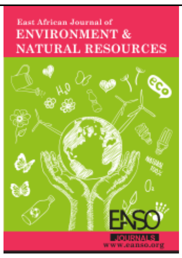

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Original Article

Scenarios for Adoption of Low-Carbon Household Cooking Fuels in Biomass-Dependent Informal Settlements of Urban Sub-Saharan Africa: A Critical Analysis of Kisumu City

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Informal Settlements, Household Carbon Emissions, Clean Fuels, Emission Reduction Scenarios, Climate Action, Fuel Stacking.

ABSTRACT

The use of unclean cooking fuels is widespread in urban informal settlements in Africa, while the adoption of clean fuels is largely done by stacking with traditional biomass fuels. Rapid urbanisation has aggravated the situation since it hampers effective planning for climate action and the provision of clean and affordable cooking fuels. It is, therefore, essential to deploy effective household carbon emissions (HCE) reduction strategies that are cognizant of the fuel use patterns and household dynamics of households in urban informal settlements. This study highlights the status of HCE in Kisumu City's informal settlements and subsequently explores possible pathways for reducing emissions through the adoption of low-carbon cooking fuels. The paper features existing and plausible emissions scenarios in the informal settlements of Kisumu City. The study adopts a descriptive correlation research design targeting a sample 419 households drawn from seven informal settlements of Kisumu City. Binary logistic regression is used to establish the relationships that exist between household characteristics and the adoption of clean fuels. Multiple linear regression analysis reveals existing and probable emission pathways, informed by varying household characteristics and adjusting fuel-stacking scenarios. Household income has a positive correlation with adoption of clean fuel combinations ($p<0.01$), while household size does not have a significant relationship with adoption of clean fuels. The annual HCE attributable to cooking in Kisumu City's informal settlements is 976 KgCO2. Fuel stacking nuances are vital considerations in choosing practical emission reduction pathways for these households. Emission reduction scenario that contemplates transitioning households that use charcoal in their fuel stacks to using LPG has the highest emission reduction potential of 72%. Although an emission scenario that includes LPG in the fuel mix of households that do not use it has an emission reduction potential of just 9%, it is the most realistic option since it accommodates the phenomenon of fuel stacking.

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INTRODUCTION

Households in Sub-Saharan Africa (SSA) rely heavily on traditional biomass fuels for cooking (Ambole et al., 2019; Gill-Wiehl et al., 2021). It is estimated that over 884 million people in SSA still use these fuels in their households (ESMAP, 2021). The situation is made worse by rapid urbanisation, which is posing a significant challenge to climate action (UN-Habitat, 2018). Urban dwellers account for 44% of the SSA population, and with the current annual urban growth rate of 3.4%, it is expected to reach 59% by the year 2050 (UN-Habitat, 2022). In Kenya, for instance, over 56% of the population in cities live in informal settlements with little access to clean and affordable energy envisioned under the Sustainable Development Goal (SDG) number 7 (UN-Habitat, 2018). The extensive dependence on biomass fuels in urban informal settlements is a major source of carbon emissions and consequently accelerates global warming in Kenyan cities (Christley et al., 2021; Waweru & Mose, 2022).

Global warming caused by anthropogenic emissions has gained a lot of attention since the industrial revolution (Keramidas et al., 2021). Despite mounting public uproar, global greenhouse gas (GHG) emissions have increased by 1.5% each year over the last decade (Rahmani et al., 2020). Scientific evidence shows that more than half of the observed upsurge in global surface temperatures in the last 50 years is a consequence of a human-induced increase in concentrations of greenhouse gases (IPCC, 2014; UNFCCC, 2022). Human activities have caused global warming of about 1.0°C compared to pre-industrial levels, and if current trends continue, this level will reach 1.5°C between 2030 and 2052 (IPCC, 2018). The Glasgow Climate Pact reaffirms the need to keep the global average temperature rise below 2.0°C and to progressively endeavour to reduce it to 1.5°C above the pre-industrial levels (UNFCCC, 2022). In order to avoid the adoption of energy systems that are carbon-intensive, decision-makers should carefully plan for upcoming deployment of energy options especially in the developing countries (IRENA, 2022).

The need to address climate change has significantly influenced the choices of energy for many countries and is driving innovations in the global energy sector (REN21, 2021). The global low-carbon energy outlook varies across different countries (Enerdata, 2020; IEA, 2020; IRENA, 2022) because the magnitude of carbon emissions usually relates to the levels of domestic income (REN21, 2021). Countries with the lowest incomes have a low carbon footmark for electricity generation (IEA, 2020). However, CO_2 emissions in these countries tend to increase quickly because of the rapid growth of the middle class, hence increasing energy needs from emerging consumers (OECD et al., 2017). Accelerated economic growth, coupled with population explosion, has occasioned a commensurate increase in the demand for energy in Africa (IRENA, 2022). This population

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explosion is driving rapid urbanisation at a rate never seen before in SSA (UN-Habitat, 2022).

With a growing consensus that the energy sector is instrumental in reducing climate change impacts, significant focus has been put on decarbonising the energy sector and the achievement of low-carbon development pathways (Ockwell & Byrne, 2017). Adoption of renewable energy sources has the potential to reduce the dependency of developing countries on expensive and unpredictable energy sources while creating jobs and reducing poverty through inclusive climate smart energy sources (IRENA, 2022). Urban areas are a significant cornerstone of Kenya's economic development due to the prevalence of industries and other service-driven economic enablers in them (Republic of Kenya, 2017b). Kisumu has been identified as one of the flagship cities of Kenya under the vision 2030, with the role of facilitating the redevelopment of the Great Lakes region's infrastructure being its major priority (County Government of Kisumu, 2013).

Kenya aims to reduce its national carbon emissions by 32% of a baseline of 143 $MtCO_2eq$ by the year 2030 (Republic of Kenya, 2020), with the emission reduction target for the energy sector set at 6.1 $MtCO_2eq$ (Republic of Kenya, 2017a). However, if the unsustainable growth of urban informal settlements is not mitigated, then these targets might not be achieved (Republic of Kenya, 2020; Rosenzweig et al., 2015). This study highlights the status of HCE in Kisumu City's informal settlements and subsequently explores plausible pathways for reducing emissions through the adoption of low-carbon cooking fuels. The prevalence of multiple fuel use (fuel stacking) among the city's dwellers should be a critical point of consideration when exploring practical HCE reduction strategies for these households (Okore et al., 2022). There is evidently a low uptake of clean cooking fuels in the informal settlements of the city, coupled with inadequate housing (Olang et al., 2018). Improper planning, insufficient provision of affordable housing and weak regulatory frameworks have accelerated the rapid growth of informal settlements in the city (County Government of Kisumu, 2018a). The findings of this study will be key in informing policy initiatives regarding the tenable emission reduction scenarios in urban informal settlements in SSA.

MATERIALS AND METHODS

Study Site

The study site is the informal settlements of Kisumu City, located in Western Kenya on the eastern shores of Lake Victoria surrounding the Winam Gulf. The city covers an area of 417 km^2, out of which 297 km^2 is on land and 120 km^2 is covered by water (County Government of Kisumu, 2018b). The city's central business district is located on a gently undulating residual hill on the Winam Gulf and is surrounded by a partial ring of informal settlements with extensive peri-urban settlements located on the hilly north and flood-prone south of the gulf (UN-Habitat, 2005). The city has a population of approximately 521,500, with informal settlements accounting for close to 50% of its inhabitants' dwellings (KNBS, 2019). The studied informal settlements include Manyatta A and B, Nyalenda A and B, Obunga, Nyawita and Nyamasaria (*Figure 1*).

Data Collection and Processing

The study embraces a descriptive correlation research design, which emphasises the use of quantitative methods in concurrently describing determinants of household energy and, consequently their relationships with HCE. 419 households were sampled proportionately across the seven informal settlements from a sampling frame of 88,496, in line with the procedure by Okore et al. (2022). Face-to-face administered questionnaires were used to obtain information regarding household socio-economic characteristics and their fuel use patterns.

