

Clean cooking and cook stove interventions in Africa: a scoping review of exposure contrasts and future steps

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Abstract

Introduction In Africa, solid biomass fuels are widely used for household cooking, heating, and lighting, generating hazardous levels of household air pollution (HAP), including fine particulate matter (PM_{2.5}), black carbon (BC), and carbon monoxide (CO). Inhalation of these pollutants is associated with adverse health outcomes. Women of childbearing age and young children experience the highest exposures due to their disproportionate time spent cooking and performing household activities. To mitigate these risks, interventions such as cleaner fuels and improved cook stove technologies have been promoted. However, evidence on their effectiveness in reducing pollutant exposure and improving health outcomes in African households remains fragmented, highlighting the need for a scoping review focused on the African context, where reliance on solid fuels is particularly high.

Objective To synthesize existing evidence and identify knowledge gaps through a scoping review of cleaner fuel and modified cook stove interventions in African households, examining changes in PM_{2.5}, BC, and CO concentrations in cooking areas and/or personal exposures compared with traditional cooking methods. This review was prospectively registered with the Open Science Framework (<https://osf.io/thwsf/>).

Methods We conducted a systematic search of Medline (PubMed), Web of Science, and CAB Abstracts. Eligible studies were intervention studies conducted in Africa that reported pre- and post-intervention household air pollution measurements. Study selection and data extraction followed JBI and PRISMA-ScR guidelines, using Colandr.

Results The review mapped available evidence on reductions in household air pollution associated with cleaner fuel and cookstove interventions. Key gaps were identified, including limited assessment of pollutants beyond PM_{2.5}, BC, and CO; inconsistent use of personal exposure measurements; uneven geographic representation across African regions; and scarce evidence on long-term effectiveness or direct links between interventions and health outcomes.

Conclusion This scoping review provides a comprehensive synthesis of evidence on clean cooking interventions in Africa and highlights critical research gaps. Addressing these gaps is essential to guide effective interventions, inform policy, and reduce household air pollution exposures among vulnerable populations.

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Keywords Indoor air pollution · Clean fuel stoves · African countries

Introduction

In Africa, solid biomass fuel is frequently used for household cooking, heating, and lighting [1]. This fuel produces hazardous levels of Household Air Pollution, such as $\text{PM}_{2.5}$, BC, and CO, which can cause significant morbidity and mortality when inhaled [2]. Due to the fact that women spend a disproportionate amount of time in the home cooking or assisting with household activities, it is known that women of childbearing age and young children have the highest Household Air Pollution exposure [3, 4, 5]. Individuals are especially susceptible to the negative effects of Household Air Pollution exposure throughout important stages of organ development such as intrauterine, infancy, and early childhood [6].

Socio-cultural, economic, and infrastructural factors frequently result in fuel or stove stacking, whereby households continue using traditional biomass stoves alongside cleaner cooking technologies. Rather than facilitating reductions in household air pollution, stove stacking substantially diminishes the potential exposure reductions achievable through clean cooking interventions and remains one of the principal barriers to successful transitions toward clean household energy [7, 8], which can reduce Household Air Pollution levels to below World Health Organization indoor air quality (WHO-IAQ 2021) guideline levels (CO 7 mg/m^3 24-h average, $\text{PM}_{2.5}$ $\mu\text{g}/\text{m}^3$ annual average) [9]. Economic development is ultimately associated with cleaner fuel transitions (e.g., to electricity, ethanol, liquid petroleum gas (LPG)) [10]. There are many different cleaner cooking options available to reduce Household Air Pollution exposure levels in the home setting, including improved cookstove [11] (ICS) (such as rocket stoves, planchas), solar stoves, improved biomass fuels (such as briquettes, biomass pellets), and behavioral changes (such as removing children from the cooking area, cooking outdoors, and opening windows) [12, 13]. For instance, LPG has the potential to lower Household Air Pollution levels below WHO 2021-IAQ guideline levels or interim targets ($\text{PM}_{2.5}$ 35 $\mu\text{g}/\text{m}^3$ annual average) but not all interventions do so [14, 15]. As a result, these interventions are typically harm mitigation measures and/or fuel efficiency, with some interventions not even lowering exposure levels [16]. Improving access to clean cooking has become a major global public health, environmental, and climate priority. The transition toward cleaner household energy contributes directly to several Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being), SDG 5 (Gender Equality), SDG 7 (Affordable and Clean Energy), and SDG 13 (Climate Action). Africa remains among the regions with the highest dependence on biomass fuels for household cooking, making African evidence particularly important for informing policies aimed at reducing household air pollution while simultaneously addressing climate mitigation and sustainable development.

Previous intervention research has been geographically concentrated within relatively few African countries and often implemented as pilot projects, limiting evidence across diverse populations and settings [17, 18, 19]. These factors highlight the urgent need to synthesize evidence on the effectiveness of interventions in reducing Household Air Pollution exposure in African contexts. Much as there is an increasing interest in clean cooking interventions, evidence from Africa remains fragmented across different intervention types, pollutants measured, exposure assessment methods, and geographical settings. Previous reviews have primarily synthesized global evidence, focused on health outcomes, or evaluated improved cookstove technologies without specifically examining exposure contrasts within African households. Consequently, there remains limited understanding of how cleaner fuels and cookstove interventions perform across diverse African contexts where reliance on biomass fuels remains among the highest globally (Table 1).

A scoping review is considered the most appropriate evidence synthesis approach because the existing literature comprises heterogeneous study designs, intervention types, pollutants measured, exposure assessment methods, and follow-up durations. Rather than estimating pooled intervention effects, the objective of this review

Table 1 Data extraction table

First author, Year, Journal	Location & setting	Population	Study Design	Intervention	Comparator	Outcome (HAP)	Effect Estimates and HAP descriptive stats	Success or failure to reduce HAP	Interpretation of Findings	Explanations given in the paper
Mortimer K 2020 Chest	Rural Malawi 150 communities within villages across 2 districts	Children < 5 years	cluster randomized controlled trial	928 intervention received 2 cleaner burning bio-mass fueled stoves with a fan (Philips)	877 control with traditional cooking methods (typically open fire)	Personal CO, 48-h continuous measure (EasyLog USBCO Lascar) and transcutaneous carboxyhemoglobin (COHb, CO-oximeters)	Median CO: Intervention = 0.34 ppm (IQR, 0.15 to 0.81) Control = 0.37 ppm (IQR, 0.15 to 0.97) crude difference = -0.46 ppm (95% CI, -0.95 to 0.012, $p = 0.06$) adj diff for other factors = -0.029 ppm (95% CI, -0.12 to 0.06) Mean COHb levels: Intervention = 5.31% (95% CI, 5.17 to 5.43)	Failure	There was no difference observed in average CO exposure, and there was only a minor difference in COHb levels between	Lack of effects from potential other sources of air pollution, the intervention did not reduce exposures sufficiently, confounding by other dimensions of poverty and causal relationship between HAP and pneumonia maybe not as strong as predicted
Mesafint Molla Adane, 2021, Environmental Health and Preventive Medicine	North West Ethiopia	Selected Households	cluster randomized controlled trial	993 intervention received Improved cook stoves locally known as met	984 control used traditional cook stoves	Concentration of PM _{2.5}	Results showed an overall reduction of about 46% from the baseline value of 859 (95% CI 837–881) to 465 (95% CI 458–472) in the intervention arm compared to only about 5% reduction from 850 (95% CI 828–872) to 805 (95% CI 794–817) in the control arm. This represents about a 58% reduction in mean longitudinal indoor PM _{2.5} concentration in $\mu\text{g}/\text{m}^3$ in the intervention arm compared to the control arm	Success	Overall there a significant reduction in HAP measures in the intervention arm compared to 5% reduction in control arm	Higher HAP might be the reflection of the complete biomass fuel use as a primary household energy source by all households, presence of extra indoor burning events such as coffee ceremony, burning incense, and local alcohol making

Table 1 (continued)

