frontiers | Frontiers in Environmental Science

TYPE Review
PUBLISHED 08 November 2022
DOI 10.3389/fenvs.2022.996038

A review on household air pollution and biomass use over Kenya

Zablon Weku Shilenje[1,2]*, Scholastica Maloba[2] and Victor Ongoma[3]

[1]Department of Atmospheric Physics, Charles University, Prague, Czech Republic, [2]Kenya Meteorological Department, Nairobi, Kenya, [3]International Water Research Institute, Mohammed VI Polytechnic University, Ben Guerir, Morocco

OPEN ACCESS

EDITED BY
Jason G. Su,
University of California, Berkeley,
United States

REVIEWED BY
Worradorn Phairuang,
Kanazawa University, Japan
Ravindra Khaiwal,
Post Graduate Institute of Medical
Education and Research (PGIMER), India

*CORRESPONDENCE
Zablon Weku Shilenje,
zablonweku@yahoo.com

SPECIALTY SECTION
This article was submitted to
Environmental Citizen Science,
a section of the journal
Frontiers in Environmental Science

RECEIVED 16 July 2022
ACCEPTED 19 October 2022
PUBLISHED 08 November 2022

CITATION
Shilenje ZW, Maloba S and Ongoma V (2022), A review on household air pollution and biomass use over Kenya. *Front. Environ. Sci.* 10:996038.
doi: 10.3389/fenvs.2022.996038

Household air pollution (HAP) causes multiple noncommunicable diseases, such as pneumonia, stroke, and ischemic heart disease, and is responsible for over 3.8 million deaths globally per year. Kenya has a high rate of HAP, mainly caused by solid fuels. This review assesses its effect and identifies factors that could improve policy in Kenya. A systematic review approach is used, mainly considering 88 research articles on the Web of Science, published from 1951 to 2022. We excluded studies on HAP caused by other forms of fuel, subjective study types, and studies focusing on animals. The results show that rural settings and urban slums have more HAP, ventilation is an important factor, HAP is high in the evening, and children and women health is significantly affected. There is a need for interventions to reduce the use of biomass fuels in Kenya. The interventions include improved access to efficient cookstoves with ventilation, community health awareness about ventilation, housing rules for better ventilation in rural and urban areas, and NGO partnership for improving access to improved cookstoves in rural areas. The government's role includes subsidizing the supply and cost of renewable energy and adopting energy policies that encourage populations to switch to more efficient cookstoves, cleaner energy, and modern biofuels.

KEYWORDS

biomass fuel, indoor air pollution, PM, LPG, Kenya, air quality

---

Abbreviations: ALRIs, acute lower respiratory infections; BMF, biomass fuel, in this context, it is used to refer to wood-/stalk-based fuel that is a major source of energy in the region; COPD, chronic obstructive pulmonary disease; DALYs, disability-adjusted life years; HAP, household air pollution; HI, high-income; ICS, improved cooking stoves; LPG, liquefied petroleum gas; PM, particulate matter; SEAR, South-East Asia Region; TCS, traditional cooking stoves; WHO, World Health Organization; WPR, western Pacific Region.

1 Introduction

Indoor human activities, such as lighting, cooking, and heating, significantly affect indoor air quality (Jung and Huxham, 2018; Lai et al., 2020). According to Pratiti (2021), using biomass fuel (BMF) is one of the leading causes of indoor air pollution. BMF accounts for more than half of the domestic energy supply in most developing countries and as much as 95% in low-income countries. Statistics show that about 3 billion people in the world depend on BMF for cooking, heating, and lighting (Hanna et al., 2016). Sub-Saharan Africa has the highest reliance on BMF globally (Figure 1), with more than half a billion people relying on BMF for cooking and heating (Johnson et al., 2017; Basagaña, 2019). The use of BMF and the ever-increasing global population and industrialization threaten both indoor and outdoor air quality (Ahmed et al., 2019). According to a report by Health Effects Institute (2019), HAP is the leading cause of death and disability globally, with a higher impact in less-developed countries (Naz, 2017). According to Julia et al. (2018), indoor smoke causes health problems, with the eyes being affected the most. In a global assessment of avoidable health risks published in 2002, the World Health Organization (Lee et al., 2020) reported that by 2022, about 7 million people would die due to HAP. In an earlier study, Martin et al. (2013) reported that HAP from solid fuel combustion is linked to the highest number of deaths worldwide. Fullerton et al. (2009) and Naz (2017) studied under-five mortality and reported a high risk in Sub-Saharan Africa as a result of charcoal and biomass usage.

Airborne emissions comprise PM and dangerous gaseous pollutants such as carbon monoxide (CO), benzene, styrene, and formaldehyde (Ezzati et al., 2004; Mutahi et al., 2021). Studies have revealed that airborne emissions from the combustion of a single index of BMF, mainly wood, crop, and dung, are much higher than that of fossil fuels, such as kerosene and liquid petroleum gas (LPG) (Budya et al., 2011). Airborne emissions produced from the combustion of BMF result in indoor air pollution, especially in poorly ventilated structures. This is a serious health concern (Naz, 2017; Gebremeskel and Kabthymer, 2021) since most people spend approximately 90% of their time indoors (Leech et al., 2002).

Although progress has been made over the years, the consumption of and reliance on clean energy sources remains low in Kenya (Mbaka et al., 2019). It is approximated that 65% of Kenya's population depends on BMF for cooking and heating (GoK, 2015). It is estimated that up to 95% of the energy consumed in rural areas is in the form of wood (Ochieng et al., 2020; Adane et al., 2021), agricultural residue, and animal waste (Environmental Protection Agency, 1997; GoK, 2006). However, advances in technology and economic growth have led to electricity and biogas being adopted by about 7% of households in Kenya (GoK, 2010). According to Ochieng et al. (2013), the use of biomass fuels, mainly to cook indoors, increases indoor CO levels and related personal exposures of BMF users in Kenya. In a recent study by Muindi et al. (2016), which focused on HAP in two slum communities in Nairobi, high levels of a mixture of solid particles and liquid droplets suspended in the air (particulate matter [PM]) were reported in

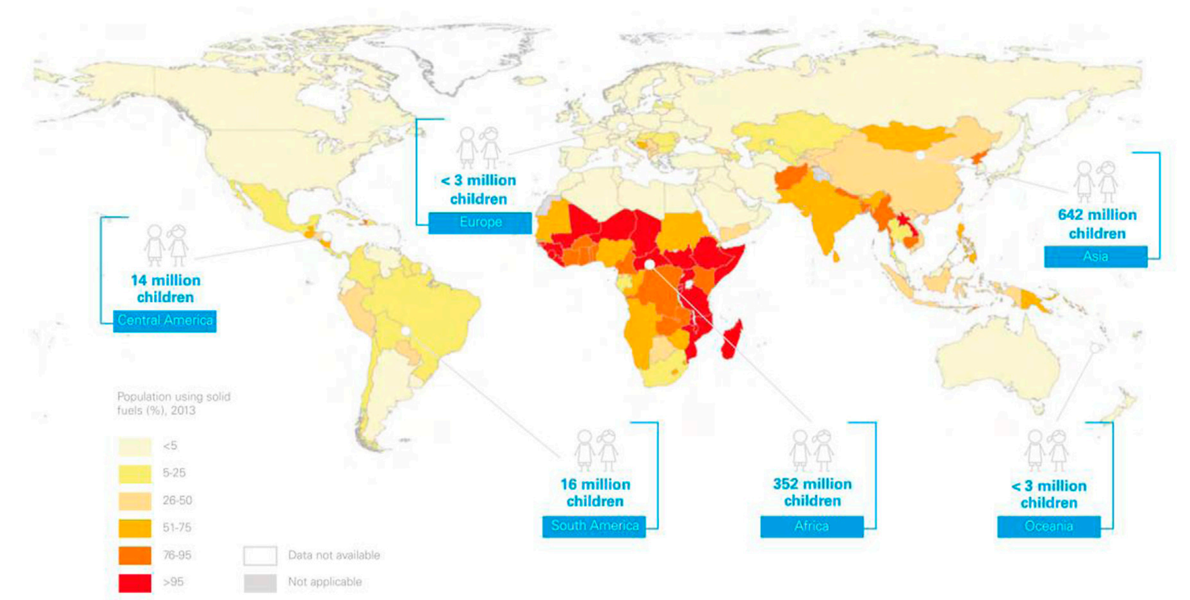

FIGURE 1
Estimated global use of solid fuels (%) in cooking and heating as of 2013 (source: UNICEF, 2019).

the homes. Mutahi et al. (2021) carried out a study in Nairobi, including some coastal towns of Kenya, which showed high levels of CO and $PM_{2.5}$. Jung and Huxham (2018) measured the levels of CO and PM in 25 households over the coast, with 53% indicating that smoke was a concern during cooking.

