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Review

Domestic fuel affordability and accessibility in urban Rwanda; policy lessons in a time of crisis?

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ABSTRACT

Background: Cooking fuel choice and fuel switching behaviours can be influenced by both social and economic contextual factors; with implications for household air pollution exposure. The Rwandan Government have recently proposed a charcoal sale ban to reduce domestic reliance upon charcoal fuels and reduce associated respiratory health harms.
Methods: A semi-structured mobile telephone survey administered to 85 participants in an informal settlement in Kigali, Rwanda to identify (i) fuel switching as a result of COVID-19 emergency health protection 'lockdown' measures (ii) awareness of proposed charcoal sale restrictions and willingness to pay for alternative domestic cooking fuels.
Results: Of the 85 interviewed participants, 15 (17.6 %) reported a change in primary cooking fuel since the first national COVID-19 emergency 'lockdown' period (March – May), with Liquid Petroleum Gas (LPG) users moving to charcoal (n = 3; 20 %), and charcoal users to firewood (n = 7; 46.7 %) or LPG (n = 4; 26.7 %) and one firewood user to charcoal (n = 1; 6.6 %). Awareness of the forthcoming LPG subsidy (81.5 %) and charcoal ban policy proposals was high among all participants (81.5 %), with 90.7 % indicating they would change their cooking fuel as a consequence. LPG was the preferred alternative fuel of choice (89.8 %), with cost, ease of use and cleanliness reported as rationale. Forty-four percent of participants reported a willingness to pay less, 38 % to pay the same and 25 % to pay more than their current cooking fuel expenditure for a cleaner alternative fuel.
Conclusion: Domestic fuel switching as a result of economic and energy market volatility, was observed in an informal settlement in urban Rwanda as a consequence of COVID-19 emergency measures, most notably by substitution of firewood for charcoal, reflecting a regressive step in the energy ladder. Our findings demonstrate a high level of awareness and engagement with forthcoming domestic fuel policy changes in Kigali, and a large proportion of those interviewed would consider transition to cleaner domestic energy sources. This novel primary research has implications for developing domestic energy resilience to disruptive economic impacts and ensuring effective clean fuel policy implementation in East Africa.

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Introduction

Domestic cooking using solid biomass fuels (wood, dung, charcoal and crop residue) causes harmful levels of Household Air Pollution (HAP) (Smith, 1993); associated with adverse health effects throughout the life course including increased risk of low birth weight, pregnancy complications (Amegah, Quansah, & Jaakkola, 2014), acute respiratory infections (Enyew, Mereta, & Hailu, 2021; World Health Organization (WHO), 2018; Dherani et al., 2008), respiratory impairment (Pathak, Gupta, Jagdish, & Suri, 2019), cardiovascular disease (Mocumbi, Stewart, Patel, & Al-Delaimy, 2019) and cognitive impairment (Krishnamoorthy et al., 2018). HAP includes carbon monoxide (CO), particulate matter (PM), among other pollutants, typically generated by burning solid fuels using inefficient cooking stoves in poorly ventilated domestic environments. With over three million solid biomass fuels users worldwide and a substantial contribution to carbon emissions, reduction in reliance upon solid biomass fuels is integral to achievement of the United Nations Sustainable Development Goals (SDGs) (specifically SDG 7 - Ensure access to affordable, reliable, sustainable and modern energy for all) (WHO, IEA, GACC, & UNDP, 2018), and rapid, sustained transition to clean energy alternatives are urgently required worldwide.

The fuel ladder (Fig. 1) illustrates that the most polluting fuels are also typically the most affordable and most readily accessible, with economic development typically associated with cleaner fuel transition (e.g., to electricity, solar energy and LPG). However, transition up the fuel ladder is recognised to often not be undertaken as a linear process among those living in low- and middle- income countries (LMICs) with household level fuel choices determined by a complex range of factors including local availability (e.g., reliability of access), affordability, cultural preferences and household and situational contextual (Smith et al., 1994). Fuel switching behaviour varies between different countries influenced by local and national factors (Shupler et al., 2019), including wealth, level of education (Jaiswal & Meshram, 2020), cost of fuel, cleanliness, ability to cook traditional dishes (Puzzolo, Pope, Stanistreet, Rehfuess, & Bruce, 2016), safety concerns and knowledge of health benefits (Shupler et al., 2019). In addition, any reduction in HAP associated with cleaner fuel usage can be attenuated by 'stove' or 'fuel stacking', whereby traditional cooking methods are used alongside cleaner fuels (Rehfuess, Puzzolo, Stanistreet, Pope, & Bruce, 2014), or by ongoing use of solid biomass fuel sources among neighbouring households (Bruce et al., 2015) contributing to ambient air pollution exposure. However, accelerating transition to cleaner sustainable fuels would deliver significant health (World Health Organization (WHO), n.d.) and socio-economic benefits for LMICs (e.g., reduced opportunity costs associated with fuel collection (Muller & Yan, 2016)), in addition to a reduction in the environmental impacts associated with charcoal and firewood use (e.g. deforestation, erosion, increased flooding risk (Chidumayo & Gumbo, 2013)) and carbon emissions. It is anticipated that with rapid economic development, cleaner fuel use as a proportion of domestic energy will continue to increase worldwide, however, total coverage is negated by rapid population growth notably in sub-Saharan Africa where the total number of biomass fuel users is at an all-time high (International Energy Agency (IEA), 2019). Further periods of global economic uncertainty (e.g., COVID-19) and disruptive economic changes may also impact on trends towards cleaner fuel transition even among rapidly emerging nations in the global south (Ravindra et al., 2021a). Understanding potentially regressive changes in fuel choices within periods of economic uncertainty, will help inform policies and interventions for the sustained uptake of cleaner fuels.

