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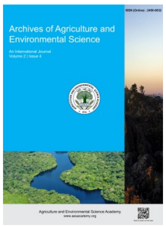

ORIGINAL RESEARCH ARTICLE

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Socio-cultural and economic determinants of clean cooking technology adoption in Uganda

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ABSTRACT

This study examined socio-cultural and economic determinants influencing clean cooking technology adoption, with emphasis on cultural norms, gender roles, income, education, and user perceptions in Uganda. A cross-sectional survey of 480 households from urban, peri-urban, and rural areas in six districts employed structured interviews and questionnaires. Awareness of improved cook stoves and alternative fuels (briquettes, LPG, ethanol) was high (74%), but adoption was low (27%). Major barriers included high upfront costs (68%), limited distribution networks (52%), and perceived incompatibility with traditional cooking methods, especially for staple dishes. Adoption was significantly ($p < 0.05$) higher among households with at least one adult completing secondary education (42% vs. 18%) and those earning above UGX 300,000 or 83.90 USD /month, who were 3.1 times more likely to adopt. Women were the primary cooks in 93% of households, with girls aged 7–16 frequently assisting. Cultural beliefs, such as firewood enhancing food flavor and symbolizing tradition, further influenced adoption decisions. The findings indicated that accelerating clean cooking adoption in Uganda requires culturally sensitive and gender-responsive interventions, integration of local knowledge, targeted behavior change communication, supportive policy frameworks, and sustained financing. Strengthening supply chains and empowering women as energy entrepreneurs are essential to achieve Sustainable Development Goal 7 (SDG 7) on universal modern energy access.

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INTRODUCTION

Globally, 2.3 billion people predominantly in low- and middle-income countries rely on traditional biomass fuels for cooking, with Sub-Saharan Africa accounting for ~80% of those without access to clean cooking. In Uganda, over 92% of households depend on biomass (firewood, charcoal, dung), contributing to indoor air pollution, deforestation, and an estimated 13,000 premature deaths annually. Access to clean and sustainable energy remains a global priority (Stephenson, 2021), forming the backbone of efforts to reduce poverty, enhance public health, empower women, and combat climate change. Energy use especially in cooking directly impacts household health, environmental sustainability, and socioeconomic outcomes (Mills *et al*., 2017; Rasel *et al*., 2024). The United Nations Sustainable Development Goal 7 (SDG 7) calls for universal access to affordable, reliable, and modern energy services by 2030 (SDG 7: Affordable and Clean Energy, SDG, 2023). However, nearly 2.3 billion people globally still rely on traditional biomass fuels (wood, charcoal, dung, and crop residues) for cooking. These fuels generate harmful indoor air pollution, contributing to over 3.2 million premature deaths annually, disproportionately affecting women and children. Therefore, the uptake of clean cooking technologies is not simply a matter of technical innovation it is a deeply social issue. Despite the development of advanced cooking technologies such as improved biomass stoves, liquefied petroleum gas (LPG), ethanol, biogas, and electric cooking solutions, their large-scale adoption has been sluggish, particularly in low- and middle-income countries (Kumar & Igdalsky, 2019). Different studies show that the decision to adopt such technologies is often influenced more by cultural norms, gender roles, social status, and household routines than by price or physical availability (Pope *et al*., 2018). For example, preferences for certain food textures, cooking methods, and flavors may limit the use of stoves that do not replicate traditional firewood functions. Moreover, the "stacking" of multiple fuels (rather than full transition) persists in many communities due to risk-averse behaviors, convenience, and fuel insecurity (Troncoso *et al*., 2019).

In sub-Saharan Africa, these challenges are magnified by structural energy poverty, weak policy enforcement, and poor access to finance and information. More than 80% of households in the region still depend on solid biomass, with minimal penetration of clean cooking alternatives. Even where national policies and international development programs have attempted to roll out improved cooking solutions, uptake has been uneven and often unsustainable (Aemro *et al*., 2021). Gender dynamics further complicate these efforts. Cooking remains largely a woman's responsibility, yet women are seldom included in energy decision-making or program design (Matinga *et al*., 2013). Limited education, access to credit, and socio-cultural constraints hinder women's ability to acquire, maintain, and promote new technologies in their communities. Uganda, like many African countries, presents a complex and culturally diverse energy landscape (Kay *et al*., 2021). Biomass primarily firewood and charcoal still accounts for over 90% of the country's total energy consumption (MEMD, 2015). While electrification and LPG expansion are gradually improving access in urban centers, rural and peri-urban households remain heavily dependent on traditional fuels. Uganda's cultural mosaic, composed of over 54 distinct ethnic groups, contributes to varying cooking practices, beliefs, and levels of receptivity to modern cooking technologies. For instance, while Baganda households in central Uganda are more open to LPG and electric stoves due to greater urban exposure, Acholi or Karimojong communities in the north and northeast may resist such transitions due to stronger ties to traditional cooking methods and food preparation techniques (Muwanga *et al*., 2023).

