RESEARCH PAPER

USAGE OF BIOMASS FUELS AND ITS ASSOCIATION WITH RESPIRATORY MORBIDITY AMONG HOUSEHOLDS OF RURAL AREAS: A NARRATIVE REVIEW

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Background:
In low and middle
income nations, household air pollution (HAP) from burning solid biomass fuels continues to be one of the main environmental risk factors for illness.

Despite substantial policy investment in clean cooking energy, a large proportion of rural Indian households continue to depend on firewood, dung cake, crop residue and charcoal for daily cooking, exposing women and young children to sustained high concentrations of respirable particulate matter.

Objectives: To synthesise the available evidence on patterns and determinants of biomass fuel use in rural households, the composition and magnitude of the resulting household air pollution, the biological mechanisms of lung injury, and the spectrum of respiratory morbidity associated with such exposure; and to identify gaps that justify continued community-based enquiry.

Methods: A narrative review was undertaken. PubMed/MEDLINE, Google Scholar, Scopus and the IndMED database were searched for literature published between January 2000 and December 2025 using combinations of the terms *biomass fuel*, *solid fuel*, *household air pollution*, *indoor air pollution*, *respiratory morbidity*, *chronic obstructive pulmonary disease*, *acute respiratory infection* and *rural India*. Systematic reviews, meta-analyses, large community-based cross-sectional studies, randomised cookstove trials, national survey reports and authoritative agency documents were prioritised.

Results: Approximately one-third of the global population, and a majority of rural Indian households, still cook with polluting fuels. Kitchen concentrations of PM2.5 during cooking in biomass-using homes commonly exceed World Health Organization air quality guidance by an order of magnitude or more. Burning solid biomass fuels to cook and heat homes causes household air pollution (HAP), which continues to be one of the leading environmental risk factors for disease in low- and middle-income countries.Cross-sectional Indian studies report a higher prevalence of cough, expectoration, wheeze and breathlessness, together with reductions in FVC, FEV1 and PEFR, among biomass users compared with users of liquefied petroleum gas. Risk rises with cumulative exposure, indexed by daily cooking hours multiplied by years of cooking. Use is patterned by poverty, low maternal education, kutcha housing, caste and geography, and fuel stacking is common even after a clean fuel connection is obtained.

Conclusion: Biomass fuel dependence is a modifiable, socially patterned determinant of respiratory ill health in rural India. Reducing the burden requires not only the provision of clean fuel connections but sustained affordability, kitchen design and ventilation improvements, and periodic community-based surveillance of respiratory morbidity at the primary care level.

Keywords: Biomass fuel; household air pollution; respiratory morbidity; rural health; India; Pradhan Mantri Ujjwala Yojana

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Introduction

The kitchen has long been recognized as an unregulated microenvironment of considerable toxicological importance. In much of rural South Asia, food is prepared over an open fire or a simple mud stove (*chulha*) fueled by wood, dried animal dung, agricultural residue or charcoal. Combustion under these conditions is grossly incomplete, and the resulting plume contains a complex mixture of respirable particulate matter, carbon monoxide, oxides of nitrogen and Sulphur, formaldehyde, benzene and polycyclic aromatic hydrocarbons.[1]Because cooking is repeated two or three times daily, over decades, and because ventilation in traditional dwellings is poor, cumulative inhaled dose in the primary cook can rival or exceed that of a moderate cigarette smoker.

The global scale of the problem is considerable. Around 2.1 billion people — roughly a third of humanity — still cook using open fires or inefficient stoves burning kerosene, biomass or coal, and household air pollution was responsible for an estimated 3.2 million premature deaths in 2020, including more than 237,000 deaths among children under five years of age.[1] Among children under five, exposure to household air pollution is held responsible for nearly half of all pneumonia deaths.[2]