The gender aspect of biomass-related pollution is evident. The biomass fuel chain is managed by women (Naz, 2017; UNEP, 2021), who work as gatherers, processors, transporters, and end-users while cooking. This implies that they are exposed to health hazards at all stages of the BMF chain more than their male counterparts (Oluwole et al., 2012; Smith et al., 2014). Collecting biomass for use as fuel takes time. Those collecting spend a considerable amount of time outside other productive works. This deprives children of time to engage in meaningful activities (Jung and Huxham, 2018), such as attending school, playing, and studying at home, while parents could otherwise spend the time on childcare and potential income-generating activities (FAO, 2000; PREDAS, 2009).

The use of biomass from wood for energy is high, comprising approximately 65% of the total primary energy supplies and consumption (Welfle et al., 2020). This is even higher in rural and slum dwellings where most households are low- to middle-income, depending on cheap and locally available sources of energy such as solid fuels and kerosene (Ministry of Energy, 2019). For instance, during the COVID-19 lockdown, when most parts of the world recorded an improvement in air quality owing to a reduction in emissions, Priyanka et al. (2021) observed an increase in $PM_{2.5}$ in lower-middle-class neighborhoods in Nairobi. This was attributed to residents' switch from LPG to biomass fuels due to loss of income. Despite the various initiatives taken both by the government and non-governmental organizations (NGOs), the uptake of clean energy, especially in rural communities, is still low. This calls for concerted efforts ranging from awareness and socio-economic empowerment to promote use of clean energy, such as wind and solar energy, and minimize the over-reliance on biomass fuel.

Kenya, like many other developing countries, has limited air quality monitoring programs and related studies. This study aimed to document the status of BMF in Kenya, focusing on its effects and suggesting alternative sources of energy for informed decision-making by both individuals and at the policy-making level.

2 Methodology

This systematic review study assesses the impact on human health due to indoor pollution from the use of BMFs in Kenya. A literature search was carried out in the Web of Science database to identify relevant peer-reviewed articles. The search threads were as follows: 'household air pollution in Kenya', 'indoor air pollution in Kenya', and 'biomass fuel in Kenya' from January 1951 to March 2022, as of 20th March 2022. The search was based on all fields: titles, abstracts, and full texts.

The duplicates were identified and removed. Furthermore, screening of the abstracts and full articles was carried out to eliminate articles with a weak association to the topic of study. Additional research studies were found through scrutiny of citations in the reviewed articles. This work also considered relevant and reliable reports and press releases from institutions of authority related to the topic. The search for the articles reviewed in this study is summarized in Figure 2**.**

Inclusion and exclusion criteria concerning the population, HAP health risks, and strategies to reduce HAP were defined to direct the article selection process (Table 1).

The study has some limitations based on the research approach adopted. Some studies may have been missed since the search for relevant studies was limited to the Web of Science, which may not be exhaustive relative to other search engines such as Google Scholar and MEDLINE. Furthermore, qualities were not determined.

3 Findings

3.1 Status of biomass-related pollution

3.1.1 Source and exposure to biomass fuel use in households

Most research studies do not study the degree of exposure to HAP; they limit themselves to understanding health outcomes due to intensive processes of collecting continuous exposure data (Mulenga and Siziya, 2019; Pritit, 2021). Across Kenya, HAP from BMF use in traditional cookstoves poses the most serious threat to public health, especially to women and children (Gebremeskel and Kabthymer, 2021).

Wood is the most frequently used biomass fuel in Kenya (Ochieng et al., 2013, 2020; Jung and Huxham, 2018), and it is used both as unprocessed wood and charcoal, the latter having a far lower impact on HAP. In Kenya, the use of biomass from wood for energy is common, accounting for 65% of the total primary energy supplies (Welfle et al., 2020). According to an earlier report by the Kenyan government, it is estimated that about up to 80% of Kenyan households depend on firewood for both cooking and heating (GoK, 2014; Ministry of Energy, 2019). This was recently affirmed by Osano et al. (2020). The percentage of households that use solid biomass increases to more than 90% in the rural population (Figure 3; Table 2). Similar figures were recently reported in Homabay County by Kitheka et al. (2019). Notably, the use of biomass fuel is higher in places without electricity connection than in those with grids (Table 3).

Although the usage of solid fuels for cooking has reduced across the globe (Mutahi et al., 2021), inequalities persist, with people in less-developed countries continuing to use and, consequently, suffer the highest pollution (Health Effects

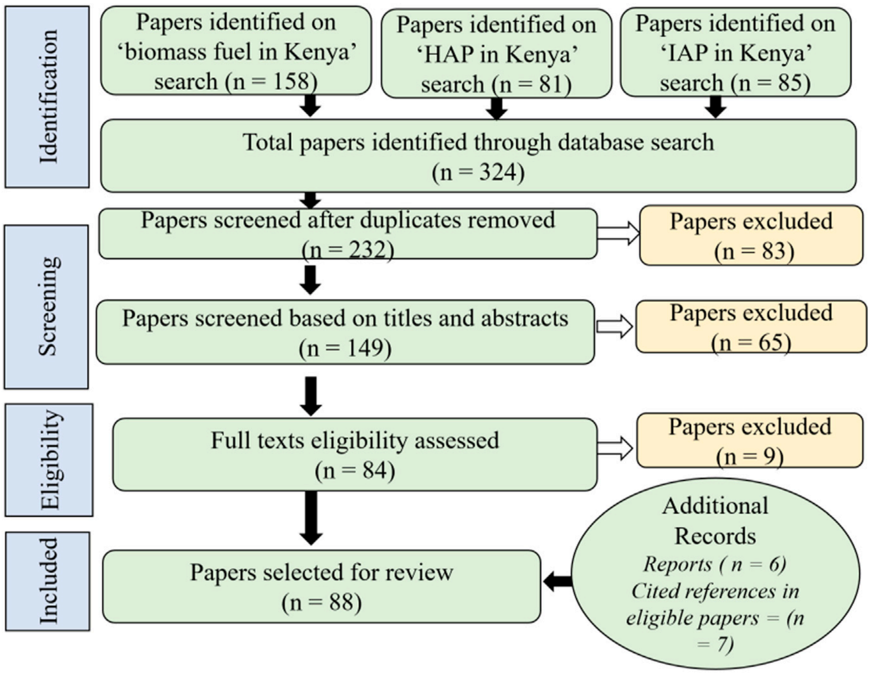

FIGURE 2
Summary of the selection of literature reviewed in this work. HAP and IAP were searched in household air pollution and indoor air pollution, respectively.

TABLE 1 Inclusion and exclusion criteria.

