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Determinants of Cleaner Cooking Fuel Choice: A study of Two Riparian Communities in Ghana

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Abstract: Background: Clean energy transitioning at the household level has been challenging for most households in Low- and Middle-Income Countries. However, there is a dearth of research on what informs the choice of cleaner fuel for cooking. Therefore, this study examined the predictors of cleaner household cooking fuel in rural and peri-urban settings among primary cooks in Ghana. **Methodology.** Data for this study was drawn from the Briquette for Cooking Fuel Project (B4CcokingF) launched in 2018 by the Volta River Authority and the University of Ghana School of Public Health to manage invasive aquatic weeds. Data were collected on the primary, secondary and tertiary fuel used, socio-economic characteristics, and waste management measures. Using a sample of 420 primary cooks and multinomial logistic regression, we assessed the determinants of clean fuel choices. **Results:** Of the 420 primary cooks interviewed, 59.2% were below 40 yrs, 79% had primary school education, and 78.8% lived in peri-urban settings. Most households used charcoal as their primary fuel (64.49%), wood fuel (44.29%) as secondary fuel, and liquefied petroleum gas (LPG) as the main tertiary fuel (48.84%). Using bivariate and multivariable models, household heads with tertiary education, waste collection by waste management companies and increased household wealth were significant predictors of household cleaner cooking fuel choice. **Conclusion:** Policies that focus on advancing higher education, increasing environmental consciousness, and transitioning people out of poverty are necessary to reduce deforestation by cutting down trees for fuel use and enacting cleaner and sustainable cooking energy sources.

Keywords: cooking fuel choice; primary cook; rural setting; peri-urban setting; biomass briquette

1. Introduction

Globally, households decide on energy consumption by choosing a mix of diverse energy sources simultaneously due to changes in socioeconomic conditions, settings, and varying end uses [1].

In Ghana, due to a lack of access to clean and reliable sources of energy, the cost of clean fuel or the quantity of inexpensive wood fuel in the surrounding area, many households rely extensively on energy sources derived from solid fuels [2]. Solid fuels are a type of fuel that can be comprised of coal, biomass, charcoal, wood, straw, animal dung, and/or crop waste [3]. They are utilized for domestic activities such as cooking, heating, lighting, boiling water, and generating income. Three billion of the world's poorest people live in developing countries, primarily in rural regions, and rely on solid fuels as a primary source of energy [4,5]. Wood fuel is the primary source of energy for the household (mostly for cooking), despite the possible health concerns that this form of energy can potentially bring, especially when it is used inside with microscopic soot particles that travel deep

into the lungs [6]. More than 60% of households in Africa and Southeast Asia rely on solid fuels for home cooking. In Sub-Saharan Africa, about 80% of the population uses biomass for energy [7].

There are several potential benefits to households transitioning to modern clean fuels, including reduced time spent on cooking and cleaning [8]. This can be explained by the higher opportunity cost of gathering and producing fuelwood. Studies have shown that households use more wood fuel when they don't have difficulty fetching it [9]. The energy ladder hypothesis postulates that when a family's income rises, it will switch from using traditional biomass fuels to more contemporary alternatives. The term "energy transition" describes this change [10], which forms the basis for household fuel choice.

1.1. Energy Ladder & Fuel Stacking Concepts

The idea of the energy ladder started to emerge in parallel to the fuel-wood crisis in the 1970s and 1980s [11]. Scholars and energy experts all over the world have employed it to explain the transition in household fuel choices. The energy ladder was designed to depict a hierarchical relationship between household economic status and fuel choice for cooking and heating [12]. As a household's income and socio-economic situation improve, it switches from dirty fuels (biomass) to intermediate fuels (charcoal, kerosene), and finally adopts cleaner and modern fuels [13]. However, the situation is quite different from the ideal in the developing world. Households do not linearly transition from biomass fuels to modern fuels, as accentuated by the energy ladder model [14,15]. Energy (fuel) stacking is a common practice in the world [16,51]. The findings from these contemporary studies are an indication that household fuel choices are influenced by a myriad of economic and non-economic factors [15].

Masera and Navia originated the concept of energy stacking as a critique of the energy ladder theory in rural Mexico [16]. The consumer economic theory recognizes that higher income necessitates higher energy consumption and vice versa. The advantages and disadvantages of fuel stacking and energy laddering are, therefore relative rather than absolute. Biomass occupies the lowest part of the energy ladder. Biomass refers to any naturally occurring combustible material. Woodfuel is a major component within this classification, but grass, crop residues, or dung also fall under biomass and are easily accessible [17,18].Charcoal is a solid fuel derived from wood through a process called pyrolysis. It involves heating the wood to burn off most of the material, leaving pure carbon [19]. Consequently, charcoal shares several advantages and disadvantages with biomass. As a historical and cultural fuel, charcoal preserves the taste of food in contrast to modern energy [20]. Like biomass, charcoal emits organic and nonorganic compounds that are harmful both to human health and the environment [19].