India carries a disproportionate share of this burden. The National Family Health Survey (NFHS-5, 2019–21) recorded that only 58.6% of Indian households used a clean cooking fuel — electricity, liquefied petroleum gas (LPG), natural gas or biogas — with a marked urban–rural gradient (approximately 90% urban versus 43% rural). Correspondingly, 40.6% of the population (9.5% urban, 56.1% rural) continued to rely on firewood, dung cake or other biomass.[3] Data from the 78th round Multiple Indicator Survey of the National Sample Survey Office similarly indicate that more than 46% of rural residents continue to cook with biomass.[4] Notably, the NFHS-6 factsheets released in May 2026 omitted the clean cooking fuel indicator altogether, leaving a conspicuous gap in the national monitoring of progress towards Sustainable Development Goal target 7.1.[5]

This persistence has occurred despite one of the largest clean cooking energy interventions ever attempted. The Pradhan Mantri Ujjwala Yojana (PMUY), launched in May 2016 to provide deposit-free LPG connections to adult women from poor households, had released more than 10.5 crore connections by 2026, and the national domestic LPG customer base expanded from 14.52 crore in April 2014 to approximately 32.97 crore in April 2025.[6] Average per capita refill consumption among PMUY beneficiaries rose from 3.01 cylinders in FY2019–20 to 3.95 in FY2023–24.[7] Yet refill rates remain well below the level required to displace biomass entirely, and *fuel stacking* — the simultaneous use of LPG and biomass — is the norm rather than the exception in many rural districts.[8]

Against this background, the association between household biomass fuel use and respiratory morbidity is of direct relevance to community medicine practice. This review synthesizes the current evidence on the epidemiology of biomass fuel use in rural households, the pollutant profile and exposure levels generated, the pathophysiological pathways of injury, and the spectrum and magnitude of associated respiratory disease. It concludes by outlining methodological considerations and research gaps relevant to community-based studies of this association.

Methodology of the Review

This is a narrative (non-systematic) review. PubMed/MEDLINE, Google Scholar, Scopus, ScienceDirect and IndMED were searched for English-language literature published between January 2000 and December 2025, with seminal earlier papers retained where they remain foundational. Search terms were combined using Boolean operators and included: *biomass fuel*, *solid fuel*, *cooking fuel*, *household air pollution*, *indoor air pollution*, *respiratory morbidity*, *respiratory symptoms*, *chronic obstructive pulmonary disease*, *chronic bronchitis*, *acute respiratory infection*, *pulmonary function*, *rural*, and *India*.

Priority was given to systematic reviews and meta-analyses, randomised cookstove intervention trials, large community-based cross-sectional and case–control studies, and reports of national surveys and international agencies (World Health Organization, Global Burden of Disease Study, International Institute for Population Sciences, Ministry of Petroleum and Natural Gas). Reference lists of retrieved articles were hand-searched. Studies were excluded where exposure was purely occupational, where outcomes were not respiratory, or where methods were insufficiently described to permit interpretation. As with any narrative review, selection was purposive rather than exhaustive, and formal risk-of-bias assessment was not undertaken; this is acknowledged as a limitation in Section 11.

Biomass Fuels: Definition, Types and Patterns of Household Use

Biomass fuel refers to any organic material of plant or animal origin used as a source of energy.[9] In the Indian rural household context, the principal forms are:

Firewood and twigs. The dominant biomass fuel nationally, gathered from common land, farm boundaries and forest fringes, often by women and children. Collection itself carries musculoskeletal, injury and time-poverty costs quite apart from the smoke exposure.[9]

Dried animal dung (dung cake, upla/kanda*).** Widely used in the Indo-Gangetic plain, including Uttar Pradesh. Dung burns at low temperature with high moisture content, producing particularly heavy smoke and elevated emission factors for particulate matter and carbon monoxide.[10]

Crop residues. Rice and wheat straw, cotton stalks, sugarcane trash, mustard stalk and similar agricultural by-products, used seasonally and often mixed with other fuels.[10]

Charcoal. Less common in rural North India than in sub-Saharan Africa, but used in some regions and for specific cooking tasks.[8]

Coal and lignite. Not strictly biomass, but grouped with solid fuels in most epidemiological classifications because of comparable combustion behaviour and health effects; relevant in coal-belt districts.[8]