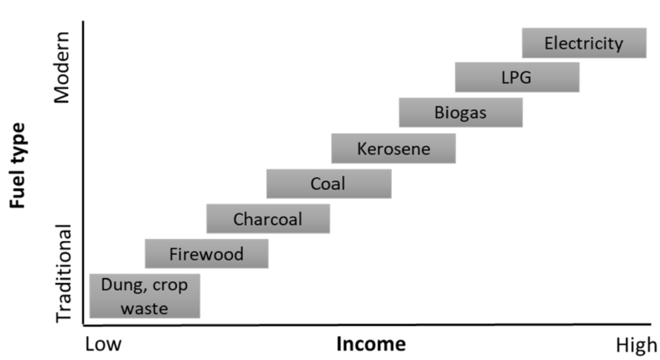

Fig. 1. The energy ladder depicting fuel within increased energy efficiency, cleanliness and cost with increasing income. Adapted from Smith, Apte, Yuqing, Wongsekiarttirat, and Kulkarni (1994).

Cost of cleaner cooking fuels and technologies is a large barrier to sustained uptake (Ravindra et al., 2021b) and therefore there needs to be an understanding of how much households are willing to pay (WTP) (Rosenbaum, Derby, & Dutta, 2015). WTP is defined as the maximum amount the participant is willing to pay for a product (Baker, Donaldson, Mason, & Jones-Lee, 2014) and has previously been used within intervention studies post-implementation for improved cookstove (Bangladesh, Malawi) (Cundale et al., 2017; Rosenbaum et al., 2015) and a LPG pay as you cook (PAYC) scheme (Kenya) (Bailis et al., 2020). WTP for improved cook stove was undervalued (Rosenbaum et al., 2015) due to affordability (Cundale et al., 2017), however, participants on the LPG PAYC scheme reported a higher WTP than the non-PAYC users (Bailis et al., 2020).

Rwanda is an ambitious, rapidly developing (GDP per capita: US$ 797.9) (The World Bank, 2021) East African country, with a high population density of 498.7 people per km^2 (The World Bank) and a population of ~13 million in 2020 (The World Bank Rwanda). In 2014, charcoal was the predominant cooking fuel used in urban Rwanda (65.5 %), with only 1.8 % of households in urban areas using cleaner cooking fuels such as LPG or electricity (National Institute of Statistics of Rwanda (NISR) & Ministry of Health (MOH), n.d.). Implementation of emergency public health restrictions, referred to as 'lockdown' measures were implemented from March–May 2020 and January–February 2021 to control the COVID-19 pandemic, with COVID-19 exerted disruptive impacts and energy market instability in sub-Saharan Africa with evidence for regressive fuel switching undertaken by informal settlement dwellers in Nairobi, Kenya reflecting changes in household circumstances, employment patterns and falling petroleum prices (Shupler et al., 2021a). Further, in May 2020 the Rwandan Government announced planned proposals to ban the use and supply of charcoal in Kigali City, to address adverse health and environmental impacts (The New Times Government) and increase the availability and uptake of LPG through a subsidy scheme. Rwanda provides a unique opportunity to explore the interplay of economic uncertainty, fuel switching behaviours and proposed policy changes. Therefore, this study aims to (i) characterise cooking fuel switching as a result of the COVID-19 emergency health protection measures; (ii) explore potential cooking fuel switching as a result of the proposed charcoal ban; (iii) investigate WTP for alternative cooking fuels, in an informal settlement in urban Rwanda.

Materials and methods

Study setting and participants

The study area was an urban informal settlement in Kigali, Rwanda, within the Kabeza cell, situated within the Muhima sectors of the Nyarugenge district. The Kabeza cell comprises seven villages (Hirwa, Ikaze, Ituze, Imanzi, Ingenzi, Sangwa, Umwezi), with a cell total of ~950 households, and predominant charcoal fuel reliance (Campbell et al., 2021; Kabera, Bartington, Uwanyirigira, Abimana, & Pope, 2020). Only one cell in Kigali was chosen due to the limitations presented by COVID-19 restrictions upon primary data collection activities, with the Kabeza cell selected due existing research undertaken with the study team (Campbell et al., 2021; Kabera et al., 2020). A convenience sample (Jupp, 2006) was identified by communication with the Kabeza cell local leader who provided mobile telephone contact numbers for eligible households and those who consented to have their number shared. One participant in each household was eligible for study participation. Of the 132 mobile telephone contact numbers provided, 119 unique residents were contacted. Of these, 85 residents completed the study questionnaire (71.4 %) and 34 (28.6 %) declined to participate.

Data collection

A semi-structured questionnaire, including open and closed questions (Leung, 2001), comprising sociodemographic characteristics, fuel usage patterns, awareness of charcoal ban and LPG subsidy proposals and willingness to pay for an alternative cooking fuel was administered by trained fieldworkers. The WTP question asked participants to state the maximum amount they would be willing to spend a month for an alternative cooking fuel, with response provided on a payment scale from 0 to 24,000 RWF, with the option to add in a value if the amount was not present on the scale. Each interview was undertaken by a single mobile telephone call on a weekday between April 2021–July 2021 during the hours of 09:00–17:00. The survey was administered verbally by simultaneous translation from English to native language (Kinyarwanda), with responses recorded in English; a method used in a previous household survey (Campbell et al., 2021) which had been demonstrated to be an effective technique.