Beyond culture, several social determinants shape renewable energy adoption in Uganda. These include household income, education levels, awareness of health and environmental risks, age of household members, and the type of food cooked (Elasu *et al*., 2022). Among these, gender and generational roles are particularly important. In most Ugandan communities, girls begin learning to cook from a young age, closely observing and assisting their mothers (Katutsi *et al*., 2020). This early immersion in traditional cooking often leads to strong attachments to biomass-based methods. Moreover, due to patriarchal household structures, women despite bearing the brunt of smoke exposure often lack decision-making power to invest in clean alternatives, which are perceived as luxury items or non-essential expenditures (Ahimbisibwe *et al*., 2025). Recent studies (Ahimbisibwe *et al*., 2025) indicate that while awareness about clean energy is growing especially in areas with donor-driven pilot projects the sustained use of advanced cooking technologies remains low (Adams *et al*., 2023; Mukelabai *et al*., 2023; Nabukwangwa *et al*., 2023). Households frequently revert to firewood or charcoal during economic shocks or fuel shortages. Additionally, limited supply chains, high upfront costs, and weak regulatory oversight continue to limit access to clean stoves and fuels across much of the country. Even where subsidies exist, they are often poorly targeted or unsustainable (Ahimbisibwe *et al*., 2025).

This study aims to critically assess the social dimensions influencing the scale-up, adoption, and sustained use of renewable and clean cooking technologies in Uganda. It recognizes that effective interventions must extend beyond infrastructure provision and affordability to become socially embedded, gender-sensitive, culturally respectful, and community-driven. By examining how culture, tradition, and identity shape cooking practices and how these practices differ across Uganda's diverse communities the study seeks to uncover the key enablers and barriers affecting household and community uptake. Drawing on empirical evidence from multiple regions, the analysis provides insights to inform policies and programs that advance Uganda's national clean energy goals while contributing to global climate change mitigation targets.

MATERIALS AND METHODS

Study design

This study employed a mixed-methods participatory approach (Ramos Montañez, 2023), integrating methodological paradigm triangulation to capture both quantitative and qualitative dimensions of energy use and cooking technologies in Uganda. A convergent parallel design was adopted to ensure the simultaneous collection and validation of diverse datasets, enhancing analytical robustness.

Quantitative data collection

A structured questionnaire was administered to 789 respondents, comprising 237 institutional representatives (30%) and 552 household respondents (70%) from four regions of Uganda (Atuhaire *et al*., 2019). Study districts included Kampala, Wakiso, Mukono, Mubende, Masaka, Jinja, Mbale, Soroti, Mbarara, Bushenyi, Gulu, and Lira. Institutions sampled were predominantly urban and peri-urban (84%) and represented sectors such as bakeries, breweries, hospitals, hotels, security agencies, and schools. Household respondents were drawn from both rural (47.2%) and urban/peri-urban (52.8%) settings. In-depth qualitative insights were gathered through five focus group discussions (FGDs), three with institutional participants and two with household participants. The FGDs, facilitated by trained researchers, explored themes related to energy adoption, accessibility, and performance (Acedillo *et al*., 2022). Additionally, key informant interviews (KIIs) were conducted with policymakers, industry experts, and energy practitioners to contextualize survey findings. A document analysis of policy and regulatory frameworks was also undertaken to triangulate insights from primary data (Jeti *et al*., 2024).

Data collection protocols

Data collection utilized electronic tools, with all survey instruments administered via tablet-based software to ensure accuracy and minimize physical contact (Thysen *et al*., 2021). In cases where direct engagement was constrained, remote methods such as phone interviews, email, SMS, and WhatsApp messages were employed. FGDs with urban participants were conducted via Zoom, while in-person FGDs in rural areas adhered to strict social distancing protocols, limiting participation to a maximum of ten respondents per session (Sanders, 2019).

Data management and analysis

Quantitative data was extracted from a secure server, cleaned, and analysed using STATA 16, applying descriptive and inferential statistical methods. Qualitative data from FGDs and KIIs was transcribed, coded using ATLAS.ti, and analysed thematically to identify patterns and relationships. A deductive-inductive approach was employed to merge emerging themes with predefined theoretical constructs. To enhance analytical rigor, methodological, data, and investigator triangulation techniques were employed, ensuring the reliability and credibility of findings (Sendall *et al*., 2018).

Ethical considerations

The study adhered to ethical research standards, including obtaining informed consent from participants, ensuring data confidentiality, and securing approvals from relevant institutional review boards. Measures were taken to anonymize responses and uphold the integrity of the research process (Ferreira *et al*., 2022).

RESULTS AND DISCUSSION

Socio-demographic and gender influences on clean cooking adoption

The respondent's groups characteristics used in this study are given in Table 1. Preference to use clean fuel, 69% were female and only 31% were males and preferred to use improved technologies (stoves), 61.9% were female and 38% were male. Women therefore were more likely to use clean fuel and improved technologies than men (Table 1). This could be attributed to the fact that the women and girls do most of the cooking and are more likely to be experiencing all the challenges resulting from use of traditional fuel and technology as suggested by Yasmin & Grundmann (2020), while the men on the other hand could be hesitant to move to improved technology and fuels for fear of the related financial implications. Women considered the following features important if they were to adopt any new cooking technology as repeatedly during the focus group discussions: the technologies should provide for; (1) space for one to cook more than one dish at a time, (2) keep food warm (3) cook food in the shortest time possible (4) and usable by the children in the house. Earlier studies have indicated that there are clear gender dimension in the household energy sector (Saito *et al.*, 2019; Yasmin & Grundmann, 2020). Some scholars have revealed that women and men do not equally bear the burden of environmental and health factors associated with biomass use, since they are responsible for the collection, transportation, processing and storing of fuels, as well as the cooking activities; while men typically make decisions of a financial nature (Sahoo *et al.*, 2023). Therefore, any technology promoted should be checked on how well it meets the expectations of certain categories of people, specifically the women, who are or should be the primary beneficiaries of improved stoves. Prior research emphasizes that environmental and health burdens from biomass fuel use disproportionately affect women, who handle fuel collection, processing, and cooking, while men predominantly make financial decisions (Ahimbisibwe *et al.*, 2025; Rasel *et al*., 2024). Given this gendered dynamic, it is crucial that any promoted cooking technology aligns closely with women's expectations and practical needs, as they are the primary beneficiaries and users of such interventions.