Two features of use, rather than fuel type alone, determine exposure. The first is **stove technology**: traditional three-stone fires and unvented mud *chulhas* achieve combustion efficiencies far below those of improved or forced-draft stoves.[9] The second is **kitchen configuration**: indoor kitchens without a chimney or dedicated flue, small room volume, low ceilings, absence of cross-ventilation and the presence of a sleeping area adjacent to the cooking space all raise both peak and time-weighted concentrations.[10] Outdoor or semi-open cooking, conversely, substantially reduces personal exposure even where fuel remains unchanged.[10]

Fuel stacking deserves particular emphasis. Households rarely make a clean binary transition from biomass to LPG.[11] Instead, LPG is reserved for quick tasks (tea, reheating) while biomass continues to be used for slow-cooking, large-volume or festival cooking, for animal feed preparation, and for water and space heating in winter. Because health risk is driven by cumulative exposure, partial transitions yield disappointingly small reductions in measured personal PM2.5 — a finding of considerable policy importance and a likely explanation for the modest health effects observed in several cleaner-fuel trials.[8,11]

Epidemiology of Biomass Fuel Use

Globally, an estimated 74% of the world's population primarily used clean fuels and technologies for cooking in 2023, up from about 49% in 2000; the South-East Asia Region recorded the largest improvement, with an eight-fold increase in coverage in rural areas.[12]Urban populations have consistently enjoyed better access than rural populations throughout this period.[12]

Within India, the socio-demographic patterning of solid fuel use is well characterised. Analyses of NFHS-5 household data (n ≈ 6,36,699 households) found that the national proportion of households using clean cooking fuel was approximately 53% by the stricter primary-reliance definition.[13] Clean fuel use was more likely among households in southern states, those with a male head of family, those in the richest wealth quintile, and those whose head had higher educational attainment. Conversely, rural residence, scheduled tribe status, kutcha housing, non-nuclear family structure and an unmarried head of family were associated with continued reliance on polluting fuels.[13] Longitudinal comparison of NFHS-4 (2015–16) and NFHS-5 shows that clean fuel use among rural households rose from roughly 23% to 41.3% over the PMUY implementation period[11] — a substantial gain, but one that still leaves the majority of rural households exposed.

The corresponding disease burden is large. Estimates from the Global Burden of Disease Study for India indicate that household air pollution remains among the leading risk factors for death and disability-adjusted life years lost, with the greatest impact in the northern and central states.[14] Global tracking data show that although exposure levels and attributable deaths have declined in many countries since 2010, they remain high across much of South Asia and sub-Saharan Africa.[15]

For studies conducted in Uttar Pradesh, the local context is particularly salient: the state has among the largest absolute numbers of PMUY beneficiaries in the country, yet also large rural populations with low refill capacity, high dung-cake availability from livestock keeping, and a cold winter season that generates additional space-heating demand.[6,14]

Incomplete combustion of biomass generates a chemically complex aerosol.[16] The principal health-relevant constituents are:

- **Fine particulate matter (PM2.5) and respirable particulate matter (PM10):** the exposure metric most closely linked to disease outcomes. Particles below 2.5 µm penetrate to the terminal bronchioles and alveoli; the ultrafine fraction can translocate into the systemic circulation.[16]
- **Carbon monoxide:** binds haemoglobin with high affinity; used in some studies as a convenient proxy for PM exposure.[16]
- **Nitrogen dioxide and sulphur dioxide:** airway irritants that heighten bronchial responsiveness.[9]
- **Polycyclic aromatic hydrocarbons (e.g. benzo[a]pyrene), benzene and formaldehyde:** known or probable human carcinogens.[16]
- **Free radicals, transition metals and endotoxin adsorbed onto particle**

surfaces: drivers of oxidative and inflammatory injury.[9]

Measured concentrations are striking. In Indian solid-fuel-using households, 24-hour average kitchen PM2.5 concentrations have been reported in the range of several hundred micrograms per cubic metre, with cooking-hour peaks substantially higher,[10] against a WHO 2021 annual guideline of 5 µg/m³ and 24-hour guideline of 15 µg/m³.[17] The WHO interim target for household fuel combustion (35 µg/m³ annual average) is rarely achieved in unvented biomass kitchens.[16] Studies comparing biomass and LPG households in rural India have consistently demonstrated significantly higher PM10 and PM2.5 concentrations during cooking hours in the biomass group, with a dose–response relationship between measured particulate concentrations and decrement in lung function indices.[18]