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Figure 1: Map of the study area showing location of study sites

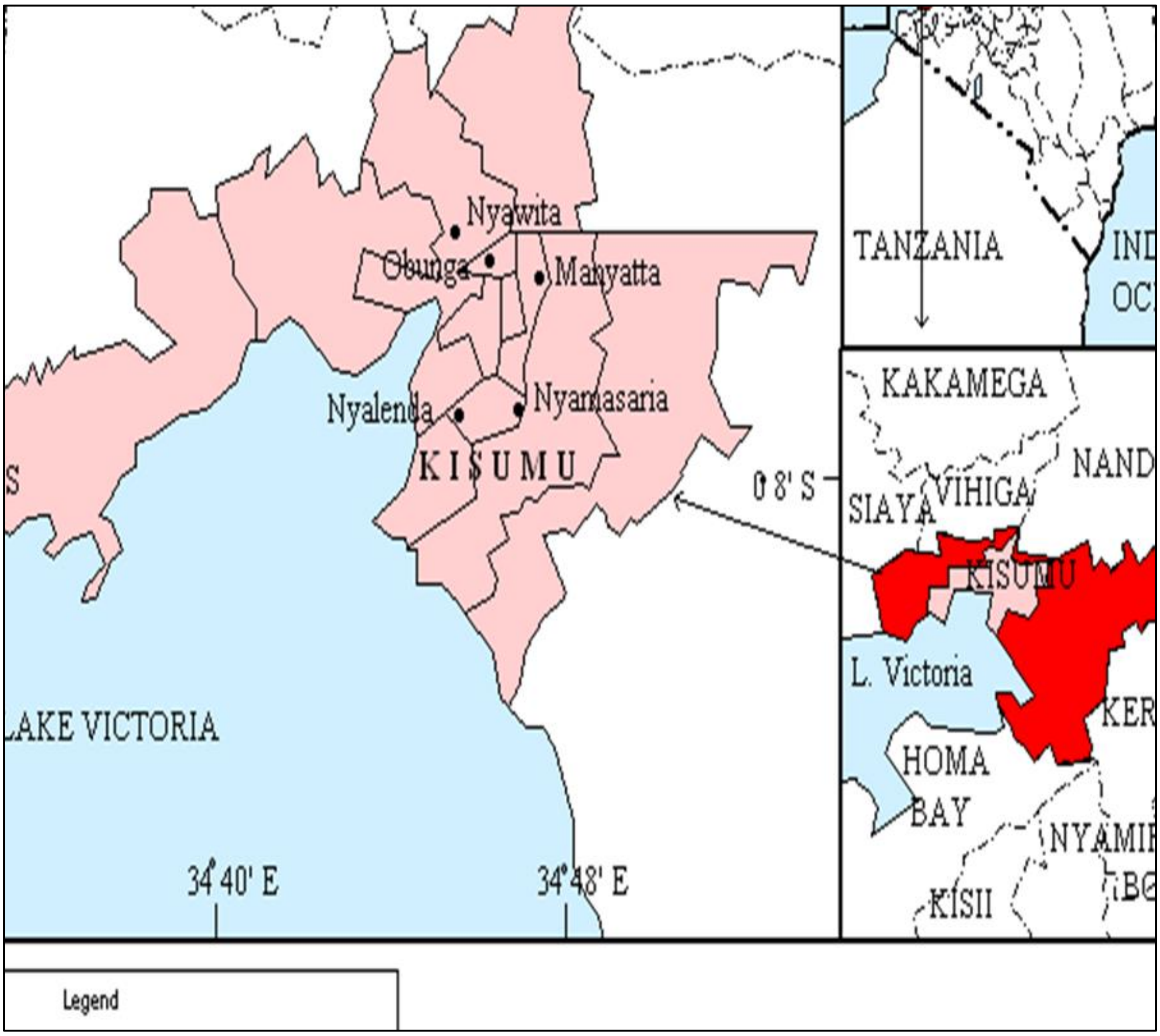

Table 1: Sample distribution across informal settlements in Kisumu City

Settlement	Number of Households (N)	Sample Size (*n*)	Percentage (%)
Manyatta A	15,044	70	17%
Manyatta B	13,269	64	15%
Nyalenda A	14,159	69	16%
Nyalenda B	13,274	61	15%
Nyawita	10,616	50	12%
Obunga	11,504	54	13%
Nyamasaria	10,624	51	12%
Total	88,496	419	100%

Source: Adapted from Kenya National Bureau of Statistics (KNBS, 2019)

The primary unit of measure for firewood at the time of collecting the data was a piece, while charcoal was measured in terms of a tin (*gorogoro*). Kerosene use is determined indirectly in litres by using the monthly prices of kerosene per litre set by the Energy and Petroleum Regulatory Authority (EPRA). Quantities of fuel used are converted into a standard measure of kilograms per week, where one piece of firewood averagely weighs 2.1 Kg while a *gorogoro* of charcoal weighs 2 Kg. Kerosene used is converted into kilograms using the conversion factor by Hu et al. (2017), where 1 litre = 0.81 Kg. Quantities of LPG used by households are determined by the number of weeks the LPG cylinders last before the next refill, depending on the size of the cylinder

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(3 Kg, 6 Kg, or 13 Kg). The annual fuel usage for all the fuels is computed using Equation 1.

$$Qnt\_Fuel_{Kg} = Weekly\_Qnt\_Fuel_{Kg} \times 52.143 \quad [1]$$

Where Qnt_Fuel_{Kg} is the quantity of fuel used by a household annually; $Weekly\_Qnt\_Fuel_{Kg}$ is the quantity of fuel used by a household weekly, and 52.143 is the weeks in a year.

The annual household CO_2 emissions are computed using Equation 2 as per the emission factors of IPCC (2006) depicted in *Table 2*.

$$CO_2Emissions_{Kg} = Qnt\_Fuel_{Kg} \times EmissionFactor_{Kg/Kg} \quad [2]$$

Where $\mathrm{CO_2Emissions_{Kg}}$ is the CO_2 emissions by a household annually; Qnt_Fuel_{Kg} is the quantity of fuel used by a household annually, and $\mathrm{EmissionFactor_{Kg/Kg}}$is the IPCC-recommended CO_2 emission factor for each fuel.

Table 2: Default fuel-based carbon dioxide emission factors recommended by IPCC

Fuel type	Default IPCC CO_2 emission factors (Kg/Kg)
LPG	2.98
Kerosene	3.15
Charcoal	3.30
Firewood (TSF)	1.75

Source: IPCC (2006)

Determination of Variables and Regression Models

The study groups variables into independent and dependent variables with the aim of establishing correlations that exist between household characteristics, clean fuel choices, fuel stacking and HCE (*Table 3*). Binary logistic regression is used to establish the relationship between household characteristics and clean fuel choices (Equations 3 and 4).

$$LogY_i = \beta o + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \beta_4 X_{i4} + \varepsilon_i \quad [3]$$

$$Log = \ln\left(\frac{p}{1-p}\right) \quad [4]$$

Where: $LogY_i$ is the clean or unclean fuel choice in the i^{th} trial; X_{i1} is the age of the household head, X_{i2} is the household size; X_{i3} is the household income; βo is the value of Y when all independent variables are equal to zero (Y-intercept); $\beta_1 - \beta_4$ is the estimated regression coefficients (slope), and ε_i is the error factor.

Multiple linear regression was deployed to establish the relationships between HCE as a dependent variable and dependent variables characterised in *Table 3*. The model is summarised in Equation 5.

$$Y_i = \beta o + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \beta_4 X_{i4} + \beta_n X_{in} + \varepsilon_i \quad [5]$$

Where: Y_i is the HCE in the i^{th} trial; X represents the independent variables outlined in *Table 3* $(X_{i1}, X_{i2}, X_{i3}, X_{i4}, \ldots X_{in})$; βo is the value of Y when all independent variables are equal to zero (Y-intercept); $\beta_1 - \beta_n$ is the estimated regression coefficients (slope), and ε_i is the error factor.

The data used in the regression analysis has been subjected to the requisite diagnostic tests for logistic and multiple linear regressions. Diagnostic tests performed on the data show that assumptions of homoscedasticity have been met, and there is no multicollinearity in the independent variables. Hence, the results can be qualified based on the assumptions embraced in descriptive correlation research and the principle of statistical significance.

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Table 3: Independent and dependent variables used in the study

a) Exploring the influence of household parameters on choice of clean or unclean fuels	
Dependent variable	**Independent variable**
Choice of clean or unclean fuel combinations (binary) Clean = 1 (*LP, Ch&LP, Ch&Ke&LP, FW&LP, FW&Ke&LP, FW&Ch&LP, FW&Ch&Ke&LP*) Unclean = 0 (*FW, Ch, Ke, FW&Ch, FW&Ke, Ch&Ke*)	• Age of household head (continuous) • Household size (continuous) • Household income (continuous)
b) Exploring the influence of household parameters and fuel stacks on CO_2 emissions	
Response (dependent) variable	**Exploratory (independent) variable**
CO_2 emissions (continuous)	• Age of household head (continuous) • Household size (continuous) • Household income (continuous) • Fuel stack choices (multiple) *FW, FW&Ch, FW&Ch&Ke&LP, FW&Ch&LP, FW&Ke, FW&Ke&LP, FW&LP, Ch, Ch&Ke, Ch&Ke&LP, Ch&LP, Ke, LP*

Key: FW = Firewood, FW&Ch = Firewood and charcoal stack, FW&Ch&Ke&LP = Firewood, charcoal, kerosene and LPG stack, FW&Ch&LP = Firewood, charcoal, and LPG stack, FW&LP = Firewood and LPG stack, Ch&Ke&LP = Charcoal, kerosene and LPG stack, Ch&LP = Charcoal and LPG stack, Ch&Ke = Charcoal and kerosene stack, Ke = Kerosene, LP = LPG.