Category	Inclusion criteria	Exclusion criteria
Population	- Humans of all ages	- Animals
Exposure	- Collecting and producing biomass	- Biomass combustion to generate electricity
	- Biomass-use for heat or cooking	- Transformation of biomass to other forms of energy that will be burned later
Impacts	- Effects on health	- Physiological parameters
	- Effects on human safety	

Institute, 2019). HAP from solid fuels is hazardous (Pritit, 2021) for those exposed to harmful concentrations for longer durations. It is well-established that pollutants emitted from indoor cooking are extremely hazardous. For example, indoor cooking with solid fuels regularly produces harmful levels of PM, over 10 times the accepted levels (Ndwiga et al., 2014; Pratiti, 2021). In a study over western Kenya, Dida et al. (2022) observed that wood and kerosene were the most used fuel types for cooking and lighting at 97.4% and 96.8%, respectively. As a result, the study established that smoke from the wood was the leading (96.8%) source of HAP.

The level of harm depends on the duration of exposure to these pollutants. The exposure degree can depend on many factors, including proximity to the source of the pollutants, time duration of contact with the pollutants, intensity of the pollutants in the household, and the number of households using BMF (Bruce et al., 2000; Polsky and Ly, 2012). For example, women and children are typically more exposed than men since they are physically present for more hours (Naz, 2017) and during the hours with the highest intensity of pollutants. Women who cook with solid fuel derived from high-intensity episodes experience half of the total exposure when they are close to the fire, especially when starting or stirring the fire (Dasgupta et al., 2004). In Rwanda, Das et al. (2018) observed that children residing in groups of enclosed dwellings, in households that cook indoors, and in households proximate to tree cover, are significantly more likely to be affected by respiratory infections. Studies using personal monitors recorded peak

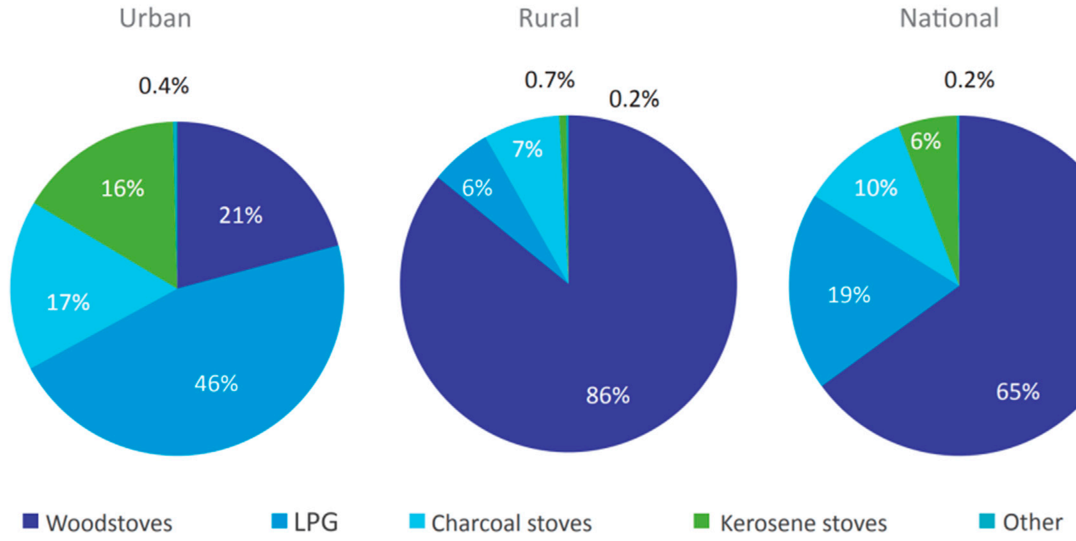

FIGURE 3
Primary fuels used by households in Kenya (urban, rural, and national) (source: Ministry of Energy, 2019).

TABLE 2 Primary stove choice—rural and urban—with or without grid access (source: Ministry of Energy, 2019).

Primary cooking technology	Urban-grid (%)	Urban-No grid (%)	All urban (%)	Rural-grid (%)	Rural-No grid (%)	All rural (%)	National-grid (%)	National-No grid (%)	National (%)
Wood stoves	10.7	62.8	20.8	74.3	91.2	85.9	39.1	87.8	64.9
LPG	55.7	6.7	46.2	14.9	1.8	5.9	37.5	2.4	18.9
Charcoal stoves	15.3	21.5	16.5	9	6.6	7.3	12.5	8.3	10.3
Kerosene stoves	17.8	8.6	16	1.2	0.4	0.7	10.4	1.4	5.6
Electric appliances	0.4	0.4	0.4	0	0	0	0.2	0	0.1
Other	0.1	0	0	0.6	0	0.2	0.3	0	0.1

TABLE 3 Clean fuel users by country income group (source: WHO Fuel Usage Database, 2012. The available data represent 61% of the world population).

Fuel	Total (%)	Low (%)	Lower middle (%)	Upper middle (%)
Electricity	6	17	1	10
LPG	65	25	67	64
Natural gas	17	29	13	24
Biogas	1	2	0	1
Kerosene	12	27	17	1
No. of countries	131	34	48	37

concentrations ranging from 20,000 to 50,000 μg/m^3 near the cooking fire (Saksena et al., 1992; Ezzati et al., 2000). Ezzati and Kammen (2001) studied HAP in Kenya by collecting data on the location and activities of all household members and the spatial dispersion of HAP over 200 days for 14–15 h per day. Since one's exposure to HAP varies throughout the day, the study aimed at developing a continuous exposure–response relationship. The study collected data on specific health outcomes, specifically the development of acute lower respiratory infections (ALRIs). The work demonstrated a log-linear relationship between PM exposure and relative risk of ALRI.

Muindi et al. (2016) assessed the levels and sources of HAP in the urban slums of Nairobi (Korogocho and Viwandani). Different from rural settings, in the urban slums, the study noted that in most of the households, over 50% used kerosene as cooking fuel. According to the study, the mean $PM_{2.5}$ levels were high in households under study. It was noted that $PM_{2.5}$ levels varied highly, especially in the evenings. The average $PM_{2.5}$ levels measured within homes at both sites were 108.9 μg/m^3 and 59.3 μg/m^3 in Korogocho and Viwandani, respectively. The residents of the two slums under study are exposed to high levels of $PM_{2.5}$ in their structures. This situation may be the case for other informal settlements in Kenya and its neighboring countries. In western Kenya, Yip et al. (2017) assessed personal exposures in two indoor settings: improved cooking stoves (ICS) and traditional cooking stoves (TCS). The study reported a reduction in mean 48-h $PM_{2.5}$ and CO concentrations in ICS compared to TCS. Similar findings were reported by Dianati et al. (2019) in their study on Korogocho and Viwandani slums in Nairobi. Despite the reduction, the level of concentrations for the two pollutants remained above WHO's air quality guidelines, calling for further reduction measures.

3.1.2 Health risks and diseases associated with BMF use

Disease burden from HAP is a consequence of exposure to extremely toxic pollutants produced by BMF burned in open fires or stoves in the home for cooking or heating. The most harmful of these pollutants include CO and particulate matter. Evidence of exposure from cooking indoors with BMF comes from several studies (Smith, 2000; Dasgupta et al., 2004; Polsky and Ly, 2012; Hanna et al., 2016; Basagaña, 2019), which associate exposure to HAP with death from certain diseases. Strong relations exist between HAP and ALRI (Smith et al., 2000; Ezzati and Kammen, 2001), chronic obstructive pulmonary disease (COPD) (Bruce et al., 2000), and lung cancer in the case of coal smoke (Smith, 1993; Bruce et al., 2000; Fullerton et al., 2008; Epstein et al., 2013; Amegah et al., 2014; Noub et al., 2015; WHO, 2014; Mock et al., 2017; Balmes, 2019).

According to the WHO (2014), based on data from 2012, an estimated 4.3 million people die prematurely annually from illness attributable to the HAP caused by the inefficient use of solid fuels. Among these deaths, 12% are due to pneumonia, 34% from stroke, 26% from ischemic heart disease (coronary artery disease), 22% from COPD, and 6% from lung cancer. The poorest and most vulnerable populations in developing countries are generally the most exposed to HAP from biomass combustion (Mishra, 2004; Agrawal, 2012; Smith et al., 2014). Earlier findings on the association between air pollution and preeclampsia (a pregnancy complication characterized by high blood pressure), mostly conducted in developed countries, however, are limited and have been inconsistent (Rudra et al., 2011; Lee et al., 2013; Pereira et al., 2013).