Role of location, education, and age in energy preferences

Geographic location plays a critical role in determining the types of energy sources accessible and preferred by households, often reflecting disparities between urban and rural settings. 74.5% of people using firewood were rural residents, and only 26.4% were urban residents. On the other hand, less than 1% (0.5) of rural residents used electricity, while 16.6% of urban residents used electricity for cooking. Therefore, residing in a rural area was closely associated with use of traditional cooking technology and fuel, while residing in an urban area was more closely associated with use of modern and clean cooking technology and fuel as Rahut *et al*. (2019) suggests the trend in technology adoption. Awareness of improved technologies, especially improved cooking stones was however almost at the same level in rural (91%) and urban (95%). Since level of awareness of improved fuels are quite high, the low rate of adoption of the same can better be attributed to accessibility, as majority of the respondents in rural areas did not have access to electricity, bio gas or LPG. This rural–urban dichotomy echoes global trends but also underscores unique local dynamics. Unlike some regions where rural areas leapfrog directly to modern fuels (e.g., LPG in parts of Asia), our data suggest that rural Ugandans continue to depend heavily on biomass despite awareness of improved technologies (Murshed, 2023). This persistence reflects infrastructural and economic constraints rather than lack of knowledge who argue that awareness alone does not translate to adoption without enabling conditions. Interestingly, the substantial charcoal use in rural areas (58.3%) indicates a transitional fuel preference not always highlighted in other contexts, suggesting opportunities for incremental upgrades rather than abrupt technology shifts (Bamwesigye *et al.*, 2020; Nzabona *et al.*, 2021; Tuyiragize & Bassi, 2024).

Educational attainment significantly influences energy choices, as higher levels of education tend to correlate with greater awareness and adoption of cleaner, more efficient technologies. Only 3% of respondents who had no formal education used clean energy, while 16% of them used traditional energy. On the other hand, 21% of respondents who had a university degree used clean energy while only 6% of them used traditional energy. This implies that the higher the level of education, the more likelihood for one to use clean energy. Gould & Urpelainen (2018) attributes this to the likelihood of educated people to understand both the environmental and health dangers of using traditional energy for cooking and for lighting. Therefore, as suggested by Shari *et al.* (2022) beyond making clean technologies available, sensitisation efforts need to be heightened especially in areas where residents have lower education levels. Higher education correlates with increased clean fuel use, the relatively low clean energy adoption even among educated groups indicates systemic barriers beyond knowledge. This contrasts with some findings from developed contexts where education alone predicts high adoption. In Uganda, even educated households may face supply, cost, or cultural barriers limiting their choices. This suggests that education enhances willingness but cannot fully overcome structural limitations, emphasizing the need for policy interventions that simultaneously improve access and affordability (Rahut *et al.*, 2019, 2020; Rasel *et al.*, 2024). Age shapes energy preferences and usage patterns, with different generations exhibiting distinct attitudes towards traditional versus modern energy options. Observations with households and institutions reveal that younger people were more flexible and willing to adopt modern cooking technologies and fuels than their older counterparts. In Bushenyi district, focus group insights highlighted intergenerational tensions in cooking choices, with younger women favouring charcoal stoves for efficiency, while older members insisted on traditional three-stone fireplaces, underscoring how cultural norms and household power dynamics influence technology adoption. When probed on the reason why the mum prefers the three stones, she noted that mum believes that the stones cook food better than the charcoal stove. Studies have generally indicated that younger people embrace technology much faster than older persons and are willing to adapt to new things faster (Gould & Urpelainen, 2018; Kumar *et al.*, 2021; Rahut *et al.*, 2019).

Income and socio-economic drivers of clean fuel adoption

Household income level is a key determinant in the adoption and use of clean fuels and improved energy technologies. It is generally true that the initial capital cost of renewable energy is relatively higher when compared to conventional sources of energy (Nabukwangwa *et al.*, 2023; Sharma *et al.*, 2020). The biggest percentage of households on the other hand, especially in the rural areas (61%) earned less than 200.000 Uganda shillings (shs) a month and of those who earned less than 200.000 shs, only 9.5% of them used clean energy while the 47% of them used traditional energy. On the other hand, households that earned between 1-5million shs, mainly used clean energy (20%) and only 3.5% of them used traditional energy. It was thus observed generally that households with higher income levels had a tendency to use more modern and clean cooking fuels and technologies such as gas and electricity. Similarly, a study in Burkina Faso revealed that as household income increased, households' firewood uses systematically decreased as well. Campbell and colleagues also established that higher income households in urban Zimbabwe had the tendency to transition to modern cooking fuel sources such as kerosene and electricity, as opposed to using wood fuels as their primary energy source like the majority of lower income residents. Generally, people with lower incomes generally focus on other priorities such as food, than type of energy used, thus tend to use the cheapest and most available energy options. The energy ladder model proposed by Barnes and others suggests that as income increases, households adopt more modern cooking fuels. This linear process as illustrated below shows that households cease to use traditional biomass fuels and adopt modern alternatives as their income level increases (Adamu *et al.*, 2020; Yadav *et al.*, 2021). The model thus proposes income as a determinant factor for fuel choice, and thus the rationale for transitioning up the energy ladder. Furthermore, point out that "the energy ladder assumes that more expensive technologies are locally and internationally perceived to signify higher status, and that families desire to move up the energy ladder not just to achieve greater fuel efficiency or less direct pollutions exposure, but to demonstrate an increase in socio-economic status." This model however focuses too rigidly on economic processes as determinants of fuel choice; with no concern for certain social, cultural and behavioural processes as determinants of energy choice. From the observations made, however, firewood/fuel wood was not only restricted to low income households. Earlier studies have provided evidence that multiple fuel use is widespread in other areas. In Guatemala for example, it was estimated that households predominantly rely on both firewood and LPG (26% and 16%, respectively), while in rural parts of South Africa 34% of households use both firewood and kerosene for their cooking needs. Similar observations can be found in Botswana, and in rural India (Joon *et al.*, 2009). Masera *et al.* (2000) provide an alternate to the energy ladder model´s linear fuel switch process, by introducing the "multiple fuel" model. The model asserts that "rural households do not 'switch fuels', but more generally follow a multiple fuel or 'fuel stacking' strategy by which new cooking technologies and fuels are added, but even the most traditional systems are rarely abandoned. Socio-cultural factors that influence the use and adoption of clean fuels and improved technology (Barrera-Santana *et al.*, 2022; Xu & Zhong, 2023).