RESULTS AND DISCUSSIONS

Household Characteristics

The mean age of household heads is 34 years, with household size averaging 3.7, while the mean household income is KES 16,269. The per capita income of the households is KES. 4,955, with 79% of them living below the poverty line (less than USD 1.9 per day. Male-headed households account for 74% of households, while most of the household heads (52%) have their highest qualification as secondary school (*Table 4*).

Table 4: Household socio-economic characteristics in Kisumu City's informal settlements

Variable	N	Mean	Std. Dev.	Min	Max
Age of household head	419	34	8.24	19	69
Household size	419	3.7	1.50	1	10
Household income (KES)	419	16,269	8,815	3,000	62,600
Per capita income (KES)	419	4,955	3,141	857	30,000
Variable	**N**	**%**			
Sex of household head					
Female	111	26			
Male	308	74			
Level of education of household head					
No formal education	2	0			
Primary (incomplete)	10	2			
Primary (complete)	63	15			
Secondary	217	52			
Post-secondary certificate	42	10			
Diploma	51	12			
Degree	34	8			

KES 1 = USD 0.0088 (exchange rate as of September 2019 at the time of data collection)

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Outlook of Carbon Emissions Based on Fuel Stacks Adopted by Households

The mean HCE attributable to cooking in the informal settlements of Kisumu City is 976 Kg of CO_2 (*Table 5*). Households that use firewood as their sole source of cooking fuel emit the most CO_2 at 3,583 Kg, followed by charcoal (951 Kg), kerosene (414 Kg) and LPG (162 Kg). Fuel stacking is a common practice in the city since households include specific fuels in their stacks due to varied motivations, as highlighted in *Table 6*. 67% of households practice fuel stacking, with charcoal being the most predominant primary fuel in their stacks. However, fuel stacks that have firewood in them emit the most CO_2, with firewood and kerosene *(FW&Ke)* combination being the most unclean combination with an average emission of 3,115 $KgCO_2$.

Households that prefer using firewood in their stacks do so because it is affordable (90%), readily available (87%) and reliable for slow-cooking foods (61%). Additionally, 71% of them perceive firewood to cook tasty food. Charcoal is preferred because of perceptions of affordability (60%), availability (74%) and that it cooks tasty foods (83%) (*Table 6*). The main driver for households' preference for LPG is its ability to prepare meals fast (98%) and its ready availability from local vendors (71%). Kerosene use is driven by its ability to cook fast (79%). However, portion affordability is also a major determinant of its preference (77%) since the fuel can be bought in small quantities when it runs out. Approximately 44% of households are inclined to use LPG because it is environmentally friendly.

The presence of LPG in a fuel stack largely subdues the amount of HCE of a household; for instance, the carbon emissions from households using firewood and LPG (*FW&LP*) stacks emit 780 Kg of CO_2, which is significantly lower than the average emissions from other firewood stacks (*Table 5*).

Table 5: Characterisation of fuel stacks based on average energy use and carbon emissions

Fuel stacks	Households	Average CO_2 emissions (Kg)	% emissions of the fuel
LP	*40*	*162*	*100%*
% of households	10%		
Ke	*23*	*414*	*100%*
% of households	5%		
Ch	*73*	*951*	*100%*
% of households	17%		
FW	*3*	*3,583*	*100%*
% of households	1%		
Ch		697	67%
Ke		339	33%
Ch&Ke	*84*	*1,036*	*100%*
% of households	20%		
Ch		572	61%
Ke		164	18%
LP		200	21%
Ch&Ke&LP	*62*	*937*	*100%*
% of households	15%		
Ch		731	77%
LP		219	23%
Ch&LP	*106*	*949*	*100%*
% of households	25%		
FW		2,202	84%
Ch		431	16%
FW&Ch	*12*	*2,632*	*100%*
% of households	3%		

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Fuel stacks	Households	Average CO_2 emissions (Kg)	% emissions of the fuel
FW		972	55%
Ch		546	31%
Ke		111	6%
LP		143	8%
FW&Ch&Ke&LP	*3*	*1,771*	*100%*
% of households	1%		
FW		1,579	72%
Ch		402	18%
LP		205	9%
FW&Ch&LP	*3*	*2,186*	*100%*
% of households	1%		
FW		2,587	83%
Ke		527	17%
FW&Ke	*5*	*3,115*	*100%*
% of households	1%		
FW		1,139	75%
Ke		201	13%
LP		188	12%
FW&Ke&LP	*2*	*1,528*	*100%*
% of households	0.5%		
FW		547	70%
LP		233	30%
FW&LP	*3*	*780*	*100%*
% of households	1%		
All households	419	976	100%
% of households	100%		

NB: Average HCE per stack or fuel choice by a household in each category is italicised

Table 6: Reasons for households' preference for specific cooking fuels in Kisumu City's informal settlements

Why households use the fuels	Firewood		Charcoal		Kerosene		LPG	
	N	%	N	%	N	%	N	%
Affordable	28	90%	206	60%	150	77%	63	29%
Readily available	27	87%	255	74%	-	-	156	71%
Large family	5	16%	14	4%	-	-	3	1%
Small family	-	-	3	1%	22	11%	11	5%
Cooks fast	10	32%	74	22%	153	79%	214	98%
Cooks tasty foods	22	71%	285	83%	29	15%	10	5%
Health benefits	-	-	8	2%	5	3%	76	35%
Eco-friendly	-	-	4	1%	-	-	96	44%
Good for slow-cooking cereals	19	61%	166	48%	-	-	-	-
Number of households using the fuel	31	100%	343	100%	194	100%	219	100%

Clean and Unclean Fuel use

Households that use clean fuels were aggregated into those that either use LPG as a single fuel or fuel combinations that include LPG (*Figure 2*). The households that use clean fuels account for 52%, while those that use unclean fuels are 48%.

Households earning by or less have a higher probability of using unclean energy *Figure 3*. It is also inferred that small households (<3 members) and larger households (>4 members) have a higher chance of using unclean energy compared to households averaging 3 or 4 members (*Figure 3*). This anomalous distinction in the interaction of household size and adoption of clean fuels contradicts previous findings that there is a negative correlation between household size and adoption of clean fuels (Karimu, 2015; Makonese

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et al., 2018; Masera *et al.*, 2000; Medina *et al.*, 2019; Xing *et al.*, 2017).

Figure 2: Aggregation of clean and unclean fuel use

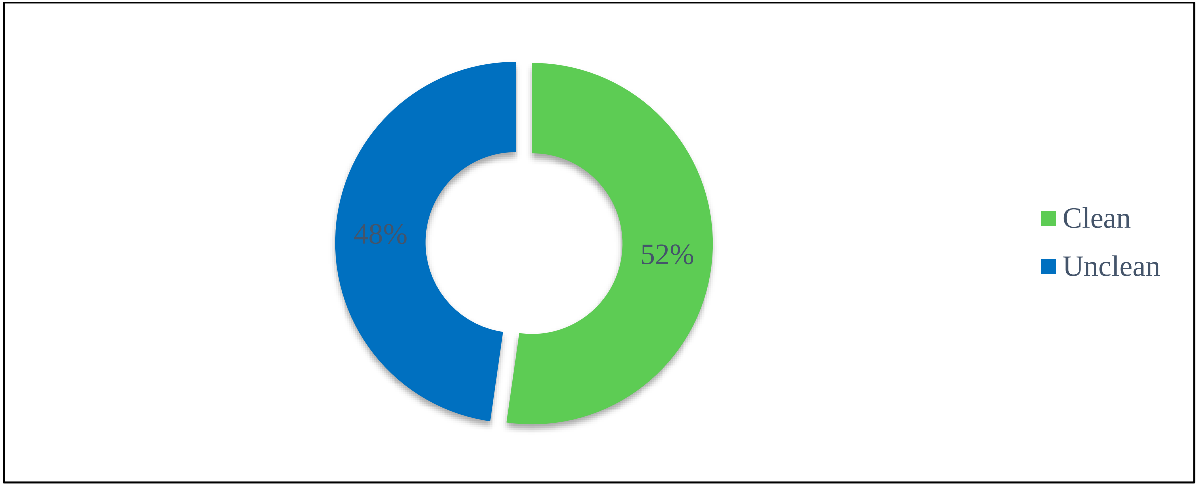
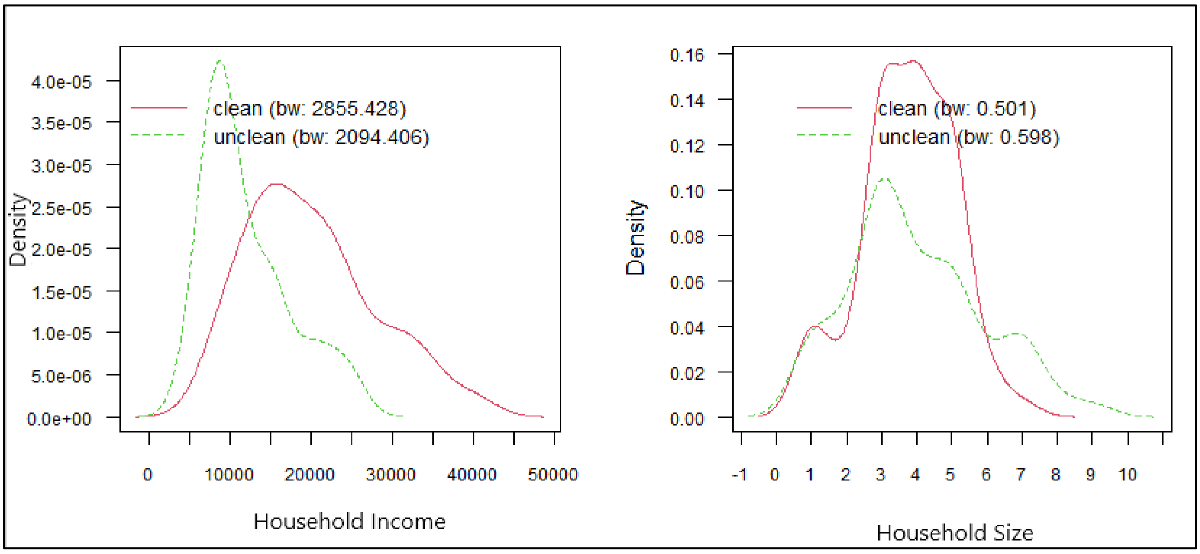