Statistical analysis

All data collation, cleaning and analysis was undertaken within R Studio (R Core Team, 2020). Participant characteristics included: Age (15–24, 25–34, 35–44, 54–54, 55–64, 65–74, 85+ years), sex (male, female), household incomes per months in Rwandan Francs (RWF). Participants' occupational details were categorised using the internationally recognised ISCO-08 code classification (International Labor Organization, 2012), with housewife classified as an elementary occupation and an additional category for no occupation. Cooking fuel options included charcoal, firewood, ethanol, LPG, biomass pellets and none of the above. Quantitative descriptive statistics provided frequencies, percentages, medians and interquartile ranges, with univariate statistics (Kruskal-Wallis or Mann-Whitney U) undertaken to determine differences between two groups. Additional R package were required in the development of the bar chart (Lattice package (S., 2008)), scatter plot (ggplot (H, 2016) and ggpubr (Kassambara, 2020)) and Sankey diagram (networkD3 (Allaire, Gandrud, Russell, & Yetman, 2017)). The open questions (n = 2) were qualitatively analysed using inductive thematic analysis (Kiger & Varpio, 2020), with coding of answers into summary topics, which were summarised in a word cloud using the wordcloud2 package (Lang & Chien, 2018) in R Studio. Factors that were associated with the WTP for cooking fuel were determined through linear regression, using the lme4 package (Bates, Mächler, Bolker, & Walker, 2015).

Ethical approval

Ethical approval for this study was received from the College of Medicine and Health Science Institutional Review Board at the University of Rwanda (No 235/CMHS IRB/2020) and the University of Birmingham Ethics Committee (ERN_19-0252B). Fully informed consent was obtained from each study participant at the start of the survey. Participants were free to withdraw at any point during the study and have their data destroyed.

Results

Participant characteristics

A total of 85 mobile telephone surveys were completed among 67 (78.8 %) women and 18 (21.2 %) males, of age range 25–74 years (Fig. 2; Appendix 1A and 1B). Overall, 42 (49.4 %) participants were employed in elementary occupation (Females: 40; Males: 2), 22 (25.9 %) as professionals (Females: 16; Males: 6), 19 (22 %) (Females: 9; Males: 10) in other occupations (services, craft, agriculture or technicians); and two (2.4 %) participants, both female, noting unemployment (at time of interview). Median household income was 60,000 RWF; IQR: 40,000–120,000 RWF with proportion of monthly household income spent on cooking fuel in the range of 3–60 % (Female: 3–60 %; Male: 6–20 %). Cooking fuel costs comprised a higher proportion of the total income in low-income households compared to high-income households ($p \le 0.001$ – Appendix 2).

Three cooking fuel types were reported to be in use at time of interview: LPG (n = 23), charcoal (n = 54) and firewood (n = 8). A significant relationship between fuel type (at time of interview) and household income was observed ($p \le 0.001$), with LPG users having the highest household incomes compared to those using firewood, who were more likely to be in the lowest household income group (Fig. 1). Among charcoal fuel

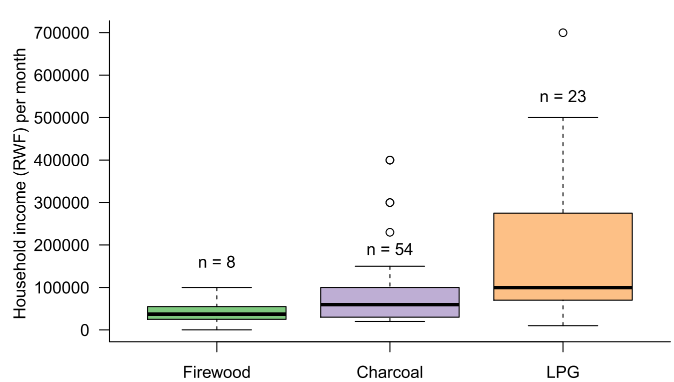

Fig. 2. Box plot of cooking fuel use at the time of interview by household income per month (median values represented by black horizontal line, maximum and minimum values represented by whiskers). A significant association was observed (H (2) = 15.7; $p \le 0.001$), assessed using the Kruskal Wallis test.

users, the majority purchased charcoal from the local market (n = 48), with fewer individuals purchasing charcoal from wholesalers (n = 4), mobile sellers (n-3) friends or family members (n = 1).

Fuel switching

Fuel type changes during COVID-19 restrictions

Prior to the COVID-19 pandemic and associated lockdown measures the majority of survey participants (n = 61; 71.8 %) reported using charcoal fuel for cooking, 22 (25.9 %) LPG and two (2.3 %) firewood. However, during the restrictions 15 (17.6 %) participants switched their cooking fuel, with three (20 %) LPG users switching to charcoal, seven (46.7 %) charcoal users switching to firewood, four (26.7 %) charcoal users switching to LPG and one (6.6 %) firewood user switching to charcoal (Fig. 3). Most respondents (79; 92.9 %) reported the quality of fuel to have changed during this period including 13/15 respondents who switched cooking fuels.

Awareness of forthcoming domestic energy policy proposals

Out of the 54 participants (Female: 49; Male: 5) who cooked using charcoal fuel, 44 (81.5 %) were aware of the proposed charcoal ban with 49 out of 54 (90.7 %) reporting that they would change their fuel if a charcoal ban was implemented. Awareness of the LPG subsidy proposals was also high among the 54 charcoal users with 44 (81.5 %) aware of specific proposals. LPG (44/49–89.8 %) was the fuel of preference for future use, with cleanliness the main reason provided (n = 23), along with speed of use (n = 16), ease of use (n = 9), cost (n = 7), personal knowledge (n = 7), availability (n = 6), good of the environment (n = 4), knowledge in the neighbourhood (n = 2) and they aspire to have LPG in their home (n = 1) (Fig. 4). However, one participant indicated they would switch to firewood due to cost constraints (Quote: "cheap and affordable") and another reported switching to an electric cooker for safety reasons (Quote: "change to the electric cooker because has low risk of fire accidents compared to LPG"). Finally, three participants reported they would switch to biomass pellets reporting ease of use (n = 2) and equivalence to using charcoal (n = 1).

