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Widening inequities in clean cooking fuel use and food security:
compounding effects of COVID-19 restrictions and VAT on LPG in
a Kenyan informal urban settlementMatthew Shupler^{1,*} , Diana Menya², Edna Sang², Rachel Anderson de Cuevas¹ , Judith Mang'eni²,
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E-mail: m.shupler@liverpool.ac.uk**Keywords:** liquefied petroleum gas, clean cooking, energy access, COVID-19, VAT, informal urban settlementSupplementary material for this article is available [online](#)**Abstract**

Universal access to cleaner cooking fuels (including liquefied petroleum gas (LPG)) is a key target of Sustainable Development Goal 7. Currently, approximately 40 million Kenyans rely on polluting cooking fuels (e.g. charcoal, wood). While the Kenyan government aims to rapidly scale up use of LPG for cooking by 2030, COVID-19 restrictions and a 16% value added tax (VAT) re-introduced on LPG in 2021 have likely hampered progress in LPG uptake. We aimed to quantify the effect of these economic shocks on food and energy security in Langas informal urban settlement in western Kenya. We further evaluated whether households most adversely affected by COVID-19 restrictions were more likely to be socioeconomically impacted by the VAT re-imposition. A cross-sectional survey ($n = 1542$) assessed changes in cooking fuel patterns, food security and livelihoods of primary cooks due to these two economic shocks. While under COVID-19 restrictions, 75% ($n = 1147$) of participants reported income declines and 18% ($n = 164$) of participants using LPG ($n = 922$) switched their primary cooking fuel to charcoal, wood or kerosene. Households reporting lower income while under COVID-19 restrictions had 5.3 times (95% CI:[3.8,7.4]) the odds of experiencing food insecurity as those with no change in income. Unemployment and food insecurity under COVID-19 restrictions were substantially higher among informal sector workers (70% and 60%, respectively) compared with business/government employees (45% and 37%, respectively). Following the VAT re-introduction, 44% ($n = 356$) of households using LPG consumed less, and 34% ($n = 276$) cooked more frequently with polluting fuels. Individuals switching away from LPG under COVID-19 restrictions had 3.0 times (95% CI:[2.1,4.3]) the odds of reducing their LPG consumption due to the VAT re-introduction as those maintaining use of LPG. COVID-19 restrictions and the VAT re-introduction disproportionately negatively affected informal sector workers' livelihoods. A zero-rating of VAT on LPG can help alleviate deepened inequities in LPG access in Kenya.

1. Introduction

Globally, approximately 2.8 billion people rely on polluting fuels (e.g. wood, charcoal, kerosene) for household energy, primarily in low- and middle-income countries (LMICs) [1]. Inefficient burning of polluting fuels emits high household air pollution (HAP)

levels, leading to an increased risk of several infectious and non-communicable respiratory and cardiovascular diseases [2, 3]. Exposure to fine particulate matter (PM_{2.5}) found in HAP is the second largest environmental risk factor for ill-health, responsible for roughly 2.3 million deaths in 2019 [4]. Residential use of polluting fuels also generates an estimated

25% of global emissions of black carbon (BC) [5], a short-lived climate forcing pollutant that is the second largest contributor to climate change after CO₂ [6, 7]. To help mitigate climate change, improve the health of billions of individuals exposed to HAP and achieve universal access to affordable, modern household energy (Sustainable Development Goal 7), rapid scale-up of cleaner cooking solutions is needed.

The fastest path to scaling cleaner cooking fuels in many LMICs includes expanding access to liquefied petroleum gas (LPG). Although a fossil fuel, LPG emits lower levels of fine particulate matter and BC than polluting cooking fuels [8, 9] and can also reduce unsustainable deforestation [10–12]. Thus, LPG can serve as a ‘bridge’ fuel for protecting public health until the infrastructure needed for renewable electricity is available to the hardest-to-reach households [13].

1.1. The state of clean cooking in Kenya

In sub-Saharan Africa (SSA), 85% of the population (approximately 900 million people) rely on polluting biomass or kerosene fuels; over twice the global average (40%) [14]. The number of Africans cooking with polluting fuels is expected to reach one billion by 2030 [15]. To help accelerate clean cooking fuel access, several countries in SSA have established ambitious goals to scale up LPG use by 2030 [16]. In Kenya, the government is targeting an expansion of LPG use from 20% of the population in 2016 to 35% by 2030 [16, 17]. In 2016, Kenya’s Treasury zero-rated the value added tax (VAT) on LPG and increased the VAT on kerosene to 16%. Partly due to these efforts, the proportion of the Kenyan population primarily cook with LPG in 2020 (24%) increased by 4% from 2016 [18].

1.2. Clean cooking access in Kenyan informal settlements

Informal settlements are characterised by high population density, informal housing and inadequate infrastructure, sanitation and water facilities [19]. In Kenyan informal settlements, energy for cooking, lighting and heating can make up roughly 30% of monthly household expenditures [20]. Residents of informal settlements generally rely on informal work and have little financial savings; thus, many cannot afford to use LPG. Those that do cook with LPG may revert to polluting cooking fuels when LPG prices increase [21]. With over half (55%) of the Kenyan population living in informal settlements [22], overcoming the affordability barrier to sustained use of LPG for cooking in urban Kenya is critical.

1.3. Economic hardship and cooking fuel decisions

Due to the emergence of the COVID-19 pandemic in 2020, the Kenyan Government implemented several containment measures, including a nationwide dusk-to-dawn curfew, closure of schools, restaurants and

businesses and restrictions on public gatherings. In the five weeks after implementation of these restrictions, household incomes declined by up to one-third [23] and over 4.6 million Kenyans lost their employment [24]. The negative impact on livelihoods was particularly severe among Kenyan informal sector workers [25].

International LPG prices also increased because of the COVID-19 pandemic, with Kenya particularly impacted given the lack of price regulations on LPG. Consequently, many Kenyans switched from LPG cheaper polluting fuels (e.g. wood) to reduce their household expenditures [23]. Our previous study conducted in an informal settlement in Nairobi found that one quarter (27%) of families switched from LPG to wood or charcoal during a COVID-19 lockdown (April 2020) [26].

On 1 July 2021, approximately 16 months after the first COVID-19 restrictions were implemented in Kenya, the Government’s exemption of LPG from VAT was nullified. The increased cost of LPG due to the VAT re-introduction was passed onto consumers. Thus, the combinations of these events may have intensified the unaffordability of LPG, particularly among poorer Kenyans living in informal settlements.

1.4. Study aims

This study evaluates if two significant events that started in 2020 and 2021 impacted households’ cooking behaviors and food security status in an informal settlement in Western Kenya. Alterations in the type of primary fuel used (e.g. from LPG to a polluting fuel) and declines in the amount of LPG consumed would broadly signal stalled progress in clean cooking access, a key monitoring indicator for United Nations Sustainable Development Goal 7. This study further investigates potential compounding impacts of COVID-19 restrictions and the VAT re-introduction on livelihoods and energy and food security to determine if particular sub-groups (e.g. lower-income households, informal sectors workers) were disproportionately affected.

