gambia (Dionisio et al., 2012)	29	65 (49, 80)	54 (42, 69)	14-179	38-82
India (Balakrishnan et al., *unpub.*)	45	281 (191, 371)	160 (113, 227)	7-1243	61-364
Peru (Fitzgerald et al., 2012)	80	126 (85, 166)	88 (74, 104)	17-1565	57-156
Peru (St. Helen et al., 2013)	93	127 (98, 157)	89 (75, 106)	6-1102	54-146
Honduras (Peel et al., *unpub.*)	105	100 (87, 114)	80 (71, 92)	18-346	51-135
Tanzania (Wylie et al., 2016)	118	49 (39, 60)	40 (37, 45)	13-528	31-54
Guatemala (McCracken et al., 2013)	216	174 (146, 202)	106 (92, 122)	3-1843	51-214
Overall	714	136 (123, 149)	85 (79, 91)	3-1843	43-155

CO (ppm)	**N**	**Mean (95% CI)**	**GM (95% CI)**	**Range**	**IQR**
Guatemala (Naeher et al., 2000)	6	2.9 (0.8, 4.9)	2.5 (1.4, 4.3)	1.5-6.7	1.9-6.7
China (Ni et al., 2016)	22	1.6 (0.9, 2.3)	1.2 (0.9, 1.7)	0.3-7.2	0.7-2.6
The Gambia (Dionisio et al., 2012)	29	0.8 (0.4, 1.1)	0.6 (0.4, 0.8)	0-4.0	0.3-0.7
India (Balakrishnan et al., *unpub.*)	45	4.9 (3.5, 6.4)	3.1 (2.2, 4.2)	0-20.3	1.4-6.9
Peru (Fitzgerald et al., 2012)	80	1.2 (0.9, 1.4)	0.8 (0.6, 1.0)	0-3.7	0.4-1.9
Peru (St. Helen et al., 2013)	93	1.1 (0.7, 1.4)	0.4 (0.3, 0.6)	0-8.0	0.1-1.2
Honduras (Peel et al., *unpub.*)	105	2.1 (1.6, 2.6)	1.5 (1.3, 1.7)	0.7-19.0	0.8-2.3
Tanzania (Wylie et al., 2016)	118	2.8 (2.3, 3.3)	2.2 (1.9, 2.5)	0.3-25.2	1.4-3.5
Guatemala (McCracken et al., 2013)	216	1.9 (1.6, 2.3)	1.1 (1.0, 1.3)	0.2-23.6	0.5-2.4
Overall	714	2.0 (1.9, 2.2)	1.2 (1.1, 1.3)	0-25.2	0.6-2.6

Eight observations reporting a zero value for CO exposure [three from The Gambia, four from Peru (St. Helen et al., 2013), three from Peru (Fitzgerald et al., 2012), and one from India] are included in the summary below because the corresponding $PM_{2.5}$ exposure concentrations are reasonable values (range: 14 to 155 μg/m^3).

Table S7. Arithmetic and geometric (GM) means (95% confidence intervals (CI)) and ranges and interquartile ranges (IQR) for 18 studies with paired measurements of cooking area $PM_{2.5}$ and CO.

$PM_{2.5}$ ($\mu g/m^3$)	**N**	**Mean (95% CI[a])**	**GM (95% CI)**	**Range**	**IQR[b]**
Guatemala (Naeher et al., 2000)	6	227 (-18, 472)	142 (48, 425)	57-528	57-528
The Gambia (Dionisio et al., 2012)	18	665 (471, 860)	545 (383, 774)	123-1604	448-942
Costa Rica (Park et al., 2003)	21	42 (27, 56)	32 (22, 46)	6-139	22-50
Honduras (Henkle et al., 2010)	25	468 (275, 661)	251 (147, 430)	17-1525	83-575
India (Balakrishnan et al. 2015)	26	274 (144, 405)	159 (103, 243)	29-1314	58-293
Indonesia (Huboyo et al., 2013)	32	190 (141, 240)	155 (124, 195)	61-670	94-249
India (Dutta et al. 2007)	36	1497 (1057, 1937)	1079 (818, 1423)	225-6108	529-2179
India (Chengappa et al. 2007)	36	540 (311, 770)	392 (308, 499)	125-4141	254-544
China (Chowdhury et al., 2013)	53	262 (205, 320)	192 (153, 241)	29-922	101-340
Guatemala (Naeher et al., 2001)	56	368 (277, 459)	230 (173, 305)	29-1606	103-547
India (Marshall et al. *unpub*.)	59	241 (193, 289)	179 (145, 221)	20-811	104-329
Peru (Fitzgerald et al., 2012)	74	242 (170, 314)	124 (94, 164)	4-1331	61-324
Peru (Pollard et al., 2014)	82	117 (86, 148)	65 (51, 84)	4-839	24-151
Peru (St. Helen et al., 2013)	94	91 (67, 116)	55 (45, 67)	1-665	34-88
China (Ni et al. 2016)	98	319 (199, 438)	152 (123, 189)	16-4429	72-308
Honduras (Peel et al., *unpub*.)	105	252 (192, 311)	137 (110, 170)	18-1654	62-369
India (Sambandam et al. 2014)	163	662 (506, 819)	316 (263, 380)	42-7333	117-701
India (Balakrishnan et al. 2013)	350	776 (667, 885)	411 (364, 465)	25-8820	187-892
Overall	1334	476 (434, 516)	210 (196, 225)	1-8820	81-533