A study by Smith et al. (2004) established that the disease burden attributed to the use of solid household fuels is dominated by that caused by ALRI in young children, which accounts for 59% of all attributed premature deaths and 78% of DALYs. COPD accounts for all the remaining deaths, with the burden from lung cancer a minor contributor, owing to the concentration of estimated use of coal in two sub-regions only. ALRI in children does not cause many years lost due to disability. However, COPD is responsible for a much larger portion of total disability.

In Kenya, the health impacts of biomass fuel use for cooking and heating are evident too. The Ministry of Energy (2019) noted that the Kenyan Ministry of Health estimated that 21,500 premature deaths occur yearly as a result of air pollution due to cooking. According to an earlier report by Stockholm Environment Institute (2016), it is estimated that acute lower respiratory infections are responsible for the second largest cause of death, accounting for 26% of all deaths reported in Kenyan hospitals.

A research study conducted by Majdan et al. (2015) in rural areas of Kwale County in Kenya assessed the total levels of indoor smoke that can be measured in association with typical local housing design and cooking practices in an ordinary rural Kenyan setting. Data were collected from 170 respondents using the inclined respiratory questionnaire. Findings suggested that biomass fuel–related HAP remains a public health challenge in Kwale. More than half of the respondents reported respiratory sickness once to twice a year, while over a third experienced such incidences three to five times a year. Asthma or COPD cases were reported in about 11 respondents, representing 6% of the total respondents.

In western Kenya, Dida et al. (2022) associated a number of health complications with indoor air pollution emanating from wood fuel and kerosene. According to the study, 92.0% of women and 95.4% of children experienced coughs of varying intensities during the year. Furthermore, women (31.5%) reported wheezing, 98% of which felt fatigued and headache. The study concluded that the use of wood fuel in the region increased coughing, phlegm, wheezing, eye problems, and headaches, especially in women and children.

In a related study, Agarwal et al. (2018) investigated and reported that HAP is associated with altered cardiac function among women in Kenya. In a study in which all interviewees used wood as the primary fuel in a traditional cook stove, CO and $PM_{2.5}$ concentrations were found to be high inside their homes. Furthermore, the findings reported a high possibility of western Kenyan inhabitants being at risk for cardiac dysfunction with increased cumulative exposure to household air pollution.

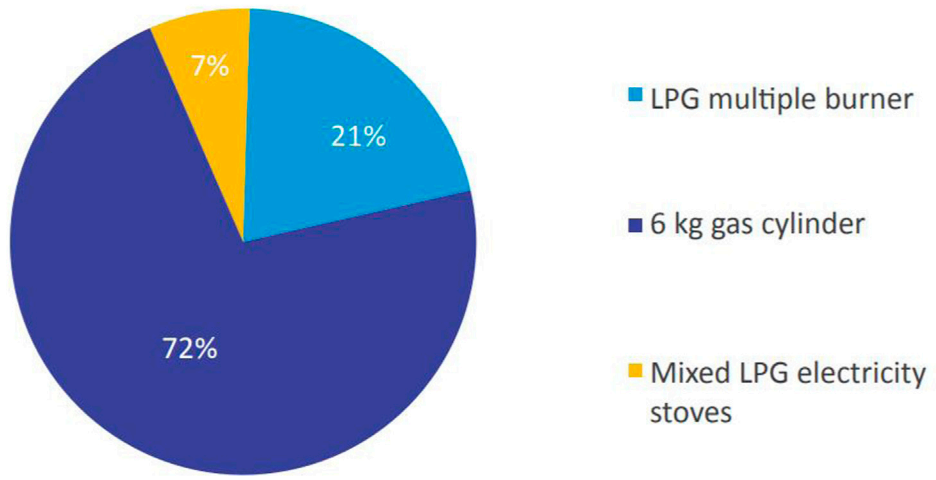

FIGURE 4
Distribution of types of LPG devices in Kenya (Ministry of Energy, 2019).

Wafula et al. (1990) assessed the indoor air pollution level and investigated its relationship with acute respiratory infections (ARI) in children below the age of 5 in the Muranga district of central Kenya. Evening peak levels of respirable suspended particles (RSP) from biomass combustion were observed. Such concentrations of RSP are known to cause harmful health effects, especially among pre-school children and women. The findings further showed high concentrations of selected polycyclic hydrocarbons in the particulate material.

3.1.3 Strategies for reducing household air pollution

Given the impacts associated with HAP, there is a need for implementing intervention measures to combat it. The interventions are alternatives to the traditional practices of household biomass fuel use for lighting, cooking, and heating. Unfortunately, there is lack of evidence on affordable, effective, and culturally acceptable interventions in most low- and middle-income countries, hence limiting their uptake (Woolley et al., 2021).

Many governments, non-governmental organizations, and international institutions have begun to devise strategies for reducing HAP for individuals at the bottom rungs of the energy ladder. One such method has been to subsidize cleaner fuel technologies (Ndwiga et al., 2014). However, other than being costly, this strategy is not very feasible in developing countries due to low levels of disposable income (Abdul Latif Jameel Poverty Action Lab, (2020).

On the other hand, electric stoves are not practical in areas with low electricity connectivity (Lai et al., 2020). Even with subsidies, kerosene and LPG are still expensive for poor households and have the additional difficulty of transportation to rural areas (Jung et al., 2018; Ministry of Energy, 2019). Additionally, these subsidy programs are expensive, especially in an age when most governments are trying to trim already overstretched budgets (GoK, 2015). According to the Ministry of Energy (2019), the distribution of types of LPG devices shows that most people are using 6-kg cylinders instead of costly ones. Dida (2022) has attributed the dominance of biomass fuel in the rural setting of western Kenya to poverty, calling for supporting the impoverished households as a way of increasing the uptake of other forms of energy (Figure 4).

4 Discussion

4.1 Exposure to indoor air pollution

Approximately 4.3 million deaths that occur annually across the globe can be attributed to the health risks of HAP (WHO, 2014). The risk is entirely within low-income and lower-middle-income countries (Smith et al., 2004), where solid fuels are used for cooking. The number of people exposed to harmful pollution from solid fuels continues to increase with rapid population growth in low-income countries (Polsky and Ly, 2012). Increased exposure to indoor PM_{10} increases the frequency of ARI. The rate of increase of exposure–response is highest for exposures between 1,000 and 2000 g/m^3. Children of the high-exposure group are at 1.6 times higher risk of infection-induced asthma than children of the low-exposure group (Ranathunga et al., 2019). Therefore, for public health programs to reduce the adverse impacts of HAP in developing countries, concentration should be on measures that reduce average exposure to below 2000 g/m^3 (Bruce et al., 2006).

Muindi et al. (2016), focusing on two Nairobi urban slums, observed that a significant proportion of houses lacked windows and thus resorted to the door as a key route to vent indoor emissions. It was also observed that a high percentage of households did not open windows and/or doors when cooking, especially in the evening, owing to security reasons (Pritit, 2021), which has implications for enhanced indoor pollutant concentrations. This observation corroborates findings in Ghana and Malawi, which found levels of fine particles to be remarkably high in kitchens (Fullerton et al., 2009; Van Vliet et al., 2013). The elevated levels of fine particles during particular times have been associated with increased individual exposure and, subsequently, poor health.

4.2 Diseases resulting from the use of biomass fuels

There is a consensus that the health effects caused by HAP may extend beyond COPD and pneumonia to other diseases. Accounting for this will increase the number of deaths attributable to HAP. According to Smith et al. (2000), children living in households using solid fuel are twice to thrice more likely to suffer from ALRI than children staying in households using clean energy. Other infections associated with HAP that occur in children include low birth weight (Sram et al., 2005) and nutritional deficiency (Mishra and Retherford, 2007). HAP infections are not only limited to young children but are also equally observed in adults as interstitial lung disease (Gold et al., 2000; Pratiti, 2021), chronic obstructive lung disease (Muula, 2007), tuberculosis (Mishra et al., 2004), lung cancer (Kurmi et al., 2012), cataracts (Pokhrel et al., 2005), and cardiovascular disease (Smith, 2002).