2. Methods

This study was conducted near the city of Eldoret, located in the Rift Valley in Uasin-Gishu county in western Kenya. Eldoret is the fifth largest city in Kenya and home to over 127 000 individuals. Eldoret is primarily an agricultural town but is rapidly urbanizing. As in many urban contexts in Africa, urbanization in Eldoret has brought with it extreme inequalities marked by residents living in overcrowded spaces in houses with poor ventilation with a lack of clean water and sanitation [27]. This study takes place in one of the poorer areas of Eldoret, specifically in Langas informal settlement, located seven kilometres from the city center.



Figure 1. Concepts assessed in the cross-sectional survey.

From August to October 2021, 1542 randomly selected primary cooks from Langas were surveyed via door-to-door sampling. The cross-sectional surveys included questions about sociodemographics, cooking behaviors, LPG consumption patterns and perceptions about using the fuel (figure 1). Surveys also asked participants to retrospectively self-assess the impact of the VAT re-levied on LPG and COVID-19 restrictions on their finances, food security and energy security.

Prior to data collection, researchers from the University of Liverpool and Moi University worked together to develop the survey questions to ensure they were culturally appropriate. After finalizing the surveys, the recruited field team was trained on the aims of the study and piloted the surveys on an online platform (Mobenzi Researcher, Mobenzi, South Africa) using smartphones.

Before being enrolled in the study, individuals were informed about the aims of the study, that their participation was voluntary, that they can choose to stop the survey at any time and that their data will be kept confidential. Following the consent process, the surveys required approximately 25 min to complete and were conducted face-to-face. Data was securely stored in the Mobenzi application on the smartphone, which provided data encryption at all times, including during wireless transfer to the cloud when connected to the internet.

Data was monitored weekly on the Mobenzi Cloud to ensure data quality and weekly meetings

were held with study coordinators to address any issues that arose in the field. At the end of data collection, the data was exported from Mobenzi and imported to statistical software, R version 3.6.0 [28] for data analysis.

Descriptive statistics, including odds ratios and 95% confidence intervals (95%CI), of the associations between COVID-19 restrictions and the VAT re-introduced on LPG with changes in food security, cooking patterns, primary cooking fuel used, income and employment. Additionally, the association between self-reported annual per capita LPG consumption (kilograms/capita yr^{-1}) with various household socioeconomic and LPG supply-side factors is examined.

Ethical approval was obtained from the Institutional Research and Ethics Committee for Moi Teaching and Referral Hospital and Moi University in Kenya and the University of Liverpool in the United Kingdom. Informed consent was obtained from all participants prior to conducting the study.

3. Results

Approximately 90% ($n = 1380$) of the 1542 sampled primary cooks were female. Participants cooking primarily with polluting fuels were seven years older (37 years), on average, than those cooking primarily with LPG (30 years) (table 1). Nearly all households (97%) had access to electricity for lighting, however,

Table 1. Characteristics of study population by type of primary cooking fuel.

Characteristic	Overall (<i>n</i> = 1542)	LPG primary cooking fuel (<i>n</i> = 576)	Polluting primary cooking fuel (<i>n</i> = 966) ^a
Demographics			
Age (mean (SD))	34.6 (21.9)	30.5 (10.6)	37.0 (26.3)
Sex			
Female	1380 (90%)	501 (87%)	879 (92%)
Household head has regular salary			
Yes	621 (40%)	249 (43%)	372 (39%)
No	914 (59%)	328 (57%)	586 (61%)
# of household members			
1–2	268 (18%)	152 (26%)	116 (12%)
3–4	662 (43%)	278 (48%)	384 (40%)
5–10	605 (39%)	147 (26%)	458 (48%)
Socioeconomic status			
Household size			
Single room	616 (40%)	221 (38%)	395 (41%)
Two rooms	595 (39%)	234 (41%)	361 (38%)
Three or more rooms	322 (21%)	121 (21%)	201 (21%)
Monthly household income			
<5000 KES	484 (31%)	155 (25%)	329 (34%)
5000–10 000 KES	379 (25%)	126 (22%)	253 (26%)
>10 000 KES	312 (20%)	153 (27%)	159 (17%)
Do not know/will not answer	360 (23%)	143 (25%)	217 (23%)
Household head education			
No education	23 (2%)	3 (1%)	20 (2%)
Primary	355 (23%)	60 (10%)	295 (31%)
Secondary	906 (60%)	345 (60%)	561 (59%)
University	234 (15%)	166 (29%)	68 (7%)
Household head occupation			
Business owner	505 (38%)	196 (40%)	309 (36%)
Informal sector worker	398 (29%)	115 (23%)	283 (33%)
Government/business employee	250 (19%)	137 (28%)	113 (13%)
Craftsperson	93 (7%)	23 (5%)	70 (8%)
Farmer	46 (4%)	5 (1%)	41 (5%)
Unemployed/retired/student	48 (3%)	17 (3%)	31 (4%)
Cooking environment			
Cooking location			
Main house (no separate room)	835 (55%)	302 (53%)	533 (56%)
Main house (separate room)	491 (32%)	262 (46%)	229 (24%)
Outside of house (separate room)	146 (10%)	9 (1%)	137 (14%)
On porch/open air	56 (4%)	2 (0%)	54 (5%)
Primary lighting fuel			
Electricity	1,492 (97%)	576 (100%)	916 (96%)
Kerosene	21 (1%)	0	21 (2%)
Solar lamp	13 (1%)	0	13 (1%)
Candle	9 (1%)	1 (0%)	8 (1%)
Heating fuel			
None	1,004 (65%)	404 (70%)	600 (63%)
Charcoal (jiko) stove	513 (33%)	165 (29%)	348 (36%)
Open fire/wood stove	11 (1%)	2 (0%)	9 (1%)
Electric heater	7 (1%)	6 (1%)	1 (0%)
Obtain any cooking fuels for free			
No	1494 (97%)	571 (99%)	930 (96%)
Yes	41 (3%)	5 (1%)	36 (4%)
Perceptions of LPG			
LPG accessibility			
Easy to obtain	1076 (81%)	456 (79%)	620 (85%)
Not so difficult to obtain	234 (18%)	114 (20%)	120 (14%)
Difficult to obtain	15 (1%)	5 (1%)	10 (1%)

(Continued.)

Table 1. (Continued.)

Characteristic	Overall (<i>n</i> = 1542)	LPG primary cooking fuel (<i>n</i> = 576)	Polluting primary cooking fuel (<i>n</i> = 966) ^a
LPG safety			
Very safe	383 (28%)	175 (30%)	208 (27%)
Safe	899 (66%)	387 (67%)	512 (67%)
Dangerous	62 (5%)	13 (3%)	49 (6%)
LPG ability to cook variety of dishes			
Easy	562 (43%)	246 (43%)	316 (43%)
Not so difficult	556 (42%)	253 (45%)	303 (40%)
Difficult	194 (15%)	70 (12%)	124 (17%)
Self-reported LPG consumption ^b (<i>n</i> = 350 among polluting primary fuel users) ^c			
Kg/capita yr ⁻¹ (mean (SD ^d))	17.2 (11.2)	19.5 (12.1)	12.2 (8.5)

^a Following the World Health Organization definition, polluting cooking fuels include firewood, charcoal, kerosene, agricultural residues and other forms of biomass.