Willingness to pay for alternative clean cooking fuel sources

Participants who cooked on charcoal were asked about the maximum they would be willing to pay per month for an alternative cooking

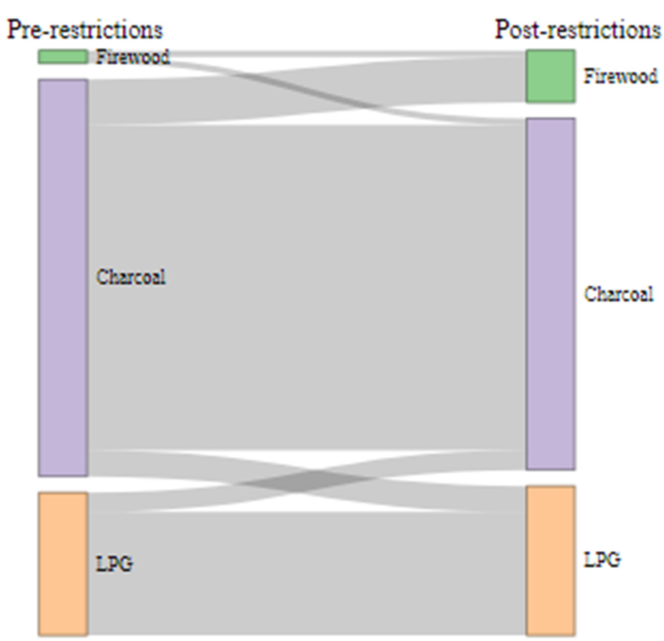

Fig. 3. Cooking fuel changes occurring among 15 study participants during a period of COVID-19 emergency health protection measures in March – May 2020.

Fig. 4. Word cloud for the rationale stated by participants (n = 49) for alternative fuel choices arising from charcoal ban implementation (clean = 23, quick = 16, easy = 11, cost = 8, personal knowledge = 7, available = 6, environment = 4, neighbourhood knowledge = 2, equivalent = 1, aspiration = 1, safety = 1).

fuel if a ban is implemented. Of the 54 charcoal users, WTP for cooking fuel ranged from 500 to 20,000 RWF, with most common reason behind the amount chosen stated to be affordability (n = 40 out of 54) (Fig. 5). Participants on higher incomes were willing to pay more for cooking fuel than those on lower incomes (p = 0.001 – Appendix 3). Overall, to change their cooking fuel to a cleaner source, 13 (25.0 %) were willing to pay more, 16 (30.8 %) the same amount for cooking fuel and 23 (44.2 %) stated they wanted to pay less. Fig. 6 illustrates that those participants who currently spend the most on charcoal are willing to pay less for cooking fuel after a charcoal ban. There was no observed difference in the amount users were willing to pay for cooking fuel and the choice of alternative cooking fuel if the charcoal ban came into force (p = 0.795 – appendix 4); nor by sex (p = 0.085 – appendix 4). However, in a regression analysis after adjusting for confounders (Table 1), for every increase (1 RWF) in WTP the participant's income increases by 0.2 RWF (95 % CI: 0.00–0.04). In addition, participants aged 65–74 years were WTP 11060 RWF (95 % CI: 2498–19,621) more for alternative fuels than those aged 25–34 years. Due to the presence of two outliers reflecting participants who currently spend a large amount on cooking fuel a sensitivity analysis was undertaken excluding these data points (Appendix 5). The sensitivity analysis showed that participants' income was no longer a significant factor.

Discussion

Our primary cross-sectional study of 85 participants residing in an informal settlement in urban Kigali has shown evidence of fuel switching (17.6 %) coinciding with the COVID-19 pandemic as reported previously elsewhere in sub-Saharan Africa. The evidence of fuel switching during the COVID-19 highlights the potential reversal of progress towards SDG-7 in sub-Saharan Africa, due to economic and societal consequences of the pandemic. The announcement of the charcoal ban in Kigali by the Rwanda Government will require charcoal using households to switch fuel. Encouragingly, a high proportion of survey participants were aware of the charcoal ban proposals and most were willing to change to using cleaner fuels (89.8 %), with the most common reasons stated being cost and cleanliness of the fuel. This indicates flexibility in fuel usage behaviour, suggesting choices can be influences by both external economic impacts and underlying personal considerations, including understanding of health impacts.

Fig. 5. Word cloud illustrating the reasons given for the chosen amount of money participants (n = 53) are willing to pay for alternative cooking fuels. (Affordable = 40, Current expenditure on fuel = 4, Equivalents to LPG or other fuels = 3, Less than charcoal = 23 Product value = 2, More than charcoal = 1).

These approaches will help formulate policies which mitigate unintended consequences in the context of national policy measures.