4.3 Strategies toward reducing household air pollution

Clean cooking technologies are beneficial beyond improving health. They protect the natural environment and reduce the emission of climate change–causing pollutants, such as greenhouse gases.

Addressing the health risks from HAP involves eliminating or dramatically reducing exposure. Exposure could be reduced through modifications to the living environment that might include improving the stove location or smoke ventilation, but switching from traditional to non-solid fuels brings about the largest reductions in HAP (WHO, 2012). Moving away from traditional stock through the introduction of improved cooking stoves has helped reduce HAP (Pilishvili et al., 2016).

On the other hand, biomass remains the most practical fuel (Polsky and Ly, 2012). This is proven by its low maintenance cost and ease of installation in different households. According to Dida et al. (2022), economic empowerment should be the first initiative in the effort to reduce exposure among rural households in rural parts of western Kenya. In addition, a structural redesign to allow adequate ventilation was emphasized as a way of reducing indoor air pollution. In a cross-sectional study on environmental health literacy and household air pollution–associated symptoms in Kenya, Raufman et al. (2020) noted that individuals with high environmental health literacy were associated with a lower risk of experiencing symptoms. This stresses the value of environmental health literacy in promoting sustainable interventions to reduce symptoms associated with HAP from solid fuel use.

The development, promotion, and subsidization of improved cooking stoves have been adopted in many parts of Kenya as part of the effort to reduce HAP. Improved cooking stoves attempt to use traditional fuels more efficiently and, therefore, do not impose a high cost on poor households (Gebremeskel and Kabthymer, 2021). Often including a chimney, they are designed to remove harmful pollutants from the kitchen. Unlike the traditional cooking stove, less soot is produced on the walls surrounding the improved cooking stove, indicating that fewer visible pollutants are being emitted into the air (Ndwiga et al., 2014). The improved cooking stove policy is, in particular, a popular administration tool (GoK, 2015) and a common measure approved by many governments. Through a collaborative government, donor, and NGO effort, Kenya handed out approximately 1.5 million Jiko stoves (GoK, 2014; North et al., 2019), while Ethiopia distributed a similar number of charcoal stoves (over 10 years) (Adane et al., 2021).

The role of institutions and NGOs in reducing HAP in Kenya is commendable. A good example is the contribution of the Global Alliance for Clean Cookstoves and The Climate and Clean Air Coalition (CCAC), which works in collaboration with the Ministry of Health in training practitioners to evaluate personal household air pollution exposure by using monitoring devices and samplers. This is key since the information is useful in decision-making on HAP reduction strategies.

In what can be regarded as a summary of strategies to reduce HAP, in a study that focused on HAP and the sustainable development goals, Amegah and Jaakkola (2016) recommend the following: implementation of the WHO indoor air quality guidelines on household fuel combustion; effective promotion and dissemination of improved cookstoves through the formation of country alliances for clean cookstoves, expansion of liquefied petroleum gas production facilities and distribution networks, harnessing renewable energy potential, promotion of biogas production at both household and community level, ensuring improved ventilation of homes through education and enforcement of building standards, and exploiting opportunities in the health and other sectors for changing health-damaging cooking behavior. The need for educating Africa's population on health issues associated with HAP had been emphasized in an earlier study by Noub et al. (2015).

4.4 Current barriers for Kenya to improve HAP

Although Kenya has huge potential bioenergy opportunities through utilization of wastes and residues from agricultural activities (Welfle et al., 2020), there is a need for minimizing indoor use of BMF. The health risks associated with HAP could be reduced substantially if solid fuel users switched to cleaner fuels for cooking (Ndwiga et al., 2014).

Despite the ongoing initiatives to improve HAP, the adoption of clean energy is still low in Kenya. The barriers to improve HAP vary by socio-cultural context. LPG is an attractive option over solid fuels and kerosene, but it is expensive. Country-specific contexts need to be taken into consideration to understand trade-offs between cleaner fuel options (Polsky and Ly, 2012). In western Kenya, Pilishvili et al. (2016) noted that the uptake of clean energy technologies is challenged by their affordability and recommended that policymakers should moot ideas addressing better solid-fuel technologies and support for its best use. In a related study, Osana et al. (2020) reported that firewood remains the most popular form of energy in other parts of Kenya: Narok, Voi, Mombasa, and Bomet. The choice of firewood is made by household income, fuel accessibility, and cost.

According to Nzengya et al. (2021), the low uptake of stoves in Machakos and Laikipia counties is a result of the high cost, design of the stove, and challenges in lighting the stove. The high cost of stoves and barriers to access to finance was also pointed out by Stevens et al. (2020), not only in Kenya but also in Uganda and Tanzania. This was agreed with by Silk et al. (2012), who noted the low adoption of stoves in households with the lowest socioeconomic status and young children present.

Lack of information can either derail decision-making or lead to uninformed decisions. In close connection to low socioeconomic status as a hindrance to the uptake of modern stoves, Osana et al. (2020) noted that most users of firewood in rural communities in Kenya are not aware of the energy efficiency, air pollution, and related health effects. This is likely to slow their uptake of better alternative sources of energy.

Atteridge and Weitz (2017) attributed the low uptake and use of clean stoves to the lack of a clear strategic direction, low levels of legitimacy among government and users, and knowledge gap. In a recent study, Karanja and Gasparatos (2019) recommended organized policy support and stakeholder involvement to scale up clean stove adoption. Furthermore, some studies (Osiolo and Kimuyu, 2017; Mbaka et al., 2019; Dida et al., 2022) proposed that the government of Kenya should prioritize increasing people's income, proper ventilation, and educational levels as HAP abatement interventions.

5 Conclusion

Most households in developing nations such as Kenya continue to rely on BMF for cooking and heating. BMF usage is high, especially in rural areas and informal urban settlements. Cooking with BMF exposes women and young children to harmful indoor air conditions. HAP from BMF extremely affects women and children and is the cause of significant mortality and morbidity. This is a neglected area for policy attention since attendant diseases affect a considerable proportion of the world's population. In Kenya, people residing in two major slum communities in Nairobi are exposed to elevated levels of fine particulate matter (PM) within their homes due to cooking and lighting fuels. Similarly, biomass fuel dominates cooking in rural settings, dictated by financial constraints to afford the alternatives. This study fully supports previous recommendations made by Dida et al. (2022) and Mbaka et al. (2019) to prioritize financial empowerment and community campaigns to create awareness of biomass fuel use among the poor in an effort to minimize biomass use, exposure, and the associated impacts.