^b Kg/capita yr⁻¹ was calculated by converting the average time between LPG cylinder refills to number of refills yr⁻¹, multiplying by the LPG cylinder size and dividing by family size.

^c This group includes a subset of primary polluting fuel users consuming LPG as a secondary cooking fuel.

^d SD = standard deviation.

only 37% (*n* = 576) of the population cooked primarily with LPG.

Charcoal (47%; *n* = 719) was the most common polluting primary cooking fuel; 7% (*n* = 108) primarily cooked with wood in three stone fires, 5% (*n* = 76) cooked with wood in the locally made traditional stoves (chepkuba) and 3% (*n* = 53) used kerosene. One third (35%) of households reported heating their homes, with charcoal almost universally used (97%) as the main heating fuel (table 1).

Four in ten participants (40%) lived in a single room and another 40% lived in a two-room home. The proportion of households cooking primarily with LPG with 1–2 residents (26%) was double that of households cooking with polluting fuels (12%). Only one-quarter (24%) of participants were household owners, and less than half (40%) reported that the household head had a regular income or salary; this proportion did not differ according to primary cooking fuel type (table 1). However, the proportion of households in the highest income bracket (>10 000 KES/month) was 10% higher among LPG users (27%) compared with those using polluting fuels (17%) (table 1).

Four times as many household heads cooking with LPG had received a university degree (29%) compared to those cooking primarily with polluting fuels (7%). One third (33%) of participants cooking primarily with a polluting fuel worked in the informal sector compared to less than one fourth (23%) of participants cooking primarily with LPG. The proportion of participants that had a government or business job was twice as high among participants primarily cooking with LPG (28%) as those cooking mainly with polluting fuels (13%) (table 1).

Nearly all (95%) participants believed that LPG is safe to cook with, and 99% did not think that

LPG was difficult to obtain in the community. However, 15% of participants believed that it was challenging to cook a variety of dishes using LPG; this proportion was 5% higher among those primarily cooking with polluting fuels (17%) compared with those mainly cooking with LPG (12%). The proportion of individuals reporting difficulty cooking most dishes using LPG was also 10% lower among those with greater than 0.5 LPG burners/capita than among those with less than 0.5 burners/capita (19%) (supplementary figure 1 available online at stacks.iop.org/ERL/17/055012/mmedia).

3.1. Differential impacts of COVID-19 restrictions by occupation

Three quarters (75%; *n* = 1147) of participants reported that a decline in income while under COVID-19 restrictions, with 30% (*n* = 452) reporting no income earned (table 2). Among the 695 (45%) households that reported earning less income while under COVID-19 restrictions, almost half (*n* = 326; 47%) indicated having less earnings for more than six months. Over half (54%) of households with the head employed as an informal sector worker that earned less income did not return to their pre-pandemic wages for six months or longer, compared with 41% of government or business employees, 37% of farmers and 18% of craftspeople (e.g. tailors, carpenters, seamstresses) (supplementary figure 5).

Nearly three quarters (70%; *n* = 316) of the 452 households that reported having no income indicated their lack of earnings lasted for more than six months. A larger percentage of informal sector workers (85%) than government or business employees (61%) stated they earned no income for at least six months (table 2).

Table 2. Impacts of COVID-19 restrictions on participants' livelihoods by select occupations^a.

Characteristic	Overall (<i>n</i> = 1528)	Informal sector worker (<i>n</i> = 398)	Business owner (<i>n</i> = 505)	Government/business employee (<i>n</i> = 250)
Income affected				
No income	452 (30%)	133 (33%)	158 (32%)	56 (23%)
Less income	695 (45%)	208 (52%)	248 (49%)	122 (50%)
No change	376 (25%)	55 (14%)	95 (19%)	67 (27%)
More income	5 (0%)	2 (1%)	2 (0%)	1 (0%)
Months earning no income (<i>n</i> = 452)				
0–2 months	76 (17%)	5 (4%)	28 (18%)	7 (12%)
3–6 months	60 (13%)	14 (11%)	18 (12%)	15 (27%)
>6 months	316 (70%)	113 (85%)	110 (71%)	34 (61%)
Time out of work				
<1 week	293 (19%)	58 (15%)	99 (20%)	52 (21%)
1 week–8 weeks (2 months)	340 (28%)	60 (15%)	146 (29%)	82 (33%)
9 weeks–6 months	279 (19%)	109 (27%)	78 (15%)	44 (18%)
>6 months	519 (34%)	171 (43%)	181 (36%)	69 (28%)
Insufficient food				
Yes	677 (44%)	237 (60%)	205 (41%)	90 (37%)
Frequency of cooking				
Less frequent cooking	558 (36%)	194 (50%)	193 (40%)	66 (27%)
No change	912 (60%)	191 (49%)	287 (59%)	173 (70%)
More frequent cooking	58 (4%)	3 (1%)	3 (1%)	4 (3%)
Changed cooking fuel				
Yes	284 (19%)	98 (25%)	96 (19%)	42 (16%)
Types of cooking fuel switching (<i>n</i> = 284)				
LPG to charcoal	138 (49%)	46 (47%)	50 (52%)	25 (60%)
LPG to kerosene	14 (5%)	7 (7%)	4 (4%)	2 (5%)
LPG to wood	12 (4%)	6 (6%)	4 (4%)	0
Charcoal to wood	35 (12%)	13 (13%)	14 (14%)	4 (10%)
Wood to charcoal	24 (8%)	7 (7%)	5 (5%)	2 (5%)
Charcoal to LPG	22 (8%)	10 (10%)	7 (7%)	4 (10%)
Wood to LPG	11 (4%)	3 (3%)	4 (4%)	1 (0%)
Other	28 (10%)	6 (6%)	8 (8%)	4 (10%)

^a Only the three most common occupations shown for brevity.

Four in five (79%) participants were out of work for at least one week due to COVID-19 restrictions, with over half (53%; *n* = 798) out of work for over nine weeks. One third (*n* = 519) of participants were not working for more than six months in 2020. The amount of time individuals were unemployed due to COVID-19 restrictions also varied substantially by occupation; 70% of informal sector workers did not work for more than two months in 2020, compared with 45% of government or business employees and 33% of farmers (figure 2).