Domestic fuel switching may be due to economic situational factors (e.g., fuel market volatility, income, energy access (Ravindra et al., 2021b)) as previously documented within Nairobi's informal settlements during the first COVID-19 lockdown in 2020 (Shupler et al., 2021a). In this large scale mobile telephone survey of 194 residents, the largest switch was from LPG to kerosene as a consequence of falling petroleum prices and therefore affordability (Shupler et al., 2021a). We find that income may influence cooking fuel choice, which may have contributed to 17 users changing to firewood, from kerosene and LPG, which is readily and freely available by collection. Our findings support these previous observations, with evidence for movement towards more affordable fuels associated with reduced household income with 46.6 % households switching from charcoal to firewood fuel. However, an approximately equal proportion switched from charcoal to LPG and LPG to charcoal, which could reflect the relative expense of charcoal compared to LPG in Rwanda. Nevertheless, charcoal remains the dominant fuel used in Kigali due to lesser start-up costs, traditional cooking practices and being able to purchase in small amounts (Campbell et al., 2021). In addition, the pay as you go (PAYGO) LPG scheme in Kenya supported cleaner cooking throughout the COVID-19 lockdown (Shupler et al., 2021b); however, there is currently no equivalent scheme within Rwanda. Interestingly, no participants reported switching to kerosene as a cooking fuel, which dominated the findings from Nairobi (Shupler et al., 2021a); however kerosene is more typically used for lighting in sub-Saharan Africa. Nevertheless, there was some indication of impacts upon fuel quality although the extent to which this factor influences fuel switching behaviour is beyond the scope of the current study. These findings are therefore indicative of the need to improve understanding and improve monitoring of fuel switching behaviour for example by longitudinal and qualitative studies in this context, as well as approaches to encourage sustained cleaner fuel switches.

We also identified flexibility in response to forthcoming domestic fuel policy proposals, with most residents indicating their readiness to switch to clean cooking alternatives. In some cases, cooking fuel expenditure makes up to 60 % of the participant's income, indicating the vulnerability of households to economic change and uncertainty, which will ultimately affect choice of cooking fuel and food security. Our findings may be influenced by social acceptability bias in this study context. In addition, there is a widespread aspiration to cook using LPG, but actual uptake may be influenced by external factors such as price of fuel, market availability and national economic situation (Alem, Beyene, Köhlin, & Mekonnen, 2015; Muller & Yan, 2016). Understanding the patterns of fuel switching, including potential for stove or fuel stacking (where polluting cooking fuels are used alongside cleaner interventions) is important given the potential for negative unintended consequences arising from fuel restriction proposals (Jun, 2021; Pachauri, 2019). Although stove and fuel stacking has not been explored within this study, it is important to recognise the ongoing access to cheap and readily available biomass is likely to increase the risk of reversion to more polluting fuels (Shankar et al., 2020). Households experiencing financial difficulty or reduced incomes may switch to freely available firewood fuel, as indicated in the COVID-19 lockdown period. This has been documented previously in other settings and risks proposals, which are negating the desired health (Woolley et al., 2021) and environmental (Bockarie, Marais, & Mackenzie, 2020) benefits. Willingness to pay less than their current fuel expenditure for cleaner fuel alternatives was reported by 44.2 % of participants. Some participants explained that the amount they are WTP was equivalent to the price of LPG suggesting that there is a level of awareness of fuel costs, and that the responses given were based on the price of cooking fuel, rather than personal choice. However, the price and WTP for cooking fuel does not address the issue of the start-up costs for LPG equipment, which requires further exploration. These findings may only be applicable to informal urban settings, and further research is required with a sample representative of the wider urban population in Rwanda.

Aside from cooking fuel costs, personal motivations towards fuel choice were dominated by availability, ease and speed of use, familiarity and knowledge; reasons which are reflected within the literature (Stanistreet, Puzzolo, Bruce, Pope, & Rehfuess, 2014). The identification

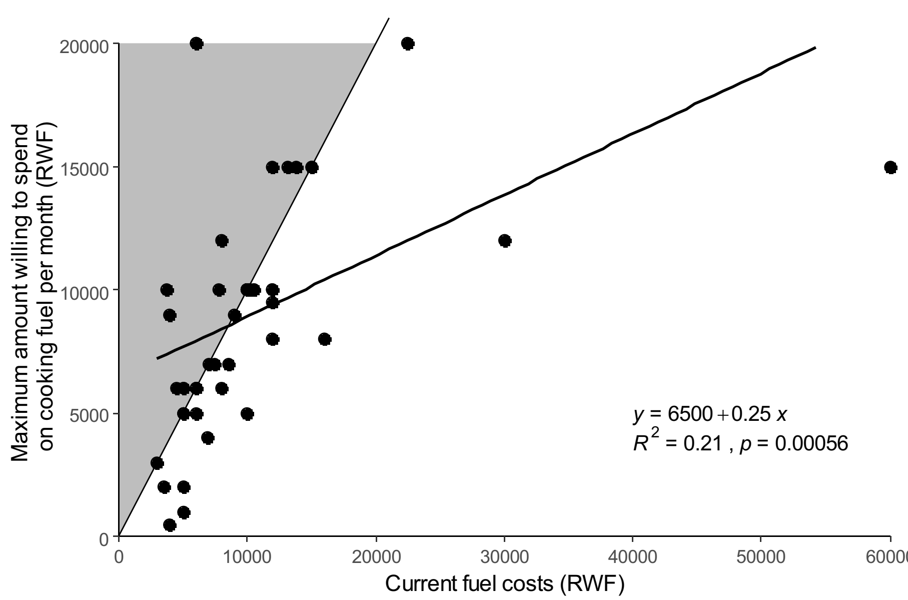

Fig. 6. Relationship between current fuel expenditure and WTP for alternative fuels (RWF) per month. (Grey area designates participants who are willing to pay more for cooking fuel than they currently do).

