

Research Article

Biomass Solid Fuel Usage and Incidences of Respiratory Symptoms Amongst Women in Households That Have Adopted ICS in Nakuru Town East Suburbs

Margaret Muchendu* , Daniel Muasya Nzengya 

School of Education and Social Sciences, St Paul's University, Limuru, Kenya

Abstract

One of the main causes of home air pollution, especially in developing nations, is the use of solid biomass fuels (wood, crop leftovers, animal dung, and coal) for cooking and heating. This has serious negative impacts on respiratory health. Chronic obstructive pulmonary disease (COPD), chronic bronchitis, asthma, and acute lower respiratory infections (ALRI) are all closely associated with long-term exposure to high amounts of particulate matter (PM_{2.5}) and carbon monoxide (CO) from these fuels. The purpose of this study was to examine the Influence of biomass solid fuel usage on incidences of respiratory symptoms amongst women adopters of ICS in Nakuru town East suburbs. The study was informed by energy stacking and theory of subsidy. The study utilized mixed method research design. Data were collected from 315 female heads from of households that had adopted ICS, two FGD and key informant interviews. Sampling techniques utilized were multi-stage cluster sampling for the women heads of households while purposive sampling was used to select KIIs and participants in the FGDs. Quantitative data was analyzed using descriptive statistics and logistic regression. Qualitative data was content analyzed. Study findings revealed that 67.8% of households relied on charcoal, while 54.9% used firewood, often alongside ICS. Households that predominantly used firewood reported the highest incidence of respiratory symptoms, highlighting the persistent dangers of solid fuel combustion. Logistic regression analysis demonstrated that women in firewood-dependent households were 2.43 times more likely to experience respiratory related symptoms than those using charcoal.

Keywords

Biomass Solid Fuels, Women, Respiratory Related Symptoms, Improved Cooking Stoves, Kenya

1. Introduction and Background

More than 2.1 billion people rely on polluting fuels and inefficient stoves for cooking, representing approximately one-third of the world's population [45]. Thus, millions of households are exposed daily to harmful levels of indoor air pollution. Because respiratory health outcomes arise from sustained exposure, the number of households affected is closely

aligned with global solid-fuel usage patterns. Estimates from various global energy-access analyses suggest that from 600–700 million households worldwide are exposed to harmful indoor air pollution levels resulting from traditional cooking practices [19].

Women disproportionately bear the health burden of indoor

*Correspondence: Margaret Muchendu (margietich2@gmail.com)

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air pollution due to gendered household roles that place them at the cooking source for several hours daily. Women in low-income countries spend an estimated 3–6 hours per day cooking or tending fires, resulting in cumulative exposure far higher than that of adult men [45]. Approximately half of the global population exposed to polluting fuels are women, thus one billion women are regularly exposed to unsafe household air pollution levels. This heightened exposure leads to disproportionately high rates of respiratory symptoms among women, particularly chronic bronchitis, reduced lung function, and COPD [10]. Furthermore, women are uniquely affected by specific health risks associated with pregnancy: exposure to biomass smoke during pregnancy increases the likelihood of low birth weight, stillbirth, and neonatal respiratory distress [46]. These risks underscore the compounded vulnerability faced by women, who are often socio-economically constrained in their ability to transition to cleaner fuels or improved stoves due to limited decision-making authority and financial barriers.

Across Sub-Saharan Africa (SSA), the burden of respiratory symptoms associated with poor indoor air quality continues to be profound, particularly in households that rely on traditional biomass fuels for daily cooking. The region records some of the highest rates of household air pollution (HAP) globally because an estimated 82 percent of households still use polluting solid fuels such as firewood, charcoal, agricultural residues, and animal dung [6]. This level of dependence exposes millions of families to concentrated levels of particulate matter and carbon monoxide, creating household environments that are often far more hazardous than outdoor settings. The World Health Organization (WHO) has consistently noted that SSA countries account for a disproportionate share of morbidity and mortality from HAP-related respiratory symptoms compared to other developing regions [44]. Recent multi-country epidemiological studies estimate that more than 420 million SSA residents from over 95 million households experience at least one form of respiratory symptom linked to the prolonged use of unimproved cooking stoves [18, 21]. Countries such as Ethiopia, Nigeria, Tanzania, the Democratic Republic of Congo, Uganda, and Kenya carry some of the highest burdens due to extensive biomass dependence and limited penetration of improved cooking technologies. In Ethiopia, for example, nearly 95 percent of rural households use biomass fuels, and between 68 and 75 percent of these households report at least one respiratory symptom among members, particularly women and children [44]. Similarly, studies from Kenya's rural and peri-urban regions indicate that 65 to 83 percent of households using three-stone fires have at least one member experiencing recurring respiratory discomfort or respiratory tract irritation [28]. These patterns underscore how widespread traditional stove use is almost always accompanied by elevated household exposure to harmful pollutants, thus amplifying the number of affected households across the region.

The continuing energy poverty in SSA has hindered transitions toward cleaner energy sources, meaning the number of affected households has remained substantially high over the years. In many contexts, the lack of improved cooking stoves overlaps with socio-economic vulnerabilities, limited governmental financing for clean cooking programme, and cultural preferences for biomass-based cooking. As a result, millions of households especially those in rural and informal settlements remain trapped in a cycle where traditional cooking methods continue to compromise respiratory health. Collectively, the evidence indicates that household-level respiratory symptoms associated with poor indoor air quality represent a severe and persistent public health challenge across SSA, affecting tens of millions of families and shaping the broader health landscape of the region.

Women in SSA face a disproportionate share of the exposure to indoor air pollution due to their culturally assigned roles as primary cooks and caregivers. Studies demonstrate that they spend an average of three to five hours per day near cooking fires, often in small, poorly ventilated kitchens where smoke accumulates rapidly [37]. This prolonged exposure translates into significantly elevated risks of respiratory symptoms, particularly chronic cough, dyspnea, chest tightness, phlegm production, and recurrent respiratory tract infections. [48] observed that approximately 280 million women in SSA are exposed daily to unsafe levels of particulate matter concentrations that exceed global health guidelines, with many experiencing direct respiratory complications. Country-specific estimates further illustrate the magnitude of the problem. In Nigeria, more than 41 million women are exposed to harmful cooking emissions, leading to high rates of respiratory discomfort and chronic respiratory diseases [3]. Kenya reports that nearly 18 million women in both rural and urban informal settlements regularly inhale biomass smoke, contributing to increased cases of chronic bronchitis, asthma exacerbations, and other adverse respiratory outcomes [14]. In Uganda, research indicates that nearly 72 percent of adult women reporting chronic cough or wheezing live in households dependent on unimproved cooking stoves [42]. Across SSA, a strong positive association has been established between biomass use and women's respiratory symptoms due to the higher intensity and duration of exposure compared to male household members.