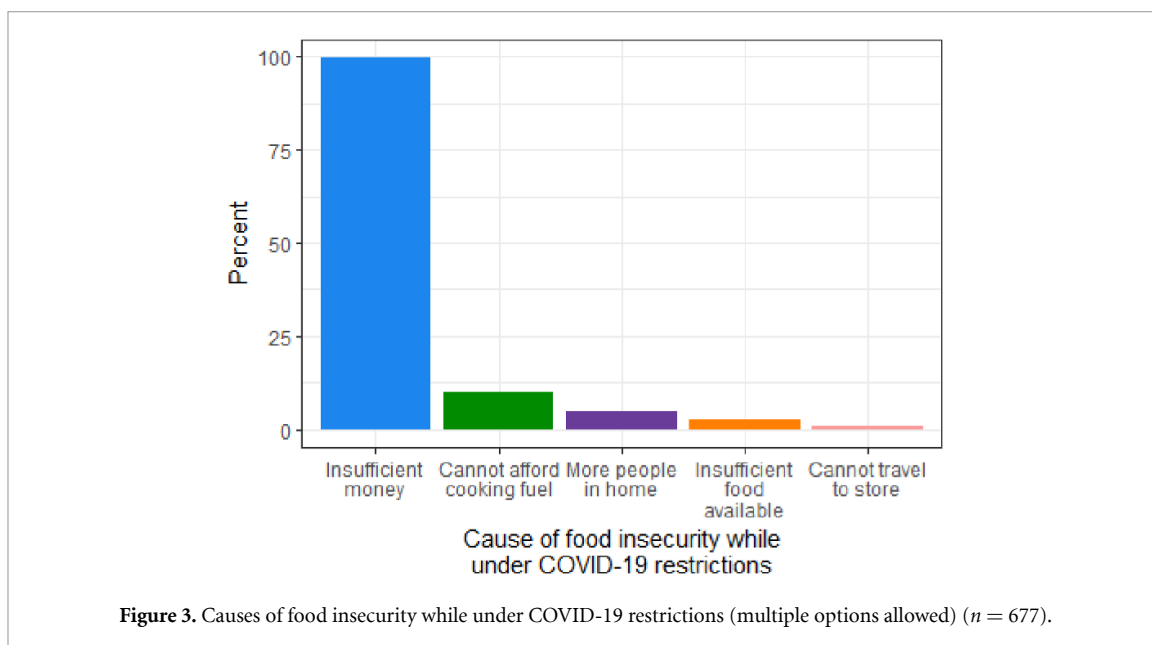
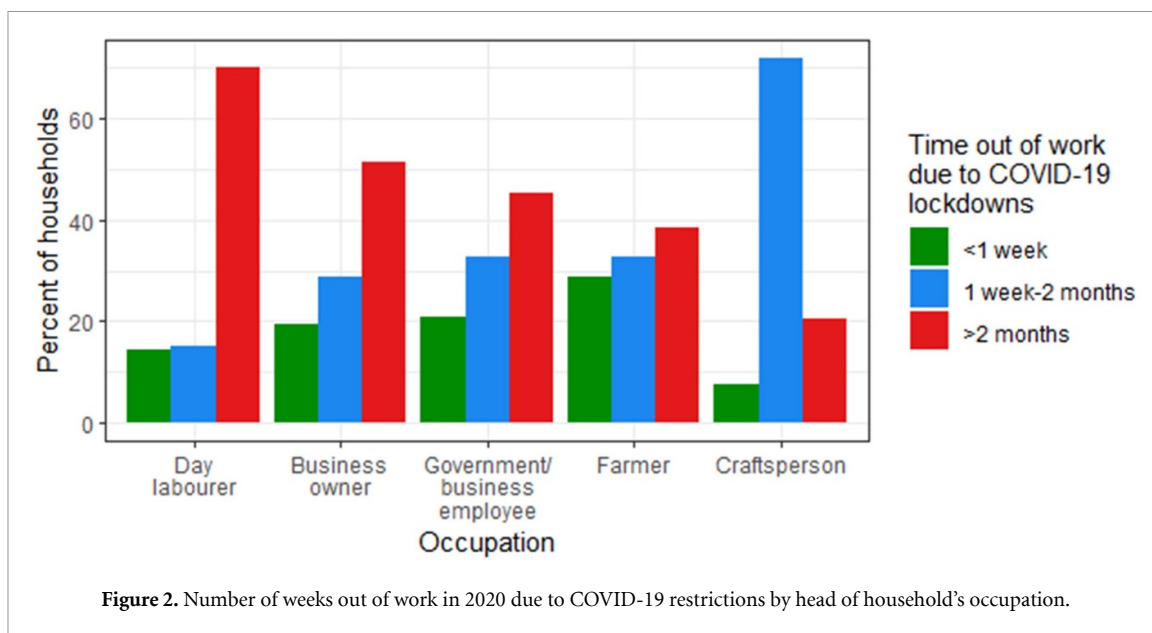
3.2. Impacts of COVID-19 restrictions on food security

Almost half (44%; *n* = 677) of participants reported not having enough food to feed their families at some point while under COVID-19 restrictions (table 2). The self-reported rate of food insecurity was about 20% higher among informal sector workers (60%) compared with business owners (41%) and business or government employees (37%) (table 2).

Among food-insecure households, 69% (*n* = 464) indicated cooking less while under COVID-19 restrictions, compared with only 11% (*n* = 94) among households (*n* = 851) with enough food to feed their families.

Universally, a decline in food security while under COVID-19 restrictions in Langas was driven by a decline in income (100%; *n* = 674) (figure 3). However, 11% (*n* = 75) of households reported that an inability to afford the cost of cooking fuels was another reason for their food insecurity. An increase in the number of people to feed led to insufficient food among 5% (*n* = 33) of households. A minority of participants reported supply-related causes of food security, namely an insufficient availability of food in stores or on their farm (3%, *n* = 20).

Additionally, households that reported a decline or cessation of income while under COVID-19 restrictions had 5.3 times (95% CI:[3.8, 7.4]) and 14.6 times (95% CI:[10.2, 20.9]) the odds, respectively, of experiencing food insecurity as those reporting no



change in their income level (figure 4). Among households reporting reduced income during COVID-19 lockdown, increasing age was associated with a greater probability of food insecurity, and also lower cooking frequency, in a monotonically increasing manner (supplementary figure 6). Individuals aged 41 and older with reduced income during COVID-19 lockdown had twice the odds of being food insecure (odds ratio: 2.1 95% CI:[1.5, 3.1]) and cooking less frequently (odds ratio: 2.0 95% CI:[1.4, 2.8]) as those aged 18–24.

3.3. Primary cooking fuel switching while under COVID-19 restrictions

One in five households (19%; $n = 284$) switched their primary cooking fuel while under COVID-19

restrictions. Among households that reported primarily cooking with LPG ($n = 922$), 18% ($n = 164$) switched to charcoal ($n = 138$), kerosene ($n = 14$) or wood ($n = 12$) while under COVID-19 restrictions (table 2). Participants that reported having a lower-than-usual household income more than six months due to COVID-19 restrictions had 2.1 times (95% CI:[1.2, 3.7]) the odds of switching away from LPG to a polluting primary cooking fuel as those that had reduced earnings for two months or less.