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Mona Abdo et al., BMC Public Health 2021	Rural Northern Ghana	Rural households that relied primarily on biomass for their cooking needs, and that included both adult women and young children	Randomized Controlled Trial	Households received improved cook stoves	Households used traditional stoves	self-reported health symptoms, biomarkers of inflammation collected from dried blood spots, and child growth measures from anthropometric s	Gyapa/Gyapa (66%), Philips/Philips (73%) and Gyapa/Philips (79%) groups. For Biomarkers, inflammation levels were lower in the intervention groups compared to the control group. CRP levels for adults: Gyapa/Gyapa group 0.41 ng/ml lower ($p=0.066$) than control after adjusting for age and baseline BMI, household tobacco smoking, baseline CRP and season (log scale); SAA levels for adults: Gyapa/Gyapa 0.46 lower ($p=0.018$), Philips/Philips 0.40 lower than control ($p=0.032$), Gyapa/Philips 0.31 lower ($p=0.094$) than control adjusting for age and baseline BMI, household tobacco smoking, baseline SAA and season (log scale); For child growth, overall underweight model was not significant, sex did emerge as a significant predictor with females being more likely to be underweight ($p=.035$)	Failure	The study observed no evidence for differences across groups among adults or children. The most intriguing evidence for possible health effects involves adults' CRP levels (lower in the Gyapa/Gyapa group relative to control) and SAA levels (lower in all three intervention groups relative to control)	A reduction in these inflammatory biomarkers and a trend in several other indicators provides suggestive evidence that intervention may have lowered the systemic pro-inflammatory status of these women. At the same time, in light of the number of tests that were run and the issue of multiple comparisons, we are cautious not to overinterpret our results. Any improvements that were achieved at the level of biomarkers did not manifest into improvements in child growth or self-reported health symptoms. Clinical outcomes (e.g., respiratory illness, mortality) were not measured in this study, and we would be underpowered to detect effects on these outcomes given our sample size
Darby W Jack 2021	Ghana	Rural Households who cooked primarily with biomass fuels	eRCT	Improved cook stoves and LPG	Traditional cook stoves	Birth weight, Pneumonia, HAP	No improvement in birth weight (the difference in mean birth weight for LPG arm births was 29 g lighter; 95% CI -113 to 56, $p=0.51$) and for biomass arm births was 9 g heavier (compared with control new births). Air pollution exposures in the LPG arm remained above WHO health-based targets (LPG median particulate matter less than 2.5 microns in diameter (PM _{2.5}) 45 µg/m ³)	Failure	Neither prenatally introduced LPG nor improved biomass cookstoves improved birth weight or reduced severe pneumonia risk in the first 12	Lower-than-expected exposure reductions in the intervention arms

Table 1 (continued)

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Susan C Aenaberg 2017, Environmental Research Letters	Mozambique	Rural	Review	Rural natural draft, Rural forced draft, Urban modern charcoal and Urban liquefied petroleum gas	Traditional biomass cookstoves (e.g. open fire) used widely in Mozambique	Reduction in household air pollution (HAP), ambient PM2.5, premature deaths, DALYs, and climate benefits (temperature reduction)	Cleaner cookstove interventions can achieve health and climate benefits	Success	Cleaner cooking technologies can yield meaningful health and climate benefits in Mozambique. Forced draft and LPG stoves show higher efficacy but depend on adoption rates, usage consistency, and cost- Despite stove stacking, behavioral use can significantly reduce exposure to harmful air pollutants	Benefits depend heavily on assumptions regarding adoption rates and real-world exposure reductions (lab-to-field extrapolation used as an adjustment factor of 0.8).—Uncertainty in baseline exposure and PM2.5 measurement data in Mozambique - Health and climate models rely on extrapolated data from other countries - Stove/fuel stacking and low displacement of traditional stoves could reduce effectiveness.— Cost-effectiveness varied by location due to differences in
Ashlim K. Quinn, 2017, Environmental Health Perspectives	Ghana	Rural Households who cooked primarily with biomass fuels	RCT	ICS	Traditional open fires using biomass	Changes in personal exposure to PM2.5, black carbon (BC), and carbon monoxide (CO); identification of	Median personal exposure reductions: • PM2.5: 78% (from 111 to 24 µg/m3) • BC: 91% (from 6.0 to 0.55 µg/m3) • CO: 83% (from 2.1 to 0.36 ppm)— 69% of participants achieved WHO-IT1 target for PM2.5 - Stove stacking observed but LPG was primary stove for 99% of participants	Success	Exclusive or primary LPG use can significantly reduce exposure to harmful air pollutants	
Fuyuen Yip, 2011, Environmental Health Perspectives	Kenya	Rural Households who cooked primarily with biomass fuels	Cross-over study	ICS Provision of biogas digesters (anaerobic fermentation system using animal/human waste) as a clean cooking fuel alternative to firewood	Households using traditional biomass fuels (wood) in open fires or traditional stoves	determinants of changes in kitchen PM2.5 levels, child CO exposure, and blood pressure (BP) in women; evaluation of health impact from clean fuel transition	Biogas technology can effectively reduce indoor air pollution and improve cardiovascular health. Even modest exposure reductions were associated with improved health indicators	Success	Cultural habits, Biogas technology can effectively reduce indoor air pollution and improve cardiovascular health. Even modest exposure reductions were associated with improved health indicators	- Context-specific variables (e.g., differences in kitchen design, ventilation, and cooking duration might influence results - Limitations include cross-sectional design and potential confounders not fully adjusted (e.g., diet, physical activity) - Results suggest scalable public health benefits in rural settings

Table 1 (continued)

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Mukesh K Dherani, 2013, Environmental Science & Technology	Rural Malawi	Households who cooked primarily with biomass fuels	Prospective observational study	Free provision of LPG stoves and continuous fuel supply (15 kg LPG/month)	Traditional three-stone fires (TSF) using wood	Changes in personal exposure to CO and kitchen CO levels; LPG stove intervention evaluation	Personal CO exposure: • Baseline: 4.0 ppm • Follow-up: 1.2 ppm 70% reduction—Kitchen CO levels: • Baseline: 10.3 ppm • Follow-up: 2.4 ppm 77% reduction	Success	Providing free LPG stoves and ensuring fuel access can achieve large and lasting reductions in household air use - Study limited to CO monitoring; no PM2.5 data collected	High stove usage compliance due to free fuel supply and household support
Mesafint Molla Adane, 2015, Environmental Health and Preventive Medicine	Rural Ethiopia	Rural households	Cluster Randomized Controlled Trial	ICS Use of advanced combustion improved biomass stoves, LPG, biogas, and electric stoves across rural Indian households	Traditional biomass stoves using firewood and cow dung	Changes in kitchen area concentrations of PM2.5 and CO; assessed across fuel types and stove technologies	PM2.5 (median 4-h kitchen concentrations): • Traditional biomass: 1,060 µg/m³ • Improved biomass: 440 µg/m³ • Biogas: 100 µg/m³ • LPG: 165 µg/m³ • Electric: 125 µg/m³ CO levels followed a similar trend - WHO interim targets exceeded in nearly all traditional and most improved stove households	Partial success	Advanced stove interventions can reduce HAP, but only clean fuels like biogas, LPG, and electricity consistently achieve levels near WHO targets. Stove stacking and usage behaviors remain challenges - Clean fuel access (not just improved biomass stoves) is critical for achieving health-protective air quality	Traditional and improved biomass stoves often used in parallel with cleaner technologies
J. Apple, 2017, Environment International	Kenya	Households who cooked primarily with biomass fuels	Descriptive study	Not an intervention study — this is a systematic review of observation al studies comparing exposure to household air pollution (from biomass) with clean fuel use	Clean fuels (e.g. LPG, electricity) used during pregnancy	Systematic review of associations between biomass fuel use and adverse birth outcomes (low birth weight, preterm birth, stillbirth)	Low birth weight (LBW): OR = 1.35 (95% CI: 1.23–1.48) - Stillbirth: OR = 1.29 (95% CI: 1.18–1.41) — evidence; some studies show increased risk, others do not — All reviewed studies indicated greater adverse outcomes among women using biomass	Partial success	Prenatal exposure to biomass smoke is associated with significantly higher risk of LBW and stillbirth. Shifting to cleaner fuels during pregnancy can reduce these risks - Consistent direction of association despite heterogeneity in study design - Strong recommendation for promoting clean fuels in pregnancy — Need for intervention trials to confirm causality and quantify benefits	Biological plausibility exists through mechanisms such as hypoxia, oxidative stress, and inflammation. — Limitations include reliance on self-reported fuel use, lack of exposure quantification, and residual confounding

Table 1 (continued)

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Isaac Osei, 2012, Journal of Exposure Science and Environmental Epidemiology	Rural Ghana		RCT	Inverted Downdraft Gasifier Stove Use of improved biomass stoves (Envirofit models) and LPG stoves in households	Traditional biomass stoves (three-stone or mud-built chulhas)	Evaluation of PM2.5 and CO exposures among users of improved biomass stoves, and LPG stoves	PM2.5 exposures (mean 48-h personal): - Traditional: ~ 528 µg/m³ - Improved biomass: ~ 368 µg/m³ - LPG: ~ 196 µg/m³ - CO exposures (mean 48-h personal): - Traditional: ~ 6.6 ppm - Improved biomass: ~ 4.3 ppm - LPG: ~ 1.6 ppm - Even LPG users had exposure levels exceeding WHO interim PM2.5 targets	LPG stoves significantly reduced exposure, but not to WHO-recommended levels; improved biomass stoves achieved moderate reductions	Clean fuels like LPG lead to substantial exposure reductions, but complete elimination of high exposures may require addressing household behaviors, ventilation, and stacking biomass may also contribute to ambient pollution levels - Highlights importance of exclusive clean fuel use and broader community-level clean energy transition	Stove stacking and poor ventilation contributed to continued elevated exposures, even among LPG users.—Improved cookstoves reduced emissions compared to traditional ones, but not enough to meet health standards - Exposure from nearby homes using biomass may also contribute to ambient pollution levels - Highlights importance of exclusive clean fuel use and broader community-level clean energy transition
Tamara Pilishvili, 2016, PLOS ONE	Rural Kenya	Rural Households	Comparative study	ICS Provision of a pay-as-you-go (PAYG) LPG stove and cylinder in periurban Kenya	charcoal, wood, and kerosene	Personal exposure to PM2.5 (measured with MicroPEM™ samplers worn by the primary cook) Secondary: self-	Baseline mean personal PM2.5 exposure was 127 µg/m ³ Post-intervention mean exposure dropped to 60 µg/m ³ The largest reductions were observed in primary cooks who fully adopted LPG However, some participants continued using	The intervention reduced HAP for full adopters, but not universally due to fuel stacking	LPG adoption through PAYG schemes can significantly reduce PM2.5 exposure, especially when exclusive use is achieved	Even when LPG is provided affordably, convenience, availability, and cultural preferences lead some households to continue using biomass Intermittent LPG usage (due to cost or supply interruptions) results in limited exposure reductions
Fikadu Mamuye, 2017, Sustainable Environment Research	Ethiopia	Rural Households	Performance evaluation	Provision and promotion of improved biomass cookstoves to rural households in Ethiopia	Baseline traditional stove use (open fire or rudimentary traditional biomass stoves)	24-h average kitchen and personal PM2.5 concentrations Black carbon (BC) levels	No significant reduction in personal PM2.5 exposure observed in users of improved cookstoves PM2.5 concentrations remained well above WHO guidelines in both intervention and control households Fuel stacking was common—households	The intervention did not result in meaningful reductions in HAP	Real-world reductions in exposure were much smaller than laboratory expectations and cooking needs unmet by the new technology	Barriers included: - Usability and acceptability of improved stoves - Cultural preferences and cooking needs unmet by the new technology