Exposure is not uniform within the household. The **primary cook**, typically an adult woman spending three to six hours daily at the stove, sustains the highest personal exposure.[19] **Infants and toddlers carried on the mother's back or seated near the hearth** form the second most exposed group. Adult men and school-going children generally have lower, though non-trivial, exposure. This gradient explains the striking sex distribution of biomass-associated COPD in India, where the male-to-female COPD ratio is approximately 1.5:1 despite a male-to-female smoking ratio of roughly 10:1.[19]

A useful summary metric in field studies is the **biomass exposure index (EI)**, calculated as average hours of cooking per day multiplied by the number of years of cooking.[20] Indian studies have found significantly higher odds of respiratory morbidity above an exposure index threshold of approximately 90 hour-years,[21] and Latin American work reported markedly elevated COPD risk above 200 hour-years of exposure.[22]

Pathophysiological Mechanisms

The route from smoke to disease involves several overlapping mechanisms.[23]

Oxidative stress. Particulate matter carries redox-active surfaces and transition metals that generate reactive oxygen species, depleting antioxidant defences in the epithelial lining fluid and initiating lipid peroxidation and DNA damage.[23]

Innate immune activation and chronic inflammation. Particle deposition activates alveolar macrophages and airway epithelium through Toll-like receptors and transient receptor potential channels, with release of IL-6, IL-8, TNF-α and other mediators, resulting in neutrophilic airway inflammation.[20] Studies of rural South Indian women have identified distinct serum chemokine and cytokine signatures in biomass-smoke-associated COPD compared with tobacco-smoke-associated COPD, supporting the notion of a partially distinct endotype.[19]

Impaired mucociliary clearance and macrophage dysfunction. Carbon-laden alveolar macrophages show reduced phagocytic capacity and impaired bacterial killing, plausibly explaining the increased susceptibility to pneumonia and tuberculosis.[8]

Airway remodelling and anthracofibrosis. Histopathological comparison indicates that lungs of biomass-exposed COPD patients show greater carbon pigment deposition and peribronchial fibrosis (bronchial anthracofibrosis) than those of cigarette-smoking COPD patients, with relatively less emphysema[24] — a phenotype that may present with more small-airway obstruction and less hyperinflation.[25]

Genotoxicity. Polycyclic aromatic hydrocarbons undergo metabolic activation to reactive epoxides forming DNA adducts, providing a mechanistic basis for the observed excess of lung cancer.[23]

Systemic effects. Ultrafine particles and inflammatory mediators entering the circulation contribute to endothelial dysfunction and prothrombotic changes, linking household air pollution to ischaemic heart disease and stroke, and providing a plausible pathway for the reported associations with low birth weight and stillbirth.[2,8]

Respiratory Morbidity Associated with Biomass Fuel Exposure

Acute lower respiratory infection and pneumonia in children

The association between household solid fuel use and childhood pneumonia is among the best-established in environmental epidemiology. Meta-analysis of community-based studies has yielded a pooled odds ratio of approximately 3.53 (95% CI 1.94–6.43) for acute respiratory infection in children exposed to biomass fuel smoke,[26] and systematic reviews of unprocessed solid fuel use and pneumonia risk in under-fives have reported an approximate doubling of risk.[27] WHO attributes nearly half of all pneumonia deaths in children under five to household air pollution.[2]

Intervention evidence is more equivocal. The Cooking and Pneumonia Study (CAPS) in rural Malawi, a large cluster-randomised trial of a cleaner-burning biomass cookstove, found no significant reduction in pneumonia incidence in children under five[28] — a result generally interpreted as demonstrating that incremental improvements in biomass stove efficiency do not reduce exposure sufficiently to alter clinical outcomes, rather than as refuting the underlying causal association.[8]