There is a need for clean energy alternatives to improve the health of the population of most Kenyans, especially that of rural dwellers who rely on biomass fuel. The cost of fuel technologies such as kerosene and especially LPG/gas should be subsidized to increase uptake. Those within the health system responsible for planning and management can make good use of information from healthcare and local research and contribute to awareness increase through the media and educational activities and advance their voices to calls for action at local, national, and international forums. The need for policies to support the identified HAP interventions cannot be underscored enough.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Acknowledgments

The authors acknowledge their respective institutions for creating research supporting environment.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Abdul Latif Jameel Poverty Action Lab (J-Pal) (2020). Biomass cookstoves to reduce indoor air pollution and fuel use. J-PAL Policy Insights. *Last Modif.* doi:10.31485/pi.2265.2020

Adane, M. M., Alene, G. D., and Mereta, S. T. (2021). Biomass-fuelled improved cookstove intervention to prevent household air pollution in northwest Ethiopia: A cluster randomized controlled trial. *Environ. Health Prev. Med.* 26 (1), 1–17. doi:10.1186/s12199-020-00923-z

Agarwal, A., Kirwa, K., Eliot, M. N., Alenezi, F., Menya, D., Mitter, S. S., et al. (2018). Household air pollution is associated with altered cardiac function among women in Kenya. *Am. J. Respir. Crit. Care Med.* 197, 958–961. doi:10.1164/rccm.201704-0832LE

Agrawal, S. (2012). Effect of indoor air pollution from biomass and solid fuel combustion on prevalence of self-reported asthma among adult men and women in India: findings from a nationwide large-scale cross-sectional survey. *J. Asthma* 49 (4), 355–365. doi:10.3109/02770903.2012.663030

Ahmed, F., Hossain, S., Hossain, S., Fakhruddin, A. N. M., Abdullah, A. T. M., Chowdhury, M. A. Z., et al. (2019). Impact of household air pollution on human health: Source identification and systematic management approach. *SN Appl. Sci.* 1 (5), 418. doi:10.1007/s42452-019-0405-8

Amegah, A. K., and Jaakkola, J. J. (2016). Household air pollution and the sustainable development goals. *Bull. World Health Organ.* 94 (3), 215–221. doi:10.2471/BLT.15.155812

Amegah, A. K., Quansah, R., and Jaakkola, J. J. (2014). Household air pollution from solid fuel use and risk of adverse pregnancy outcomes: a systematic review and meta-analysis of the empirical evidence. *PLoS One* 9 (12), e113920. doi:10.1371/journal.pone.0113920

Atteridge, A., and Weitz, N. (2017). A political economy perspective on technology innovation in the Kenyan clean cookstove sector. *Energy Policy* 110, 303–312. doi:10.1016/j.enpol.2017.08.029

Balmes, J. R. (2019). Household air pollution from domestic combustion of solid fuels and health. *J. Allergy Clin. Immunol.* 143 (6), 1979–1987. doi:10.1016/j.jaci.2019.04.016

Basagaña, X. (2019). Household air pollution as an important factor in the complex relationship between altitude and COPD. *Eur. Respir. J.* 53, 1802454. doi:10.1183/13993003.02454-2018

Bruce, N., Perez-Padilla, R., and Albalak, R. (2000). Indoor air pollution in developing countries: a major environmental and public health challenge. *Bull. World Health Organ* 78, 1078–1092. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2560841/.

Bruce, N., Rehfuess, E., Mehta, S., Hutton, G., and Smith, K. (2006). "Indoor air pollution," in *Disease control priorities in developing countries*. Editor D. T. Jamison. 2nd Edn (Washington D.C.New York: World BankOxford University Press).

Budya, H., and Yasir Arofat, M. Y. (2011). Providing cleaner energy access in Indonesia through the megaproject of kerosene conversion to LPG. *Energy Policy* 39 (12), 7575–7586. doi:10.1016/j.enpol.2011.02.061

Das, I., Pedit, J., Handa, S., and Jagger, P. (2018). Household air pollution (HAP), microenvironment and child health: strategies for mitigating HAP exposure in urban Rwanda. *Environ. Res. Lett.* 13 (4), 045011. doi:10.1088/1748-9326/aab047

Dasgupta, S., Huq, M., Khaliquzzaman, M., Pandey, K., and Wheeler, D. (2004). *Indoor air quality for poor families: new evidence from BangladeshPolicy research working paper; No.3393*. Washington, D.C. World Bank: World Bank. Available at: https://openknowledge.worldbank.org/handle/10986/14131.

Dianati, K., Zimmermann, N., Milner, J., Muindi, K., Ezeh, A., Chege, M., et al. (2019). Household air pollution in nairobi's slums: A long-term policy evaluation using participatory system dynamics. *Sci. Total Environ.* 660, 1108–1134. doi:10.1016/j.scitotenv.2018.12.430

Dida, G. O., Lutta, P. O., Abuom, P. O., Mestrovic, T., and Anyona, D. N. (2022). Factors predisposing women and children to indoor air pollution in rural villages, Western Kenya. *Arch. Public Health* 80 (1), 46. doi:10.1186/s13690-022-00791-910.1186/s13690-022-00791-9

Environmental Protection Agency (1997). Particulate matter standards. Available at: www.epa.gov/airscience/air-particulatematter.html (Accessed February 15, 2018).

Epstein, M. B., Bates, M. N., Arora, N. K., Balakrishnan, K., Jack, D. W., and Smith, K. R. (2013). Household fuels, low birth weight, and neonatal death in India: The separate impacts of biomass, kerosene, and coal. *Int. J. Hyg. Environ. Health* 216 (5), 523–532. doi:10.1016/j.ijheh.2012.12.006

Ezzati, M., and Kammen, D. M. (2001). Indoor air pollution from biomass combustion and acute respiratory infections in Kenya: An exposure-response study. *Lancet* 358 (9282), 619–624. doi:10.1016/s0140-6736(01)05777-4

Ezzati, M., Mbinda, B. M., and Kammen, D. M. (2000). Comparison of emissions and residential exposure from traditional and improved cookstoves in Kenya. *Environ. Sci. Technol.* 34, 578–583. doi:10.1021/es9905795

Ezzati, M., Lopez, A. D., Rodgers, A. A., and Murray, C. J. L. (2004). in Comparative quantification of health risks: Global and regional burden of disease attributable to selected major risk factors. Available at: https://apps.who.int/iris/handle/10665/42770 (Accessed January 10, 2019).

FAO (FoodAgricultural Organization) (2000), *The State of the World's Forest*. Rome: FoodAgricultural Organization

Fullerton, D. G., Bruce, N., and Gordon, S. B. (2008). Indoor air pollution from biomass fuel smoke is a major health concern in the developing world. *Trans. R. Soc. Trop. Med. Hyg.* 102 (9), 843–851. doi:10.1016/j.trstmh.2008.05.028

Fullerton, D. G., Semple, S., Kalambo, F., Suseno, A., Malamba, R., Henderson, G., et al. (2009). Biomass fuel use and indoor air pollution in homes in Malawi. *Occup. Environ. Med.* 66 (11), 777–783. doi:10.1136/oem.2008.045013

Gebremeskel Kanno, K., and Hussen Kabthymer, H. R. (2021). Association of low birthweight with indoor air pollution from biomass fuel in sub-saharan Africa: A systemic review and meta-analysis. *Sustain. Environ.* 7 (1), 1922185. doi:10.1080/27658511.2021.1922185

Gold, J. A., Jagirdar, J., Hay, J. G., Addrizzo-Harris, D. J., Naidich, D. P., and Rom, W. N. (2000). Hut lung: A domestically acquired particulate lung disease. *Medicine* 79 (5), 310–317. doi:10.1097/00005792-200009000-00004

Government of Kenya (GoK) (2006). *Kenya integrated household budget survey*. Nairobi: Kenya National Bureau of Statistics-KNBS.

Government of Kenya (GoK) (2010). *Kenya demographic and health survey*. Nairobi: Kenya National Bureau of Statistics-KNBS.

Government of Kenya (2014). Forest policy. Available at: http://www.environment.go.ke/wp-content/uploads/2014/03/FOREST-POLICY-2014.pdf (Accessed February 25, 2022).

Government of Kenya (GoK) (2015). *Draft National Energy PolicyGoK*. Nairobi, Kenya: Kenya National Bureau of Statistics-KNBS.

Hanna, R., Duflo, E., and Greenstone, M. (2016). Up in smoke: The influence of household behavior on the long-run impact of improved cooking stoves. *Am. Econ. J. Econ. Policy* 8 (1), 80–114. doi:10.1257/pol.20140008

Health Effects Institute (2019). *State of global air 2019. Special report*. Boston, MA: Health Effects Institute.