In Kenya, indoor air pollution (IAP) arising from reliance on polluting fuels and traditional cooking stoves continues to be a major public health concern. National estimates consistently indicate that a majority of households still depend on biomass fuels—predominantly firewood and charcoal—and kerosene for daily cooking [46]. Limited access to improved cooking stoves and clean fuels results in high household concentrations of particulate matter, carbon monoxide, and other products of incomplete combustion, which in turn drive acute and chronic respiratory symptoms across Kenyan households [16]. The widespread use of traditional cooking stoves is strongly linked to elevated respiratory morbidity. According

to national estimates synthesized by the Kenya Institute for Public Policy Research and Analysis as well as international partners, between 21,500 and 23,000 Kenyans die annually due to diseases attributable to household air pollution, most of them from acute lower respiratory infections, chronic obstructive pulmonary disease, and ischemic heart disease [15]. These mortality figures mask a much larger population experiencing non-fatal but debilitating respiratory symptoms associated with poor indoor air quality.

In Kenya, rural households largely depend on biomass fuels and are therefore at the highest risk for household air pollution. According to national energy assessments, approximately 92% of rural households rely on wood-based stoves as primary or secondary cooking technologies, and only about 8% of rural residents have access to clean cooking fuels [46].

Research indicates that rural women face intense exposure. [11] in their results indicated that in rural Trans Nzoia, over 90 percent of women experienced cough, 62.5% experienced sputum production, and nearly one-third experienced wheezing, symptoms strongly associated with indoor cooking using wood fuel in poorly ventilated kitchens. The Ministry of Energy's indoor air quality assessment similarly documented extremely high levels of carbon monoxide and particulate matter in rural kitchens, even after adoption of improved stoves, indicating that ventilation challenges remain substantial [16]. Environmental health studies have measured average 24-hour $PM_{2.5}$ concentrations in rural Kenyan kitchens exceeding WHO interim targets by a factor of more than 10, with levels often reaching 400–600 $\mu g/m^3$ during peak cooking periods. These concentrations align with observed high prevalence of cough, difficulty breathing, and eye irritation among rural women [46]. Given that roughly two-thirds of Kenya's poor reside in rural communities and that rural women often spend several hours per day cooking in smoke-filled environments, this demographic constitutes one of the most severely affected groups in the country. Air quality monitoring studies in Nairobi's informal settlements have recorded mean indoor $PM_{2.5}$ concentrations ranging from 59.3 to 108.9 $\mu g/m^3$ with significantly high peaks observed during cooking times. Households using charcoal or kerosene showed the highest particulate concentrations [27]. Participatory modelling conducted in Korogocho and Viwandani indicates that long-term exposure levels substantially exceed WHO guidelines, putting female cooks at heightened risk [40]. The objective of this study was to analyze the Influence of biomass solid fuel usage on incidences of respiratory symptoms amongst women adopters of ICS in Nakuru Town East Suburbs.

2. Theoretical and Empirical Review

The study was informed by Energy Stacking Theory. The theory assumes that income is not the only factor affecting fuel choice as presupposed by the energy ladder theory. Various other elements play a role in fuel decisions, as observed by

[23]. In developing countries, there has been a recent discussion regarding households utilizing a variety of fuels, with some opting to combine clean cook stoves with dirtier solid fuels, rather than following the anticipated linear progression outlined by the energy ladder theory [25]. This suggests that instead of households progressively adopting more advanced and cleaner fuels as their income rises; they find themselves with an array of fuel options to choose from, hence energy stacking. Thus, the transition in energy consumption does not adhere to a straightforward sequence of stages. Households employ multiple fuels at the same time. [23] suggests that there are various other elements that affect energy transition. Furthermore, the shift from one fuel to another happens gradually, with many individuals simultaneously utilizing multiple types of fuels. This varied use of fuels is linked to several factors such as insufficient funds to purchase a new appliance when it is discovered, particularly in cases where individuals have already made significant investments in traditional appliances, the high expense of modern energy services, and the need for energy security related to the ownership and use of multiple fuel types [39]. Although many researchers have focused on the economic dimensions of energy transition and highlighted income and financial standing as key factors influencing households' shift from "unclean" to "clean" fuels, the idea of a straightforward progression does not hold true for most households. This phenomenon is attributed to additional influences beyond income, such as cultural beliefs, social peer pressure, and accessibility issues. Consequently, this theory serves as a critique of the energy ladder theory, offering insights into the various underlying factors that extend beyond economic considerations. To that effect, this research investigated how various cooking fuels impact indoor air quality, focusing on the smoke generated during cooking and its effects on the respiratory health of women, making the energy stacking theory pertinent in interpreting the results.

Empirical Review

Indoor air pollution (IAP) stemming from cooking with solid biofuels remains one of the most significant and pervasive public health threats in Kenya. It is estimated that approximately 68% of Kenya's population—over 35 million people—rely on biomass fuels for cooking, with even higher rates in rural regions where access to modern energy remains minimal [27]. In rural areas, wood remains the dominant energy source for over 90% of households, whereas charcoal use dominates in urban and peri-urban informal settlements [28]. This reliance results in substantial exposure to IAP, particularly among populations who spend extended periods near cooking zones. According to [22], 50% of households in Kenya prepare meals indoors, with 30% lacking a designated room or kitchen for cooking. In contrast, a significant majority of rural households (63%) have a separate structure for cooking, whereas only 8% of urban households do.