Table 1
Unadjusted and adjusted linear regression for the association between WTP for alternative cooking fuels and participants' characteristics (n = 52).

	Unadjusted		Adjusted	
	β (95 % CI)	p value	β (95 % CI)	p value
Monthly household income (RWF)	0.03 (0.01–0.04)	0.001	0.02 (0.00–0.04)	0.027
Proportion of income spent on cooking fuel monthly (%)*	−94.9 (−267–76.9)	0.272	16.3 (−161–194)	0.854
Age (years)				
25–34	Ref.		Ref.	
35–44	1381 (−1523–4285)	0.344	434 (−2368–3235)	0.756
45–54	−324 (−3908–3260.8)	0.857	564 (−2815–3944)	0.738
55–64	3510 (−2123–9142)	0.216	4445 (−754–9643)	0.092
65–74	12,177 (2922–21,431)	0.011	11,060 (2498–19,621)	0.013
Sex				
Female	Ref.		Ref.	
Male	4311 (−477–9100)	0.077	1785 (−3136–6705)	0.469
Occupation				
Elementary	Ref.		Ref.	
Non-elementary	2132 (−526–4786)	0.113	1311 (−1392–4014)	0.333

Footnote: 95 % CI = 95 % confidence interval, Ref. = reference group for categorical variables. * = missing data – two participants did not provide a proportion of income spent of cooking fuel. $R^2 = 0.341$.

of the value of community knowledge in cooking fuel choice, presents a potential opportunity for community initiatives to support cleaner fuel transition. However, barriers to LPG use could also be identified as those participants who did not choose LPG as their choice of fuel after the charcoal ban is introduced cited "safety" and "similarity of fuel to charcoal" as reasons for their choice of fuel. Therefore, there is a need to address and reduce these barriers to cleaner fuel use, to complement legislative fuel restrictions. Supporting sustained use of cleaner fuel use to reduce HAP exposure is a complex public health policy intervention requiring a multifaceted approach. The Rwandan Government has proposed a LPG subsidy to complement the charcoal fuel restrictions thereby providing support from a financial perspective during the transition phase. The need for such provision is supported by encouraging results from the PAYGO LPG pilot, which highlighted the benefits of being able to buy small amounts of LPG and help with equipment costs; but high levels of stove and fuel stacking remained (Perros, Buettner, & Parikh, 2021). Therefore, without integrating the knowledge and education support into policies, a long-term uptake of cleaner fuels could be sub-optimal.

Despite the complexities of undertaking remote research in a pandemic, 85 surveys were undertaken, with a response rate of 64.4 %. However, as a result of undertaking telephone surveys there is the potential that the non-respondents were unavailable due to work or other external commitments, and could explain the higher proportion of female compared to male respondents; in addition, to potentially missing households without a mobile telephone. Although this study is of a small scale undertaken among residents living in one cell within Kigali, demonstrates the ability to conduct rapid and responsive research via mobile phone and has the potential to scale-up future research coverage to wider areas across urban Rwanda, to compare and contrast different fuel switching behaviours (Bartington, Pinchoff, & Avis, n.d.). Further research is required to better understand long-term trends in transient fuel usage and switching, both prior to and after the charcoal ban thereby capturing both negative and positive consequences. Investigating these patterns has implications for formulating successful fuel transition policies which improve both access and uptake whilst minimising potential for harmful or negative outcomes, thereby optimising health and environmental benefits.

Conclusion

We identified primary evidence via telephone interview of domestic fuel switching among residents in an urban informal settlement during the early phase of the COVID-19 pandemic in Kigali Rwanda; notably towards more polluting fuels. Households are evidently highly vulnerable to fuel price volatility, with a high proportion of income spent on cooking fuels, particularly among existing biomass fuel households. Long-term policy proposals to phase out charcoal and subsidise LPG access will require careful consideration to mitigate risk of unintended consequences arising from switching to more polluting solid fuels (e.g., firewood) and to enable cleaner fuel to be affordable at a household level.

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CRediT authorship contribution statement

Conceptualization, K.E.W., S.E.B., G.N.T; methodology, K.E.W., S.E.B., G.N.T, S.J.; investigation, K.E.W., A.M., C.M., O.A.; resources, K.T.; data curation, K.E.W.; visualization, K.E.W.; writing—original draft preparation, K.E.W.; writing—review and editing, S.E.B., G.N.T., F.D.P., S.G., K.T., S.J. funding acquisition, K.E.W., S.E.B., G.N.T., F.D.P. All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

The authors declare no conflict of interest.

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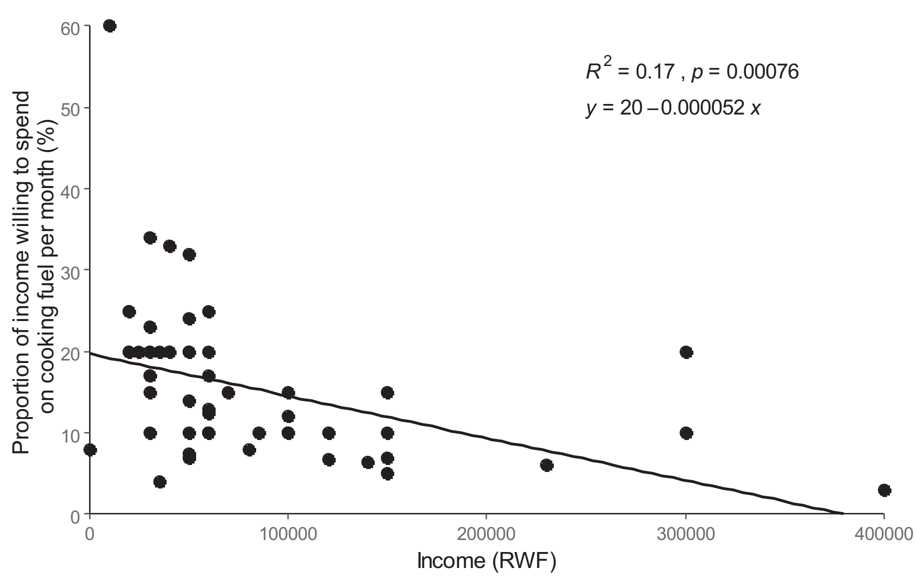
Appendix A

Appendix 1
Participant characteristics by (A) sex and (B) current fuel use.