Figure 3: Density of households using clean and unclean fuels based on their incomes and sizes



Results from the binary logistic regression model show that, keeping all other factors constant, an increase in household income reduces the likelihood of a household using unclean fuel combinations by 0.004 units ($p<0.01$) (*Table 7*). Household size does not have a significant influence on the choice of clean or unclean fuels, a finding that conforms to previous studies in Kisumu and Vihiga Counties (Ang'u *et al.*, 2023; Pundo & Fraser, 2006). However, when both household income and household size are incorporated as covariates, they have a significant relationship with the choice of clean fuels ($p<0.01$). The interaction between income and household size implies that keeping other factors constant increases the likelihood of a household using unclean energy by 0.00003 units if the household size increases by a value of 1 (*Table 7*). This means that, if the size of a household increases, they tend to move towards using unclean fuels irrespective of whether their income increases or not. In other studies, the influence of household size and income were both presented, but it was done independently of each other (Masera *et al.*, 2000; Shankar *et al.*, 2020), though covariance of these two predictors was not considered.

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Table 7: Binary logistic regression results for household characteristics and clean fuel adoption

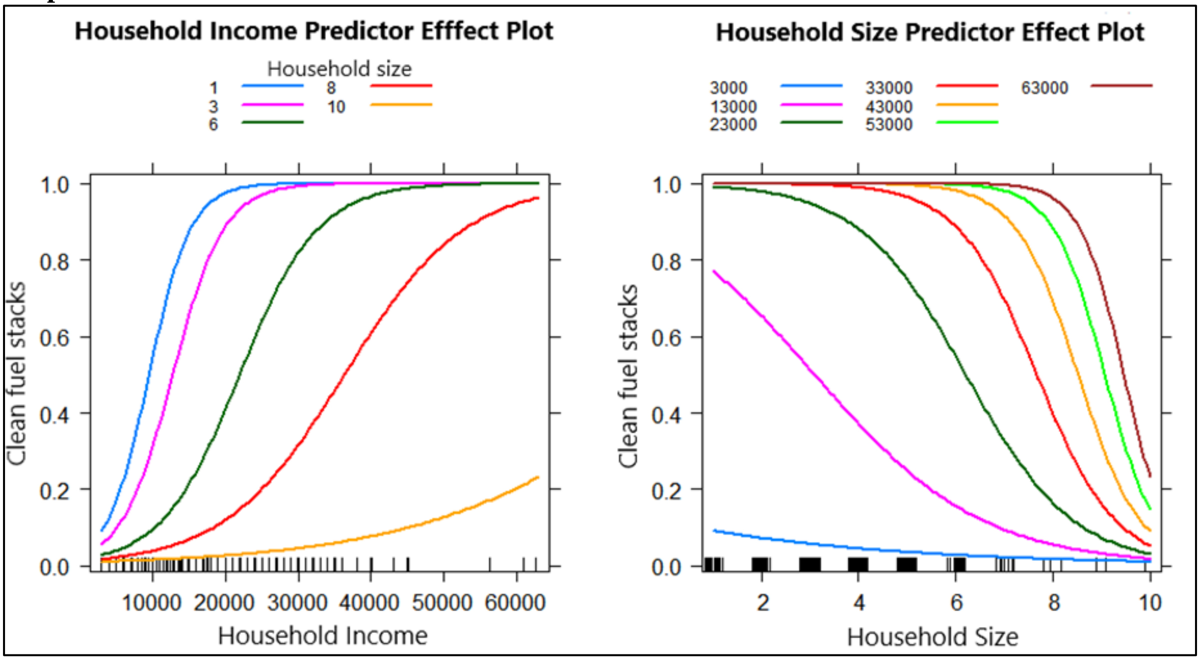
Independent variable	Clean fuel combination	
Household income	-0.0004***	(0.0001)
Household size	0.152	(0.190)
(Household income) x (household size)	0.00003***	(0.00001)
Constant	3.204***	(0.739)
Observations	419	

*Standard errors ( ), *** p<0.01, ** p<0.05, * p<0.1*

When household income remains constant and there is an increase in household size, there is a higher probability that households with less earnings will shift to using unclean energy much quicker than households that have higher incomes (*Figure 4*). The predictor effect plot shows that the probability of a household using unclean energy reduces with an increase in the total household income.

Smaller households tend to undertake most of their cooking using LPG, which is the most common clean fuel since it cooks fast (*Table 6*). It is important to note that if the smaller households are subjected to an increase in their household income, they tend to shift quickly into using clean energy as compared to larger households (*Figure 4*).

Figure 4: Predictor effect plots showing a relationship between household income and size and adoption of clean fuel combinations



Household Carbon Emission Reduction Scenarios

Emission Scenarios Based on Changes in Household Characteristics

The average per capita household income in informal settlements of Kisumu City is KES 4,955 (*Table 4*). In scenario one (Adjusted Model 1), the fuel combinations used by a household are retained at the household choices without any change from the base model. The total household income was increased by 25% to an average of KES 6,193, which is just above the monthly per capita income, depicting one living just above the poverty line. Additionally, household size was reduced by 25% to an average 2.8 from 3.7 members per household.

The new model is represented by the equation:

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$$HCE = \beta o + \beta_1 AgeOfHouseholdHead + \beta_2 NewHouseholdSize + \beta_3 NewHouseholdIncome + \beta_4 FuelCombination + \varepsilon_i$$

After reducing the household size to 2.8, the new model infers that a unit increase in the household size will increase the HCE by 167 Kg (*Table 8*). When the total household income is increased by 25%, then a unit increase in household income will reduce the household carbon emissions per household by 0.006 Kg (*Table 8*).

Table 8: Linear regression results for adjusted household size income and fuel combinations versus carbon emissions

	Independent variables	Annual household carbon emissions	
	Age of household head	12.668***	(2.586)
	Household size	167.207***	(19.232)
	Household income	-0.006***	(0.002)
Fuel choices	*Ch&Ke*	224.499***	(51.975)
	Ch&Ke&LP	71.368	(59.167)
	Ch&LP	119.532**	(53.326)
	FW	2,272.380***	(190.412)
	FW&Ch	1,431.401***	(101.760)
	FW&Ch&Ke&LP	756.798***	(188.249)
	FW&Ch&LP	1,147.271***	(198.066)
	FW&Ke	2,166.584***	(148.150)
	FW&Ke&LP	664.263***	(165.995)
	FW&LP	60.592	(319.929)
	Ke	-135.316	(82.517)
	LP	-366.183***	(70.605)
	Constant	50.491	(90.409)
	Observations	419	
	R^2	0.765	
	Adjusted R^2	0.756	
	F Statistic	87.400*** (df = 15; 403)	

*Standard errors (), *** p<0.01, ** p<0.05, * p<0.1*

In this model, an increase in household size increases the net effect of a unit increase of household size on carbon emissions from 125 $KgCO_2$ to 167 $KgCO_2$, while the net emission effect of a unit increase in income is reduced from 0.007 $KgCO_2$ to 0.006 $KgCO_2$. However, the model does not deviate from the base model. In this scenario, an alteration in a household's income and size, without a commensurate adjustment in fuel types they use, would have no effect on the per capita CO_2 emissions of members of the household.

The regression model still makes reliable predictions on the trend of carbon emissions from informal households within Kisumu City. This is because the actual versus the predicted carbon emission values lie close to the line of best fit (*Figure 5*).