The connection between household cooking practices and respiratory health symptoms has become an increasing concern in many parts of the world, especially in low- and middle-

income countries (LMICs). In these regions, cooking with solid biomass fuels—such as firewood, charcoal, and agricultural residues—is still the norm, and women, as primary caregivers and cooks, bear the greatest burden of exposure to indoor air pollution (IAP). This prolonged exposure has been directly linked to a range of respiratory ailments, from chronic cough to acute lower respiratory infections (ALRIs) and reduced lung function. The transition to improved cooking stoves (ICS) and cleaner fuels is therefore widely promoted as a critical public health strategy to mitigate these risks.

Recent research strongly supports this linkage. A cross-sectional study by [36] in Balakong found significant associations between children's respiratory symptoms—such as cough and wheezing—and indoor concentrations of volatile organic compounds (VOCs) and CO₂. Though their sample was limited to children aged 5 to 6, the study reinforces how fuel choice and indoor cooking practices impact respiratory health. Similarly, [47] conducted a study in Suzhou, China in which they found that pollutants like PM_{2.5}, PM₁₀, NO₂, and SO₂ were statistically linked to viral respiratory tract infections in children under three. While these studies focused on younger age groups, their implications are broader—highlighting how early exposure to pollutants can compromise respiratory development. A particularly striking study in the Northwest region of Cameroon by [30] found that over 83% of reported respiratory symptoms were in children, with the risk of acute respiratory infections (ARI) being 3.6 times higher among those exposed to smoke from indoor cooking. Similarly, in urban Bangladesh, [16] observed that children under five living in households using biomass fuels were significantly more likely to experience respiratory symptoms compared to those using cleaner fuels (OR = 1.18; 95% CI: 1.04–1.36).

In Kenya, where the proposed study is situated, the findings in the afore mentioned studies are consistent. [11] conducted a cross-sectional survey in rural communities and reported that over 92% of biomass fuel users—primarily women—experienced acute respiratory symptoms. The primary drivers were exposure in poorly ventilated kitchens and long hours spent cooking over open flames. On the same note, [12] found that children under two living in households using improved ceramic stoves (upesi jiko) had significantly lower rates of cough and pneumonia compared to those using traditional three-stone fires. Additional evidence from Ethiopia also confirms the protective role of ICS. In a study by [2], children living in homes with improved stoves were 57% less likely to develop ALRI than those in households using traditional biomass stoves (AOR = 0.43; 95% CI: 0.28–0.67). However, this study focused exclusively on children under three, while the proposed research focused on women.

Objective measurements have added rigor to the evidence base. In Cameroon, [24] used spirometry to assess lung function in women and found that those exposed to biomass fuel had significantly lower forced expiratory volume (FEV) and forced vital capacity (FVC). In Sri Lanka, [36] used both questionnaires and carbon monoxide breath tests, revealing that

women who used firewood had significantly higher odds of respiratory symptoms and higher levels of carboxyhemoglobin compared to LPG users. Importantly, gendered dimensions of exposure must be emphasized. In most cultures, women and girls spend significantly more time in cooking areas than men, making them more vulnerable. A study by [20] in Udipi, India found a clear correlation between cumulative biomass exposure (measured in hour-years) and not only respiratory symptoms but also cardiovascular and eye conditions among women. Yet, even with access to ICS, many women continued to use traditional stoves—a practice known as stove stacking. This undermines the full potential of ICS in reducing IAP-related illnesses.

Woolley et al [43] working in Kigali, Rwanda, explored women's perceptions of ICS. While there was appreciation for features like faster cooking and multi-pot capabilities, most users were unaware of the health benefits associated with reduced emissions. This highlights the need for accompanying educational campaigns to foster awareness and behavior change. In the same vein, [4] used DHS data from Tanzania to show that households using cleaner fuels or cooking outdoors had significantly lower smoke exposure risk (SER), with socioeconomic status and education acting as strong protective factors. Despite growing enthusiasm around ICS, several barriers to their sustained use remain. Economic constraints are a primary issue, particularly in low-income households. The initial costs of ICS, as well as the ongoing expenses for clean fuels, often deter adoption. Cultural factors also play a role; some communities find that ICS are incompatible with traditional cooking methods, especially when preparing dishes that require prolonged cooking or high heat. [35] analyzed DHS data in Afghanistan. They found a higher prevalence of respiratory infections among children in households using solid fuels compared to those using cleaner alternatives (PR = 1.19; 95% CI: 1.08–1.32).

Compounding these challenges is behavioral inertia—the tendency of households to revert to traditional practices despite having access to modern alternatives. This behavior, as highlighted by [32, 38] is often influenced by habit, familiarity, and convenience. In their Ethiopian study, Sanbata and colleagues found that the odds of ARI were nearly three times higher in households using biomass fuels (OR = 2.96; 95% CI: 1.38–3.87).

Finally, [1, 25] found similar associations between solid fuel use and higher rates of respiratory symptoms among children under five, although both studies relied on national survey data rather than household-level empirical evidence.

Taken together, the evidence paints a compelling picture: exclusive use of improved cooking stoves or clean fuels correlates with significantly reduced respiratory symptoms and better lung health, particularly for women and children. Studies that incorporate both subjective reports and objective physiological measures (e.g., CO breath analysis, spirometry) provide the most reliable data. Yet, the relationship is not automatic. It is mediated by a host of factors—including stove type,

consistency of use, ventilation, socioeconomic status, cultural compatibility, and user education. In many low- and middle-income countries (LMICs), the simple act of preparing daily meals carries serious health risks—particularly for women and children. This is largely due to the continued use of solid biomass fuels such as firewood, charcoal, and crop residues for cooking, which release harmful pollutants like fine particulate matter (PM_{2.5}) and carbon monoxide (CO). For households relying on traditional stoves, cooking becomes more than just a routine chore—it becomes a source of chronic smoke exposure, increasing the risk of respiratory diseases, including bronchitis, chronic obstructive pulmonary disease (COPD), and even reduced lung function.

Improved cooking stoves (ICS) have emerged as a critical solution to this problem. These stoves are designed to burn fuel more efficiently and with fewer emissions, thereby reducing indoor air pollution (IAP) and offering potential health benefits. While the promise of ICS is clear, understanding how these benefits are realized—and the conditions under which they are maximized—requires unpacking both the science and human behavior behind adoption and use.