Table 1 (continued)

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Ricardo Piedrahita, 2019, Elsevier	Ghana	Households (primarily mothers and children) in rural Northern Ghana	RCT	under the Distribution of improved cookstoves to three intervention groups: Two Philips forced draft stoves Two Gyapa rocket stoves (locally made) One Philips and one Gyapa stove	Control group using traditional three-stone fires (TSF)	Fuel use Primary: 24 h average personal CO exposure (ppm) Secondary: Relationship between CO and carbonaceous PM2.5 (elemental carbon [EC] and organic carbon [OC]) Compliance, seasonal effects, behavioral influences	continued to use traditional stoves alongside Philips/Philips group: 30.3% reduction in CO exposure (0.39 ppm vs. 0.55 ppm in control; $p=0.08$) Gyapa/Gyapa: 10.5% reduction ($p=0.62$) Gyapa/Philips: 10.2% reduction ($p=0.61$) 8.2% of daily samples exceeded WHO Tier 1 CO guidelines Weak correlation between CO and PM2.5 (EC $R=0.07$, OC $R=0.19$)	CO exposure was reduced, especially in the Philips/Philips group, but reductions were not statistically significant. CO exposure levels were already relatively low, and traditional stoves continued to be used	adoption, CO exposure reductions suggest potential benefits from improved stoves, particularly the Philips stoves. However, high continued use of traditional fires diluted intervention effects. The weak relationship between CO and PM2.5 indicates that CO is not a reliable surrogate for overall exposures. Instrument calibration and measurement uncertainty may have dampened the observed exposure differences	Lack of sustained support and Stove adoption was partial, and many households continued using traditional stoves. Seasonal changes, stove preference (e.g., for cooking specific dishes), fuel type/moisture, and behavior strongly influenced exposure. Philips stoves had lower emissions in field tests, but charcoal use in these stoves could increase CO. Outdoor cooking and low ambient pollution in the study region contributed to lower overall exposures. Instrument calibration and measurement uncertainty may have dampened the observed exposure differences
Danielle N Medgyesi, 2024, Environmental Epidemiology	Ghana	Pregnant women in rural Ghana	Cross-sectional observational study using air quality monitoring, personal exposure measurement, and household interviews	Use of the Patsari improved cookstove (designed to burn wood more efficiently and vent emissions outdoors)	Traditional open fire cookstoves (referred to as fogón abierto)	Carbon monoxide (CO) levels in the kitchen environment and personal exposure of women Self-reported health symptoms related to smoke exposure Fuel consumption and stove	Patsari stoves reduced CO concentrations in kitchens by about 74% (from a geometric mean of 10.3 ppm in open fire households to 2.7 ppm in Patsari households) Women's personal CO exposure was reduced by 50% on average Reduced reports of eye irritation and headaches among Patsari stove users Fuelwood use decreased by approximately 50%	Substantial reductions in kitchen and personal CO levels, and reported health symptoms	The study provides clear evidence that improved chimney-based ventilation systems were effective in reducing smoke and CO exposure. Cultural acceptability and correct usage influenced the level of benefit achieved. Proper maintenance and user training were noted as critical for optimal performance	The Patsari stove's improved combustion efficiency and chimney-based ventilation system were effective in reducing smoke and CO exposure. Cultural acceptability and correct usage influenced the level of benefit achieved. Proper maintenance and user training were noted as critical for optimal performance

Table 1 (continued)

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Seyram Kaali MD, 2025	Rural Ghana	Pregnant women in rural Ghana	RCT	LPG	traditional open-fire cookstoves	Health outcomes	Median 48-h personal CO exposure decreased by 52% (from 5.9 ppm to 2.8 ppm) among pregnant women 87% of households were still using the improved stove four months after distribution However, traditional stoves were still being used concurrently (stove stacking)	Significant reduction in personal CO exposure, but not elimination	This study demonstrates that improved biomass stoves can significantly reduce harmful CO exposure in real-world rural settings. A 52% HAP reduction in personal CO exposure is meaningful, especially for vulnerable populations like pregnant women. However, the persistence of	The Philips stove burned fuel more efficiently and reduced CO exposure. Stove stacking (continued use of traditional stoves alongside the improved stove) likely limited the full potential of HAP reduction. High acceptability but barriers such as cooking preferences, meal types, and fuel availability contributed to continued use of traditional stoves.
Anindita Dutta, 2021, Environmental Research	Nigeria	24 healthy, pregnant, nonsmoking Nigerian women (≤ 18 weeks gestation), using firewood or kerosene for cooking at baseline	RCT	(ICS) CleanCook stove and ethanol	firewood/kerosene	Fetal biometric parameters via serial ultrasound: Biparietal Diameter (BPD) Head Circumference (HC) Femur Length (FL) Abdominal Circumference (AC) Ultrasound Estimated Fetal Weight (U-	No statistically significant differences in fetal growth trajectories between ethanol and control groups Borderline significant increase in U-EFW in the highest PM2.5 exposure quartile compared to the lowest ($p=0.046$), but in an unexpected direction Ethanol intervention did reduce PM2.5 exposure levels compared to controls, but this did not translate into improved fetal growth	The intervention successfully reduced PM2.5 exposure, but failed to significantly improve fetal growth outcomes	Despite the thoughtful design and robust execution, this study did not demonstrate a significant benefit of ethanol stove use on fetal growth, even though the intervention clearly lowered HAP exposure (PM2.5). This suggests that reduction in personal exposure may need to be more	High background ambient air pollution in the study location may have diluted the intervention's effect. Cross-contamination from neighboring households using biomass fuels may have influenced personal exposure. The lack of observed benefits may also be due to the short duration of exposure reduction (starting mid-pregnancy), variability in compliance, or residual confounding.

Table 1 (continued)

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Matthew Shupler, Lancet Planet Health 2024	Cameroon, Ghana, and Kenya		RCT	ICS (LPG)	Wood	EFW48-h personal exposure to CO and PM _{2.5} Stove usage behavior	The mean PM _{2.5} kitchen concentration was five times higher among households cooking with charcoal than those using LPG in the Kenyan community (297 µg/m ³ , 95%CI 216–406, vs 61 µg/m ³ , 49–76), but only 4 µg/m ³ higher in the Ghanaian community (56 µg/m ³ , 45–70, vs 52 µg/m ³ , 40–68). The mean CO kitchen concentration in charcoal-using households was double the WHO guideline (6.11 parts per million [ppm]) in the Kenyan community (15.81 ppm, 95%CI 8.71–28.72), but below the guideline in the Ghanaian setting (1.77 ppm, 1.04–2.99). In all communities, mean PM _{2.5} cook exposures only met the WHO interim-1 target (35 µg/m ³) among LPG users staying indoors and living more than 10 min walk from a road	Partial success	substantial or Community-level variation in the relative difference in HAP exposures between LPG and wood cooking fuel users in periurban sub-Saharan Africa might be attributed to differences in ambient air pollution levels. Thus, mitigation of indoor and outdoor PM _{2.5} sources will probably be critical for obtaining significant exposure reductions in rapidly urbanising settings of sub-Saharan Africa	Community-level variation in the relative difference in HAP exposures between LPG and wood cooking fuel users in periurban sub-Saharan Africa might be attributed to differences in ambient air pollution levels. Thus, mitigation of indoor and outdoor PM _{2.5} sources will probably be critical for obtaining significant exposure reductions in rapidly urbanising settings of sub-Saharan Africa
Anindita Dutta, Science of the total Environment 2021	Nigeria	Rural Nigeria	RCT	ICS	TCS	lung function	Mean age of the children was 2.9 years (standard deviation = 0.3); 120 were boys (53.8%) and 103 were girls (46.2%). Higher postnatal PM _{2.5} exposures were significantly associated with higher airway reactance at 5 Hz (X5 Hz; p = 0.04) in adjusted models. There were no significant associations between prenatal or postnatal PM _{2.5} exposure levels and other oscillometry parameters in adjusted regression analysis	While prior exposure measurements indicated some reduction in PM _{2.5} and CO (especially with Philips stove), this did not translate into statistically significant improvements in birth outcomes	The findings provide some evidence that increased postnatal HAP This study indicates that ambient air pollution and indoor oscillometry sources beyond a low-cost cooking may have contributed to exposures Inadequate reduction in HAP with the improved stoves used	Continued use of traditional stoves (stove stacking) likely diminished the impact of the intervention Ambient air pollution and indoor sources beyond cooking may have contributed to exposures Inadequate reduction in HAP with the improved stoves used