Johnson, F. X., Mayaka, E. K., Ogeya, M., Wanjiru, H., and Ngare, I. (2017). Energy access and climate change in sub-saharan Africa: Linkages, synergies and conflicts. Available at: http://transrisk-project.eu/sites/default/files/Documents/4.4.3_Energy%20Access%20and%20Climate%20Change%20in%20Sub-Saharan%20Africa%20-%20linkages%2C%20synergies%20and%20conflicts.pdf (Accessed October 10, 2020).

Jung, J., and Huxham, M. (2018). Firewood usage and indoor air pollution from traditional cooking fires in Gazi Bay, Kenya. *Biosci. Horizons Int J Student Res* 11, 1–12. doi:10.1093/biohorizons/hzy014

Karanja, A., and Gasparatos, A. (2019). Adoption and impacts of clean bioenergy cookstoves in Kenya. *Renew. Sustain. Energy Rev.* 102, 285–306. doi:10.1016/j.rser.2018.12.006

Kitheka, E., Ogutu, C., Oduor, N., Ingutia, C., Muga, M., and Githiomi, J. (2019). Piloting Biomass energy audit for energy and environmental conservation in Homa-bay County, Kenya. *E Afri Agri J* 84 (1), 136–146.

Kurmi, O. P., Lam, K. B. H., and Ayres, J. G. (2012). Indoor air pollution and the lung in low- and medium-income countries. *Eur. Respir. J.* 40, 239–254. doi:10.1183/09031936.00190211

Lai, A. M., Clark, S., Carter, E., Shan, M., Ni, K., Yang, X., et al. (2020). Impacts of stove/fuel use and outdoor air pollution on chemical composition of household particulate matter. *Indoor Air* 30, 294–305. doi:10.1111/ina.12636

Lee, P. C., Talbott, E. O., Roberts, J. M., Catov, J. M., Bilonick, R. A., Stone, R. A., et al. (2013). Ambient air pollution exposure and blood pressure changes during pregnancy. *Environ. Res.* 117, 46–53. doi:10.1016/j.envres.2012.05.011

Lee, K. K., Bing, R., Kiang, J., Bashir, S., Spath, N., Stelzle, D., et al. (2020). Adverse health effects associated with household air pollution: A systematic review, meta-analysis, and burden estimation study. *Lancet Glob. Health* 8 (11), e1427–e1434. doi:10.1016/s2214-109x(20)30343-0

Leech, J. A., Nelson, W. C., Burnett, R. T., Aaron, S., and Raizenne, A. M. E. (2002). It's about time: A comparison of canadian and American time–activity patterns. *J. Expo. Sci. Environ. Epidemiol.* 12, 427–432. doi:10.1038/sj.jea.7500244

Majdan, M., Svaro, M., Bodo, J., Taylor, M., and Muendo, R. M. (2015). Assessment of the biomass related indoor air pollution in Kwale district in Kenya using short term monitoring. *Afr. Health Sci.* 15, 972–981. doi:10.4314/ahs.v15i3.35

Martin, W. J., II, Glass, R. I., Araj, H., Balbus, J., Collins, F. S., Curtis, S., et al. (2013). Household air pollution in low- and middle-income countries: Health risks and research priorities. *PLoS Med.* 10 (6), e1001455. doi:10.1371/journal.pmed.1001455

Mbaka, C. K., Gikonyo, J., and Kisaka, O. M. (2019). Households' energy preference and consumption intensity in Kenya. *Energ Sustain Soc.* 9, 20. doi:10.1186/s13705-019-0201-8

Ministry of Energy (2019). Assessment of the supply and demand of cooking solutions at the household level. Kenya household cooking sector study. Available at: https://eedadvisory.com/wp-content/uploads/2020/09/MoE-2019-Kenya-Cooking-Sector-Study-compressed.pdf (Accessed January 20, 2022).

Mishra, V., and Retherford, R. D. (2007) Does biofuel smoke contribute to anaemia and stunting in early childhood? *Int J Epidemiol* 36: 117–129. doi:10.1093/ije/dyl234

Mishra, V., Dai, X., Smith, K. R., and Mika, L. (2004). Maternal exposure to biomass smoke and reduced birth weight in Zimbabwe. *Ann. Epidemiol.* 14, 740–747. doi:10.1016/j.annepidem.2004.01.009

C. N. Mock, R. Nugent, O. Kobusingye, and K. R. Smith (Editors) (2017). *Injury prevention and environmental health. Disease control priorities*. 3rd Edition (Washington, DC: World Bank), 7. doi:10.1596/978-1-4648-0522-6

Muindi, K., Kimani-Murage, E., Egondi, T., Rocklov, J., and Ng, N. (2016). Household air pollution: Sources and exposure levels to fine particulate matter in Nairobi slums. *Toxics* 4 (3), 12. doi:10.3390/toxics4030012

Mulenga, D., and Siziya, S. (2019). Indoor air pollution related respiratory ill health, a sequel of biomass use. *SciMedicine J.* 1, 30–37. doi:10.28991/SciMedJ-2019-0101-5

Mutahi, A. W., Borgese, L., Marchesi, C., Gatari, M. J., and Depero, L. E. (2021). Indoor and outdoor air quality for sustainable Life: A case study of rural and urban settlements in poor neighbourhoods in Kenya. *Sustainability* 13, 2417. doi:10.3390/su13042417

Muula, A. S. (2007). Prevalence and determinants of cigarette smoking among adolescents in Blantyre City, Malawi. *Tanzan. J. Health Res.* 9, 48–53. doi:10.4314/thrb.v9i1.14292

Naz, S., Page, A., and Agho, K. E. (2017). Household air pollution from use of cooking fuel and under-five mortality: The role of breastfeeding status and kitchen location in Pakistan. *PLoS One* 12 (3), e0173256. doi:10.1371/journal.pone.0173256

Ndwiga, T., Kei, R. M., Jepngetich, H., and Korrir, K. (2014). Assessment of health effects related to the use of biomass fuel and indoor air pollution in Kapkokwon sub-location, Bomet country, Kenya. *Open J. Air Pollut.* 3 (03), 61. doi:10.4236/ojap.2014.33007

North, C. M., MacNaughton, P., Lai, P. S., Vallarino, J., Okello, S., Kakuhikire, B., et al. (2019). Personal carbon monoxide exposure, respiratory symptoms, and the potentially modifying roles of sex and HIV infection in rural Uganda: A cohort study. *Environ. Health* 18 (1), 73. doi:10.1186/s12940-019-0517-z

Noubiap, J. J. N., Essouma, M., and Bigna, J. J. R. (2015). Targeting household air pollution for curbing the cardiovascular disease burden: A health priority in sub-saharan Africa. *J. Clin. Hypertens.* 17, 825–829. doi:10.1111/jch.12610

Nzengya, D. M., Maina Mwari, P., and Njeru, C. (2021). "Barriers to the adoption of improved cooking stoves for rural resilience and climate change adaptation and mitigation in Kenya," in *African handbook of climate change adaptation*. Editors N. Oguge, D. Ayal, L. Adeleke, and I. da Silva (Cham: Springer). doi:10.1007/978-3-030-45106-6_133

Ochieng, C. A., Vardoulakis, S., and Tonne, C. (2013). Are rocket mud stoves associated with lower indoor carbon monoxide and personal exposure in rural Kenya? *Indoor Air* 23, 14–24. doi:10.1111/j.1600-0668.2012.00786.x

Ochieng, C. A., Zhang, Y., Nyabwa, J. K., Otieno, D. I., and Spillane, C. (2020). Household perspectives on cookstove and fuel stacking: A qualitative study in urban and rural Kenya. *Energy Sustain Dev.* 59, 151–159. doi:10.1016/j.esd.2020.10.002

Oluwole, O., Otaniyi, O. O., Ana, G. A., and Olopade, C. O. (2012). Indoor air pollution from biomass fuels: A major health hazard in developing countries. *J. Public Health* 20, 565–575. doi:10.1007/s10389-012-0511-1