Carrión et al [9] work in rural Peru makes these theories tangible. Their observational study found that households using ICS experienced a 70% reduction in PM_{2.5} levels in kitchens and a 30% decrease in self-reported respiratory symptoms, particularly among women. This not only validates the theoretical linkage but underscores the potential of ICS as both a technological and public health intervention.

A substantial and growing body of research has provided numeric evidence linking ICS usage with better respiratory health. For instance, [17] in a rural Bangladeshi context, used a mixed-methods approach to demonstrate that ICS-using households experienced 42% less exposure to PM_{2.5}, which was strongly associated with fewer respiratory issues, particularly among adult women. Importantly, [17] also considered variables such as kitchen ventilation, cooking frequency and spatial layout—showing that health gains are often amplified by supportive environmental conditions. In Kenya, [33] evaluated six different ICS models and found that the type of stove, whether it was used exclusively, and how much fuel was consumed were all independently linked to pollutant levels in households. PM_{2.5} reductions ranged from 11.9% to 42.3%, depending on the stove model, suggesting that not all ICS perform equally and that user behavior matters greatly. Similarly, a randomized trial in Uganda by [7] revealed more modest but statistically significant improvements. The introduction of Envirovit ICS led to a 12% reduction in PM_{2.5} and an 11.6% reduction in wood fuel use. While these numbers may seem small, they reflect meaningful progress toward safer household environments—especially when scaled across communities.

Real-world observations further reinforce the benefits of ICS. In Bangladesh, [8] tested emissions from eight different ICS models in 45 households and found significantly lower

levels of PM_{2.5}, PM_{5.0}, black carbon, and CO compared to traditional stoves. These reductions were consistent across all models tested, pointing to the general effectiveness of ICS technologies in reducing exposure to harmful pollutants. In Bolivia, [5] examined how ventilated ICS impacted indoor air quality and found that average CO levels dropped from 10.8 ppm to 2.3 ppm after installation—a reduction of almost 80%. Though the study focused on carbon monoxide, the implications for respiratory health are clear, especially since CO is a known respiratory irritant. Kenya has been a fertile ground for ICS research. In Nairobi's urban slums, [26] documented significantly higher PM_{2.5} levels in homes using traditional biomass stoves than those using ICS. A broader study by [29] spanned both rural and urban contexts, reporting PM_{2.5} levels reaching up to 1,276.6 µg/m³ with an average of 235.3 µg/m³—nearly 10 times the WHO's recommended 24-hour limit.

Munyao et al [28] working in Western Kenya, compared the Chepkube ICS to traditional firewood stoves. The findings were stark: households using ICS had PM_{2.5} levels of 682.6 µg/m³ and CO levels of 8.7 ppm, compared to 4,272.4 µg/m³ and 75.4 ppm, respectively, in households using traditional stoves. Similarly, [47] confirmed that six ICS models tested in the Nyanza region consistently reduced pollutant concentrations over 48-hour periods, regardless of specific stove design. However, owning an ICS is not a guarantee of improved health. The way households use the stoves matters just as much as the stoves themselves. A common challenge is “stove stacking”—when families use both improved and traditional stoves simultaneously. Study by [33] shows that over 60% of ICS users still rely on traditional stoves for certain types of cooking, such as preparing large meals or dishes that require extended boiling. This practice continues to expose users to harmful smoke and dilutes the health benefits of ICS.

Cultural acceptance and maintenance issues are additional barriers. [43] found that some women viewed ICS as unreliable or unsuitable for their daily cooking needs, particularly for traditional meals. These perceptions were especially prevalent in cases where the stoves were distributed through donor-led projects without proper training or after-sales support. [41] reinforced these findings, noting that stove breakages and high repair costs often led households to revert to traditional methods. The physical layout of the home matters. [9] observed that households with semi-open or outdoor kitchens benefited more in terms of air quality improvements than those with enclosed cooking areas. In high-altitude Peruvian regions, Carrión (ibid.) further noted that oxygen scarcity reduced combustion efficiency, prompting the need for location-specific stove modifications.

Education plays a pivotal role in whether households not only adopt ICS but use them effectively and consistently. In rural Nigeria, [31] found that women who were made aware of the health dangers of traditional stoves—and trained on how to properly operate ICS—were significantly more likely to use them exclusively. Access to knowledge-built trust,

changed perceptions, and encouraged healthier cooking habits. In Rwanda, [43] linked health education with tangible health improvements. Their study found that households exposed to targeted awareness campaigns recorded lower PM_{2.5} levels, a 22% reduction in low birth weight, and a 97-gram increase in average birth weight—demonstrating that the health benefits of ICS can span generations when adoption is supported with information and training. Despite the strong evidence supporting ICS, limitations in the research design and data collection methods must be acknowledged. Many studies rely on self-reported symptoms rather than clinical measurements like spirometry, which can introduce bias [9]. Others, such as [43], highlight issues with recall bias and social desirability, which can affect participants reporting on stove use and health effects. Most existing studies only cover short timeframes, often focusing on immediate post-adoption effects without capturing long-term behavior and health outcomes. As emphasized by [16] future research must prioritize longitudinal studies, sensor-based tracking of stove usage, and standardized methodologies to better assess the lasting impacts of ICS. The objective of the study was to analyze influence of biomass solid fuel usage on incidences of respiratory symptoms amongst women in homes that have adopted ICS in Nakuru Town East suburbs.

3. Study Methods

This study used a cross-sectional, concurrent triangulation mixed-methods approach with a focus on 219,200 homes in Nakuru Town East. A sample of 315 houses with improved cooking stoves was chosen. Additionally, the study included two focus groups and eleven key informant interviews. SPSS

(version 25) was used to analyze quantitative data obtained from questionnaires, while NVivo (version 12) was used to process qualitative data from semi-structured interviews using theme analysis. The anonymity and confidentiality of participant data were guaranteed by the approval received from the appropriate ethics organizations. The findings reported here are a subset of a larger study called "Influence of Improved Cooking Stoves, Biomass Solid Fuel Usage on Respiratory Related Symptoms Among Women in Nakuru East Suburbs, Kenya."