CO (ppm)	**N**	**Mean (95% CI)**	**GM (95% CI)**	**Range**	**IQR**
Guatemala (Naeher et al., 2000)	6	3 (0.8, 5.2)	2.5 (1.2, 5.0)	1.3-5.7	1.3-5.7
The Gambia (Dionisio et al., 2012)	18	9.4 (6.8, 11.9)	7.7 (5.4, 11.0)	1.6-20.1	5.2-10.8
Costa Rica (Park et al., 2003)	21	1.3 (1.0, 1.6)	1.1 (0.9, 1.4)	0.5-3.3	0.7-1.8
Honduras (Henkle et al., 2010)	25	11.4 (7.8, 15.0)	12.4 (9.5, 16.1)	0-27.5	5-15.5
India (Balakrishnan et al. 2015)	26	10.3 (6.7, 13.9)	7.6 (5.3, 11.0)	0-33.5	3.5-14.3
Indonesia (Huboyo et al., 2013)	32	2.5 (1.9, 3.1)	1.7 (1.1, 2.6)	0-7.0	1.1-3.7
India (Dutta et al. 2007)	36	14.1 (11.1, 17.0)	11.4 (9.1, 14.4)	3.1-33.5	7.0-20.6
India (Chengappa et al. 2007)	36	8.6 (6.4, 10.8)	6.9 (5.6, 8.6)	2.1-29.9	4.1-10.1
China (Chowdhury et al., 2013)	53	4.1 (3.2, 5.0)	3.0 (2.3, 3.8)	0.2-15.2	1.6-6.3
Guatemala (Naeher et al., 2001)	56	4.5 (3.4, 5.7)	2.3 (1.5, 3.5)	0-18.7	1.3-7.2
India (Marshall et al. *unpub*.)	59	3.5 (2.8, 4.3)	2.0 (1.4, 2.9)	0.02-11.2	1.4-5.2
Peru (Fitzgerald et al., 2012)	74	3.6 (2.5, 4.7)	1.7 (1.3, 2.4)	0-24.8	0.7-4.5
Peru (Pollard et al., 2014)	82	5.4 (4.0, 6.8)	1.9 (1.2, 2.9)	0-34.0	0.7-9.0
Peru (St. Helen et al., 2013)	94	3.4 (2.1, 4.8)	0.9 (0.6, 1.4)	0-46.9	0.2-3.7
China (Ni et al. 2016)	98	2.0 (1.2, 2.8)	1.0 (0.8, 1.2)	0.1-34.8	0.5-1.8
Honduras (Peel et al., *unpub*.)	105	3.9 (2.6, 5.2)	1.9 (1.5, 2.3)	0.7-40.3	0.8-3.3
India (Sambandam et al. 2014)	163	5.6 (4.6, 6.5)	2.9 (2.3, 3.6)	0-32.8	1.1-7.3
India (Balakrishnan et al. 2013)	350	2.2 (1.9, 2.5)	1.0 (0.8, 1.1)	0.2-11.0	0.3-3.0
Overall	1334	4.2 (3.9, 4.5)	1.8 (1.7, 2.0)	0-46.9	0.6-5.7