The proportion of households switching away from LPG as their primary cooking fuel also differed by the head of household's occupation (figure 5). For example, informal sector workers had a higher probability (15%) of switching away from LPG

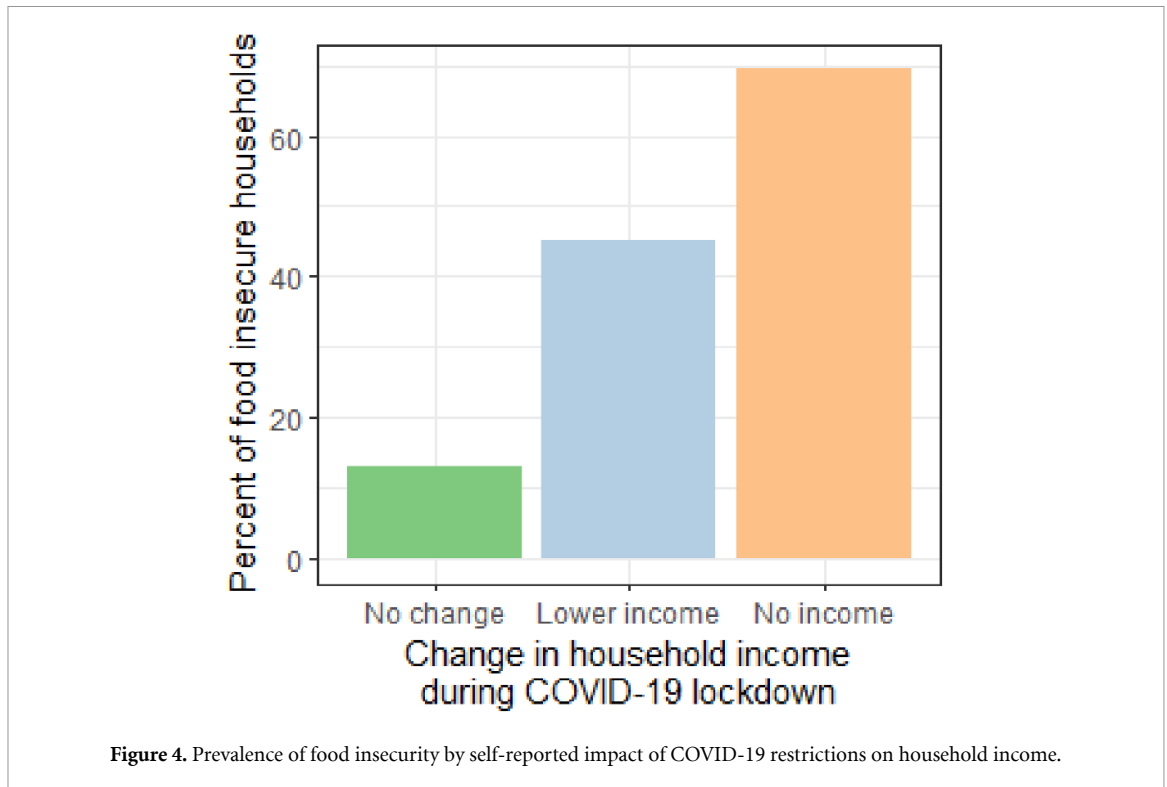


Figure 4. Prevalence of food insecurity by self-reported impact of COVID-19 restrictions on household income.

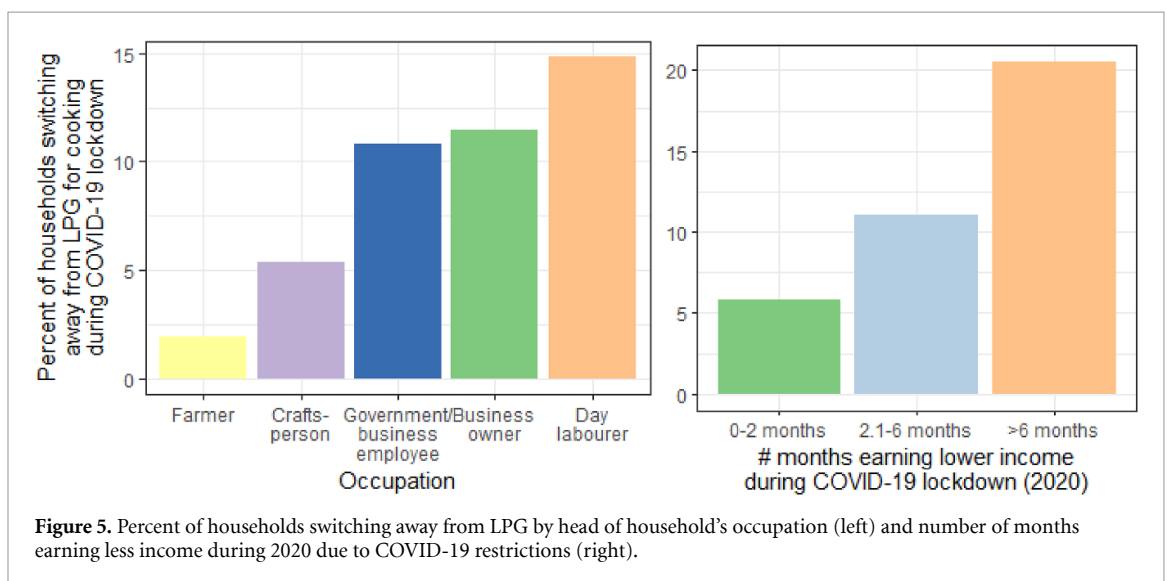


Figure 5. Percent of households switching away from LPG by head of household's occupation (left) and number of months earning less income during 2020 due to COVID-19 restrictions (right).

than government or business employees (11%), craftspeople (6%) and farmers (2%).

While 12% ($n = 33$) of households that changed their primary cooking fuel while under COVID-19 restrictions switched from a polluting fuel to LPG (table 2), the overall prevalence of polluting primary cooking fuel use while under COVID-19 restrictions in the community increased by an estimated 9%. One-in-five households that altered their primary cooking fuel while under COVID-19 restrictions switched between different types of polluting fuels: charcoal to wood (12%; $n = 35$) or wood to charcoal (8%; $n = 24$).

3.4. Effect of VAT on LPG consumption

After the VAT was re-introduced on LPG in July 2021, nearly nine in ten (88%; $n = 815$) participants using LPG as a primary (37%; $n = 576$) or secondary fuel (23%; $n = 346$) noticed an increase in the price of LPG. However, less than half (47%, $n = 437$) of these 815 individuals had heard about the re-introduction of the VAT at the time of the survey. Among the ($n = 815$) LPG users that noticed a price increase, almost half (44%; $n = 356$) reduced their LPG consumption. Over three quarters of these 356 households (77%; $n = 276$) reported cooking more frequently with polluting fuels due to the LPG price

Table 3. Characteristics of LPG users by whether they reduced LPG consumption because of the VAT introduction.

Characteristic	LPG users who decreased their LPG usage due to the VAT ($n = 356$)	LPG users who did not change their LPG usage due to the VAT ($n = 459$)
Age group		
18–24	72 (33%)	149 (67%)
25–31	118 (47%)	133 (53%)
32–40	98 (49%)	104 (51%)
>40	68 (48%)	73 (52%)
Household size		
1–2	56 (35%)	104 (65%)
3	58 (34%)	111 (66%)
4	75 (52%)	70 (48%)
5+	79 (56%)	61 (44%)
Occupation		
Government/business employee	65 (41%)	94 (59%)
Business owner	119 (40%)	180 (60%)
Informal sector worker	95 (53%)	83 (47%)
Craftsperson	21 (54%)	18 (46%)
Student/unemployed/retired	21 (53%)	20 (47%)

increase. One quarter (27%; $n = 220$) of LPG users that noticed a price increase indicated that it would affect their future decision-making on whether to discontinue using LPG.