Table 1. Socio-demographic, economic, cultural, and sectoral factors influencing adoption of clean cooking fuels and technologies in Uganda.

Theme / Factor	Key results & statistics	Insights & practical significance
Gender Influence on Adoption	• 69% of clean fuel users were female; 31% male. • 61.9% using improved tech were female; 38% male. • Women desire tech that cooks multiple dishes, keeps food warm, cooks quickly, and is child-friendly.	Women's greater involvement in cooking and exposure to health impacts drives higher adoption. Men's financial concerns limit uptake. Technologies should align with women's practical needs to ensure successful adoption.
Location (Urban vs Rural)	• 74.5% of firewood users are rural; 26.4% urban. • Electricity use: 0.5% rural, 16.6% urban. • Awareness of improved tech: rural 91%, urban 95%. • Charcoal use in rural areas is 58.3%.	Rural households rely on traditional fuels due to limited access despite high awareness. Urban residents favor modern fuels. Charcoal presents an entry point for promoting improved cooking technologies in rural areas.
Education Level	• Clean energy use among those with no education: 3%. • Clean energy use among university graduates: 21%.	Higher education correlates with clean fuel adoption but systemic barriers persist. Need for targeted awareness in low education areas.
Age Influence	• No clear statistical link between age and clean cooking adoption. • Younger people more open to modern tech.	Cultural attachment to traditional methods among elders impacts adoption. Interventions should consider generational differences.
Income & Socio-Economic Factors	• 61% of rural households earn < 200,000 UGX/month; only 9.5% use clean energy. • Households earning 1–5 million UGX mainly use clean energy (20%).	Higher income increases likelihood of adopting clean fuels. Fuel stacking common; many households use multiple fuel types simultaneously.
Cultural & Staple Food Preferences	• Certain ethnic groups prefer traditional firewood for staple foods (e.g., Baganda cooking matooke).	Cultural food preparation practices strongly influence fuel choice. Mixed fuel use accommodates different cooking needs.
Cooking Stones & Kitchen Practices	• Traditional cooking setups enable multitasking (breastfeeding, peeling, washing) while sitting/kneeling.	New technologies should consider household ergonomics and multi-functionality to gain acceptance.
Social & Cultural Functions of Fire/Smoke	• Fire provides social bonding, warmth, snack preparation, and odor control. • Smoke symbolizes cooking skill and status.	Non-cooking benefits of traditional fires are key barriers to clean fuel adoption. Interventions must address these cultural values.
General Community Attitude	• Positive toward improved tech despite barriers. • Past failures linked to ignoring socio-cultural factors.	Cultural sensitivity and user-centered design critical for technology adoption and sustainability.
Challenges in Sector	• Lack of production standardization, inefficient equipment, high costs, and counterfeit products. • Weak regulation.	Addressing production quality, market regulation, and reducing costs essential for scaling clean fuels and stoves.
Recommended Interventions	• Support through subsidies, tax incentives, capacity building for quality testing. • Long-term behavior change campaigns. • Scale briquette production.	Policy support and sustained awareness needed to overcome economic and behavioral barriers to adoption.

Influence of cultural preferences and staple food preparation on cooking fuel choices

Different ethnic groups in Uganda have different staple foods. It was observed that certain cultures preferred their staple food to be cooked in the most traditional manner and seemed to argue that certain technologies could not be used to cook certain foods. A few people still hold the norm that food prepared with fuelwood tastes better than food prepared with other heat sources. In Wakiso district, Baganda respondents expressed contrasting views on the ideal method for cooking matooke. Older participants predominantly favoured firewood on three-stone fireplaces, associating it with the dish's authentic taste, aroma, and texture. Others argued that similar results could be achieved with charcoal stoves through slow-burning techniques, while some households blended methods reserving three-stone cooking for matooke and using modern stoves for quicker meals such as rice, sauces, and vegetables. These divergent perspectives reveal how cultural traditions, generational preferences, and practical considerations interact to shape cooking technology choices (Kajumba *et al*., 2022).