The evidence linking biomass smoke to chronic airflow limitation in non-smoking women is robust and consistent across settings. Key pooled estimates include:

- Chronic bronchitis in women: OR ≈ 2.52 (95% CI 1.88–3.38)[26]

- COPD in women: OR ≈ 2.40 (95% CI 1.47–3.93)[26]
- A meta-analysis of community-based studies across South Asia, sub-Saharan Africa and Latin America reported a 1.38-fold increased risk of COPD and a 2.11-fold increased risk of chronic bronchitis in women cooking with biomass fuel relative to unexposed women.[29]
- Indian meta-analytic work has reported a pooled COPD prevalence of approximately 10% among biomass-fuel-exposed individuals.[30]

Biomass smoke is now recognised in international guidance as a risk factor for COPD of comparable order of magnitude to tobacco smoke,[31] and is a principal explanation for the large burden of COPD among non-smokers in India,[25] conservatively estimated at around 30 million cases nationally.[19,32]

Asthma and wheeze

Findings here are less consistent. Some meta-analyses report no significant association between biomass fuel exposure and asthma in either children or women,[26] while individual cross-sectional studies report higher prevalence of wheeze and physician-diagnosed asthma in exposed groups.[32] Heterogeneity likely reflects differing case definitions (symptom-based versus physician-diagnosed versus bronchodilator-responsive), difficulty in distinguishing asthma from fixed obstruction in adults, and confounding by atopy and environmental tobacco smoke.[23] Cautious interpretation is warranted.

Pulmonary tuberculosis

Systematic review evidence indicates a positive association between indoor air pollution from solid fuel and tuberculosis,[33] and Indian burden estimates have used a pooled adjusted odds ratio of approximately 2.33 (95% CI 1.65–3.28) for tuberculosis in relation to biomass cooking fuel exposure.[34] Impaired alveolar macrophage function is the leading mechanistic explanation.[8] However, residual confounding by crowding, undernutrition, poverty and indoor tobacco smoke is difficult to exclude, and the quality of the underlying primary studies is variable.[33] The association should therefore be regarded as probable rather than definitively causal.

Lung cancer

Solid fuel smoke exposure has been associated with increased lung cancer risk in systematic review and meta-analysis, with the strongest and most consistent evidence for coal smoke and more modest, heterogeneous estimates for wood and other biomass.[35] Approximately 6% of deaths attributable to household air pollution are due to lung cancer.[2] Indoor emissions from household combustion of coal are classified by the International Agency for Research on Cancer as carcinogenic to humans (Group 1), and emissions from household combustion of biomass fuel, primarily wood, as probably carcinogenic (Group 2A).[36]

Respiratory symptoms and lung function

Community-based Indian studies consistently report a higher prevalence of cough, chronic expectoration, wheeze, chest tightness, breathlessness on exertion and eye irritation among biomass users than among LPG users.[37] Spirometric studies show significant reductions in FVC, FEV1, PEFR and FEF25–75% in biomass-exposed women.[38] In one rural Indian study of 310 women, biomass fuel use was associated with markedly increased odds of an abnormal pulmonary function test (OR 8.01, 95% CI 4.80–13.36), with a further independent effect of exposure duration (OR 1.16 per unit increase, 95% CI 1.13–1.20).[18] Another Indian study reported that biomass fuel use, age above 60 years and an exposure index greater than 90 hour-years were each independently associated with higher odds of respiratory morbidity.[21]

The pattern of impairment observed in biomass-exposed women frequently combines obstructive and restrictive features, with a preserved or even elevated FEV1/FVC ratio in some series[38] — consistent with the small-airway and fibrotic phenotype described in Section 6.4, and an important caution against relying solely on the FEV1/FVC ratio for case definition in field studies.