Osano, A., Maghanga, J., Munyeza, C. F., Chaka, B., Olal, W., and Forbes, P. B. C. (2020). Insights into household fuel use in Kenyan communities. *Sustain. Cities Soc.* 55, 102039. doi:10.1016/j.scs.2020.102039

Osiolo, H. H., and Kimuyu, P. (2017). Demand for indoor air pollution abatement interventions. *BioPhysical Econ. Resour. Qual.* 2, 1–19. doi:10.1080/09603123.2017.133234710.1007/s41247-017-0029-9

Pereira, G., Haggar, F., Shand, A. W., Bower, C., Cook, A., and Nassar, N. (2013). Association between pre-eclampsia and locally derived traffic-related air pollution: A retrospective cohort study. *J. Epidemiol. Community Health* 67, 147–152. doi:10.1136/jech-2011-200805

Pilishvili, T., Loo, J. D., Schrag, S., Stanistreet, D., Christensen, B., Yip, F., et al. (2016). Effectiveness of six improved cookstoves in reducing household air pollution and their acceptability in rural western Kenya. *PLoS One* 11, e0165529. doi:10.1371/journal.pone.0165529

Pokhrel, A. K., Smith, K. R., Khalakdina, A., Deuja, A., and Bates, M. N. (2005). Case–control study of indoor cooking smoke exposure and cataract in Nepal and India. *Int. J. Epidemiol.* 34, 702–708. doi:10.1093/ije/dyi015

Polsky, D., and Ly, C. (2012). The health consequences of indoor air pollution: A review of the solutions and challenges. White Paper: University of Pennsylvania. Available at: https://www.cleancookingalliance.org/resources_files/the-health-consequences-of-HAP.pdf (Accessed Dec 10, 2020).

Pratiti, R. (2021). Household air pollution related to biomass cook stove emissions and its interaction with improved cookstoves. *AIMS Public Health* 8, 309–321. doi:10.3934/publichealth.2021024

PREDAS (Programme for the Promotion of Household and Alternative Energy Sources) (2009). –Women and household energy in Sahelian countries. *Boil. Point* 56, 25–34. Available at: www.hedon.info/docs/BP56_PREDAS.pdf (Accessed December 12, 2019).

Priyanka, N. S., Oriama, P. A., Pedersen, P. P., Franck, C. O., Ayah, R., Kahn, R., et al. (2021) Spatial variation of fine particulate matter levels in Nairobi before and during the COVID-19 curfew: implications for environmental justice. *Environ Res Commun* 3, 071003. doi:10.1088/2515-7620/ac1214

Ranathunga, N., Perera, P., Nandasena, S., Sathiakumar, N., Kasturiratne, A., and Wickremasinghe, R. (2019). Effect of household air pollution due to solid fuel combustion on childhood respiratory diseases in a semi urban population in Sri Lanka. *BMC Pediatr.* 19, 306. doi:10.1186/s12887-019-1674-5

Raufman, J., Blansky, D., Lounsbury, D. W., Mwangi, E. W., Lan, Q, Olloquequi, J., et al. (2020). Environmental health literacy and household air pollution-associated symptoms in Kenya: a cross-sectional study. *Environ. Health* 19, 89. doi:10.1186/s12940-020-00643-5

Rudra, C. B., Williams, M. A., Sheppard, L., Koenig, J. Q., and Schiff, M. A. (2011). Ambient carbon monoxide and fine particulate matter in relation to preeclampsia and preterm delivery in Western Washington State. *Environ. Health Perspect.* 119, 886–892. doi:10.1289/ehp.1002947

Saksena, S., Prasad, R., Pal, R. C., and Joshi, V. (1992). Patterns of daily exposure to TSP and CO in the garhwal himalaya. *Atmos. Environ. a Gen. Top.* 26 (11), 2125–2134. doi:10.1016/0960-1686(92)90096-4

Silk, B. J., Sadumah, I., Patel, M. K., Were, V., Person, B., Harris, J., et al. (2012). A strategy to increase adoption of locally produced, ceramic cookstoves in rural Kenyan households. *BMC Public Health* 12 (1), 359. doi:10.1186/1471-2458-12-359

Smith, K. R., Samet, J. M., Romieu, I., and Bruce, N. (2000). Indoor air pollution in developing countries and acute lower respiratory infections in children. *Thorax* 55 (6), 518–532. doi:10.1136/thorax.55.6.518

Smith, K. R., Mehta, S., and Maeusezahl-Feuz, M. (2004). Indoor air pollution from household use of solid fuels. *Comp. Quantification Health Risks* 18, 1435–1493.

Smith, K. R., Bruce, N., Balakrishnan, K., Adair-Rohani, H., Balmes, J., Chafe, Z., et al. (2014). Millions dead: How do we know and what does it mean? Methods used in the comparative risk assessment of household air pollution. *Annu. Rev. Public Health* 35, 185–206. doi:10.1146/annurev-publhealth-032013-182356

Smith, K. R. (1993). Fuel combustion, air pollution exposure, and health: The situation in developing countries. *Annu. Rev. Energ Environ.* 18, 529–566. doi:10.1146/annurev.eg.18.110193.002525

Smith, K. R. (2002). Indoor air pollution in developing countries: Recommendations for research. *Indoor Air* 12 (3), 198–207. doi:10.1034/j.1600-0668.2002.01137.x

Šrám, R. J., Binková, B., Dejmek, J., and Bobak, M. (2005). Ambient air pollution and pregnancy outcomes: a review of the literature. *Environ. Health Perspect.* 113 (4), 375–382. doi:10.1289/ehp.6362

Stevens, L., Santangelo, E., Muzee, K., Clifford, M., and Jewitt, S. (2020). Market mapping for improved cookstoves: Barriers and opportunities in east Africa. *Dev. Pract.* 30, 37–51. doi:10.1080/09614524.2019.1658717

Stockholm Environment Institute (2016). Bringing clean, safe, affordable cooking energy to Kenyan households: An agenda for action. Retrieved from https://mediamanager.sei.org/documents/Publications/SEI-NCE-DB-2016-Kenya-Clean-Cooking.pdf (Accessed February 20, 2022).

UNEP (2021). Seven things yu should know about household air pollution. Available at: https://www.unep.org/news-and-stories/story/seven-things-you-should-know-about-household-air-pollution.

Van Vliet, E. D., Asante, K., Jack, D. W., Kinney, P. L., Whyatt, R. M., Chillrud, S. N., et al. (2013). Personal exposures to fine particulate matter and black carbon in households cooking with biomass fuels in rural Ghana. *Environ. Res.* 127, 40–48. doi:10.1016/j.envres.2013.08.009

Wafula, E. M., Onyango, F. E., Thairu, H., Boleij, J. S., Hoek, F., Ruigewaard, P., et al. (1990). Indoor air pollution in a Kenyan village. *East Afr. Med. J.* 67, 24–32.

Welfle, A., Chingaira, S., and Kassenov, A. (2020). Biomass and bioenergy decarbonising Kenya's domestic & industry sectors through bioenergy: An assessment of biomass resource potential & GHG performances. *Biomass Bioenergy* 142, 105757. doi:10.1016/j.biombioe.2020.105757

WHO (2012). *Database on solid and non-solid fuel usage*. Geneva: WHO.

WHO (2014). *WHO indoor air quality guidelines: Household fuel combustion*. Geneva: WHO.

Woolley, K. E., Dickinson-Craig, E., Bartington, S. E., Oludotun, T., Kirenga, B., Mariga, S. T., et al. (2021). Effectiveness of interventions to reduce household air pollution from solid biomass fuels and improve maternal and child health outcomes in low- and middle-income countries: A systematic review protocol. *Syst. Rev.* 10, 33. doi:10.1186/s13643-021-01590-z

Yip, F., Christensen, B., Sircar, K., Naeher, L., Bruce, N., Pennise, D., et al. (2017). Assessment of traditional and improved stove use on household air pollution and personal exposures in rural Western Kenya. *Environ. Int.* 99, 185–191. doi:10.1016/j.envint.2016.11.015