This implies that some households could not rely on one type of fuel or technology, because of what they perceived could be cooked or not by the different technologies. In the northern part of the country however, respondents noted that they could prepare *kalo* (millet paste) on any cooking technology, including LPG and improved charcoal stoves as well as they did on firewood and cooking stones. Cultural identity and staple food preferences play a significant role in shaping household choices of cooking fuels and technologies (Barasa *et al*., 2022). In Uganda, certain ethnic groups such as the Baganda prefer traditional methods like firewood and three-stone stoves for preparing staple foods like matooke, citing taste and authenticity as key reasons (Kajumba *et al*., 2022; Nsamba *et al*., 2021). This cultural attachment often overrides considerations of efficiency or cleanliness, particularly among older adults. Similar findings have been reported in studies across sub-Saharan Africa, where food type and cultural perceptions significantly influence stove and fuel preferences (Aseete *et al*., 2018). Some households adopt a mix of cooking technologies, using traditional fuels for specific meals and modern ones for others, reflecting a complex interplay of practicality, tradition, and adaptability. These insights suggest that clean cooking interventions must be culturally sensitive, addressing not only access and affordability but also compatibility with traditional cooking practices.

Perceived complements of cooking stones to other activities

Respondents especially mothers noted that when they cook using firewood, they either have to kneel down or sit down in the kitchen. Many of them noted that when they do this, they are also able to conduct other activities at the same time, such as breast feeding, peeling food or washing dishes. Other technologies such as LPG or electricity does not seem to favour that the focus group discussions revealed that traditional cooking spaces serve multiple functions beyond food preparation, including childcare, food preparation tasks such as peeling, and dishwashing while seated or kneeling. This multifunctional use partly explains resistance to modern appliances like electric stoves, which often require standing and more frequent movement. Transforming household cooking practices, therefore, may require parallel improvements in kitchen infrastructure such as ergonomically designed dishwashing areas or drying racks to preserve convenience while introducing new technologies. Traditional cooking methods, particularly three-stone stoves using firewood, serve multiple household functions beyond meal preparation (Moses & MacCarty, 2019; Muwanga *et al*., 2023). Many mothers interviewed noted that cooking while kneeling or sitting on the floor allows them to simultaneously breastfeed, peel food, or wash dishes activities not easily accommodated by modern upright cooking technologies like LPG or electric stoves. This highlights that traditional kitchens are designed for multi-functionality, which newer technologies may disrupt. The implication is that clean cooking interventions must consider not only fuel and stove design but also the broader domestic context and ergonomic preferences. As noted by (Nabukwangwa *et al*., 2023), successful adoption of clean cooking technologies depends not just on efficiency or affordability but on their compatibility with household routines, spatial layout, and cultural practices.

The hidden utilities of fire: Warmth, social bonding, and daily tasks

Respondents also often noted that one of the barriers for the adoption of modern fuels and improved cooking technologies, are the “other” benefits of fire that can seemingly only be enjoyed with the traditional technologies especially the cooking stones. Many argued that many families gather in the kitchen, especially children in the evening and there is a lot of socialising that takes place around these fires regardless of what is being cooked. Parents also noted that this is the time they get to speak to their children about issues like behaviour, culture, providing guidance and many other things. Doing away with such technologies might seemingly be threatening to some of the families for its potential to erode social cohesion. Two participants during an FGD in Jinja pointed out that their family stays in the kitchen all the day and only go to the main house for sleeping unless guests or strangers were around. Other uses of fire mentioned also included preparing certain snacks such as roasted maize which they said you could not do on certain technologies such as LPG. Other studies also found that in rural areas, people argued that they prefer to use firewood, as the smoke from the firewood helped to reduce the smell from the animals especially in communities where humans shared shelter with the animals. The continued reliance on traditional fire-based cooking methods is not solely a matter of fuel access or affordability it is also rooted in the multifunctional role that fire plays in rural life. In addition to cooking, respondents highlighted the value of fire for specific domestic tasks such as roasting maize or heating water for bathing, which are difficult or impractical to perform with modern technologies like LPG. Moreover, in some pastoral communities, firewood smoke is deliberately used to neutralize odours from livestock when humans and animals share living spaces a practice that modern stoves cannot replicate. These practical utilities, often invisible in mainstream energy access metrics, demonstrate that traditional fires fulfil a broad spectrum of household needs beyond meal preparation. Studies confirm that such non-cooking functions of biomass use can significantly influence fuel preferences and adoption decisions, particularly in rural settings where multi-functionality and cultural fit matter just as much as efficiency or cleanliness (Robinson *et al*., 2022).

Perceived benefits of smoke: Cultural and practical perspectives

In some communities, wood smoke was simultaneously recognized as harmful to eye and respiratory health yet perceived to have practical and social benefits. Respondents associated firewood use with increased durability of cooking utensils and viewed visible kitchen smoke as a sign of household status and the cook’s competence. Such perceptions align with findings from other African contexts, including rural Ethiopia, where smoke has been culturally linked to household prestige and maternal–infant well-being. These beliefs illustrate how cultural symbolism and perceived utility can sustain the use of traditional cooking methods despite known health risks. While the health hazards of wood smoke such as eye irritation and respiratory problems were widely acknowledged by respondents, many still viewed smoke as having practical and symbolic value (Cartwright *et al*., 2022). For instance, several participants believed that saucepans used over firewood last longer and are less prone to damage, attributing durability to exposure to smoke. Social perceptions also influence these attitudes; in some communities, a smoke-free kitchen might be interpreted as a sign of poverty or poor domestic management. One respondent noted, "If someone's kitchen does not bring out any smoke, the neighbours might think that you are poor or that your wife is not a good cook." Similar cultural beliefs have been documented in rural Ethiopia, where smoke is associated with household status and even maternal and neonatal care, with traditions holding that smoke provides health benefits for new-borns and mothers in the postpartum period. These deeply held beliefs highlight that resistance to clean cooking solutions is not solely based on cost or access, but also on cultural symbolism and perceived functional benefits of traditional methods. Addressing these beliefs is critical in designing culturally sensitive clean energy interventions (Cartwright *et al.*, 2022).