Other outcomes

Emerging evidence links household air pollution to low birth weight, stillbirth, upper respiratory and ear infections, cataract, and nasopharyngeal, laryngeal and cervical cancers.[2,34] The Household Air Pollution Intervention Network (HAPIN) trial, which randomized pregnant women in four countries to LPG stoves and fuel versus continued biomass use, found no significant difference in birth weight or in severe pneumonia in the first year of life, despite achieving substantial reductions in measured personal PM2.5[39] — underscoring both the difficulty of achieving fully clean exposure in real-world settings and the possible importance of exposure earlier in the life course.[40]

Determinants of Continued Biomass Fuel Use in Rural Households

Understanding why households persist with biomass despite available alternatives is essential to any intervention.[11]

Economic factors. The recurring cost of an LPG refill, paid as a lump sum, competes with other essential expenditure in households with irregular cash income, whereas biomass is typically gathered without monetary cost. Cylinder price volatility and the requirement to pay up front before receiving direct benefit transfer subsidy are recognised barriers.[7,11]

Availability and access. Distance to the LPG distributor, delivery reliability in remote villages, and the absence of local refill points raise effective cost.[11]

Education and awareness. Low educational attainment of the head of family and of the primary cook is consistently associated with solid fuel use, and awareness of the health risks of smoke exposure is often low.[13]

Housing and household characteristics. Kutcha construction, absence of a separate kitchen, larger household size, non-nuclear family structure and scheduled caste/tribe status all predict continued biomass use.[13]

Cultural and culinary preference. Perceived superior taste of food cooked on a *chulha*, suitability for traditional preparations and large-volume cooking, and continued need for fuel for cattle-feed preparation and winter space heating.[8,11]

Livestock ownership. Households keeping cattle have a free, continuous supply of dung, reducing the incentive to purchase fuel.[10]

Gender and decision-making. Where household energy purchasing decisions rest with men who are not the primary cook, the health cost of smoke exposure is externalised from the decision-maker — a structural reason why women-centred schemes such as PMUY were designed with the connection issued in the woman's name.[6,13]

Methodological Considerations in Assessing Exposure and Morbidity

Community-based studies of this association face recurring methodological challenges, and awareness of these is relevant both to interpreting the literature and to designing new work.

Exposure assessment. Approaches range in rigour from (a) self-reported primary cooking fuel — simple, cheap, but crude and prone to misclassification because of fuel stacking; through (b) structured exposure indices incorporating fuel type, stove type, kitchen ventilation, cooking hours per day and years of cooking;[20,21] to (c) direct area monitoring of kitchen PM2.5/PM10 and CO;[10] and (d) personal exposure monitoring using wearable gravimetric or light-scattering monitors, which is the reference standard but is costly and logistically demanding.[16] Studies relying on fuel type alone will tend to underestimate true effect sizes because of non-differential exposure misclassification.[8]

Outcome assessment. Symptom ascertainment is most commonly performed using the British Medical Research Council (BMRC) questionnaire on respiratory symptoms[41] or the IUATLD/ECRHS instruments, translated and validated locally. Objective assessment requires spirometry performed to ATS/ERS acceptability and repeatability criteria,[42] with post-bronchodilator testing and appropriate reference equations for the Indian population.[31] Where feasible, chest radiography and sputum examination add diagnostic specificity, particularly for tuberculosis.

Confounding. Active and passive tobacco smoking, occupational dust exposure, biomass burning for space heating, ambient air pollution from crop-residue burning, socioeconomic status, nutritional status and childhood respiratory infection are all potential confounders and should be measured and adjusted for.[14,23]

Study design. Cross-sectional designs — the most common in this field — establish association but not temporality, and are vulnerable to the healthy-worker-type effect whereby symptomatic women may reduce their cooking role. Case–control and prospective cohort designs, and randomized trials of fuel or stove substitution, address this but at substantially greater cost.[28,39]

Reporting. Adherence to STROBE guidance for observational studies improves comparability and is increasingly required by journals.[43]

Interventions and Policy Response

Clean fuel substitution. The evidence base supports a strong preference for complete transition to clean fuels (LPG, piped natural gas, biogas, electricity) over incremental stove improvement, because health benefits appear to require crossing a substantial exposure threshold.[8,16] India's PMUY represents the largest such programmed globally, having released over 10.5 crore deposit-free connections since 2016, supported by a targeted subsidy per 14.2 kg cylinder delivered by direct benefit transfer.[6,7] Its principal remaining challenge is not connection coverage — which is now near saturation — but *sustained use*, reflected in per capita refill consumption.[7,11]