The proportion of households with four or more family members that decreased their LPG usage due to the VAT re-introduction (56%) was 20% higher than among families of three or less (34%) (table 3). Participants aged 25 and older and those working in the informal sector also had a higher probability of reducing their LPG consumption as a result of the VAT levy than participants aged 24 and younger and those working as a government or business employee, respectively (table 3). Additionally, households with a lower number of LPG stove burners per capita (0.05–0.2 burners/capita) had 3.3 times the odds (95% CI:[2.0, 5.6]) of reducing their LPG use because of the VAT re-introduction as those with >0.5 burners/capita.

3.5. LPG supply-related factors modified the impact of the VAT re-introduction on LPG consumption

The proportion of households reducing their LPG consumption because of the VAT re-introduction was influenced by LPG supply-related factors. Two-thirds (66%) of individuals reporting that LPG was unavailable at least 4 times during the previous year used less LPG as a result of the VAT introduction, compared with only 39% of those that found LPG to always be available at the retailer (figure 6). Thus, those unable to obtain cylinder refills four or more times per year, on average, had three times the odds (95% CI:[1.5, 5.8]) of reducing their LPG consumption due to the VAT re-introduction as households that reporting consistent access to refills.

Additionally, a lower number of LPG stove burners/capita was associated with a lower probability of reducing LPG consumption following the VAT

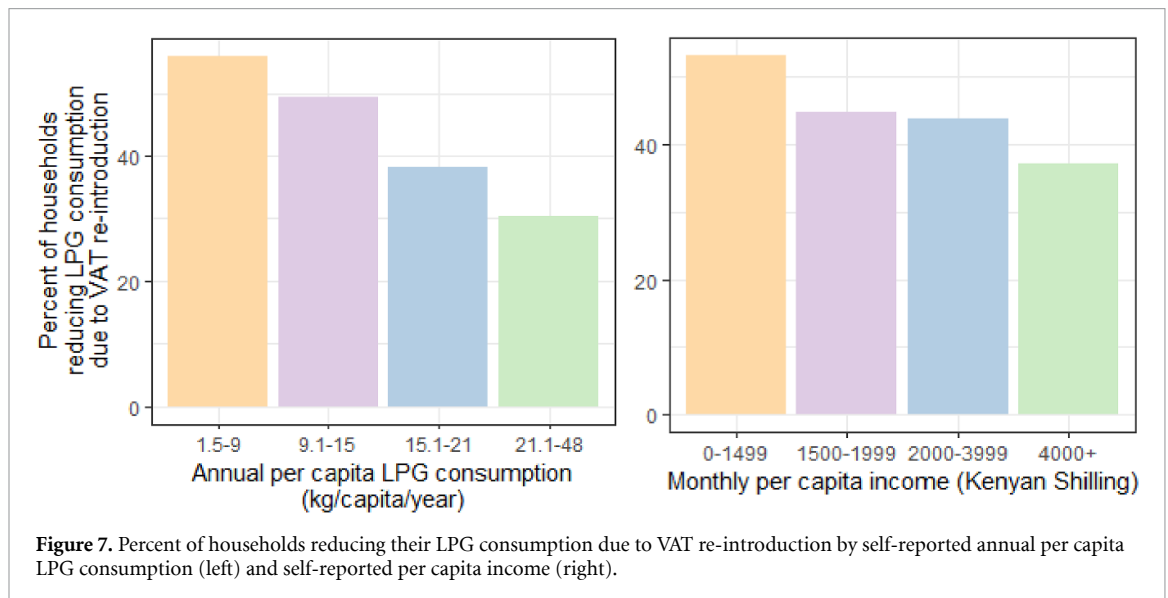
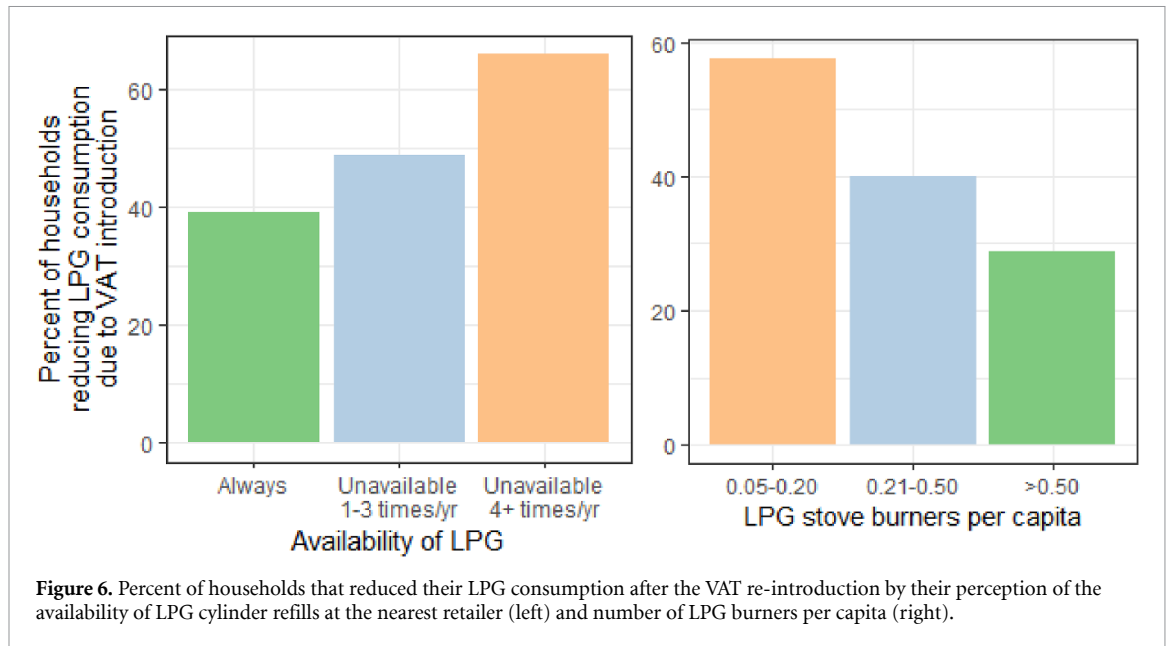
re-introduction, in a monotonically decreasing manner (figure 6); households with <0.2 stove burners/capita had 3.3 times the odds (95% CI:[2.0, 5.6]) of reducing their consumption of LPG as those with greater than 0.5 burners/capita. Moreover, the proportion of households reporting a reduction in LPG consumption because of the VAT re-introduction increased with greater travel time to the LPG retailer (supplementary figure 7). Only 30% of participants traveling 5 min or less to the LPG retailer reported reducing their LPG consumption, compared with 50% of those traveling more than 5 min to the retailer.