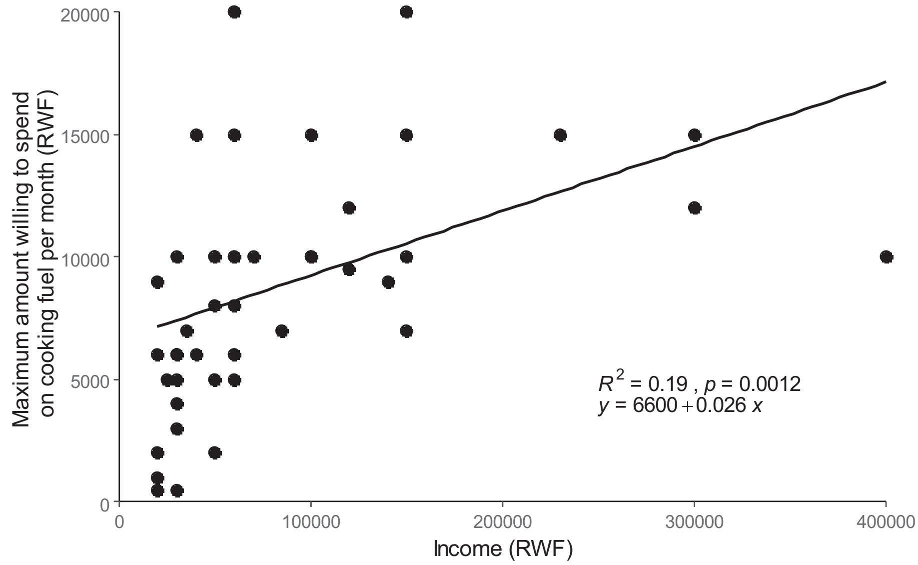
A	Female (n = 67)	Male (n = 18)	Total (n = 85)	P value
Age (years)				0.616
25–34	22 (32.8 %)	7 (38.9 %)	29 (34.1 %)	
35–44	27 (40.3 %)	9 (50.0 %)	36 (42.4 %)	
45–54	14 (20.9 %)	1 (5.6 %)	15 (17.6 %)	
55–64	3 (4.5 %)	1 (5.6 %)	4 (4.7 %)	
65–74	1 (1.5 %)	0 (0.0 %)	1 (1.2 %)	
Cooking fuels used at time of interview				<0.001
Charcoal	49 (73.1 %)	5 (27.8 %)	54 (63.5 %)	
Firewood	8 (11.9 %)	0 (0.0 %)	8 (9.4 %)	
LPG	10 (14.9 %)	13 (72.2 %)	23 (27.1 %)	
Occupation				<0.001
Elementary	42 (62.7 %)	2 (11.1 %)	44 (51.8 %)	
Non-elementary	25 (37.3 %)	16 (88.9 %)	41 (48.2 %)	
Monthly household income (RWF)				<0.001
Mean (SD)	78,510 (73146)	236,944 (199095)	112,061 (128319)	
		For Charcoal users only		
	N = 49	N = 5	N = 54	
Proportion of income spent on cooking fuel monthly (%)				0.538
Missing	1	1	2	
Mean (SD)	15.7 (9.0)	13.3 (5.9)	15.5 (7.4)	
Maximum willing to spend on cooking fuel per month (RWF)				0.077
Missing	0	1	1	
Mean (SD)	8439 (4592)	12,750 (4500)	8764 (4686)	

B	Charcoal (n = 54)	Firewood (n = 8)	LPG (n = 23)	Total (n = 85)	P value
Age (years)					0.995
25–34	18 (33.3 %)	3 (37.5 %)	8 (34.8 %)	29 (34.1 %)	
35–44	22 (40.7 %)	4 (50.0 %)	10 (43.5 %)	36 (42.4 %)	
45–54	10 (18.5 %)	1 (12.5 %)	4 (17.4 %)	15 (17.6 %)	
55–64	3 (5.6 %)	0 (0.0 %)	1 (4.3 %)	4 (4.7 %)	
65–74	1 (1.9 %)	0 (0.0 %)	0 (0.0 %)	1 (1.2 %)	
Sex					<0.001
Female	49 (90.7 %)	8 (100.0 %)	10 (43.5 %)	67 (78.8 %)	
Male	5 (9.3 %)	0 (0.0 %)	13 (56.5 %)	18 (21.2 %)	
Occupation					0.003
Elementary	34 (63.0 %)	5 (62.5 %)	5 (21.7 %)	44 (51.8 %)	
Non-elementary	20 (37.0 %)	3 (37.5 %)	18 (78.3 %)	41 (48.2 %)	
Monthly household income (RWF)					<0.001
Mean (SD)	87,315 (87877)	41,898 (29717)	194,565 (183234)	112,061 (128319)	