4. Results and Discussion

Community health workers interviewed during KII interviews described the following fuel sources as predominant in the study site; firewood, wood pulp, sawdust wood chips from the neighboring forests /sawmills. Other households were reported to use charcoal and briquettes. Those who had farms used maize cobs and stalks (*mafefe* and *masheshe*), and others used paraffin lamps and stoves (Simba). This stove has a "choking smell like tear gas". Most of these sources are attributed to producing a lot of smoke. During the FGDs, the following solid biofuels were frequently mentioned; Firewood, *mashakwe*, *mafefe*, sawdust, cow dung, plastics, sacks, and sponge mattresses used to light the fire. The briquettes used are made from cow dung, coffee husks, firewood, charcoal balls; *maranda*, and plastic bottles. Households preferred to use firewood when cooking *githeri* to save charcoal and the fact that firewood cooks much faster. Some of the firewood would be wet leading to more smoke. Table 1 summarizes findings on women's self-reported incidents of respiratory symptoms associated with exposure to indoor air pollution.

Table 1. Self-reported incidents of respiratory symptoms associated with exposure to biomass cooking smoke amongst the ICS adopters only (n=315).

Reported incidence/Symptom	YES - F (%)	NO - F (%)
Cough with/without phlegm	204 (64.8%)	111 (35.2%)
Wheezing	131 (41.6%)	184 (58.4%)
Difficulties in breathing	125 (39.7%)	190 (60.3%)
Running nose	102 (32.4%)	213 (67.6%)
Teary eyes	84 (26.7%)	231 (73.3%)
Congested chest	88 (27.9%)	227 (72.1%)
Sneezing	118 (37.5%)	197 (62.5%)

Source: Author (2025)

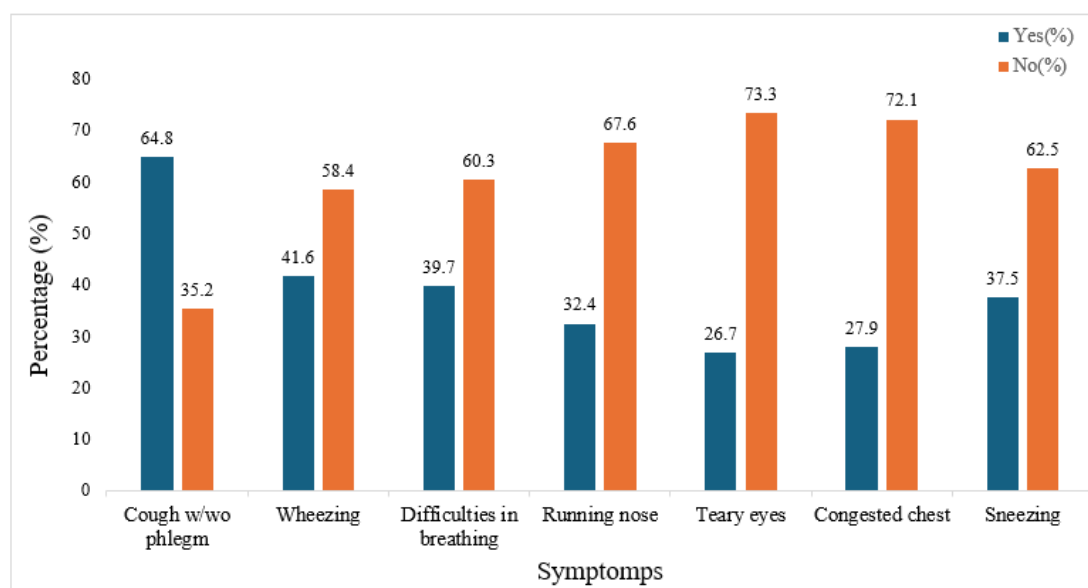


Figure 1. Proportion of participants reporting experiences of respiratory symptoms amongst the ICS adopters only (n=315) Source: Author (2025).

The data presented in Figure 1 provides a detailed profile of the proportion of respiratory symptoms reported among participants who adopted ICS (n = 315). Although the adoption of ICS demonstrates a notable reduction in the prevalence of several respiratory symptoms associated with indoor air pollution (IAP), the persistence of significant respiratory morbidity among these households remains evident. Among ICS adopters, the most frequently reported symptom was cough with or without phlegm, reported by 64.8% of participants. This was followed by sneezing (37.5%), wheezing (41.6%), difficulty in breathing (39.7%), runny nose (32.4%), congested chest (27.9%), and teary eyes (26.7%). These figures demonstrate that despite access to ICS, substantial proportions of ICS adopters continue to experience respiratory symptoms commonly linked to prolonged exposure to biomass smoke. When these findings are compared to the overall prevalence rates observed in the full sample of 400 participants, clear improvements emerge. In the general population (which included both ICS and non-ICS users), the prevalence of cough was considerably higher at 72%, wheezing at 54%, difficulty breathing at 53%, sneezing at 51%, runny nose at 47%, congested chest at 43%, and teary eyes at 42%. The observed reductions in respiratory symptoms among ICS adopters thus range from 7% to 15% for most symptoms. Notably, the greatest reductions were observed for cough (7.2% reduction), wheezing (12.4% reduction), and difficulty breathing (13.3% reduction), suggesting that ICS adoption has a meaningful protective effect particularly for lower respiratory tract conditions. The protective benefits of ICS adoption become even more apparent when these self-reported health outcomes are triangulated with the indoor air quality (IAQ) measurements obtained from household environmental monitoring. In non-ICS households, IAQ assessments revealed alarmingly high

concentrations of PM_{2.5}, reaching up to 1752 µg/m³, and CO levels peaking at 130.34 ppm. These levels vastly exceed WHO recommended safety thresholds of 35 µg/m³ for PM_{2.5} and 87 ppm for CO, respectively. By contrast, ICS households demonstrated substantial reductions in pollutant concentrations. PM_{2.5} levels ranged from as low as 7 µg/m³ (Household H18) to 397 µg/m³ (Household H12), while CO concentrations remained lower but still exhibited occasional exceedances. These findings are further in agreement with the findings by [31] conducted in Nigeria which indicated that there was a low prevalence of coughing and wheezing in both the biomass and non-biomass groups which may be linked to the underreporting of respiratory problems that the general public often considered normal. This requires public sensitization on sustained use and adoption of cleaner cooking fuels to minimize respiratory symptoms.