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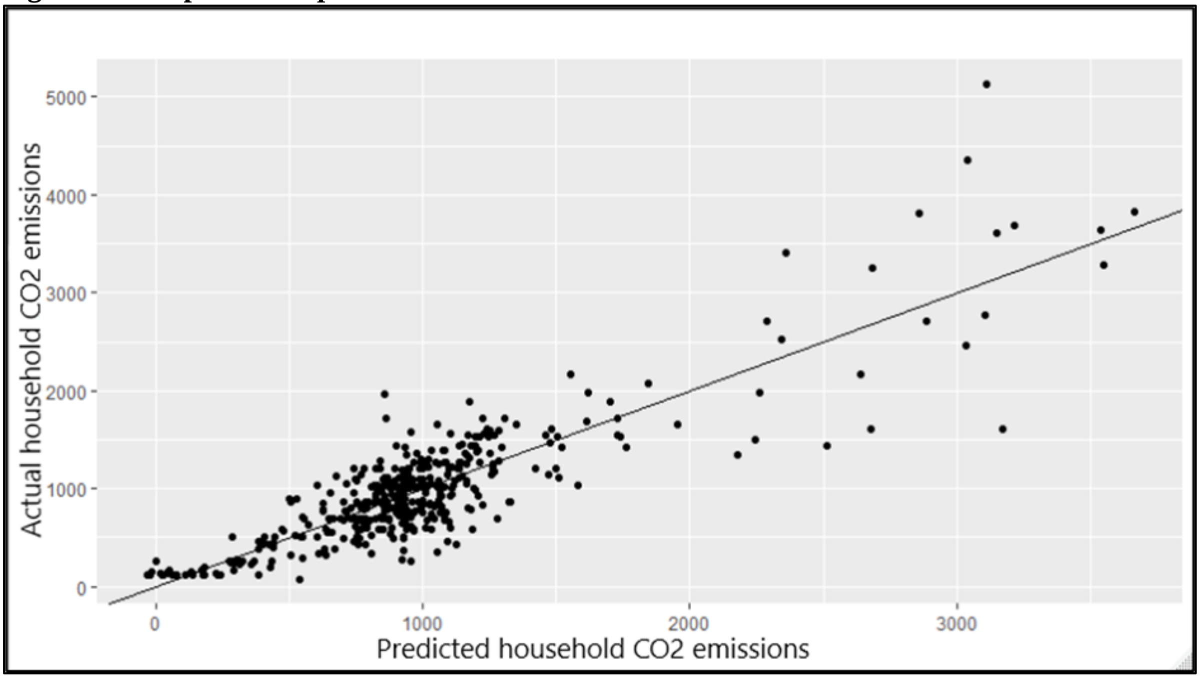
Table 9: Comparison of emission scenarios of adjusted models with the base model developed from the survey data

Model	Emissions scenario	Avrg HCE (Kg)	Deviation (Kg)	Deviation %
Base Model	Actual emission status based on emission estimates from the household survey data	976	N/A	N/A
Adjusted Model 1	Emission scenario based on changes in household size and income	976	0	0
Adjusted Model 2	Emission scenario based on transitioning households that use firewood in their mixes to use LPG	808	- 169	- 17%
Adjusted Model 3	Emission scenario based on transitioning households that use charcoal in their mixes to use LPG	278	- 699	- 72%
Adjusted Model **4**	Emission scenario based on including LPG in the fuel mix of households that do not use it	892	- 84	- 9%

Figure 5: Comparison of predicted versus actual annual CO_2 emissions



Emission Scenarios Based on Changes in Cooking Fuels Used by Households

Several scenarios were explored based on the adoption of new household fuels. Three resultant scenarios are subsequently chosen for inference based on the influence of policy, training, and advocacy interventions that would motivate their considerations. The first scenario is based on transitioning households that use firewood in their mixes to use LPG. The second scenario involves transitioning households that use firewood in their mixes to use LPG. The third scenario is anchored on including LPG in the fuel mix of households that do not use it. The scenarios are depicted as follows:

Transitioning households that use firewood in their mixes to use LPG

Households that rely on firewood for cooking in the informal settlements of Kisumu City are only 7%, however, they account for the highest average carbon emissions because of using firewood (*Table 5*). These households that use firewood in their fuel mix are largely inclined to use the firewood due to its affordability and availability (*Table 6*). Under this second scenario (Adjusted Model 2), households using firewood or any fuel combination with firewood are transitioned into using LPG (*Table 10*). *Figure 6* visualises the emissions outlook based on this scenario.

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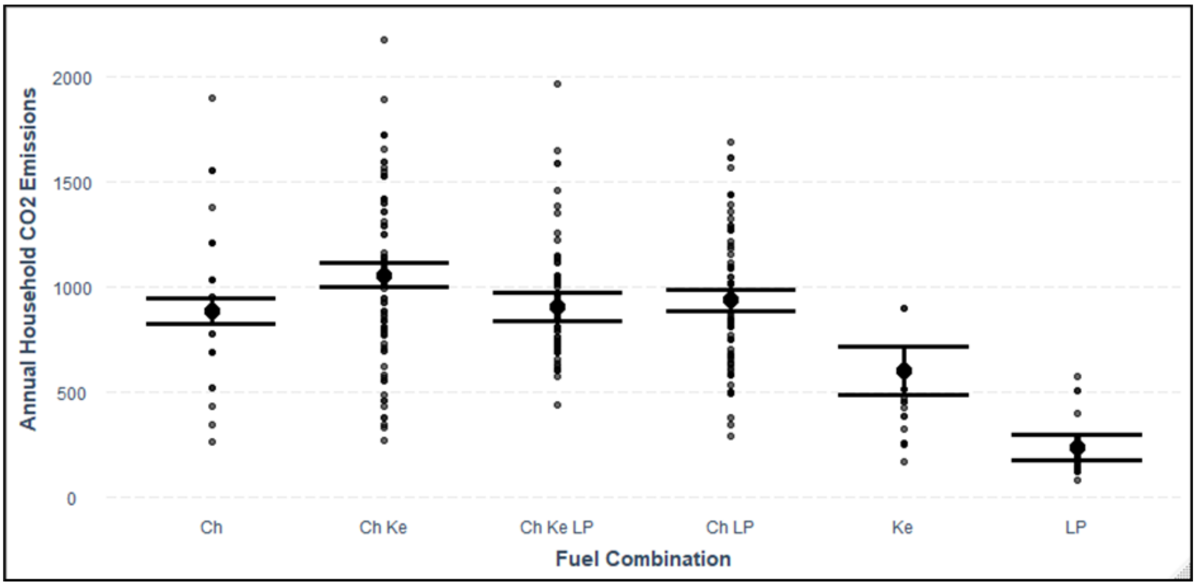
Figure 6: HCE by fuel combinations based on transitioning households from using firewood to LPG



A unit increase in household size and age will increase the carbon emissions by 88 $KgCO_2$ and 4 $KgCO_2$, respectively (*Table 10*). Approximately 63% of the variation in the total carbon emissions is attributed to the age of the household head, household size and fuel combinations used. Considering the fuel combinations, on average, we expect households that use *Ch&Ke* combinations to produce 172 $KgCO_2$ emissions more annually than those using *Ch*. We also expect, on average, households that use *Ke* to produce less 283 $KgCO_2$ emissions than households using *Ch* do. On average, households using *LP* produce less emission by 650 $KgCO_2$ than households using *Ch* (*Table 10*). The scenario under Adjusted Model 2 will lead to 17% reduction in the overall HCE.

Table 10: Linear regression results for household characteristics and carbon emissions based on transitioning firewood household to LPG use

	Independent variables	Annual household carbon emissions	
	Age of household head	4.339**	(1.933)
	Household size	88.915***	(10.846)
	Household income	-0.002	(0.002)
Fuel choices	*Ch&Ke*	171.515***	(42.250)
	Ch&Ke&LP	21.916**	(48.007)
	Ch&LP	53.309**	(43.065)
	Ke	-283.004***	(66.297)
	LP	-650.063***	(45.145)
	Constant	432.806***	(66.530)
	Observations	419	
	R^2	0.633	
	Adjusted R^2	0.626	
	F Statistic	88.511*** (df = 8; 410)	

*Standard errors (), *** p<0.01, ** p<0.05, * p<0.1*

Transitioning households that use charcoal in their mixes to use LPG

The most common fuel type used in the informal settlements of Kisumu is charcoal (82%), either as a single fuel or in combination with other fuels (*Table 5*). Transitioning these households to using LPG, which is a clean fuel, would yield significant emission reduction. This third scenario (Adjusted Model 3) represents a transition for households

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using charcoal or any fuel combination with charcoal to using LPG. The visualised emission scenario in *Figure 7* shows a stepwise emission reduction from the most unclean fuel (firewood) to the cleanest option (LPG).