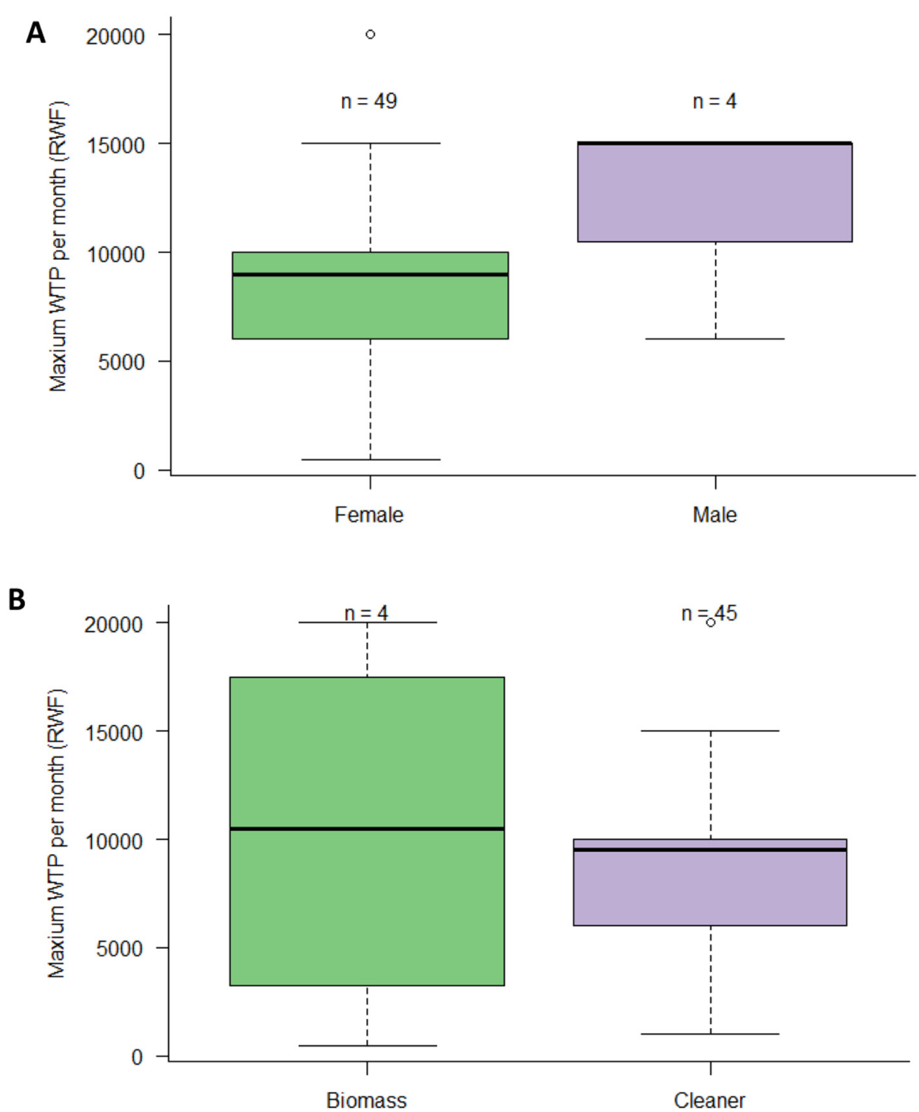
Footnote: Continuous variables reported as mean and standard deviation (SD). Categorical variables reported as count (n) and percentage (%).
Abbreviations: RWF = Rwandan franc.



Appendix 2. Relationship between the proportion of income willing to spend and current income per month



Appendix 3. Relationship between willingness to pay for cooking fuel and participant's income per month.



Appendix 4. Box plots of the different in the amount willing to pay for cooking fuel per month against (A) Sex (B) Proposed fuel type to change to when the charcoal ban is enforced. Difference between groups determined with a Mann-Whitney U test (A) $U = 97.5$; p = 0.795 (B) U = 47; p = 0.085. (Abbreviation: WTP - Willingness to pay)

Appendix 5

Unadjusted and adjusted linear regression excluding outliers for the association between WTP for alternative cooking fuels and participants' characteristics (n = 50).

	Unadjusted		Adjusted	
	β (95 % CI)	p value	β (95 % CI)	p value
Monthly household income (RWF)	0.03 (0.01–0.05)	0.006	0.02 (−0.00–0.05)	0.076
Proportion of income spent on cooking fuel monthly (%)*	−100.35 (−273.19–72.49)	0.249	23.59 (−174.37–221.56)	0.811
Age (years)				
25–34	Ref.		Ref.	
35–44	1366.07 (−1542.66–4274.80)	0.349	436.96 (−2471.37–3345.29)	0.743
45–54	715.28 (−2936.98–4367.53)	0.695	560.06 (−2957.68–40.77.80)	0.749
55–64	3770.83 (−1743.95–9285.62)	0.175	4434 (−2471.37–3345.29)	0.102
65–74	12,437.50 (3402.32–21,472.68)	0.008	10,972.31 (2021.28–19,923.33)	0.018
Gender				
Female	Ref.		Ref.	
Male	3468.09 (−1970.05–8906.22)	0.206	1990.59 (−3470.85–7452.04)	0.466
Occupation				
Elementary	Ref.		Ref.	
Non-elementary	1751.74 (−936.91–4440.38)	0.196	1289.12 (−1553.72–4131.97)	0.365

Footnote: 95 % CI = 95 % confidence interval, Ref. = reference group for categorical variables. * = missing data – two participants did not provide a proportion of income spent of cooking fuel. $R^2 = 0.311$.

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