Findings from quantitative surveys with adopters' access to cooking solid fuels are summarized in Table 2. Table 2 presents descriptive statistics of ICS adopters in Homes Using Solid Fuels.

Table 2. Descriptive statistics of participants' self-reported biomass solid fuel usage (n = 315).

Variable	Category	F (%)
Uses firewood - ever uses firewood	Yes	173 (54.9%)
	No	142 (45.1%)
Mainly uses Charcoal	Yes	272 (86.3%)
	No	43 (13.7%)

Variable	Category	F (%)
Used charcoal for cooking today	Yes	210 (66.7%)
	No	105 (33.3%)
How easy to find a charcoal vendor	Not easy	14 (4.4%)
	Somewhat easy	61 (19.4%)
	Very easy	240 (76.2%)

Source: Author (2025)

Table 2 presents descriptive statistics on participants' self-reported fuel access characteristics related to the use of ICS. The findings show that 54.9% of respondents reported using firewood at some point, while 45.1% had never used it. A significant majority (86.3%) indicated that they mainly use charcoal as their cooking fuel, with 66.7% reporting having used charcoal for cooking on the day of the survey. Regarding charcoal accessibility, most participants (76.2%) stated that it was *very easy* to find a charcoal vendor, 19.4% found it *somewhat easy*, and only 4.4% found it *not easy*. These statistics suggest a strong reliance on charcoal for cooking and generally easy access to charcoal vendors among the participants.

The results of a binary logistic regression analysis – **Table 3** that examines the influence of access to ICS solid fuel on the self-reported incidences of cough with or without phlegm among women ICS adopters in the three months prior to the survey are presented as follows. The regression model estimates the odds of not experiencing coughing symptoms relative to experiencing them, using various fuel-related variables as predictors. The findings show that none of the variables included in the model were statistically significant at the conventional 0.05 level, although two variables—*ever used fire-*

wood and access to charcoal is challenge—approached significance, suggesting a potential relationship worth further exploration. Specifically, women who had ever used firewood had lower odds of reporting no coughing symptoms, with a negative coefficient of -0.443 ($p = 0.074$) and an odds ratio (OR) of 0.642. This indicates that prior exposure to firewood may be associated with a higher likelihood of experiencing coughing, though the result is only marginally significant. Similarly, those who reported that access to charcoal is a challenge had a higher likelihood of reporting coughing symptoms, as shown by a positive coefficient of 0.955 ($p = 0.080$) and an odds ratio of 2.599. This suggests that women who struggle to access charcoal may rely on more polluting alternatives like firewood or cook under less optimal conditions, potentially increasing their exposure to respiratory irritants. On the other hand, the variable indicating whether charcoal was used for cooking on the day of the survey had a negative association with coughing (coefficient = -0.256, OR = 0.775), but this was not statistically significant ($p = 0.359$), implying that same-day charcoal use was not strongly linked to a reduction or increase in coughing incidences. Ease of finding a charcoal vendor was also not significantly associated with coughing symptoms. Compared to those who found it *not easy*, respondents who found it *somewhat easy* (OR = 1.170, $p = 0.805$) or *very easy* (OR = 1.584, $p = 0.432$) did not show statistically significant differences in the odds of reporting coughing symptoms. Finally, using charcoal as the main cooking fuel was not a significant predictor (coefficient = -0.012, $p = 0.976$), suggesting that the mere use of charcoal—compared to other fuels—did not have a strong direct effect on the presence or absence of cough. In summary, while most variables did not show statistically significant relationships, the findings suggest that historical use of firewood and difficulties accessing charcoal may increase the likelihood of respiratory symptoms such as coughing among ICS adopters. These results point to the importance of not just promoting cleaner fuels but also ensuring reliable access to them, alongside discouraging reversion to traditional firewood use.

Table 3. Logistic regression: Influence of biomass solid fuel use on Incidences of respiratory symptoms amongst ICS women adopters during last three months prior to survey.

		Coughing with/without phlegm	Wheezing	Difficulties in breathing	Runny nose	Teary eyes	Congested chest	Sneezing
Explanatory variable		OR	OR	OR	OR	OR	OR	OR
Ever uses firewood	(No)							
	Yes	0.642	0.480**	1.270	0.618**	1.067	1.100	0.690
Main type cooking fuel-Charcoal	(No)							

		Coughing with/without phlegm	Wheezing	Difficulties in breathing	Runny nose	Teary eyes	Congested chest	Sneezing
Used charcoal for cooking to- day	Yes	0.988	0.696	0.965	1.029	0.496**	1.330	0.571
	(No)							
How easy to find a charcoal vendor	Yes	0.775	1.300	0.979	1.329	1.567	1.051	1.892**
	(Not easy)							
	some- what easy	1.170	2.688	0.519	1.413	1.651	0.732	0.502
Access to char- coal is a chal- lenge	very easy	1.584	2.707	0.516	1.128	1.264	0.590	0.452
	(No)							
	Yes	2.599*	0.859	0.654	1.005	1.032	1.942	0.653

Note. Estimates represent the log odds of "Binary Indicator = No vs. Yes"
Reference category in bracket
 *Significant at 0.1, ** significant at 0.05, *** significant at 0.01

Source: Author (2025)

The results from a binary logistic regression analysis examining factors associated with the likelihood of high incidences of wheezing among ICS women adopters in the three months prior to the survey are as follows. The dependent variable is a binary indicator of wheezing incidence (No vs. Yes), and the table includes several explanatory variables related to cooking fuel use and accessibility. The analysis reveals that using charcoal as the main type of cooking fuel is associated with a decrease in the odds of wheezing, with a negative coefficient of -0.362, though this effect is not statistically significant ($p = 0.340$), and the odds ratio (OR) is 0.696. Similarly, whether a woman used charcoal for cooking on the day of the survey shows a positive but non-significant association with wheezing. The ease of finding a charcoal vendor also appears to influence wheezing outcomes. Compared to those who found it "not easy" to find a vendor, respondents who found it "somewhat easy" or "very easy" had increased odds of wheezing, with coefficients of 0.989 ($p = 0.175$) and 0.996 ($p = 0.146$) respectively, corresponding to ORs of 2.688 and 2.707. However, these associations are not statistically significant at conventional levels. Notably, ever having used firewood is significantly associated with reduced odds of wheezing, as indicated by a negative coefficient of -0.733 ($p = 0.002$) and an OR of 0.480. This suggests that those who have ever used firewood have about half the odds of wheezing compared to those who have never used it. On the other hand, facing challenges in

accessing charcoal does not show a meaningful or statistically significant relationship with wheezing incidence. Overall, while some variables related to charcoal accessibility and use show trends towards affecting wheezing, only the history of firewood use is significantly linked to reduced wheezing incidence in this sample.