3.6. Exacerbated inequities in clean energy consumption due to VAT

A monotonically decreasing trend existed between increasing average annual per capita LPG consumption and the likelihood of reducing LPG consumption following the VAT levy (figure 7). Participants with the lowest self-reported annual per capita LPG consumption (1.5–9 kg/capita yr⁻¹) had 2.9 (95% CI:[1.9, 4.6]) times the odds of reducing their LPG consumption following the VAT re-introduction as households with the highest per capita LPG consumption (21.1–48 kg/capita yr⁻¹). Additionally, households in the lowest self-reported per capita income category (0–1499 KES/capita/month) had 1.9 (95% CI:[1.2, 3.1]) times the odds of reducing their LPG consumption following the VAT re-introduction as households in the highest per capita income group (4,000+ KES/capita/month).

3.7. Compounding effect of COVID-19 restrictions and VAT on the poorest households

Participants most adversely impacted economically by COVID-19 restrictions were more likely to be negatively impacted by the VAT re-introduction on LPG. A higher proportion (59%) of households that switched away from LPG while under COVID-19



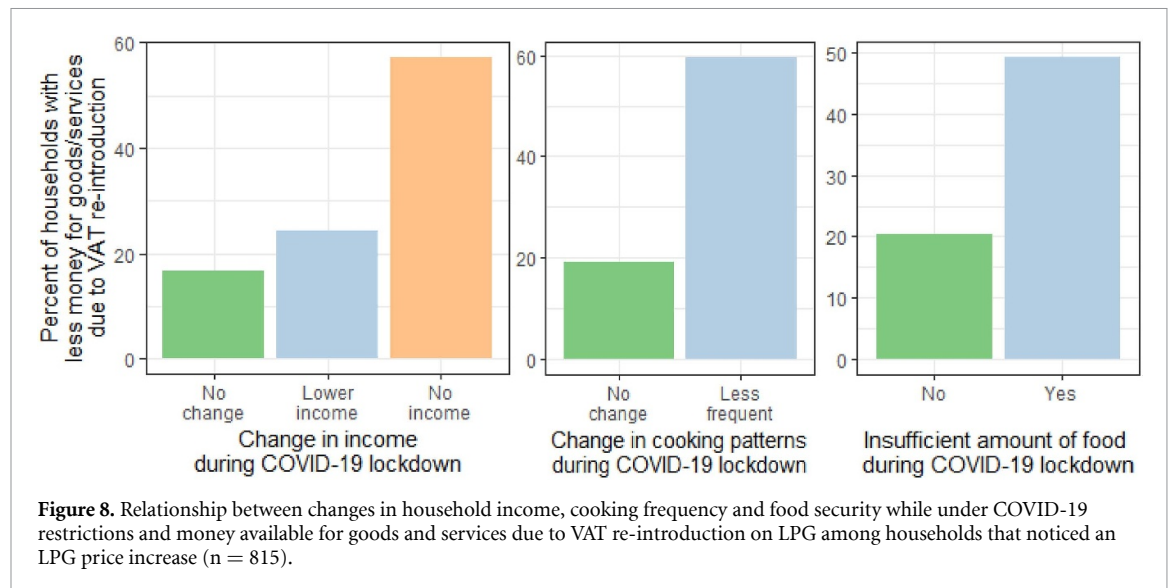
restrictions consumed less LPG as a result of the VAT re-introduction compared with those that maintained their use of LPG (41%). Thus, individuals switching away from LPG while under COVID-19 restrictions had three times (95% CI:[2.1, 4.3]) the odds of reducing their LPG consumption due to the VAT re-introduction as those that continued using LPG while under COVID-19 restrictions. Moreover, 57% ($n = 133$) of participants that reported having no income while under COVID-19 restrictions in 2020 reported a decline in available income for other goods and services, compared with only 17% ($n = 33$) among those not experiencing any decline in earnings while under COVID-19 restrictions (figure 8).

Participants that reduced their cooking frequency while under COVID-19 restrictions and who did not have enough food to feed their families during this period had 6.2 times the odds (95% CI:[4.5, 8.7])

and 3.8 times the odds (95% CI:[2.8, 5.2]), respectively, of having a lower capacity to purchase other goods and services because of the increased cost of LPG (figure 8).

4. Discussion

This study characterised the adverse impacts of two successive economic shocks on LPG consumption in Langas informal urban settlement. While under COVID-19 restrictions, three quarters (75%) of households in Langas reported lower (45%) or no income (30%), which is similar to results from our study conducted in an informal settlement in Nairobi [29]. The financial impacts of COVID-19 restrictions were felt well after the stay-at-home orders were lifted in Kenya, as nearly half of households did not regain their income for at least six months after



implementation of COVID-19 restrictions (table 2). Informal sector workers in Langas were disproportionately affected by COVID-19 restrictions, with a higher proportion reporting lower income for at least six months compared with government/business employees and farmers (supplementary figure 5). Additionally, informal sector workers and lower income households (<5000 KES/month) were more likely to decrease their cooking frequency and switch away from LPG as their primary cooking fuel while under COVID-19 restrictions. Thus, informal sector workers and poorer households' decreased ability to pay for cooking fuels while under COVID-19 restrictions led to an exacerbation of inequities in clean cooking fuel use.

Vulnerability to economic downturns and the interconnectedness of energy and food security among the urban poor was highlighted during the period COVID-19 restrictions [26]. Declining incomes alongside the rising cost of LPG had a negative spillover effect of increased food insecurity; 11% of households reported that the rising price of cooking fuel was a reason for them having insufficient food to feed their families (figure 3). COVID-19 restrictions disproportionately worsened rates of food insecurity among informal sector workers (table 2), which is consistent with results from other studies conducted in the context of COVID-19 restrictions [30, 31]. Moreover, our finding of higher food insecurity among those reporting income loss due to COVID-19 restrictions is supported by a previous study conducted in Kenyan informal settlements, which found that households with no income during COVID-19 restrictions were 15% more likely to skip a meal than those employed [32].

Consistent with other studies [33], we also find that older study participants were more prone to food insecurity due to COVID-19 restrictions (supplementary figure 6), which may be due to greater

difficulty completing agricultural labor, or having greater dependence on others for food, among other concerns [34, 35]. As older Kenyans living in informal settlements were found to be at greater risk of food insecurity prior to the pandemic [36], rates of food insecurity between younger and older Kenyans may have been exacerbated by COVID-19 restrictions.

While the VAT re-introduction made LPG unaffordable to Langas residents via a different mechanism than COVID-19 restrictions, it led to a similar impact: reduction in use of LPG among 44% of households and increased use of polluting biomass fuels among one-third of households cooking with LPG. The VAT re-introduction similarly made clean cooking with LPG increasingly unattainable primarily for the poorest study households (<1500 KES (<\$13 USD)/capita/month), who had twice the odds of reducing their LPG consumption as the highest earning households (>4000 KES (>\$35 USD)/capita/month). Furthermore, lower consumers of LPG (<9 kg/capita yr⁻¹) had three times the odds of reducing their consumption while under COVID-19 restriction as the highest consumers (>21 kg/capita yr⁻¹), which is consistent with findings in an informal settlement of Nairobi [26].