General positive attitude

Overall, the study found the communities had a positive attitude towards using improved technologies and modern fuels in spite the barriers that they experienced in accessing them as well as the perceptions that they had towards the benefits of the traditional cooking technologies and fuels. It is argued that technological absorption cannot occur without the proper social, cultural, considerations as these influence the adoption (Vigolo *et al.*, 2018). When not considering socio-cultural aspect, it may inevitably lead to project failure in the long run. There are various examples of stove programmes that have been unsustainable due to failure to consider the local social and cultural setting of intended beneficiary communities. One such example comes from rural Mexico where LPG stoves were introduced so as to reduce people's over reliance on firewood for cooking (Betina *et al.*, 2022). It was soon noticed that communities did not abandon the use of fire wood, as a result of a cultural incompatibility of the new stoves. It was discerned that the new stoves were not adequate for the cooking of the popular tortilla. Since tortillas are customarily prepared over open wood fire, it was reported that the tortillas prepared over a gas flame were distasteful. Furthermore it was also noticed that the design of the LPG stove did not allow for the large enough surface, necessary for efficiently cooking tortillas (Medina *et al.*, 2019; Schilmann *et al.*, 2021).

There are also cases where a stove developed and designed for use in one developing country, is unsuitable for another. The jiko stove of Kenya is a ceramic stove suitable for more efficient burning of charcoal. The design of the stove was largely a bottom up initiative and production was carried out by local artisans, enabling for its wide spread acceptance and popularity in Kenya (Ang'u *et al.*, 2022). When the same jiko stove was introduced in neighbouring Tanzania, it proved to be unpopular amongst households as it failed to meet consumer preferences. This demonstrates the culture specific context in which stoves should be designed. Only after design modifications to suit the Tanzanian local needs, was the stove later adopted according to Kammen & Karekezi, 2000). Unfortunately, the authors do not elaborate why the jiko stove did not work well in Tanzania. Such cases however call for more attention to socio-cultural dynamics within household energy choice. Household cooking interventions may also be in the form of household modification and awareness raising campaigns (Grimsby *et al.*, 2016). It is also important to recognise that technologies should be appropriate to people's needs, rather than trying to change people's behaviour to suit the technological option (Pillarisetti *et al.*, 2014).

Barriers to market access and scale-up of clean fuels and improved technologies

Standardization of materials for use in the production process, still remains a challenge and this leads to production of fuels and stoves that are not homogeneous in quality and other physical attributes. There is low tech and unautomated equipment and production lines in the production of briquettes an efficient fuel as discovered by this study. This makes the production process inefficient and in the long run increases the cost of production. The production costs and other associated costs of manufacturing improved technologies and cleaner fuels still remain higher than traditional fuels and technologies. This makes the prices of the same higher and thus not affordable by both the households and institutions as established by this study. Presence of counterfeit products that have low performance features. These were discovered in all the markets visited. Weak regulation of the sector that makes entry for new players into the market easy and unregulated. Though this is good, it has allowed in players that produce unstandardized products. High cost of capital for suppliers and manufacturers. This translates into the high prices for clean fuels and improved stoves. Low markets for clean fuels and improved technologies mainly brought about by the competition due to presence of alternative fuels and stoves with low performance attributes (Tesfay *et al.*, 2024).

The study highlights several systemic barriers that constrain the effective dissemination and adoption of clean cooking technologies and fuels in Uganda. Chief among these is the lack of standardized production processes, which results in inconsistent quality and performance of clean fuel products, especially briquettes. This inconsistency erodes consumer confidence and undermines widespread adoption. The prevalence of low-tech, non-automated production methods also contributes to inefficiencies, raising unit costs and rendering these alternatives economically uncompetitive when compared to traditional fuels like firewood and charcoal (Rahim Malik *et al.*, 2023). Furthermore, the sector faces regulatory weaknesses. While a liberalized market allows for innovation, it has simultaneously enabled an influx of substandard and counterfeit products, creating market distortion and discouraging investment in quality products (Alizadeh *et al.*, 2020; Tesfay *et al.*, 2024). High capital costs and limited financing mechanisms for producers and suppliers exacerbate the issue, restricting production scale and innovation, particularly for small and medium enterprises (SMEs)(Bruce *et al.*, 2015). The market environment is also shaped by consumer preferences and price sensitivity. Clean technologies, while offering long-term benefits, have higher upfront costs—making them unaffordable for most low-income households. In the absence of robust subsidies or financing options, users continue to opt for cheaper and more familiar options, even if they are environmentally harmful or health-damaging. Additionally, the dominance of traditional fuels in the market, reinforced by cultural familiarity and ease of access, poses stiff competition to cleaner alternatives. Addressing these challenges calls for a multi -pronged approach that includes improving regulatory oversight, supporting local manufacturers with access to finance and technology upgrades, enforcing quality standards, and implementing targeted consumer awareness and subsidy programs. This aligns with global lessons from similar contexts where policy coherence, technical support, and demand stimulation have proven critical to scaling clean energy solutions (Tesfay *et al*., 2024).