Table 1 (continued)

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Anirban Banerjee, Inflammation 2011	Ghana	Rural women	RCT	LPG	Improved biomass stoves		The neutrophil count in blood and sputum was significantly higher ($p < 0.05$) in biomass users than the control group. Flow cytometric analysis revealed marked increase in the surface expression of CD35 (complement receptor-1), CD16 (FC γ receptor III), and $\beta 2$ Mac-1 integrin (CD11b/CD18) on circulating neutrophils of biomass users. Besides, enzyme-linked immunoassay showed that they had 72%, 67%, and 54% higher plasma levels of the proinflammatory cytokines tumor necrosis factor- α , interleukin-6, and interleukin-12, respectively, and doubled neutrophil chemoattractant interleukin-8	Success	This study provides compelling evidence that transitions to clean fuels and consistent use of LPG only (mini-mal stove stacking) can result in dramatic reductions in household air pollution exposures for pregnant women in low resource settings. Unlike improved biomass stoves (which often show marginal	The large reductions in exposure were attributed to the clean combustion properties of LPG and consistent use of LPG only (mini-mal stove stacking). The provision of free fuel and regular support likely contributed to high adherence. Exposure reductions achieved in this study approach the WHO interim target for PM _{2.5} .
Mari E. Titcombe, Springer Science 2010	Tanzania		Descriptive study	None	None	PM2.5	PM2.5 average personal exposure was 14 $\mu\text{g}/\text{m}^3$ (± 3 , $n = 3$) for LPG, 88 $\mu\text{g}/\text{m}^3$ (± 42 , $n = 3$) for Electronic supplementary material The online version of this article (10.1007/s10661-010-1799-3) contains supplementary material, which is available to authorized users. M. E. Titcombe (B) Departments of Chemistry and Mechanical Engineering, University of Minnesota, 111 Church Street SE, Minneapolis, MN 55455, USA e-mail: titco006@umn.edu M. Simcik Department of Public Health, University of Minnesota, Minneapolis, MN 55455, USA for kerosene/charcoal mix, 588 $\mu\text{g}/\text{m}^3$ (± 347 , $n = 3$) for charcoal alone, and 1574 $\mu\text{g}/\text{m}^3$	Success		

Table 1 (continued)

First author, Year, Journal	Location & setting	Population	Study Design	Intervention	Comparator	Outcome (HAP)	Effect Estimates and HAP descriptive stats	Success or failure to reduce HAP	Interpretation of Findings	Explanations given in the paper
Misbath Daouda,	Ghana		RCT	liquefied petroleum gas (LPG) stove or improved biomass stove	open fire cooking	Blod pressure and HAP	Intention-to-treat analyses identified that DBP z-score at 4 years of age was lower among children born in the LPG arm (LPG b = -0.20; 95% CI: -0.36, -0.03) as compared with those in the control arm, and females were most susceptible to the intervention. Higher CO exposure in late gestation was associated with higher SBP and DBP z-score at 4 years of age, whereas higher late-first-year-of-life CO exposure was	Failure	These findings suggest that prenatal and first-year-of-life HAP exposure are associated with reductions in exposure to HAP, with interventions such as cleaner cooking beginning in pregnancy	These findings suggest that prenatal and first-year-of-life HAP exposure are associated with reductions in exposure to HAP, with interventions such as cleaner cooking beginning in pregnancy
Alawia K Suli-man, Journal of Health & Pollution 2021	Sudan		RCT	ICS	TCS	HAP	O-oximetry were repeated Results. Sixty-five women and 33 children were assigned to the study group and 46 women and 19 children were assigned to the control group in 2016. Women were enrolled in 2016 with CO levels of 17.8% and 17.4%, respectively. One year later some of the study group women had lower CO levels and others higher, while the CO levels of the controls were stable. An intensive HAP education program was started for the study group women. By 2019, the last study year, the CO levels of both the study and control group women had dropped to normal levels of 2.9% and 3.1%, respectively. Control group women may have benefited from the HAP education and modeled behavior of those in the study group	The health impact of the change in cooking location was unclear, yet both groups reported fewer health care visits in 2019	Education and an outside cooking location resulted in lower CO levels of Sudanese women and children	NA

Table 1 (continued)

First author, Year, Journal	Location & setting	Population	Study Design	Intervention	Comparator	Outcome (HAP)	Effect Estimates and HAP descriptive stats	Success or failure to reduce HAP	Interpretation of Findings	Explanations given in the paper
Steven N. Chilrud, Journal of Exposure Science and Environmental Epidemiology 2021	Ghana	Rural women and Children	RCT	LPG	Traditional stove	HAP	We obtained 5 655 48-h maternal CO exposure estimates and 1 903 for children, as well as 1 379 maternal PM2.5 exposure estimates. Median baseline CO exposures in the Control, improved biomass, and LPG arms were 1.17, 1.17, and 1.30 ppm, respectively. Based on a differences-in-differences approach, the LPG arm showed a 47% reduction (95% CI: 34–57%) in mean 48-h CO exposure compared to the control arm. Mean maternal PM2.5 exposure in the LPG arm was 32% lower than the control arm	targets compared to three-stone fires		In a large controlled trial of cleaner cooking interventions, an LPG stove and fuel intervention reduced indoor air pollution exposure in a vulnerable population in a low-resource setting
Brendon Barnes, Journal of energy in Southern Africa 2021	South Africa		Quasiexperimental	Behavior change intervention		HAP	The net median reductions associated with the intervention were: PM10=57%, CO=31% and CO (child)=33% amongst households that burned indoor fires	Success	Results showed that while overall indoor air pollution indicators were reduced by a similar magnitude in both groups, when stratified	The study provides evidence that a health behaviour change intervention (based on a novel community counseling model) has the potential to reduce indoor air pollution settings among rural communities who are unlikely to benefit from technical
Gould, C, 2019	Ghana		Randomized Controlled Trial (RCT) with three arms (control, LPG, improved biomass stove)	Provision of LPG stove+free fuel	Traditional cooking practices	48-h personal exposure to CO (carbon monoxide) and PM2.5 (particulate matter) assessed via monitors	CO exposure (LPG arm): Mean 0.89 ppm (46% reduction from baseline), compared to 1.30 ppm baseline PM2.5 exposure (LPG arm): 32% lower than control (52 µg/m3 vs 77 µg/m3) Biomass arm: No significant reduction in CO or PM2.5 compared to control Two-thirds of LPG arm PM2.5 exposure values still exceeded WHO Interim-1 guideline (35 µg/m3)	Partial success for LPG arm: Significant reduction in CO and PM2.5 Failure for biomass arm: No significant improvement over traditional cooking	This study reinforces that LPG stoves are significantly more effective than improved biomass stoves in reducing harmful household air pollution exposure during pregnancy. However, even with LPG,	LPG showed clear exposure reductions due to cleaner combustion The improved biomass stove failed likely due to continued stove stacking or insufficient emission reduction Even with LPG, residual exposure may come from ambient pollution or occasional biomass use

Table 1 (continued)

First author, Year, Journal	Location & setting	Population	Study Design	Intervention	Comparator	Outcome (HAP)	Effect Estimates and HAP descriptive stats	Success or failure to reduce HAP	Interpretation of Findings	Explanations given in the paper
Bassazin Ayalew Mekonnen	Rural Ethiopia			ICS	TCS	HAP	The performance testing result of the model has shown an improved thermal efficiency of 32% compared to the three-stone stove (14%). The stove reduced CO concentration by 42% and PM2.5 concentration by 99.5% over the three-stone stove. The average concentration exposure for an hour (3.1 µg/m3 CO) of the new stove satisfies the World Health Organization indoor air quality standard. Furthermore, the stove showed a 43%	Success	exposures Fuel resulted in the reduction of CO2 gas emissions by 1.3 tCO2/year Therefore, it is assumed that the rocket stove has a considerable improvement over the openfire stove and its	NA
Steve Hankey, Energy for Sustainable Development	Uganda		Before-and- after observational intervention study	Distribution of subsidized Ugastove-brand rocket stoves to 54 households	traditional three-stone fires	Change in kitchen PM2.5 and CO concentrations after stove introduction Stove use patterns recorded by temperature loggers	PM2.5: 37% reduction (mean decrease: 0.68 mg/m3; 95% CI: 0.2–1.2; p<0.01) CO: 8% reduction (mean decrease: 1.4 ppm; 95% CI: -5.2 to 7.9), not statistically significant Stove adoption: 47% used primarily the Ugastove 12% used primarily the three-stone fire 41% used both (stove stacking) Pollution levels: Lower in households using primarily the Ugastove compared to other patterns	PM2.5 exposure reduced significantly, but CO levels showed no meaningful change Mixed stove adoption patterns (only 47% primarily used the new stove) reduced the potential for full impact Ugastove can reduce particulate pollution in rural African households, but their effectiveness depends heavily on user behavior and stove adoption patterns. The modest reductions in PM2.5 and lack of significant CO reduction suggest that simply providing	This study demonstrates that rocket-style improved biomass stoves like the Ugastove can reduce particulate pollution in rural African households, but their effectiveness depends heavily on user behavior and stove adoption patterns. The modest reductions in PM2.5 and lack of significant CO reduction suggest that simply providing	The improved combustion efficiency of the Ugastove led to reductions in PM2.5 Persistent use of traditional stoves in 53% of households likely blunted CO reduction Variation in adoption was captured by objective stove use monitors, revealing real-world behavioral heterogeneity