4.1. Compounding impacts of COVID-19 restrictions and VAT re-introduction

COVID-19 restrictions and the VAT re-introduction largely affected the same households; a much higher proportion of participants earning no income while under COVID-19 restrictions reported having less money for other goods and services due to the VAT re-introduction (57%) compared with only those not experiencing any decline in earnings while under COVID-19 restrictions (17%) (figure 8). Additionally, food-insecure participants during COVID-19 restrictions had 3.8 times the odds (95% CI:[2.8, 5.2]) of having a lower capacity to purchase other goods

and services because of the increased LPG cost due to the VAT re-introduction (figure 8). These results emphasize the fragility of many families to sudden increases in household energy prices. There is therefore a need for social protection programmes that allow poorer Kenyan households to become more resilient to economic downturns.

4.2. LPG accessibility influences resilience to energy price shocks

In the absence of economic stability, the accessibility of LPG cylinder refills impacts LPG use [17, 37, 38]. This study highlights that supply-related factors also impact customers' ability to mitigate the effects of LPG price increases. For example, participants who reported an inability to purchase LPG refills at the retailer at least four times/year had three times the odds of lowering their consumption due to the VAT re-introduction as those reporting a consistent supply of cylinder refills at the retailer. Home deliveries are more commonly being offered by LPG retailers in Langas as a competitive advantage to increase their market share of customers. The convenience of home delivery in the community likely increased use of LPG for cooking (table 1). This may be attributed to the reduction in the 'refill gap' that cylinder home deliveries can provide [39]; households receiving cylinder home deliveries had a 15% lower probability of having a 1 week gap between cylinder swaps as LPG users walking to the retailer to obtain a new cylinder (36%) (supplementary figure 3).

With nearly 30% of LPG users in Langas waiting over a week before swapping their LPG cylinder (table 1), increasing cylinder home deliveries can potentially lead to substantial gains in LPG consumption [40]. In other communities in Eldoret, a similar, negative correlation between increasing travel time and decreasing LPG consumption was found [29]. Studies in India indicated some difficulties that women experience when obtaining cylinder refills due to associated travel costs or the inability to carry the heavy LPG cylinders [41]. These barriers often necessitate that women wait for their spouse to obtain the cylinder refill [42].

4.3. Utility of multi-burner LPG stoves

This study demonstrates that a higher number of LPG stove burners/capita may have helped households maintain their rates of LPG consumption during periods of economic volatility. A lower number of LPG burners/capita was associated with significantly higher odds of switching from LPG to a polluting primary cooking fuel while under COVID-19 restrictions (supplementary figure 4) and reduced LPG consumption due to the VAT re-introduction (figure 5). As average annual LPG consumption was much higher among households with >0.5 LPG burners/capita than among those with <0.5 burners/capita (supplementary figure 2), the ability to cook multiple

dishes simultaneously with LPG may make families more likely to increase their consumption.

Estimated mean annual LPG per capita consumption in Langas (17.2 kg/capita yr⁻¹) was 34% greater than the average national rate (12.8 kg/capita yr⁻¹) estimated in an assessment conducted in 2017/2018 [43]. It is uncertain if the higher LPG consumption level found in Langas is due to significant geographical variation within Kenya, population-level increases in LPG consumption from 2018–2021 or possible self-reporting bias, which has occurred in previous studies [29, 44]. Nevertheless, the self-reported average LPG consumption rate in Langas is over 50% lower than the 40 kg/capita yr⁻¹ typically consumed by households in more developed countries with stronger LPG supply chains, such as Brazil, Indonesia, and Peru [17].

4.4. Strengths and limitations

This study was conducted a couple of months after the VAT re-introduction on LPG in July 2021, enabling an assessment of participants' LPG consumption in response to the policy with minimal recall bias. Random sampling ensured a representative study population, facilitating community-level characterisation of the impacts of COVID-19 restrictions and VAT re-introduction. While questions about participants' experiences while under COVID-19 restrictions required a longer period of recall (i.e. up to 1.5 years), the striking effect of the pandemic on livelihoods is likely to enhance participants' memory of events. Moreover, the study findings regarding the impacts of COVID-19 restrictions on income, food security and cooking behaviours are consistent with a study we conducted in an informal settlement in Nairobi in April 2020, immediately following the mandatory stay-at-home order issued by the Kenyan government [26].

This study did not quantify the extent of the reductions in LPG use at a household level, and subsequent increase in polluting fuel use among households. More research is needed to measure declines in kilograms of LPG consumed, and also monitor household air pollution levels to better estimate the potential health and climate impacts of these policies.

4.5. Conclusions

This study outlines numerous downstream negative impacts of COVID-19 restrictions and the 16% VAT on LPG among families living in an informal urban settlement in western Kenya. Prolonged economic downswings caused many participants, particularly informal sector workers and lower income households, to decrease their cooking frequency and switch from LPG to polluting primary cooking fuels. The LPG price increase in 2021 due to the VAT compounded the negative effects of COVID-19 restrictions by also forcing nearly half of households to

reduce their LPG consumption, with those working in the informal sector again being most affected.

These results clearly demonstrate a reversal in progress made prior to the onset of the pandemic toward increased access to clean cooking fuels in Kenya. With the Kenyan government affirming their target of countrywide clean energy access by 2030 (a key component of Sustainable Development Goal (SDG) 7) at COP26, reducing major setbacks in LPG usage during future economically unstable periods will likely be important for maintaining continued progress toward a rapid, equitable transition to universal clean energy access.

4.6. Recommendations

Firstly, the Kenyan Government should consider returning to a zero-rated VAT on LPG to remove prohibitive cost increases disproportionately felt by poorer consumers. Further, as this study uncovered how improved access to LPG can enhance users' ability to maintain its use during economic downturns, policies that expand the number of LPG retailers and lower the cost of multi-burner LPG stoves should be prioritized. Additional regulatory mechanisms should also be implemented to control LPG price fluctuations during periods of market volatility.

As participants reporting lower income for extended periods of time had a greater likelihood of switching from a clean to polluting cooking fuel, establishing broad-reaching safety net programmes, such as those implemented in South Africa [34], can help poorer households retain their use of clean cooking fuels. These programs can include services such as temporary compensation (e.g. food/vouchers, conditional cash transfers), universal one-off cash payments or microloans to informal workers that are unemployed for longer periods [45]. While the County government of Uasin-Gishu and Eldoret town did provide some families with monthly food parcels and cash transfers of \$9 USD during COVID-19 restrictions, this benefit did not reach all intended households [27]. Highly coordinated social protection schemes are needed.

With fuel and food supply shortages likely to persist due to the war in Ukraine and the lingering events of COVID-19, governments can learn from the lessons of 2020 and 2021 by directing economic support to low-income households and investing in the clean energy supply chain. Doing so can lead to numerous health, climate and social co-benefits via economic empowerment [46] and reductions in household air pollution exposures [9], deforestation [10, 47], and greenhouse gas emissions [48, 49].

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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Conflict of interest

The authors have no competing interests to declare.

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