This model predicts an average annual 277 $KgCO_2$ emissions per household. Approximately 90% of the variation in the total carbon emissions is attributed to the age of the household head, household size, income and the fuel combinations used by a household. Considering the fuel combinations, on average, we expect households that use the *FW&Ke* combination to have an annual emission reduction of 441 $KgCO_2$ compared to the baseline emission of *FW* (*Table 11*). It is expected, on average, that households that use *FW&Ke&LP* combinations will produce less 2,026 $KgCO_2$ emissions than those households using *FW*. From the model, it is expected that households using *FW&LP* combinations will produce 2,776 $KgCO_2$ emissions less than households using only *FW* will. Households that use *Ke* are expected to produce less 3,135 $KgCO_2$ emissions than households using only *FW* do. Households using *LP* will have the highest emission reduction of 3,365 $KgCO_2$ in comparison to households using *FW* to cook (*Table 11*). The overall emission reduction of Adjusted Model 3 is, therefore 699 $KgCO_2$, representing a negative deviation of 72% from the base emission of 976 $KgCO_2$ (*Table 9*).

Figure 7: Household carbon footprint by fuel combinations based on transitioning households from using charcoal to LPG

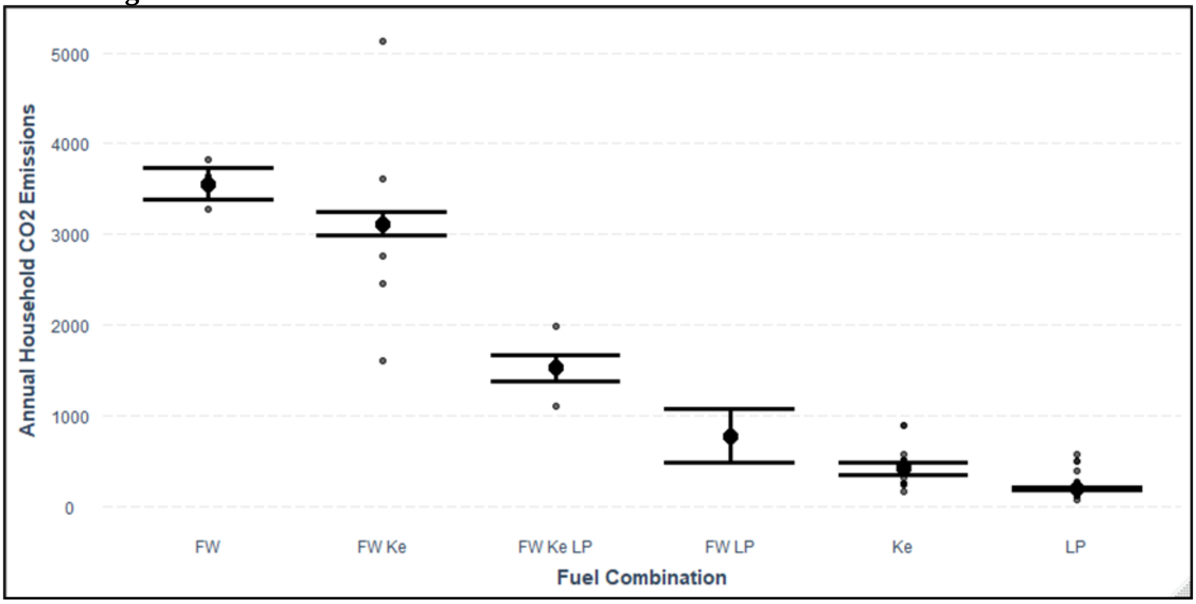

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Table 11: Linear regression results for household characteristics and carbon emissions based on transitioning charcoal household to LPG use

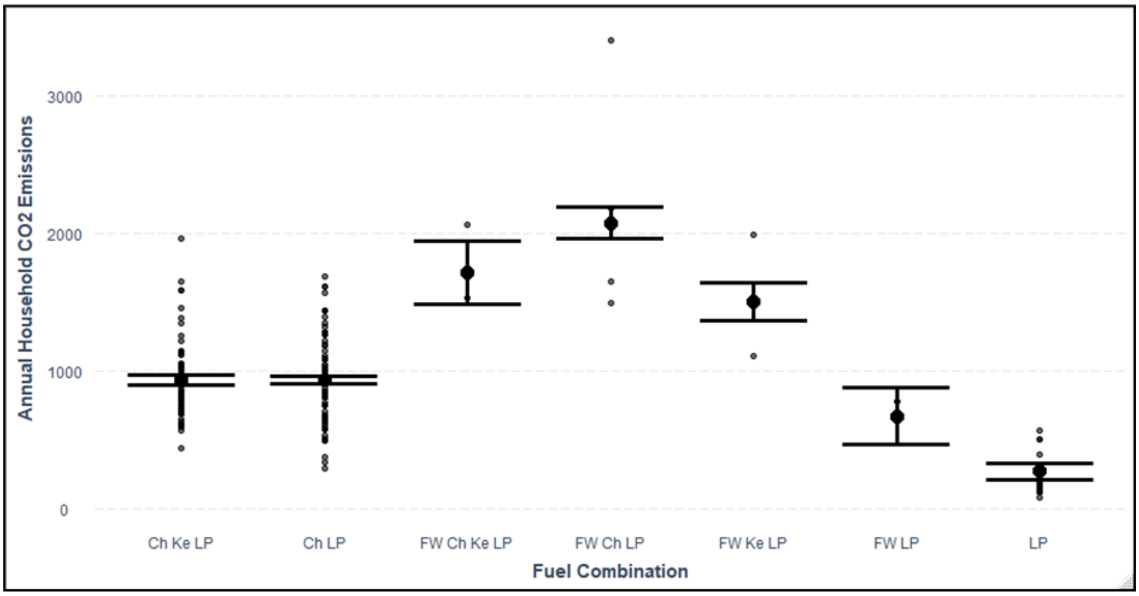
Independent variable		Annual household carbon emissions	
Age of household head		-0.331	(1.098)
Household size		8.241	(6.056)
Household income		-0.0004	(0.001)
Fuel choices	*FW&Ke*	-441.315***	(109.892)
	FW&Ke&LP	-2,025.605***	(115.552)
	FW&LP	-2,775.490***	(171.699)
	Ke	-3,134.757***	(94.142)
	LP	-3,365.327***	(87.797)
Constant		3,544.531***	(94.482)
Observations		419	
R^2		0.903	
Adjusted R^2		0.901	
F Statistic		474.847*** (df = 8; 410)	

*Standard errors (), *** p<0.01, ** p<0.05, * p<0.1*

Including LPG in the fuel mix of households that do not use it

Since stacking is a predominant phenomenon in the informal settlements of Kisumu City, the option of 'greening' household fuel combinations by including LPG for households that do not have it already in their fuel mix was explored (*Table 12*). This fourth scenario (Adjusted Model 4) reveals that households using *FW&Ch&LP* are the highest carbon emitters, while those that use *LP* emit the least (*Figure 8*). In this scenario, approximately 79% of the variation in the total annual carbon emission is dependent on the predictor variables of the model (*Table 10*). From the model, we infer that a unit increase in the household size will increase the total carbon emissions by 37 Kg, whereas a unit increase in the total income will reduce the total carbon emissions by 0.003 Kg. From the model, we can infer that households using the *Ch&LP* combination will produce 0.489 KgCO_2 emissions more than households using the *Ch&Ke&LP* combination will. From the model, households using the *FW&Ch&Ke&LP* combination will produce 780 KgCO_2 emissions more than households using the *Ch&Ke&LP* combination (*Table 12*).

Figure 8: Household carbon emissions by fuel combinations based on including LPG in the fuel mix of households that do not use it



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Households using *FW&Ch&LP* fuel combination will produce 1,142 KgCO_2 emissions more than households using *Ch&Ke&LP*. Households using *FW&Ke&LP* will produce 570 KgCO_2 emissions more than households using *Ch&Ke&LP* combination. It is expected that households using *FW&LP* fuel combination will produce 262 KgCO_2 emissions less than households using *Ch&Ke&LP*. Households using only *LP* will produce 665 KgCO_2 emissions less in comparison to households using *Ch&Ke&LP* combination. From this emission reduction scenario (Adjusted Model 4), the average predicted emission reduction of 84 KgCO_2 emissions represents a -9% deviation from the base emission (*Table 9*). However, this scenario represents a more realistic pathway since it accommodates the reality of fuel stacking in urban informal settlements.