Table 1 (continued)

First author, Year, Journal	Location & setting	Population	Study Design	Intervention	Comparator	Outcome (HAP)	Effect Estimates and HAP descriptive stats	Success or failure to reduce HAP	Interpretation of Findings	Explanations given in the paper
Sepegedeh Saleh	Malawi		Convergent Design				ing a convergent design mode of synthesis. Results: Individual exposure monitoring pre- and post-cookstove intervention involved a sample of 18 participants (15 female; mean age 43). Post-intervention PM2.5 exposures (median 9.9 µg/m³ [interquartile range: 2.2–46.5]) were not significantly different to pre-intervention (11.8 µg/m³ [3.8–44.4]); $p=0.71$. On analysis by activity, background exposures were found to be Ninety percent of baseline kerosene lamp use was displaced at 1-month follow-up, corresponding to average PM2.5 reductions of 61% and 79% in main living areas and pupils' bedrooms, respectively. Average 48-h exposure to PM2.5 fell from 210 to 104 µg/m³ (–50%) among adults, and from 132 to 35 µg/m³ (–73%) among pupils Solar lamps displaced most kerosene lamp use in at least the short term	No impact	el saving and shorter cooking times. Conclusions: The cookstove intervention had no impact on cooking related PM2.5 exposures. A significant reduction in	
N. L. Lam, Wiley 2017	Kenya		A paired "before-and-after" design/quantitative research approach	Solar Lamps	Kerosene lamps	HAP	Ninety percent of baseline kerosene lamp use was displaced at 1-month follow-up, corresponding to average PM2.5 reductions of 61% and 79% in main living areas and pupils' bedrooms, respectively. Average 48-h exposure to PM2.5 fell from 210 to 104 µg/m³ (–50%) among adults, and from 132 to 35 µg/m³ (–73%) among pupils Solar lamps displaced most kerosene lamp use in at least the short term	Success	this study has shown the following: (i) that kerosene lamp use in Busia county, Kenya, is associated with substantial measurable exposure to PM2.5, both in adult and school pupil	Achieving safe levels of exposure for all family members would likely require use of solid-fuel stoves also addressing use of solid-fuel stoves

Table 1 (continued)

First author, Year, Journal	Location & setting	Population	Study Design	Intervention	Comparator	Outcome (HAP)	Effect Estimates and HAP descriptive stats	Success or failure to reduce HAP	Interpretation of Findings	Explanations given in the paper
Habtemu Demelash Enyew, Environmental Research 2024	Ethiopia		Randomized Control Trial	chimney fitted improved stove		HAP	At baseline, the average 24-h kitchen PM2.5 concentrations were 482 µg/m3 (95% CI: 408, 557) for the control and 405 µg/m3 (95% CI: 318, 492) for the intervention groups. Despite remaining elevated at 449 µg/m3 (95% CI: 401, 496) in the control group, PM2.5 concentrations reduced to 104 µg/m3 (95% CI: 90, 118) in the intervention group, indicating a statistically significant difference ($t=6.97$, $p<0.001$)	Failure	lamp users; (ii) the before-and-after approach, 76% when comparing groups, and 74% for difference in analysis. Beyond the overall reduction,	While the intervention achieved a significant PM2.5 reductions, unfortunately remained above the WHO's safe limit, highlighting the need for further interventions
Daniel LaFave	Ethiopia		randomized controlled trial	Mirt stove	Traditional cookstoves	HAP	Reductions in PM2.5 was observed	success	we find evidence suggesting the change in PM2.5 due to the Mirt stove is enough to cause improvements in height-for-age, though not enough to see noticeable differences in older individuals	From a policy perspective these gains may appear modest given the null impact on adults and older children. Still, over the course of a child's life they represent significant benefits due to the laterlife impacts of early-life health improvements

CRCT clustered randomised controlled trial, *RCT* Randomised controlled trials, *I* Intervention group number, *C* Control/Comparator group where applicable, *ICS* Improved Cook Stove, *LP* Liquified Petroleum Gas, *HAP* Household Air Pollution, *ICS* Traditional Cook Stove

was to comprehensively map existing evidence, identify research gaps, and characterize the breadth of available studies in accordance with the Joanna Briggs Institute guidance for scoping reviews.

To our knowledge, this is the first Africa-specific scoping review that synthesizes evidence on cleaner fuel and cookstove interventions by simultaneously examining intervention characteristics, reductions in household and personal pollutant exposures, geographical distribution of studies, and remaining evidence gaps. By identifying methodological and geographical research priorities, this review provides evidence to guide future research, policy development, and implementation of clean cooking interventions across Africa.

Methods

This scoping review (ScR) mapped evidence on household air pollution reductions associated with clean cooking interventions in Africa, including improved biomass cookstoves, liquefied petroleum gas (LPG), electricity, ethanol, biogas, and other cleaner household energy technologies.

The protocol for this study was developed using the Joanna Briggs Institute's (JBI) framework for ScR [20]. The scoping review was registered prospectively on 'The Open Science Framework', available at <https://osf.io/thwsf/> [21]. Our reporting structure was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis extension for Scoping Reviews (PRISMA-ScR) [22]. All the review stages were iterative to ensure full exploration and understanding of the literature's content. The study selection and data extraction process followed JBI and PRISMA-ScR guidelines using Colandr (an open-access, collaborative platform that helps researchers manage the systematic review process from literature search and screening to data extraction using automation and machine learning to improve efficiency and reduce bias).

Operationalization of key concepts

For this review, clean cooking interventions were defined as interventions promoting transitions from traditional biomass fuels toward cleaner energy sources such as liquefied petroleum gas (LPG), electricity, ethanol, biogas, or solar cooking technologies, as well as improved biomass combustion technologies designed to reduce emissions.

Cookstove interventions referred to technological interventions intended to improve combustion efficiency, reduce household air pollutant emissions, or replace traditional three-stone fires and conventional biomass stoves.

Exposure contrasts referred to measurable differences in household or personal concentrations of pollutants including PM_{2.5}, carbon monoxide (CO), black carbon (BC) before and after intervention or between intervention and traditional cooking conditions.

The six-step scoping review framework

This review followed the Joanna Briggs Institute (JBI) methodological framework for scoping reviews, comprising six iterative stages:

1. Identifying the review question.
2. Identifying relevant studies.
3. Selecting eligible studies.
4. Charting the data.
5. Collating, summarizing, and reporting the evidence.
6. Consultation with experts to strengthen interpretation and knowledge translation.

Identifying and developing the review questions

The research questions, inclusion and exclusion criteria were guided by JBI's Population, Concepts, Context (PCC) and study type search framework.

Although randomized controlled trials, quasi-experimental studies, and intervention evaluations formed the primary eligible study designs, some included publications incorporated mixed-methods, descriptive, or qualitative components alongside intervention evaluations. These publications were retained because the intervention component satisfied the predefined eligibility criteria and reported pre and post intervention household air pollution measurements.

In consultation with a social evidence synthesis librarian, the review question was developed to explore the state of current ICS evidence (Concept) that could be promoted among the populations in Africa to reduce household air pollution.

Review question How have cleaner fuel and modified cookstove interventions in households in Africa altered concentrations of household air pollution, such as PM_{2.5}, BC, CO, and other air pollutants (e.g., PM₁₀ and nitrogen dioxide) in the cooking area and/or personal exposures, when compared to traditional cooking methods, such as three stone fire or traditional biomass cookstove?

Inclusion and exclusion criteria

We restricted the scoping review to studies that reported both pre- and post-values of Household Air Pollution outcomes. Such studies included randomized controlled trials (RCTs), non-randomized controlled studies and studies such as program evaluations. Cleaner fuel and cookstove interventions were included if the study took place in Africa.

Studies that were lab-based or field-based cooking tests of improved cookstove, performed only for the duration of the cooking exercise, and cross-sectional studies (one point in time with no pre/post measures), were excluded.