Strategic interventions to overcome barriers to clean cooking technologies and fuels

There is need to support manufacturers, distributors and suppliers of clean fuels and improved technologies with production and distribution subsidies to ease on the costs incurred along the value chain. Many retailers with interest in the supply of the improved devices find it hard to stock in large qualities because the stoves require higher capital than the traditional devices. The recommended support can be in form of carbon credits, subsidies, tax holidays or exceptions especially to local manufacturers to help ease on production and distribution costs. This will translate into affordable prices of the devices and fuels there by increasing the levels of affordability in urban but also in rural areas. There is need to conduct a well-planned, extensive behavior change campaign over an extended length of time to help entice/ persuade, inform, guide and support households and institutions to steadily switch to clean and efficient energy practices of cooking, heating, lighting among other energy consumption forms. There is need to build capacity of research institutions and testing labs with quick, accurate, easy to use systems of testing the performance/ efficiency of the available clean fuels and devices. The empowerment of research institutions and private professionals/ firms with capacity to conduct energy efficiency assessment will reduce the level of counterfeit products on the market because implementation and enforcement of the quality standards of the fuels and devices will be easier since increase in the suppliers of these services translates into reduced charges and reduced time of testing. UNDP and its partners may reward energy efficient institutions, households and some real estate settlements with reduced energy bills, reduction in rent taxes, among others to ensure that institutions and households continue to register cleaner and more efficient energy systems.

The manufacturers, importers, wholesalers, and retailers involved on the clean fuel and device distribution chain should be assessed and be rewarded with tax-holidays and other energy use incentives to the increase their supply and help balance out the associated prices on the demand side. Briquettes which was the cheapest fuel should be scaled up by supporting manufacturers with production equipment that can produce many tones of the fuel at a time. They should also be supported to strengthen the distribution of the fuel across the sales points in the country. To effectively scale up clean cooking technologies and fuels in Uganda, a strategic, multi-level intervention framework is required. A key recommendation is the provision of targeted production and distribution subsidies to local manufacturers, distributors, and retailers. These can take the form of tax exemptions, carbon credits, or concessional financing measures that have proven effective in accelerating clean energy access in countries like India and Kenya (Rosenthal *et al*., 2017, 2018). This support would help offset high initial capital requirements, allowing businesses to lower end-user prices and improve affordability. Beyond financial incentives, consumer behavior change is vital. Sustained, culturally grounded awareness campaigns can dismantle misinformation and increase household willingness to shift from traditional biomass fuels to modern alternatives. These campaigns must be complemented by investments in the capacity of local research institutions and labs to carry out fuel performance and safety testing. Strengthening these institutions can reduce the proliferation of counterfeit products and improve trust in new technologies (Thompson, 2019). Moreover, recognition and rewards for early adopters such as reductions in utility bills, tax breaks, or public recognition can create positive social norms around clean energy adoption. Real estate developers and institutions, especially in urbanizing areas, can play a leading role if incentivized to integrate sustainable energy systems. Finally, briquettes identified as one of the cheapest and most promising fuels should be prioritized for scaling through mechanization and streamlined distribution. Support to manufacturers to acquire high-volume equipment and expand their sales networks will unlock a critical pathway for transitioning households away from firewood and charcoal. Lessons from Ethiopia and Rwanda show that such coordinated support along the value chain leads to higher adoption and greater environmental and health co-benefits (Thompson, 2019).

Decision ladder framework for adoption of clean cooking fuels and technologies

Based on the findings of the study, we unleash a decision criteria based on the 5 parameters of awareness, accessibility, availability, affordability, and performance. The figure 1 demonstrates the hierarchy of decision steps that households and institutions follow in making a decision to adopt a clean fuel and or an improved technology. It also demonstrates the rate at which households and institutions drop off as they go higher of the decision ladder. The shape of the figure shows that many households and institutions can get messages about clean fuels and technologies but drop off as they go higher the ladder and a few adopt. The decision points considered at each stage of the decision ladder include the following:

Awareness: What is considered at this level is: awareness of the advantages, and benefits of improved technologies and clean fuels. Awareness of the health benefits of using clean fuels and improved technologies. This determines whether an institution or household will move to the next level on the decision ladder. At this level, interventions should focus on mass communication drives that target creating awareness of the benefits, and advantages as shown in figure 2.

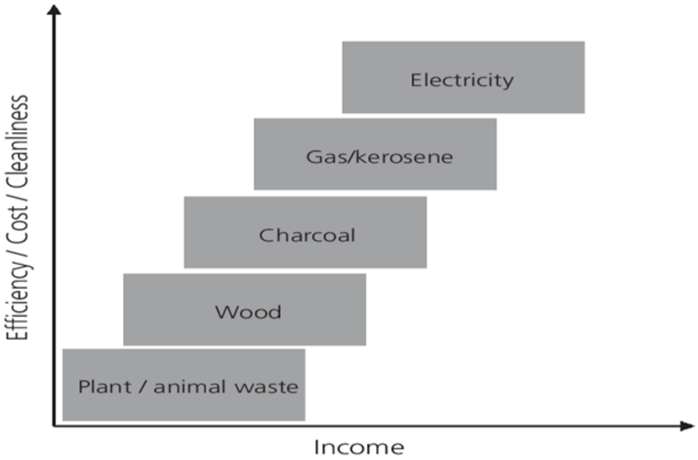

Figure 1. *Energy ladder model: Relationship between household income and transition to cleaner, more efficient cooking fuels.*