Improved and advanced cookstoves. Forced-draft and gasifier stoves reduce emissions substantially under laboratory conditions, but real-world reductions are attenuated by user acceptability, maintenance requirements and continued parallel use of traditional stoves.[10] Trials such as CAPS suggest that improved biomass stoves alone are unlikely to deliver measurable reductions in serious respiratory outcomes.[28]

Kitchen design and ventilation. Chimneys and smoke hoods, an increase in kitchen window and door area, separation of the cooking area from the sleeping area, and shifting cooking outdoors or to a semi-open veranda are low-cost measures with plausible benefit, particularly where fuel substitution is not immediately achievable.[9,16]

Behavioural measures. Keeping infants and young children away from the hearth during cooking, drying fuel adequately before use (moisture content strongly influences emissions), avoiding the use of kerosene or plastic as a fire-starter, and covering pots to reduce cooking time are all actionable at household level and appropriate content for health education by frontline workers.[9,16]

Health system response. Integration of a brief cooking-fuel exposure history into routine primary care assessment, opportunistic screening of long-term biomass-exposed women for chronic respiratory symptoms, and availability of spirometry at community health centre level under the National Programme for Prevention and Control of Non-Communicable Diseases would allow earlier detection of biomass-associated COPD, a condition currently and substantially under-diagnosed in rural India.[25,32]

Intersectoral action. Because energy poverty is the proximate cause, durable progress requires coordination between the health sector and the ministries responsible for petroleum and natural gas, rural development, women and child development, and new and renewable energy, alongside strengthened routine monitoring of the clean fuel indicator in national surveys.[5,44]

11. Research Gaps and Limitations

Several gaps in the current evidence base merit attention:

1. **Quantifying fuel stacking.** Most epidemiological studies classify households by primary fuel, obscuring the substantial residual biomass exposure among nominally “clean fuel” households. Validated field instruments for measuring stacking are needed.[11]
2. **Longitudinal data.** Prospective cohort studies tracking lung function trajectory in relation to changing fuel use over time are scarce in India.[23]
3. **Post-PMUY epidemiology.** Community-level data on respiratory morbidity in the period following near-saturation LPG connection coverage are limited, and the omission of the clean fuel indicator from the NFHS-6 factsheets compounds this gap.[5]
4. **Paediatric lung function.** Long-term consequences of early-life biomass exposure on attained lung function in adolescence and adulthood are under-studied.[40]
5. **Regional specificity.** Fuel mix, kitchen architecture and climate vary substantially across India; state- and district-level evidence, including for Uttar Pradesh, remains uneven.[14]
6. **Economic evaluation.** Cost-effectiveness data on kitchen ventilation retrofits and on refill subsidy design, from an Indian perspective, are limited.[7]

Limitations of this review. As a narrative review, article selection was purposive and no formal quality appraisal or quantitative synthesis was undertaken; publication bias and language bias cannot be excluded. Much of the underlying primary literature is cross-sectional, limiting causal inference, and effect estimates are heterogeneous across settings owing to differences in exposure assessment and outcome definition.[8,26]

Conclusion

Biomass fuel use remains a defining feature of rural household energy in India and a major, modifiable determinant of respiratory ill health. The evidence linking it to acute lower respiratory infection in children and to chronic bronchitis and COPD in adult women is consistent and biologically coherent;[26,29] associations with tuberculosis and lung cancer are probable,[33,35] and with asthma remain uncertain.[26] Risk is graded by cumulative exposure and concentrated among women who cook and the young children beside them,[19,21] which makes it simultaneously a respiratory health problem, a gender equity problem and an energy poverty problem.

Substantial national investment has expanded clean fuel access, yet exposure persists because connection does not equate to consumption.[6,11] Reducing the burden will require attention to affordability and reliability of refills, to kitchen ventilation and design where substitution is incomplete, to household-level behavioural change delivered through frontline health workers, and to routine surveillance of respiratory morbidity in exposed rural populations.

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