Inclusion criteria

Studies were included if they assessed household air pollution outcomes, specifically reporting air quality or pollutant concentration measurements. Eligible interventions focused on cleaner fuels, modified cookstoves, or solar-based cooking technologies. The review was limited to studies conducted in Africa and considered randomized controlled trials as well as program evaluations with pre- and post-intervention measurements, mixed methods and cross-sectional studies evaluating household air pollution.

Exclusion criteria

Studies were excluded if they did not measure household air pollution, focused solely on health outcomes without air quality measurements, or evaluated behavioral interventions without a cookstove or fuel component. Research conducted outside Africa was excluded. In addition, laboratory-based studies, field-based cooking tests.

Problem

Reported measurements of Household Air Pollution changes from cookstove interventions in the home, including concentrations of PM_{2.5}, BC, and/or CO.

Concept

Cookstove interventions: cleaner fuel and cookstove interventions such as electricity, modified biomass fuel/stoves, LPG, solar, biofuel (e.g., ethanol), charcoal pellets, ethanol, or other forms of cleaner fuels/stoves.

Context

The review included intervention studies conducted anywhere within Africa. Countries were classified according to the United Nations geographical regions (Eastern, Western, Central, Northern, and Southern Africa) to facilitate assessment of geographical representation and identification of regional evidence gaps. Detailed regional classifications are provided in map of Africa.

Study type

We focused on any intervention study that reported both baseline and post-intervention values of household air pollution outcomes including randomized controlled trials (RCTs).

Identifying relevant studies and eligibility criteria

Types of sources

This scoping review considered both experimental and quasi-experimental study designs including randomized controlled trials, non-randomized controlled trials, before and after studies and interrupted time-series studies.

Search strategy

A set of keywords (indoor air pollution; clean fuel stoves; African countries) was drafted by PK, AN and BY with the help of an Evidence Synthesis Librarian (Assistant Professor Anna Ferri) and was centered around improved cookstove interventions and Household Air Pollution exposures, including National Library of Medicine MeSH terms and free text words used to describe them and the full search design and search queries that were used for each database can be found in the registered protocol on OSF (<https://osf.io/thwsf/>) and in supplemental Table [21].

A search was conducted on March 18th 2025 by Anna Ferri, via the Colorado State University Library on the following databases: Medline and PMC (PubMed), Web of Science Core Collection, and CAB Abstracts (1973-present, EBSCO).

Evidence selection/Selecting eligible studies

Following the search, all identified citations were collected and uploaded into Zotero reference management software to manage bibliographic data and related research materials. Potentially relevant sources were retrieved in full and their citation details imported into the online application Colandr, a free tool that is open-source (<https://www.colandrapp.com/signin>; <https://hslib.jabsom.hawaii.edu/colandr>). Any duplicates were removed through the free online de-duplicator program (<https://sr-accelerator.com/#/deduplicator>). The full text of selected citations was assessed in detail against the inclusion criteria by three independent reviewers. Reasons for exclusion of sources of evidence at full text that did not meet the inclusion criteria were recorded. Any disagreements that arose between the reviewers at each stage of the selection process were resolved through discussion. The results of the search and the study inclusion process are reported in full in the results section and presented in a Preferred

Reporting Items for Systematic Reviews and Meta-analyses extension for scoping review (PRISMA-ScR) flow diagram [22].

Data charting/extraction

After searching the literature with the search strategy described, three reviewers (PK, AN and BNY) used the following steps to select the studies. First, they screened the titles and abstracts against the inclusion and exclusion criteria. Those studies potentially eligible based on the first screening were selected and saved as a full text in Zotero. Each reviewer then read through the full text to determine if it was eligible. Then, all reviewers compared their selected articles and any discrepancies were discussed and new studies were added to the agreement list. Each paper in the agreement list was then fully reviewed to confirm eligibility and create the final selection list. From the final selection list, key data were extracted into the data extraction form.

Data was extracted from papers included in the scoping review by three independent reviewers using Colandr. Colandr supported both article selection and data extraction. The data extracted included specific details about the population, concept, context, study methods and key findings relevant to the research question. The draft data extraction tool was modified and revised as necessary during the process of extracting data from each included evidence source. Any disagreements that arose between the reviewers were resolved through discussion.

The following information was extracted from each article: authors, date, journal, search engine source, study location (e.g., country) and general setting (e.g., urban, rural, peri-urban), population characteristics, study design, type of intervention, length of follow-up, comparator (group, condition, or intervention against which the experimental or primary intervention is evaluated), household air pollution measurements (effect estimates and descriptive statistics, such as pre and post values, control and intervention arms and length of pre and post intervention measurements and duration of exposure measurements). During data charting, two studies were excluded after full-text review because they did not report extractable data relevant to the review objectives or were found not to meet the predefined PCC eligibility criteria. All exclusions at this stage were documented with reasons and reflected in the PRISMA-ScR flow diagram.

Evidence synthesis and presentation

Three reviewers (PK, BNY, AN) independently extracted data from included studies. Non-African sites were excluded at the data charting stage to ensure the review remained focused on the African context. Extracted data were organized into three main categories: study characteristics (including authors, year, journal, location, population, and study design), intervention details (type of intervention and comparator), and outcomes (effectiveness in reducing cooking area air pollution and personal exposure to air pollutants). This approach allowed us to systematically summarize the evidence and identify patterns and gaps across studies.

Consultation with experts

We engaged with experienced researchers and an evidence synthesis librarian, all with extensive experience in Household Air Pollution, cookstove research and scoping review studies in LMICs to develop review questions, themes, methodology, and data extraction processes.

Results

Overview of studies

The scoping review identified substantial evidence from multiple studies across African settings demonstrating that cleaner cookstove interventions, particularly those using liquefied petroleum gas (LPG), biogas, and electric stoves, were associated with significant reductions in Household Air Pollution. Despite variability in intervention types, study designs, and follow-up durations, several consistent patterns emerged.

Overall, the review included a total of 32 studies and all were peer-reviewed articles. Reviewed studies were conducted in only 11 out of 54 African countries, most of which were in rural areas as presented in Fig. 1.

Geographic distribution of studies

The geographic distribution of studies revealed a substantial imbalance in the African evidence base as illustrated in Fig. 2. Intervention studies were conducted in only 11 countries, despite widespread dependence on biomass fuels throughout the continent. The concentration of evidence in Eastern and Central Africa, with relatively few studies from Northern, Southern and Western African countries, limits the generalizability of current findings. Differences in culture, cooking practices, housing characteristics, fuel availability, and socioeconomic conditions

Fig. 1 PRISMA flow diagram of selection of studies included in Household Air Pollution

