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Review article

# Real-life effectiveness of 'improved' stoves and clean fuels in reducing $PM_{2.5}$ and CO: Systematic review and meta-analysis

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ABSTRACT

*Background:* 2.8 billion people cook with solid fuels, resulting in almost 3 million premature deaths from household air pollution (HAP). To date, no systematic assessment of impacts on HAP of 'improved' stove and clean fuel interventions has been conducted.
*Objective:* This systematic review synthesizes evidence for changes in kitchen and personal $PM_{2.5}$ and carbon monoxide (CO) following introduction of 'improved' solid fuel stoves and cleaner fuels in low- and middle-income countries (LMIC).
*Methods:* Searches of published and unpublished literature were conducted through databases and specialist websites. Eligible studies reported mean (24 or 48 h) small particulate matter (majority $PM_{2.5}$) and/or CO. Eligible interventions were solid fuel stoves (with/without chimneys, advanced combustion), clean fuels (liquefied petroleum gas, biogas, ethanol, electricity, solar) and mixed. Data extraction and quality appraisal were undertaken using standardized forms, and publication bias assessed. Baseline and post-intervention values and percentage changes were tabulated and weighted averages calculated. Meta-analyses of absolute changes in PM and CO were conducted.
*Results:* Most of the 42 included studies (112 estimates) addressed solid fuel stoves. Large reductions in pooled kitchen $PM_{2.5}$ (ranging from 41% (29–50%) for advanced combustion stoves to 83% (64–94%) for ethanol stoves), and CO (ranging from 39% (11–55%) for solid fuel stoves without chimneys to 82% (75–95%) for ethanol stoves. Reductions in personal exposure of 55% (19–87%) and 52% (−7–69%) for $PM_{2.5}$ and CO respectively, were observed for solid fuel stoves with chimneys. For the majority of interventions, post-intervention kitchen $PM_{2.5}$ levels remained well above WHO air quality guideline (AQG) limit values, although most met the AQG limit value for CO. Subgroup and sensitivity analyses did not substantially alter findings; publication bias was evident for chimney stove interventions but this was restricted to before-and-after studies.
*Conclusions:* In everyday use in LMIC, neither 'improved' solid fuel stoves nor clean fuels (probably due to neighbourhood contamination) achieve $PM_{2.5}$ concentrations close to 24-hour AQG limit values. Household energy policy should prioritise community-wide use of clean fuels.



**Contents**



*Abbreviations:* AQG, air quality guidelines; CO, carbon monoxide; DALY, disability-adjusted life year; HAP, household air pollution; IT-1, interim target 1; LMIC, low- and middle-income country; LPG, liquefied petroleum gas; $mg/m^3$, milligrams per cubic metre; $NO_2$, nitrogen dioxide; $PM_{2.5}$, small particulate matter with aerodynamic diameter of <2.5 μm; $PM_4$, respirable particulate matter with aerodynamic diameter of <4 μm; ppm, parts per million; WHO, World Health Organization.

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## 1. Introduction

Approximately 2.8 billion people use solid fuels (wood, animal dung, agricultural wastes, charcoal and coal), little changed since 1980 (Rehfuess et al., 2006; Bonjour et al., 2013). Solid fuel combustion leads to high levels of health-damaging household air pollution (HAP) including carbon monoxide (CO), particulate matter (PM), nitrogen dioxide ($NO_2$) and polycyclic aromatic hydrocarbons (Naeher et al., 2007). Studies consistently show very high HAP levels in households using solid fuels with $PM_{2.5}$ approximately 10 to 50+ times the World Health Organization (WHO) annual average Air Quality Guideline (AQG) limit (Saksena et al., 2003; WHO, 2006). CO levels also frequently exceed the WHO 24-hour AQG limit albeit by a smaller margin of 2–5 times (WHO, 2010). Women and young children experience especially high levels of HAP exposure due to traditional gender- and age-based household roles (Torres-Duque et al., 2008).

Globally, HAP from solid fuel use, primarily for cooking, was estimated in 2015 to account for 2.9 (2.2–3.6) million premature deaths and 8.4% (7.0–9.8) of disability adjusted life years (DALYs) totalling 85.6 million DALYs (Forouzanfar et al., 2016). Accordingly, HAP is ranked 8th in terms of global burden when compared to 79 risk factors contributing to the Global Burden of Disease calculations for the year 2015 (7th among women) (Forouzanfar et al., 2016).

Interventions to reduce exposure to HAP can be classified broadly as (i) those acting to change the primary household fuel, (ii) those promoting cleaner-burning and more efficient solid fuel stoves, (iii) those improving the living environment and (iv) those modifying user behaviour (Ballard-Tremeer & Mathee, 2000).

Switching from biomass fuels or coal to cleaner fuels such as liquefied petroleum gas (LPG), biogas, ethanol or solar cooking, is likely to bring about the largest reductions in HAP, provided these fuels are used to fulfil a majority of household energy tasks. However, in the short- to medium-term, the assumption that these cleaner alternatives completely replace traditional practices rarely holds, with so-called fuel stacking, i.e. the parallel use of multiple fuels and multiple stoves, being a common phenomenon (Rehfuess et al., 2014). Some of these interventions present distinct additional limitations, for example solar cookers have been estimated to be able to meet at most one-third of a household's cooking needs, even under ideal geographical and climatic conditions (Wentzel & Pouris, 2007).