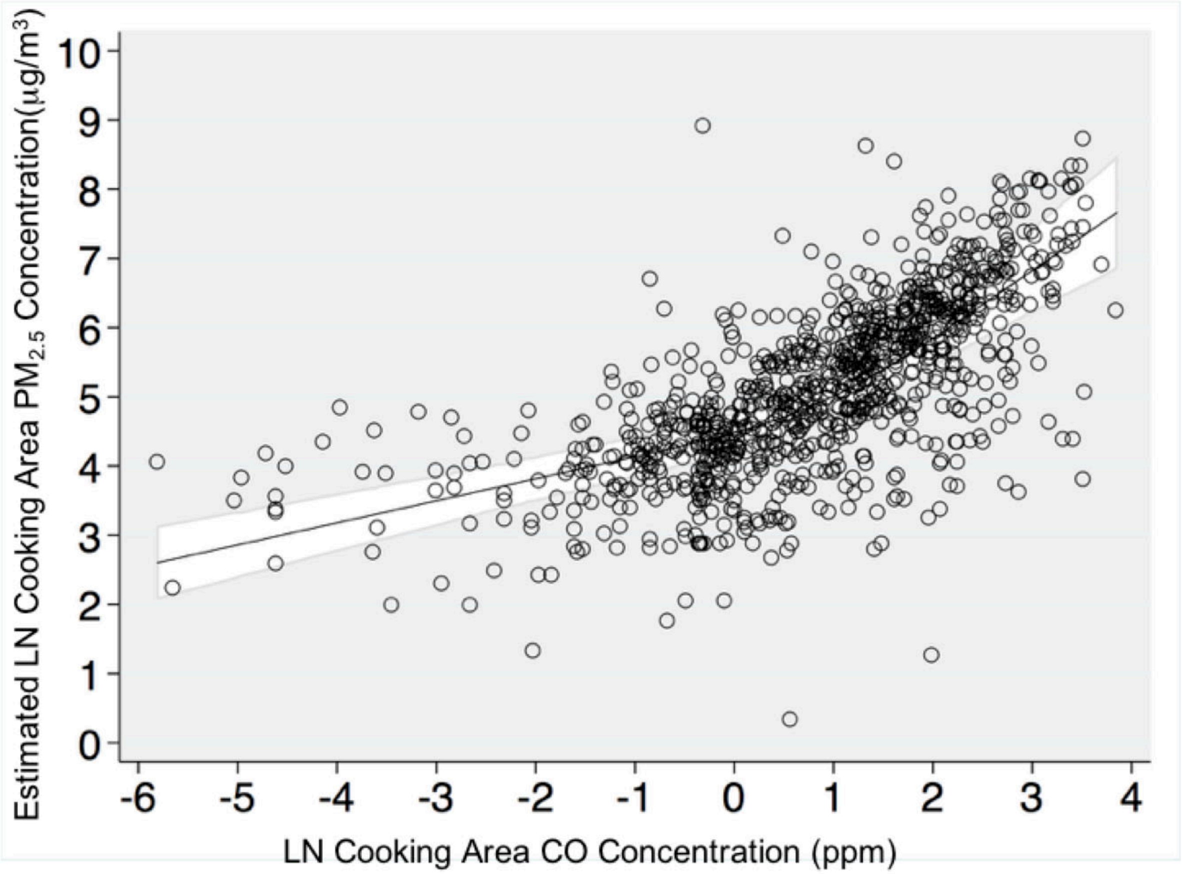
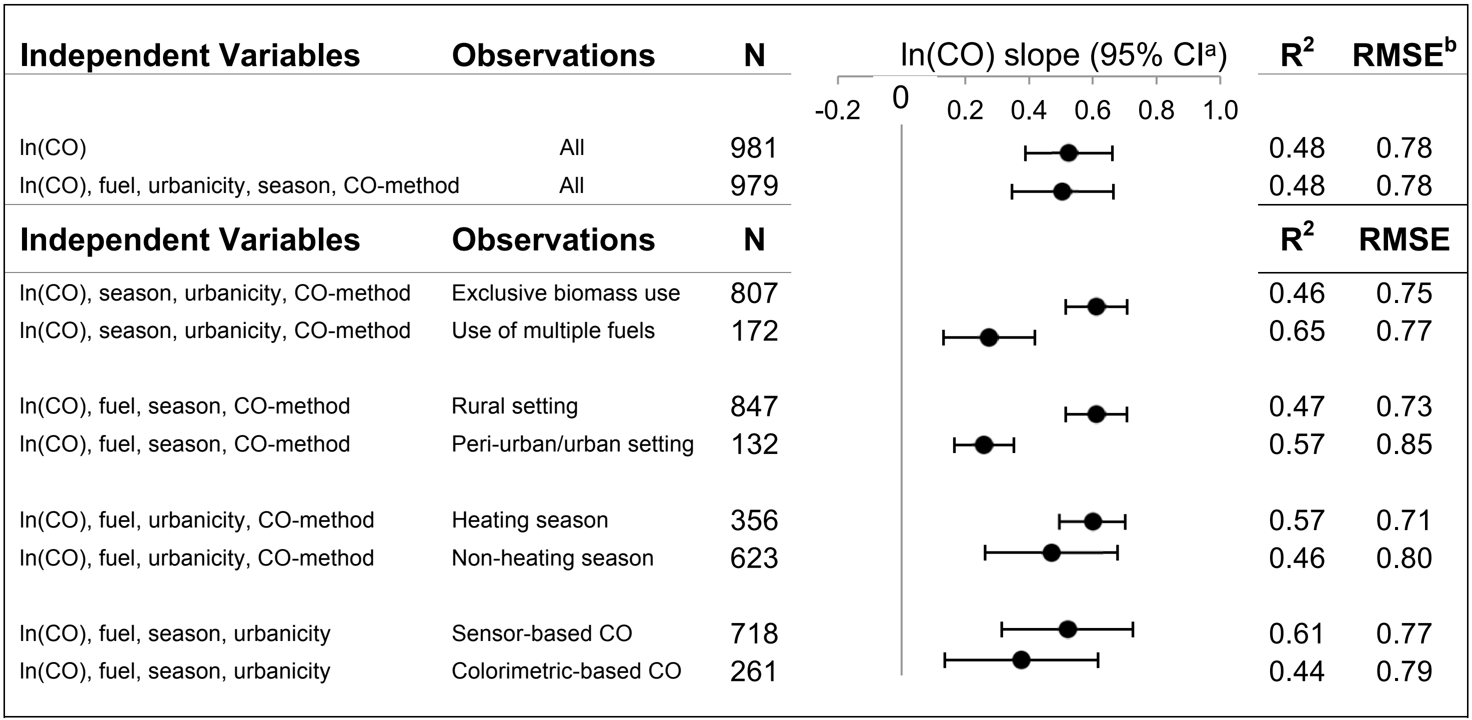