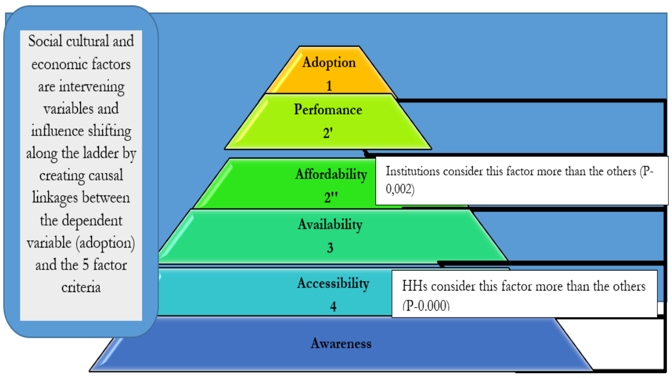

Figure 2. *Decision ladder for uptake of renewable energy fuels and technologies.*

Accessibility: What is considered at this level is: Source of the fuel or device (market, nearby shop, private/public, main grid etc. Distance from the supplier/shop or device outlet. The institution or household is concerned with the ease/flexibility with which it can get a refill of the fuel or can get a replacement or repair of the technology without incurring additional costs from the cost of refill or purchase.

Availability: What is key at this level is: consistency of the supply of the fuel or the device/technology and the reliability of the supplier or the fuel or device in terms of quality, uniformity and meeting physical characteristic requirements. Quality characteristics are also considered here.

Affordability: What is key at this level is the prices of fuel/devices, operation and maintenance costs of the devices and fuels, distance and associated costs and cost drivers of fuel and devices e.g. policy, inflation etc. The household/institution is concerned with installation costs/initial purchase costs as well as regular costs of refilling the fuel. The decision whether the switching costs are within the acceptable range according to the decision maker.

Performance: What is key at this level is the anticipated fuel saving for the improved stove the anticipated time saving while cooking the food at home and at the institution, the ease to ignite the fuel and the stove other attributes such as cleanliness of the fuel/device, emissions and additional benefits of using the stove or fuel. It is at this level that the household will decide to adopt the fuel/device or reject it.

Adoption: The household/institution will adopt the technology based on the available information concerning availability, accessibility, affordability and performance of the device as explained above. It is therefore important that any promotion of clean fuels or improved technologies should focus first on making the fuels and devices accessible, available whenever needed, are priced well and perform better than the existing fuels and technologies if the objective is to achieve sustainable use.

NB: The decision criteria is based on findings from this study and therefore the use of the same should put in consideration the context of the study.

The decision ladder mirrors findings from other clean energy adoption studies, which show that awareness alone is not sufficient to trigger uptake. According to the International Energy Agency, affordability and consistent supply are the strongest determinants of household transition to modern fuels. Furthermore, accessibility and trust in performance strongly influence repeat use and long-term adoption (Rosenthal *et al.*, 2018). In Uganda and similar contexts, the availability of fuels like LPG or briquettes may be limited to urban centers, and the cost remains a barrier for poorer communities. This is consistent with insights from (Nabukwangwa *et al.*, 2023), who emphasize that affordability and proximity often outweigh awareness when it comes to household energy choices. The decision ladder thus provides a useful diagnostic and planning tool. It can guide policymakers, NGOs, and private sector players in targeting interventions at each stage ensuring that not only are communities informed, but also able to access, afford, and trust the clean fuels and devices they are being encouraged to adopt.

Conclusion

This study provides compelling evidence that scaling up clean cooking solutions in Uganda can yield substantial environmental, health, and socio-economic benefits, directly supporting the country's commitments under the Nationally Determined Contributions (NDCs) and the National Development Plan IV (NDP IV). Household survey results revealed that over 78% of respondents still rely on biomass fuels, leading to significant indoor air pollution exposure, with average $PM_{2.5}$ concentrations exceeding 120 μg/m^3, more than eight times the WHO safe limit. Transitioning to efficient biomass stoves and modern fuels such as LPG, biogas, and electricity could reduce household emissions by 60–80%, avert an estimated 12,000 premature deaths annually linked to household air pollution, and lower deforestation rates in the cattle corridor by 15–20% over a decade. Furthermore, the socio-economic analysis showed that households adopting clean cooking solutions reported a 35% reduction in fuel expenditure and an average of 3.2 hours saved per day, time that can be reallocated to education, income generation, or community participation. These findings confirm that clean cooking is not merely a technological upgrade but a transformative pathway for environmental sustainability, gender equity, and rural-urban development. From a scientific perspective, this research makes a significant contribution by integrating behavioural adoption patterns, life-cycle emissions analysis, and socio-economic impacts into a single evidence base an approach rarely applied in sub-Saharan Africa's clean cooking discourse. By combining quantitative household survey data with spatial deforestation models, the study advances methodological frameworks for assessing the co-benefits of energy transitions in low-income settings. The results underscore the need for policy interventions that move beyond technology dissemination to include behavioural change campaigns, targeted subsidies, and community-driven financing models. Importantly, this study highlights that achieving universal access to clean cooking by 2030 is feasible if Uganda adopts a coordinated multi-sector approach, engaging ministries responsible for energy, environment, health, and gender, while leveraging international climate finance. The evidence presented here strengthens the global case for integrating clean cooking into climate change mitigation strategies, demonstrating that socially inclusive, context-specific interventions can deliver measurable health, environmental, and economic gains at scale.

DECLARATIONS

Author contribution statement: Conceptualization: A.M. and R.H.; Methodology: R.H. and A.M.; Software and validation: A.M., N.E. and R.H.; Formal analysis and investigation: A.M.; Resources: R.H.; Data curation: A.E., I.N. and M.A.; Writing original draft preparation: A.M.; Writing review and editing: N.E. and M.A.; Visualization: A.M.; Supervision: N.E.; Project administration: R.H. and BO; Funding acquisition: R.H, BO. All authors have read and agreed to the published version of the manuscript.

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