The results of a binary logistic regression analysis estimating the likelihood of high incidences of difficulties in breathing among ICS women adopters during the three months prior to the survey indicate that model examines several explanatory variables related to cooking fuel use and accessibility, with the outcome variable being a binary indicator for the presence or absence of breathing difficulties. The results indicate that using charcoal as the main type of cooking fuel has a negligible and statistically insignificant effect on the odds of experiencing breathing difficulties (coefficient = -0.035, $p = 0.926$, odds ratio [OR] = 0.965). Similarly, whether charcoal was used for cooking on the day of the survey does not significantly influence breathing difficulties (coefficient = -0.021, $p = 0.937$, OR = 0.979). Regarding the ease of finding a charcoal vendor, respondents who found it "somewhat easy" or "very easy" compared to "not easy" showed reduced odds of breathing difficulties, with coefficients of -0.656 ($p = 0.295$, OR = 0.519) and -0.661 ($p = 0.250$, OR = 0.516), respectively. However, these relationships are not statistically significant. The

analysis also reveals that having ever used firewood is associated with a slight but non-significant increase in the odds of breathing. Lastly, experiencing challenges in accessing charcoal corresponds to a decrease in the odds of breathing difficulties but this effect is also not statistically significant. In summary, none of the variables related to cooking fuel type, charcoal use, accessibility, or firewood use show statistically significant associations with the incidence of breathing difficulties among the women in this sample during the studied period.

The binary logistic regression results estimating the likelihood of high incidences of runny nose among ICS women adopters during the three months prior to the survey are presented as follows. The model assessed the influence of various factors related to cooking fuel use and accessibility on the occurrence of this respiratory symptom. The analysis shows that using charcoal as the main cooking fuel has a minimal and statistically insignificant effect on the odds of experiencing a runny nose. Similarly, whether charcoal was used for cooking on the day of the survey does not significantly affect the likelihood of runny nose. Regarding accessibility, finding a charcoal vendor "somewhat easy" or "very easy" compared to "not easy" was associated with increased odds of runny nose respectively. However, these associations are not statistically significant. Interestingly, having ever used firewood shows a borderline statistically significant negative association with runny nose suggesting that women who have ever used firewood have lower odds of experiencing a runny nose compared to those who have never used firewood. Lastly, experiencing challenges in accessing charcoal does not have any significant impact on the likelihood of runny nose. In summary, most variables related to cooking fuel type, charcoal use, and accessibility do not show significant associations with the incidence of runny nose among the women studied, except for a near-significant protective effect linked to having ever used firewood.

The results of a binary logistic regression analysis estimating the likelihood of high incidences of teary eyes among ICS women adopters during the three months prior to the survey as the model examines several factors related to cooking fuel usage and charcoal accessibility are as follows. The findings indicate that using charcoal as the main cooking fuel is associated with a reduced likelihood of experiencing teary eyes, with a coefficient of -0.702 and an odds ratio (OR) of 0.496. This suggests nearly a 50% decrease in odds compared to those who do not use charcoal as their main fuel, although this effect is marginally non-significant with a p-value of 0.078. On the other hand, using charcoal for cooking on the day of the survey is associated with increased odds of teary eyes (coefficient = 0.449, OR = 1.567), but this relationship is not statistically significant ($p = 0.141$). The ease of finding a charcoal vendor shows a positive but non-significant relationship with teary eyes. Respondents who found it "somewhat easy" or "very easy" to find a vendor had higher odds of teary eyes compared to those who found it "not easy," with ORs of 1.651

and 1.264 respectively, but the p-values (0.496 and 0.734) indicate no statistical significance. Having ever used firewood has a minimal and non-significant effect on teary eyes (coefficient = 0.065, $p = 0.804$, OR = 1.067). Similarly, facing challenges in accessing charcoal shows no meaningful association with the incidence of teary eyes (coefficient = 0.032, $p = 0.957$, OR = 1.032). Overall, the results suggest that while there is a trend towards lower odds of teary eyes among charcoal users as the main fuel, none of the explanatory variables show statistically significant associations with teary eyes in this sample.

The results of a binary logistic regression analysis estimating the likelihood of high incidences of congested chest among ICS women adopters during the three months prior to the survey as the analysis explores how various factors related to cooking fuel use and charcoal accessibility influence the occurrence of this respiratory symptom are as follows. The results indicate that using charcoal as the main type of cooking fuel is associated with a slight but non-significant increase in the odds of experiencing congested chest, with a coefficient of 0.285 and an odds ratio (OR) of 1.330 ($p = 0.510$). Similarly, whether charcoal was used for cooking on the day of the survey shows a negligible and statistically insignificant effect on congested chest (coefficient = 0.049, OR = 1.051, $p = 0.864$). Regarding charcoal accessibility, respondents who found it "somewhat easy" or "very easy" to find a charcoal vendor had reduced odds of congested chest compared to those who found it "not easy," with ORs of 0.732 and 0.590, respectively. However, these effects are not statistically significant ($p = 0.634$ and 0.380). Having ever used firewood shows a minimal and non-significant association with congested chest (coefficient = 0.095, OR = 1.100, $p = 0.712$). Lastly, facing challenges in accessing charcoal is linked to higher odds of congested chest (coefficient = 0.664, OR = 1.942), though this relationship does not reach statistical significance ($p = 0.336$). In summary, none of the examined variables show statistically significant associations with the incidence of congested chest among the women surveyed. The findings suggest that factors such as cooking fuel type, charcoal use, and ease of access to charcoal do not have a clear impact on congested chest symptoms within this population during the study period.