Table 12: Linear regression results for household characteristics and carbon emissions based on including LPG in the fuel mix of households that do not use it

	Independent variable	Annual household carbon emissions	
	Age of household head	4.142**	(1.615)
	Household size	36.555***	(8.766)
	Household income	-0.003**	(0.001)
Fuel choices	*Ch&LP*	0.489	(22.909)
	FW&Ch&Ke&LP	779.694***	(119.632)
	FW&Ch&LP	1,141.621***	(59.530)
	FW&Ke&LP	569.514***	(70.681)
	FW&LP	-261.731**	(105.448)
	LP	-664.734***	(33.879)
	Constant	710.298***	(51.452)
	Observations	419	
	R^2	0.791	
	Adjusted R^2	0.787	
	F Statistic	172.348*** (df = 9; 409)	
	*Standard errors (), *** p<0.01, ** p<0.05, * p<0.1*		

Institutional Arrangements for Household Carbon Emission Reduction

Kenya's carbon emission reduction is guided by its latest submission of NDC to the UNFCCC with an abatement target of 32% by the year 2030 against a BAU emission scenario of 143 MtCO2eq (Republic of Kenya, 2020). Analysis of policies, legislations, and institutional mechanisms indicate that the adoption of clean cooking fuels and fuel-use efficiency are priority emission reduction options for the Kenyan government (*Table 13*). Kenya's constitution provides for the right of every citizen to a clean and healthy environment that is anchored on the sustainable utilisation of energy resources. The country's seminal law on environmental management, The Environmental Management and Co-ordination Act 2015, equally emphasises the need for adoption of low-carbon energy options at all levels of society (*Table 13*). Policy frameworks that advocate and guide HCE reduction include the Kenya Vision 2030, the National Climate Change Action Plan, the National Policy on Climate Finance, and the County Integrated Development Plan for Kisumu (*Table 13*)

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Table 13: Policy, legal and institutional provisions that anchor HCE reduction

	Framework	Implementing institution	Provision on HCE reduction
Policy framework	Kenya Vision 2030 (Republic of Kenya, 2018a)	• Various state and non-state actors	• Enhance LPG supply by boosting LPG import handling and storage capacity at Mombasa Port. • Boosting capacity of LPG handling facilities across Kenya's major cities and urban areas
	National Climate Change Action Plan (Republic of Kenya, 2018b)	• Various state and non-state actors	• Established BAU emission scenario and first country NDC to the UNFCCC • Promotion of transition to clean cooking fuels and fuel-efficient biomass stoves
	National Policy on Climate Finance (Republic of Kenya, 2016)	• Various state and non-state actors	• Provides a basis for mobilising resources for the adoption of low-carbon cooking fuels through international carbon finance mechanisms
	County Integrated Development Plan: Kisumu County (County Government of Kisumu, 2018b)	• County Government of Kisumu	• Mainstreaming climate change in development planning with the number of households that have adopted clean energy sources is a key indicator for the adoption of renewable household energy
Legal framework	Constitution of Kenya 2010 (The Constitution of Kenya, 2010)	• Various state and non-state actors	• Article 42 provides for the right of every Kenya to a clean and healthy environment. • Article 72 provides for the enactment of requisite legislation that would aid in the protection of the environment, including environmentally friendly energy options at all levels.
	Environmental Management and Co-ordination Act, 1999, amended in 2015 (Environmental Management and Co-Ordination Act, 2015)	• National Environment Management Authority (NEMA)	• Article 49 provides that NEMA, in consultation with relevant entities to, promote utilisation of renewable energy through research and utilisation of incentives. • Article 78(d) provides for NEMA to give guidelines on minimisation of carbon emissions, including relevant technologies that will guide climate change mitigation. • The first schedule provides that if there is any law on energy use, other than the Constitution of Kenya, which is in conflict with the provisions of this law, then the EMCA shall prevail.
	Climate Change Act 2016 (Climate Change Act, 2016)	• Climate Change Directorate	• Article 3(2a) provides for mainstreaming climate change in development planning at both national and county government levels.
		• National Climate Change Council	• Article 3(2g) provides for the promotion of low-carbon technologies, including fuel-efficient biomass and LPG stoves. • Article 6 provides for periodic implementation of Climate Change Action Plans and management of the Climate Change Fund, which are key anchors of low-carbon household energy transition.
	The Energy Act, 2019 (The Energy Act, 2019)	• Energy and Petroleum Regulatory Authority	• Article 75 (2g) provides for utilisation of international mechanisms such as CDM and other carbon finance instruments in reducing carbon emissions, including at the household level.
		• Rural Electrification and Renewable Energy Corporation	• Provides for the creation of the Consolidated Energy Fund that shall support the implementation of clean energy technologies such as LPG stoves
	Forest Conservation and Management Act, 2016 (Forest Conservation and Management Act, 2016)	• Kenya Forest Service	• Provides for utilisation of tax and fiscal incentives that promote utilisation of other sustainable energy sources, which will reduce dependency and degradation of forest resources

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Implementation of the provisions of the relevant legal instruments to limit dependency on biomass fuel (Climate Change Act, 2016; Forest Conservation and Management Act, 2016; The Energy Act, 2019) and subsequent actualisation of the NCCAP (Republic of Kenya, 2018b) are vital in the actualisation of emission reduction envisioned in Adjusted Models 2-3 (*Table 9*). Policy interventions that would limit the accessibility and affordability of firewood, such as the imposition of an embargo on logging as the one imposed in February 2018 to date, could drive these households to abandon the use of the fuel. When the survey was conducted in 2019, the government had instituted tax incentives for LPG. If the tax incentives are backed by robust initiatives aimed at increasing access to LPG, then this option portends a greater promise of emission reduction in comparison to the other two scenarios (Adjusted Models 1 and 2). Adoption of LPG promotes the use of clean cooking fuel alternatives to households using *FW*, *Ch*, and *Ke* as single fuels and those using *FW&Ch* and *Ch&Ke* combinations.

Adjusted Model 4 presents an emission scenario of including LPG in the various existing fuel stacks that households use (*Table 10*). However, this scenario leads to the least emission reduction of 84 $KgCO_2$, compared to 169 $KgCO_2$ and 699 $KgCO_2$, respectively, for Adjusted Models 2-3. The scenario acknowledges the existence of fuel stacking and, therefore, a more realistic HCE reduction option. This option is supported by Kenya's priority emission reduction preferences that outline the adoption of improved biomass cookstoves and increasing access to LPG (Republic of Kenya, 2017a, 2018b). This emission reduction pathway acknowledges the intricate connection that exists between Kenyan households and the use of biomass fuels, which is driven by culture, accessibility, and perceptions on the use of firewood and charcoal.

CONCLUSION

The study explores existing and plausible emission reduction options through the adoption of clean fuels for informal settlements of Kisumu City. The study shows that household income has a positive influence on the adoption of clean fuels, while 'greening' of fuel stacks through the inclusion of LPG is the most practical option for achieving sustainable HCE reduction. Policy and fiscal interventions that either reduce household size or increase household income do not have an influence on household CO_2 emissions unless households adopt clean fuels in their cooking. Transitioning households that use charcoal into adopting LPG has the highest emission reduction potential; however, this scenario does not give credence to the reality of fuel stacking in informal settlements. Therefore, incorporating LPG in household fuel mixes and reducing the amount of charcoal they consume by improving the efficiency of cooking devices is the most pragmatic scenario in reducing carbon emissions targeted at 32% of Kenya's business as usual emission of 143 MtCO2eq by the year 2030.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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REFERENCES

Ambole, A., Musango, J. K., Buyana, K., Ogot, M., Anditi, C., Mwau, B., Kovacic, Z., Smit, S., Lwasa, S., Nsangi, G., Sseviiri, H., & Brent, A. C. (2019). Mediating household energy transitions through co-design in urban Kenya, Uganda and South Africa. *Energy Research and Social Science*, *55*(2019), 208–217. https://doi.org/10.1016/j.erss.2019.05.009

Ang'u, C., Muthama, N. J., Mutuku, M. A., & M'IKiugu, M. H. (2023). Determinants of the sustained use of household clean fuels and technologies: Lessons from Vihiga county,

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Article DOI: https://doi.org/10.37284/eajenr.7.1.1704

Kenya. *Energy Reports*, *9*, 1990–2001. https://doi.org/10.1016/J.EGYR.2023.01.026

Christley, E., Ljungberg, H., Ackom, E., & Fuso Nerini, F. (2021). Sustainable energy for slums? Using the Sustainable Development Goals to guide energy access efforts in a Kenyan informal settlement. *Energy Research & Social Science*, *79*, 102176. https://doi.org/10.1016/J.ERSS.2021.102176

County Government of Kisumu. (2013). *Kisumu Integrated Strategic Urban Development Plan*. https://www.kisumu.go.ke/wp-content/uploads/2018/11/ISUD-Part-2-version-2013-12-17-small-filesize.pdf

County Government of Kisumu. (2018a). County Urban Institutional Development Strategy: Kisumu City.

County Government of Kisumu. (2018b). *Kisumu county integrated development plan II, 2018-2022*. County Government of Kisumu.

Enerdata. (2020). *World Energy Consumption Statistics*. Global Energy Statistical Yearbook 2020. https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html

ESMAP. (2021). *Tracking SDG7: The Energy Progress Report*. Energy Sector Management Assistance Program. https://trackingsdg7.esmap.org/results

Gill-Wiehl, A., Ray, I., & Kammen, D. (2021). Is clean cooking affordable? A review. *Renewable and Sustainable Energy Reviews*, *151*(August 2020), 111537. https://doi.org/10.1016/j.rser.2021.111537

Hu, X., Hu, S., Jin, F., & Huang, S. (2017). *Physics of Petroleum Reservoirs*. Springer Berlin, Heidelberg. https://doi.org/https://doi.org/10.1007/978-3-662-53284-3

IEA. (2020). Sustainable Recovery: World Energy Outlook Special Report. In *World Energy Outlook*. International Energy Agency.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (Simon Eggleston, Leandro Buendia, Kyoko Miwa, Todd Ngara, & Kiyoto Tanabe (eds.); 2nd ed.). Institute for Global Environmental Strategies (IGES).