Figure S2. Natural cubic spline model (3 knots) of the ln($PM_{2.5}$)-ln(CO) relationship with 95% confidence intervals for cooking area $PM_{2.5}$ and CO concentrations (n=981 paired observations from 17 of 18 studies in the pooled analysis).



Independent Variables	Observations	N	R^2	RMSE[b]
ln(CO)	All	981	0.48	0.78
ln(CO), fuel, urbanicity, season, CO-method	All	979	0.48	0.78

Independent Variables	Observations	N	R^2	RMSE
ln(CO), season, urbanicity, CO-method	Exclusive biomass use	807	0.46	0.75
ln(CO), season, urbanicity, CO-method	Use of multiple fuels	172	0.65	0.77
ln(CO), fuel, season, CO-method	Rural setting	847	0.47	0.73
ln(CO), fuel, season, CO-method	Peri-urban/urban setting	132	0.57	0.85
ln(CO), fuel, urbanicity, CO-method	Heating season	356	0.57	0.71
ln(CO), fuel, urbanicity, CO-method	Non-heating season	623	0.46	0.80
ln(CO), fuel, season, urbanicity	Sensor-based CO	718	0.61	0.77
ln(CO), fuel, season, urbanicity	Colorimetric-based CO	261	0.44	0.79

[a]confidence intervals, [b]root mean squared error

Figure S3. Comparison of estimates of the slope of ln($PM_{2.5}$) on ln(CO) (±95% confidence intervals) for cooking area concentrations using univariate and multivariate linear regression models for the full dataset and stratified by fuel use, setting, season, and CO measurement. The R^2 values and RMSE for each model are reported to the right of the plotted ln(CO) slope.

Table S8. Comparison of R^2 and root mean squared error (RMSE) are reported for models of $\ln(PM_{2.5})$ exposure on un-transformed CO exposure, [CO], using all data and stratified subsets.

Independent Variables	**Observations**	**N**	**R^2**	**RMSE**
[CO]	All	714	0.14	0.76
[CO], fuel, urbanicity, season, CO method	All	714	0.19	0.76
[CO], urbanicity, season, CO method	Exclusive biomass use	573	0.24	0.77
[CO], urbanicity, season, CO method	Use of multiple fuels	141	0.21	0.77
[CO], fuel, season, CO method	Rural	482	0.31	0.80
[CO], fuel, season, CO method	Peri-urban	232	0.24	0.68
[CO], fuel, urbanicity, CO method	Heating	458	0.39	0.80
[CO], fuel, urbanicity, CO method	Non-heating	256	0.12	0.69
[CO], fuel, season, urbanicity	Sensor CO	539	0.27	0.80
[CO], fuel, season, urbanicity	Colorimetric CO	175	0.35	0.66

Table S9. Comparison of R^2 and root mean squared error (RMSE) are reported for models of ln($PM_{2.5}$) exposure on un-transformed CO cooking area concentrations, [CO], using all data and stratified subsets.