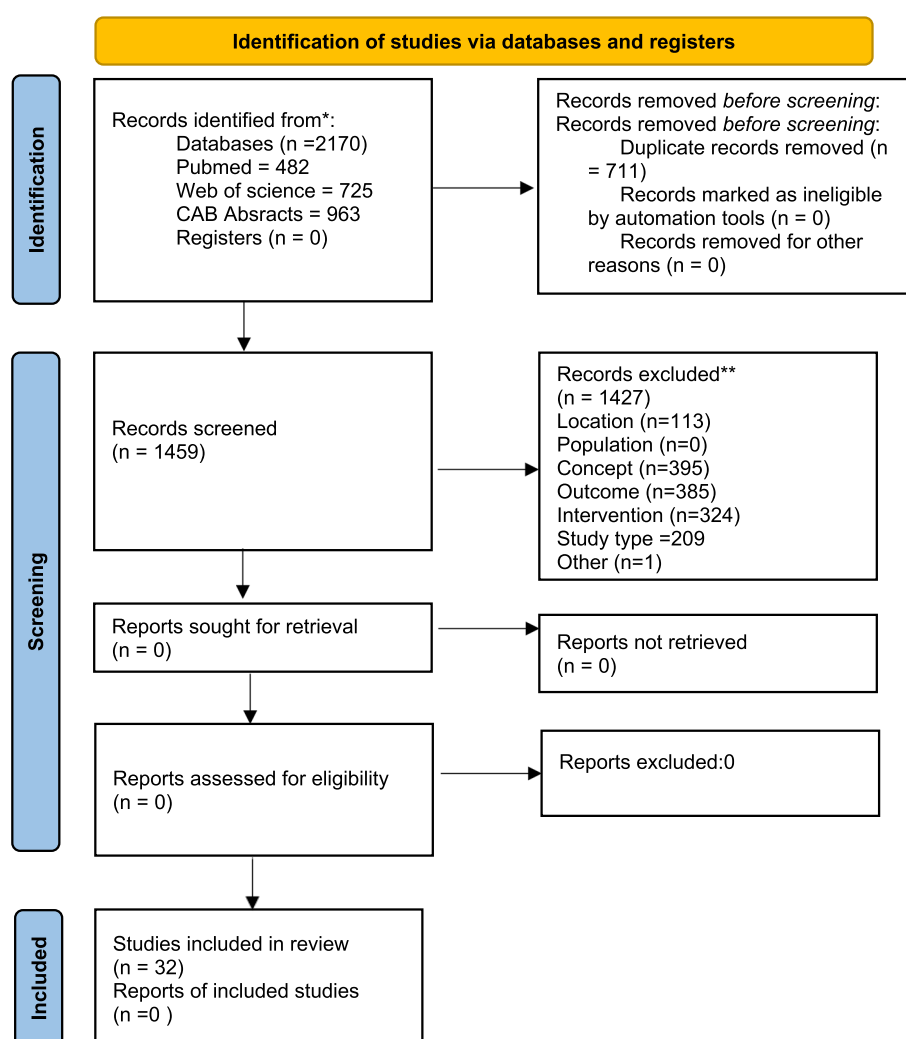




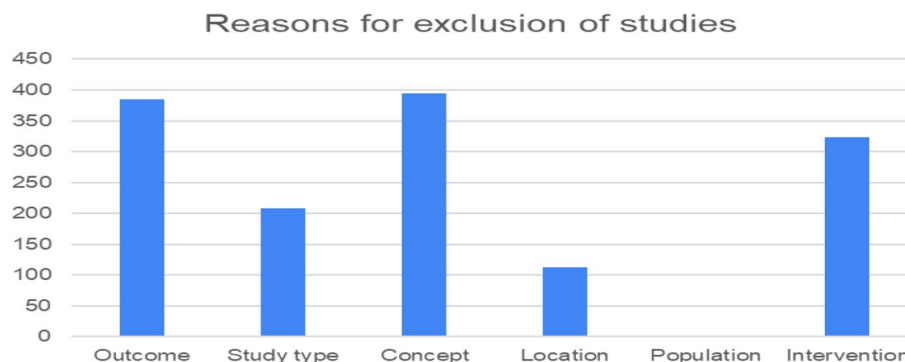
Fig. 2 Geographic distribution of countries represented in the scoping review of clean cooking and cookstove interventions in Africa. Countries highlighted in red indicate those in which at least one eligible intervention study was conducted and included in this review. Countries shown in grey had no eligible studies identified during the review period

across African regions may influence both intervention adoption and effectiveness. Future research should therefore prioritize underrepresented regions to generate evidence that better reflects the diversity of clean cooking challenges across Africa.

The review included a variety of study designs, with individual randomized controlled trials (RCTs) being the most common ($n=13$), followed by mixed methods studies ($n=4$) and cluster randomized controlled trials (cRCTs) ($n=5$). Other designs represented included descriptive studies ($n=2$), and single instances of comparative studies, reviews, cross-over studies, prospective observational studies, cross-sectional observational studies with measurements and interviews, quasi-experimental designs, before-and-after observational intervention studies, convergent designs, and a paired “before-and-after” design using a quantitative research approach (each $n=1$).

The reviewers screened 1459 titles and abstracts where they excluded a total of 395 articles due to key concepts, 385 for outcomes, and 324 based on interventions. Study types led to exclusion of 209 studies, while information on study location excluded 113 entries and other reasons excluded only 1. The main reasons for exclusion of studies during title and abstract screening are summarized in Fig. 3.

Fig. 3 Summary of reasons for exclusion of records during title and abstract screening



Section a: characteristics of improved cookstove, household air pollution

Characteristics of improved cookstove

Across the reviewed interventions, improved biomass stoves (ICS) were the most commonly implemented, appearing in 12 studies. Liquefied petroleum gas (LPG) interventions followed, featuring in 7 studies, often involving free fuel provision or pay-as-you-go systems. Biogas digesters and electric or ethanol stoves each appeared in 2 interventions, highlighting their more limited but notable use as clean fuel alternatives. Solar lighting systems were included in 2 interventions, typically as complementary technologies alongside clean cooking solutions. Additionally, 3 interventions employed mixed stove or fuel packages, combining technologies such as ICS and LPG or incorporating solar components (additional file 1).

Air pollution exposure reduction

Carbon Monoxide (CO) The selected studies showed substantial reductions in personal and kitchen CO exposure across interventions [23, 24]. For example, in one longitudinal study, personal CO exposure declined from 4.0 ppm at baseline to 1.2 ppm post-intervention, reflecting a 70% reduction, while kitchen CO levels dropped from 10.3 ppm to 2.4 ppm (77% reduction) [25]. Similarly, median 48-h CO exposure among pregnant women decreased by 52%, from 5.9 ppm to 2.8 ppm [26].

In LPG interventions, mean personal CO exposure dropped by 46–47%, and exposure levels were consistently lower among biomass users. For example, LPG users had average exposures of 0.89–1.6 ppm, compared to ~6.6 ppm in traditional biomass users [27, 25, 26, 28]. Notably, Patsari stove users showed a 74% reduction in kitchen CO and 50% reduction in women’s personal exposure [29]. However, improved biomass stoves generally resulted in modest or non-significant CO reductions, with reductions ranging from 10 to 30%, often lacking statistical significance [30, 31].

Particulate Matter (PM_{2.5}) Across intervention types, reductions in PM_{2.5} concentrations varied considerably. Traditional biomass stoves consistently produced the highest household PM_{2.5} concentrations, frequently exceeding 1,000 µg/m³. Improved biomass stoves generally reduced PM_{2.5} concentrations relative to traditional cooking; however, pollutant levels remained substantially above WHO 2021 Interim Target and Air Quality Guideline values [31, 32]. In contrast, LPG, electric, and biogas interventions achieved markedly greater reductions, with several studies reporting household concentrations approaching WHO 2021 interim targets, although few reached guideline values under routine household conditions. However, fuel stacking (use of multiple stove types) was common and often with limited exposure reduction. Two interventions reported no statistically significant

reductions in personal PM_{2.5} exposure despite improved stove adoption. Reported concentrations remained substantially above the WHO 2021 annual PM_{2.5} Air Quality Guideline (5 µg/m³) and Interim Target 1 (35 µg/m³) [30, 33].

Black Carbon (BC) and Other Pollutants In households where kerosene lighting was displaced, personal BC exposure dropped by 91% (from 11.9 µg/m³ to 1.1 µg/m³) [34]. PAH exposures followed a similar trend: LPG users had < 1 ng/m³ of total PAHs compared to 334–5040 ng/m³ among charcoal and open fire users.

Adoption, usage patterns, and sustainability

Adoption rates varied; 95% of households used LPG as their primary cooking fuel 18 months after intervention in one study, 87% of households continued using improved stoves 4 months after distribution. However, fuel stacking remained prevalent (e.g., 41% of households used both improved and traditional stoves concurrently) [13]. The effectiveness of interventions was often moderated by adherence, cultural practices, and fuel access. Even in settings with high adoption, many LPG users continued to exceed WHO 2021 interim targets for PM_{2.5} exposure [33].

Discussion

This scoping review included a total of 32 studies and all were peer-reviewed articles. Reviewed studies were conducted in only 11 out of 54 African countries, all of which were in rural areas. The review included a variety of study designs, with individual randomized controlled trials (RCTs) being the most common (n = 13), followed by mixed methods studies (n = 4) and cluster randomized controlled trials (cRCTs) (n = 5). Other designs represented included descriptive studies (n = 2), and single instances of comparative studies, reviews, cross-over studies, prospective observational studies, cross-sectional observational studies with measurements and interviews, quasi-experimental designs, before-and-after observational intervention studies, convergent designs, and a paired “before-and-after” design using a quantitative research approach (each n = 1). The review aimed to systematically chart existing evidence on cleaner fuel and cookstove interventions in Africa and identify gaps to guide future research, policy efforts and explore user perspectives of improved cookstove.

This review contributes several important insights to the existing literature. First, it provides the first comprehensive synthesis focused exclusively on cookstove and cleaner fuel intervention studies conducted in Africa. Second, it demonstrates that while improved biomass stoves generally reduce household air pollution compared with traditional cooking methods, clean fuel interventions including LPG, electricity, and biogas consistently achieve substantially greater reductions in PM_{2.5} and CO exposure. Third, the review identifies important geographical inequities in research activity, with intervention studies concentrated in relatively few African countries despite widespread dependence on biomass fuels across the continent. Finally, the review highlights persistent methodological heterogeneity in exposure assessment, limiting comparison across studies and emphasizing the need for standardized monitoring approaches.

Collectively, these findings demonstrate that successful clean cooking transitions extend beyond stove technology alone. Intervention effectiveness depends upon sustained adoption, affordability, fuel availability, behavioral practices, and reductions in stove stacking. Consequently, future interventions should be evaluated using implementation science approaches that integrate technological performance with social, economic, and behavioral determinants of sustained clean fuel adoption. The identification of only 32 intervention studies across just 11 of the 54 African countries highlights a substantial lack of evidence in a region that remains heavily dependent on biomass fuels and consequently among countries that experiences high levels of household air pollution. This gap underscores the urgent need for expanded field testing of cleaner cooking alternatives across Africa. The review

further revealed considerable heterogeneity in how ICS characteristics, designs, supporting interventions, and emission metrics (e.g. $\mu\text{g}/\text{m}^3$) were described and measured. Such variability hindered meaningful cross-study comparisons of Household Air Pollution emission levels and was exacerbated by limited reporting of key contextual factors, including fuel moisture content, cookstove features (e.g., chimney and draft systems), and household characteristics such as ventilation and kitchen structure.