IPCC. (2014). *Climate Change 2014 Synthesis Report* (R. K. Pachauri, L. Meyer, J.-P. Van Ypersele, S. Brinkman, L. Van Kesteren, N. Leprince-Ringuet, & F. Van Boxmeer (eds.)). Intergovernmental Panel On Climate Change.

IPCC. (2018). Summary for Policymakers. In Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, (Issue October). Oxford University Press. www.environmentalgraphiti.org

IRENA. (2022). *World Energy Transitions Outlook 2022: 1.5°C Pathway*. International Renewable Energy Agency. www.irena.org

Karimu, A. (2015). Cooking fuel preferences among Ghanaian Households: An empirical analysis. *Energy for Sustainable Development*, *27*, 10–17. https://doi.org/10.1016/j.esd.2015.04.003

Keramidas, K., Fosse, F., Diaz-Vazquez, A., Schade, B., Tchung-Ming, S., Weitzel, M., Vandyck, T., & Wojtowicz, K. (2021). Global Energy and Climate Outlook 2020 : A New Normal Beyond Covid-19. In *JRC Science for policy report*. Publications Office of the European Union. https://doi.org/10.2760/608429

KNBS. (2019). 2019 Kenya population and housing census Volume II: Distribution of population by administrative units. In *2019 Kenya population and housing census: Vol. II*. Kenya National Bureau of Statistics.

Makonese, T., Ifegbesan, A. P., & Rampedi, I. T. (2018). Household cooking fuel use patterns and determinants across southern Africa:

Article DOI: https://doi.org/10.37284/eajenr.7.1.1704

Evidence from the demographic and health survey data. *Energy and Environment*, *29*(1), 29– 48. https://doi.org/10.1177/0958305X17739475

Masera, O., Taylor, B. S., Kammen, D. M., Masera, O. R., & Saatkamp, B. D. (2000). From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model. *World Development*, *28*(12), 2083–2103. https://doi.org/10.1016/S0305-750X(00)00076-0

Medina, P., Berrueta, V., Cinco, L., Ruiz-García, V., Edwards, R., Olaya, B., Schilmann, A., & Masera, O. (2019). Understanding household energy transitions: From evaluating single cookstoves to "clean stacking" alternatives. *Atmosphere*, *10*(11). https://doi.org/10.3390/atmos10110693

Ockwell, D., & Byrne, R. (2017). *Sustainable Energy for All: Innovation, technology and pro-poor green transformations*. Taylor & Francis Group. https://s3-us-west-2.amazonaws.com/tandfbis/rt-files/docs/Open+Access+Chapters/9781138656925_oachapter01.pdf

OECD, IEA, & IRENA. (2017). Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System. *International Energy Agency*, 204.

Okore, M. K. L., Koske, J., & Letema, S. (2022). Household-based determinants of cooking and heating fuel mixes in informal settlements of Kisumu City, Kenya. *Energy for Sustainable Development*, *71*, 64–72. https://doi.org/10.1016/J.ESD.2022.09.002

Olang, T. A., Esteban, M., & Gasparatos, A. (2018). Lighting and cooking fuel choices of households in Kisumu City, Kenya: A multidimensional energy poverty perspective. *Energy for Sustainable Development*, *42*, 1–13. https://doi.org/10.1016/J.ESD.2017.09.006

Pundo, M., & Fraser, G. (2006). Multinomial logit analysis of household cooking fuel choice in rural Kenya: The case of Kisumu district. *Agrekon*, *45*(1), 24–37.

Rahmani, O., Rezania, S., Beiranvand Pour, A., Aminpour, S. M., Soltani, M., Ghaderpour, Y., & Oryani, B. (2020). An overview of household energy consumption and carbon dioxide emissions in Iran. *Processes*, *8*(8). https://doi.org/10.3390/PR8080994

REN21. (2021). *Renewables 2021 Global Status Report*. REN21 Secretariat. https://abdn.pure.elsevier.com/en/en/researchoutput/ren21(5d1212f6-d863-45f7-8979-5f68a61e380e).html

The Constitution of Kenya, (2010). http://kenyalaw.org:8181/exist/kenyalex/actview.xql?actid=Const2010

Environmental Management and Co-Ordination Act, Pub. L. No. 8, 3 81 (2015). http://www.kenyalaw.org/

Climate Change Act, Pub. L. No. 11 (2016). http://kenyalaw.org:8181/exist/rest//db/kenyalex/Kenya/Legislation/English/Acts and Regulations/C/Climate Change Act - No. 11 of 2016/docs/ClimateChangeAct11of2016.pdf

Forest Conservation and Management Act, Pub. L. No. 34, 155 60 (2016). http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/ForestConservationandManagementActNo34of2016.pdf

Republic of Kenya. (2016). *National Policy on Climate Finance*. The National Treasury and Planning.

Republic of Kenya. (2017a). Nationally Determined Contribution (NDC) Sector Analysis Report: The Evidence Base for Updating Kenya's National Climate Change Action Plan. Ministry of Environment and Natural Resources. http://lecrd.co.ke/download/nccap/downloads/NDC-Sector-Analysis-Report-2017.pdf

Article DOI: https://doi.org/10.37284/eajenr.7.1.1704

Republic of Kenya. (2017b). *Programme Operations Manual: Kenya Urban Support Programme, Volume I*. http://projects.worldbank.org/P156777?lang=en

Republic of Kenya. (2018a). Kenya Vision 2030: Third Medium Term Plan (2018-2022). In *Transforming Lives : Advancing socio-economic development through the "Big Four."* The National Treasury and Planning. https://vision2030.go.ke/publication/third-medium-term-plan-2018-2022/

Republic of Kenya. (2018b). *National Climate Change Action Plan 2018-2022*. Ministry of Environment and Forestry. www.kcckp.go.ke/nccap-ii-2018-2022/

The Energy Act, Pub. L. No. 1, 29 1 (2019). http://kenyalaw.org:8181/exist/rest//db/kenyalex/Kenya/Legislation/English/Acts and Regulations/E/Energy Act - No. 1 of 2019/docs/EnergyAct1of2019.pdf

Republic of Kenya. (2020). *Kenya's Updated Nationally Determined Contribution*. Ministry of Environment and Forestry. https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Kenya First/Kenya's First NDC (updated version).pdf

Rosenzweig, C., Solecki, W., Romero-Lankao, P., Mehrotra, S., Dhakal, S., Bowman, T., & Ali Ibrahim, S. (2015). *Second Assessment Report on Climate Change in Cities: Summary for City Leaders*. www.uccrn.org/casestudies

Shankar, A. V., Quinn, A. K., Dickinson, K. L., Williams, K. N., Masera, O., Charron, D., Jack, D., Hyman, J., Pillarisetti, A., Bailis, R., Kumar, P., Ruiz-Mercado, I., & Rosenthal, J. P. (2020). Everybody stacks: Lessons from household energy case studies to inform design principles for clean energy transitions. *Energy Policy*, *141*(June 2019), 111468. https://doi.org/10.1016/j.enpol.2020.111468

UN-Habitat. (2005). *Situation Analysis of Informal Settlements in Kisumu: Kenya Slum Upgrading Programme*. United Nations Human Settlements Programme (UN-HABITAT). https://unhabitat.org/sites/default/files/download-manager-files/Situation Analysis of informal settlements in Kisumu.pdf

UN-Habitat. (2018). *Pro-poor climate action in informal settlements*. https://reliefweb.int/sites/reliefweb.int/files/resources/Pro-poor Climate Action in Informal Settlements - WEB.pdf

UN-Habitat. (2022). World Cities Report 2022: Envisaging the Future of Cities. In *World City Report 2022*. United Nations Human Settlements Programme (UN-Habitat).

UNFCCC. (2022). Report of the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement on its third session, held in Glasgow from 31 October to 13 November 2021. *Decisions Adopted by the Conference of the Parties Serving as the Meeting of the Parties to the Paris Agreement, March*, 1–46.

Waweru, D., & Mose, N. (2022). Household Fuel Choice in Urban Kenya: A Multinomial Logit Analysis. *Financial Internet Quarterly*, *18*(2), 30– 41. https://doi.org/https://doi.org/10.2478/fiqf-2022-0011

Xing, R., Hanaoka, T., Kanamori, Y., & Masui, T. (2017). Greenhouse Gas and Air Pollutant Emissions of China's Re sidential Sector: The Importance of Considering Energy Transition. *Sustainability*, *9*(4), 614. https://doi.org/10.3390/su9040614

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