The binary logistic regression results estimating the likelihood of high incidences of sneezing among ICS women adopters during the three months prior to the survey as the analysis investigates how different factors related to cooking fuel use and charcoal accessibility are associated with the occurrence of sneezing gave the following findings. The results show that using charcoal as the main type of cooking fuel is associated with a reduction in the odds of sneezing, with a coefficient of -0.561 and an odds ratio (OR) of 0.571. Although this suggests nearly a 43% decrease in odds compared to those who do not use charcoal as the main fuel, the association is not statistically significant ($p = 0.145$). Conversely, women who used charcoal for cooking on the day of the survey have significantly higher odds of sneezing (coefficient = 0.638, $p =$

0.023, OR = 1.892), indicating that these individuals are almost twice as likely to report sneezing compared to those who did not use charcoal that day. The ease of finding a charcoal vendor appears to be associated with lower odds of sneezing, with those who found it “somewhat easy” or “very easy” having reduced odds (ORs of 0.502 and 0.452 respectively) compared to those who found it “not easy.” However, these relationships are not statistically significant ($p = 0.276$ and 0.172). Having ever used firewood is linked to a decrease in the odds of sneezing (coefficient = -0.371 , OR = 0.690), but this effect is not statistically significant ($p = 0.124$). Finally, reporting challenges in accessing charcoal corresponds with lower odds of sneezing (OR = 0.653), although this association is also not significant ($p = 0.431$). The significant finding in this analysis is that using charcoal for cooking on the survey day increases the likelihood of sneezing among ICS women adopters; while other factors related to fuel type and accessibility show no significant associations with sneezing incidence. This might be related to the material used during lighting the charcoal.

The implications for respiratory health are both urgent and multifaceted, as charcoal’s modest risk reductions suggest it mitigates exposure less severely than firewood’s 11.40% increase, supporting evidence of charcoal’s lower particulate matter (PM_{2.5}) emissions compared to firewood, potentially reducing COPD risks for prime cooks [38]. Firewood’s risk, however, triples exposure for youth-heavy homes, heightening second-hand smoke dangers for children, a pattern amplified in Nakuru Town East’s overcrowded settings, where 56.4% of households include children under 18 [34]. Easy charcoal access offers a pathway to safer cooking, but access challenges and non-ICS ownership demand subsidies or local ICS production to halve risks and address urban poverty, a strategy proven effective in low- and middle-income countries (LMICs) to boost adoption and health outcomes [13]. These insights compel targeting firewood users and access-limited women with ICS to reduce respiratory symptoms, providing a model for urban LMIC research on respiratory health.

Globally, these findings align with research on solid fuel use and respiratory health, where charcoal use often reduces risks by 3-5% compared to firewood’s 10-15% increase, mirroring Nakuru Town East’s patterns and reinforcing the protective potential of cleaner fuel options in biomass-reliant settings [46]. Urban slum dynamics in Nakuru Town East amplify these challenges, urging ICS strategies to address firewood reliance and access barriers, in contrast to rural isolation where access lags, as noted in comparative studies [38]. This framework offers a valuable approach for mitigating respiratory symptoms in similar urban contexts worldwide.

Firewood use is the strongest predictor of respiratory illness and women who have ever used firewood are significantly more likely to report respiratory problems. Easier access to charcoal reduces the likelihood of respiratory symptoms, likely due to reduced reliance on firewood. Difficulty in accessing charcoal increases respiratory illness risk, possibly because it forces women to use more polluting fuel alternatives.

Charcoal use itself does not significantly impact illness risk, but access to it matters. Under policy it’s essential to encourage cleaner fuel alternatives to reduce firewood use and improve charcoal accessibility to reduce dependence on firewood. There is need to educate households about the risks of firewood smoke exposure and promote ICS adopt.

5. Conclusion and Recommendation

Conclusion

While ICS technologies utilizing solid biofuels do deliver important health benefits, their dependence on solid fuels inherently sustains residual pollutant emissions. Even among ICS users, significant proportions of women continued to report respiratory symptoms: cough (64.8%), wheezing (47.9%), and breathing difficulties (46.4%). Variability in pollutant concentrations among ICS households was strongly influenced by fuel characteristics, such as moisture content and combustion quality, as well as operational inconsistencies and household behaviors. Improper stove use, mixed fuel practices, and suboptimal fuel preparation all contributed to incomplete reductions in household pollutant levels. These findings suggest that while ICS-based interventions represent meaningful progress, the ultimate resolution of IAP-related respiratory illness will require broader transitions toward cleaner cooking fuels and exclusive ICS utilization supported by proper user education.

Recommendations

Long-term policy should promote greater access to cleaner fuel alternatives such as liquefied petroleum gas (LPG), ethanol, biogas, and electric cooking technologies. These fuels offer substantially greater health benefits by virtually eliminating household smoke emissions. National energy policy must prioritize infrastructure development, affordability mechanisms, and supply chain expansion to make clean fuels accessible and affordable to low-income households. Financial instruments such as targeted subsidies, microcredit schemes, and pay-as-you-go financing models may help address the affordability barrier that currently prevents many households from transitioning to cleaner fuels.

Additional research is warranted to deepen understanding of fuel stacking behaviors and the social, cultural, and economic factors that influence household decision-making around fuel usage. Qualitative and mixed-methods research incorporating behavioral science, ethnography, and household energy economics could illuminate why households continue to revert to use of traditional cooking fuels like firewood despite the availability of ICS and more cleaner cooking fuels.

Abbreviations

ALRI	Acute Lower Respiratory Infections
COPD	Chronic Obstructive Pulmonary Disease
COR	Crude Odds of Respiratory Illness

CO ₂	Carbon Dioxide
HAP	Household Air Pollution
FEV	Forced Expiratory Volume
FGD	Focus Group Discussions
FVC	Forced Vital Capacity
LMICs	Low- And Middle-Income Countries
IAP	Indoor Air Pollution
ICS	Improved Cooking STOVE
KII	Key Informants Interviews
LPG	Liquefied Petroleum Gas
OR	Odds Ratio
PM _{2.5}	Particulate Matter
SAA	Sub-Saharan Africa
WHO	World Health Organization

Author Contributions

Margaret Muchendu: Conceptualization, Formal Analysis, Investigation, Methodology, Validation, Writing – original draft, Writing – review & editing

Daniel Muasya Nzengya: Data curation, Software, Supervision, Validation

Conflicts of Interest

The authors declare no conflicts of interest.

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