Independent Variables	Observations	N	R^2	RMSE
[CO]	All	992	0.23	0.95
[CO], fuel, urbanicity, season, CO method	All	990	0.28	0.91
[CO], urbanicity, season, CO method	Exclusive biomass use	815	0.20	0.95
[CO], urbanicity, season, CO method	Use of multiple fuels	172	0.67	0.74
[CO], fuel, season, CO method	Rural	854	0.17	0.93
[CO], fuel, season, CO method	Peri-urban	136	0.58	0.83
[CO], fuel, urbanicity, CO method	Heating	358	0.56	0.76
[CO], fuel, urbanicity, CO method	Non-heating	632	0.30	0.92
[CO], fuel, season, urbanicity	Sensor CO	728	0.27	0.94
[CO], fuel, season, urbanicity	Colorimetric CO	262	0.56	0.82

Table S10. Comparison of univariate and multivariate model results for individual studies, adjusting for as many covariates as there was variation to do so. The R^2 and root mean squared error (RMSE) are reported for each model.

Independent Variables	**N**	**R^2**	**RMSE**
China (Ni et al., 2016)			
ln(CO)	22	0.42	0.59
ln(CO), fuel, season	22	0.51	0.58
Peru (St. Helen et al., 2015)			
ln(CO)	89	0.05	0.83
ln(CO), fuel, season	89	0.08	0.83
Peru (Fitzgerald et al., 2012)			
ln(CO)	77	0.32	0.63
ln(CO), fuel, season	77	0.37	0.61
India (Balakrishnan et al., 2015)			
ln(CO)	44	0.19	1.02
ln(CO), fuel, season	44	0.32	0.94
Tanzania (Wylie et al., 2016)			
ln(CO)	118	0.11	0.50
ln(CO), fuel, setting, season	118	0.13	0.50
The Gambia (Dionisio et al., 2012)			
ln(CO)	26	0.01	0.65
ln(CO), fuel, season	26	0.20	0.61

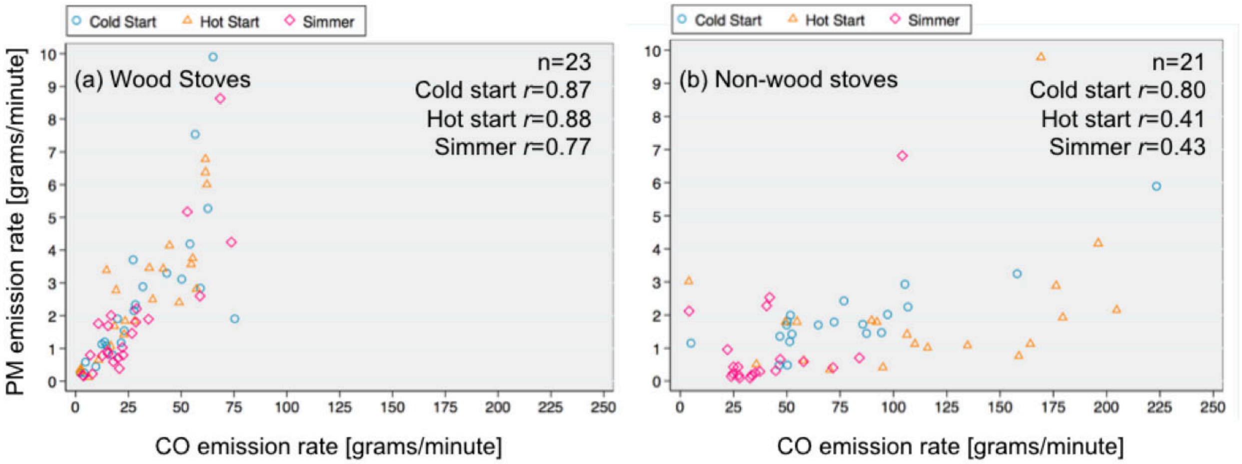


Figure S4. PM versus CO emission rates (grams/minute) from standardized Water Boiling Tests conducted by Jetter et al. (2012) for stove-fuel combinations tested with wood fuel only (a) and stove-fuel combinations tested with non-wood fuel (b) under conditions of cold start, hot start, and simmering.

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