Collected evidence indicates that ICS generally reduce $\text{PM}_{2.5}$ concentrations compared to traditional cookstove; however, none achieved levels approaching the WHO 2021 indoor air quality guideline. All traditional and most improved biomass stove users exceeded WHO 2021 interim targets for $\text{PM}_{2.5}$, while biogas and electric users approached safer levels [31, 32]. In 48-h personal exposure estimates, LPG users consistently had lower $\text{PM}_{2.5}$ levels compared to other cooking technologies.

Among stove types, electric, Patsari and LPG cookstove consistently demonstrated the greatest reductions in both household and personal exposure to $\text{PM}_{2.5}$ and CO, likely due to improved combustion efficiency. However, improved biomass stoves generally resulted in modest or non-significant CO reductions. This inconsistency may reflect the primary role of chimneys in redirecting smoke rather than eliminating emissions, as well as inadequate reporting on chimney height and kitchen ventilation.

Personal exposure is strongly influenced by user behavior such as time spent cooking and proximity to the stove which may not accurately reflect stove performance and also influenced by other sources of exposure both in and outside the household environment [35].

However, when combined with kitchen-level measurements, personal exposure data can provide valuable insights into behavioral changes associated with ICS [36].

Clean fuel interventions, particularly those promoting LPG, biogas, and electric cooking, consistently demonstrated the greatest reductions in both $\text{PM}_{2.5}$ and CO exposures, aligning with findings from global clean cooking initiatives [27, 37]. In contrast, improved biomass stoves, though often marketed as cleaner alternatives, generally yielded modest or non-significant exposure reductions in real-world settings [31, 38]. This discrepancy is largely attributed to fuel stacking, lower-than-expected field performance, and persistent reliance on traditional cooking methods [33].

While exposure reductions with LPG and biogas were substantial, many users still exceeded WHO 2021 interim targets, particularly for $\text{PM}_{2.5}$, indicating that clean fuel use alone may be insufficient in high ambient pollution settings or in households with partial adoption [39]. These findings underscore the importance of both technology adoption and behavioral change in achieving meaningful exposure reductions and also necessary to address other sources of air pollution to achieve optimal gains from cookstove improvements [10].

The long-term success of cookstove interventions is contingent not only on their technical efficiency but also on user adoption, acceptability, affordability, and access to reliable fuel supply [40, 41]. While some studies reported high rates of sustained use (e.g., 95% LPG use at 18 months), others documented persistent use of multiple stove types, a practice that often-blunted expected gains in exposure reduction [42].

Behavioral, economic, and infrastructural barriers continue to limit full transitions to clean cooking [41]. Even when improved stoves or clean fuels are adopted, households often revert to traditional fuels during periods of fuel scarcity or for cooking specific foods [31]. These findings call for a systems-based approach that addresses not only stove technology but also fuel availability, affordability, and user preferences [25].

This review included diverse studies with varying designs, sample sizes, exposure assessment methods, and outcome measures. While this heterogeneity reflected the complexity of real-world interventions, it also limits the ability to make direct comparisons or meta-analytical inferences. Additionally, most studies had relatively short follow-up durations, raising questions about the long-term sustainability of exposure reductions and health improvements.

Further, exposure assessment methods and fuel use determination varied considerably, from real-time monitors to self-reported fuel use, and many studies lacked baseline measurements or control groups. These methodological differences may have introduced bias or masked true intervention effects.

The review reinforces the urgent need to prioritize clean fuel transitions in public health and climate policy. Incremental improvements in stove design while potentially beneficial for fuel efficiency do not appear sufficient to substantially reduce Household Air Pollution related health risks in African settings. Instead, policies should focus on scaling access to LPG, biogas, and electricity, alongside strategies to address behavioral change, financing mechanisms, and supply chain strengthening.

Moreover, interventions should be coupled with rigorous monitoring and evaluation frameworks that incorporate exposure measurements, health outcomes, and implementation fidelity over longer time horizons. These efforts are critical for identifying the most effective, acceptable, and scalable approaches in different African contexts.

Strengths

This review has several strengths. It followed internationally recognized JBI guidance and PRISMA-ScR reporting standards and was prospectively registered with the Open Science Framework. A comprehensive search strategy was developed with an evidence synthesis librarian and applied across multiple databases. Independent screening and data extraction by multiple reviewers reduced selection bias. Furthermore, focusing exclusively on African intervention studies allowed identification of regional research gaps that are often obscured within global reviews.

Limitations

Several limitations should be acknowledged. As a scoping review, our objective was to map available evidence rather than evaluate intervention effectiveness quantitatively; therefore, no meta-analysis or formal risk of bias assessment was performed. Considerable heterogeneity existed across intervention types, exposure assessment methods, pollutants measured, outcome reporting, and follow-up duration, limiting direct comparison among studies. Publication bias may also exist because only peer-reviewed articles published in English were included. Furthermore, relatively few studies evaluated long-term intervention sustainability or linked exposure reductions with health outcomes.

More broadly, scoping reviews are designed to describe the extent and characteristics of available evidence rather than establish causal relationships or generate pooled estimates of intervention effectiveness. Consequently, while this review successfully identifies knowledge gaps and research priorities, it cannot determine which interventions are most effective under specific African contexts. Future systematic reviews and meta-analyses will become increasingly feasible as the evidence base expands.

Future steps

Based on the findings of this scoping review, several strategic actions are recommended to enhance the effectiveness, sustainability, and scalability of cookstove and clean fuel interventions in low- and middle-income settings, particularly in Africa:

Strengthen behavior change strategies to improve adoption

Stove stacking remains a persistent challenge that undermines the potential benefits of clean cooking interventions. Future research and intervention programs should incorporate robust behavior change communication (BCC) strategies tailored to local cooking practices, beliefs, and fuel preferences. Community-based outreach and the inclusion of peer educators can facilitate exclusive use of clean stoves.

Enhance longitudinal and real-world exposure monitoring

Many existing studies lack long-term follow-up and fail to capture seasonal or behavioral variability. Future research should invest in longitudinal designs that assess exposure and health outcomes across multiple time points and seasons. The integration of real-time exposure monitoring using wearable or household-based sensors will allow for more accurate estimation of individual-level pollutant exposures and stove usage patterns.

Expand access to clean fuels and infrastructure

To achieve sustained reductions in Household Air Pollution, interventions must move beyond improved biomass stoves to focus on clean fuels such as LPG, electricity, and biogas moving beyond household-level approaches and utilizing community and regional-level approaches. This requires coordinated investments in fuel supply chains, distribution networks, and infrastructure—particularly in rural and peri-urban areas. Hybrid systems (e.g., solar-electric + LPG) could enhance reliability while reducing biomass dependence.

Establish supportive policy and regulatory frameworks

Governments should integrate clean cooking into national development, energy, and health policies. This includes setting national emissions and efficiency standards for cookstove, aligning clean cooking programs with Sustainable Development Goals (e.g., SDG 3, 5, 7, and 13), and developing incentive structures that promote adoption and scale-up. Policy frameworks should also support the inclusion of clean cooking in universal health coverage and climate financing mechanisms.

Foster cross-sectoral partnerships

Effective implementation of clean cooking solutions requires collaboration across health, energy, environment, and finance sectors. Partnerships with local NGOs, women's groups, and private sector actors can enhance reach, innovation, and local ownership. Capacity building at the community level and among local entrepreneurs will be critical for supply chain sustainability and service delivery.

Design context-specific and culturally appropriate interventions

Future clean cooking interventions should adopt integrated implementation strategies that combine cleaner stove and fuel technologies with behaviour change interventions, improved kitchen ventilation, culturally appropriate kitchen design, and strengthened fuel supply systems. Because cooking practices differ substantially across African communities, intervention packages should be locally adapted through participatory design approaches that account for household architecture, traditional cooking practices, food preparation requirements, and seasonal fuel availability. In some settings, multiple cooking spaces or purpose-specific kitchens may be necessary to promote sustained adoption while reducing household air pollution exposure. Intervention success is highly context-dependent. Future programs should be informed by ethnographic research and participatory design processes to ensure compatibility with local customs, housing types, fuel access, and cooking behaviors. Tailoring technologies to user-needs and preferences will increase acceptance and sustained use.

Conclusions

In conclusion, cookstove interventions in Africa show potential to reduce Household Air Pollution and improve health, particularly when clean fuels are used and sustained adoption is achieved. However, the effectiveness of improved biomass stoves remains limited under current field conditions. To achieve the full health and environmental benefits of clean cooking, interventions must move beyond stove distribution to address the broader social, economic, and infrastructural determinants of fuel choice and sustained behavior change.

This review provides the first comprehensive Africa-specific synthesis of cleaner fuel and cookstove interventions aimed at reducing household air pollution exposure. The evidence demonstrates that clean fuel interventions, particularly LPG, electricity, and biogas, consistently produce greater reductions in PM_{2.5} and carbon monoxide exposures than improved biomass stoves, although WHO 2021 guideline levels are seldom achieved under routine field conditions. The review also reveals substantial geographical and methodological gaps that limit understanding of intervention effectiveness across Africa. Addressing these evidence gaps through standardized exposure assessment, longer-term implementation studies, and context specific intervention research will be essential for informing clean cooking policies, accelerating progress toward universal access to clean household energy, and reducing the health burden associated with household air pollution.

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Declarations

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