Kerosene is ranged above charcoal. Kerosene is derived from petroleum and is produced during the distillation of crude oil [21]. Compared to its immediate predecessor and biomass, kerosene burns more cleanly and more efficiently and is of an advantage in terms of both user health and the environment. In urban and other resource scarce settings, obtaining kerosene may require less time than gathering biomass [22]. Liquefied petroleum gas (LPG) comes next after kerosene. It is derived from petroleum. It contains propane, butane, or a combination of the two. In particular, LPG releases much less sulphur dioxide than kerosene or biomass [22]. LPG stove presents an "investment barrier" due to the cost of the equipment [16]. Households must additionally pay a deposit for the cylinders that contain the gas [23]. To combat the risks associated with distribution, a household may purchase multiple canisters, increasing the uptake costs of LPG further (Heltberg 2005). After these initial fixed costs, however, the cost of LPG every month may be less than the cost of purchasing biomass [23,24]. In this study, LPG is used as a clean fuel.

At the top of the energy ladder is electricity. In Ghana, about 85% of the population has access to electricity, but very few use it as cooking fuel despite it being clean and the most efficient source of energy for cooking, with minimal health implications with all safety precautions in place. Electricity can be generated from large-scale sources such as nuclear, water, gas, or coal (grid-based) or non-grid sources such as small-scale oil generators or renewable energy [25]. The tasks of

collecting, purchasing, or replenishing supplies largely do not apply, except for prepaid electricity, for which users must visit a utility to make payments or purchase online [23,26].

Many people continue to use cooking fuel concurrently even those who have access to clean cooking continue in a practice known as "fuel stacking". To understand why people, use multiple fuels concurrently, a study reviewed 100 articles and concluded that fuel stacking is largely driven by the Physical Opportunity domain of the COM-B model [51]. This suggests that the persistence of biomass cooking is less culturally anchored than has previously been assumed, and highlights the importance of providing reliable, affordable access to clean fuels.

1.2. Health, Economic and Environmental Risks Associated with Cooking Fuels

The dependence on less clean fuels for cooking and heating is a major source of House Air Pollution (HAP) globally. This phenomenon is significantly associated with respiratory and cardiovascular morbidities, widening the global mortality rate [27]. Major health issues mediated by pollutants from biomass consumption include upper and lower respiratory tract infections, lung cancer, stroke, obstructive pulmonary diseases, burn injuries and premature deaths.

According to the World Bank's 2020 report, 4 billion people worldwide lack access to clean, efficient, convenient, safe, reliable, and affordable cooking energy [28]. In low- and middle-income countries, poorly constructed cookstoves and open fires give rise to about 95% of the 300,000 global cooking-related mortalities annually [29]. Women and children bear a disproportionate share of the burden of collecting and processing firewood in developing countries [2,30]. This cultural practice takes away from productive time and reduces opportunities for women's engagement in beneficial economic endeavours [31].

According to the 2022 world outlook energy report, the world produces 37 billion tonnes carbon dioxide (CO_2) emission yearly of which household cooking fuel combustion is thought to produce 25% of global emissions – black carbon, the second largest contributor to climate change after CO_2 [27,32]. Black carbon absorbs a million times more energy per unit mass than CO_2 but has a shorter half-life, and its effects are amplified on a regional scale in areas close to the source of emissions [27], causing global warming and disrupting regional environmental systems. According to the International Energy Agency (IEA), more than half of all wood harvested globally is used for fuel [33] and is harvested from nearby forests, depleting our forest area of some species and causing deforestation.

Governments in developing countries have enacted policy interventions focused on promoting the transition from traditional fuels by households towards the adoption of cleaner and modern fuels for HAP reduction. The promotion of LPG access, increased electricity consumption, and the adoption of improved cookstoves with chimneys are some of the interventions aimed at reducing HAP exposure [34]. Nonetheless, most people in sub-Saharan Africa are caught in a dilemma in terms of fuel choice due to socio-economic reasons [4,35–38]. The cost of using a cleaner and more sustainable source of energy plus maintaining a particular cooking culture culminates in the fuel choices made for cooking. With limited information on what may influence these choices, this study focuses on examining the determinants of cleaner fuel choice for cooking in Ghana.

2. Materials and Methods

2.1. Study Setting, Sampling, and Sample Size Calculation

The data presented here is a component of the baseline study of the Briquette for Cooking Fuel Project (B4CcokingF), a cluster randomized controlled trial in two riparian towns in the Eastern (Kpong) and Greater Accra (Asutuare) regions (Figure 1). Kpong is one of the main towns in the Lower-Manya Krobo Districts with 16 communities and mostly dominated by the Krobos, but there are also Akans, Ewes, Hausas, and Gas. Asutuare is in the Greater Accra region's Shai-Osudoku District. Six communities divide the town; the Ga-Adangme and Ga tribes make up most of the population with other tribes rediding there. Farming, fishing, or fish mongering are the main sources

of income for the communities. Most households (HHs) use open fires, or charcoal stoves, or a combination of open fires and charcoal stoves, or LPG cookstoves for cooking and warming food.
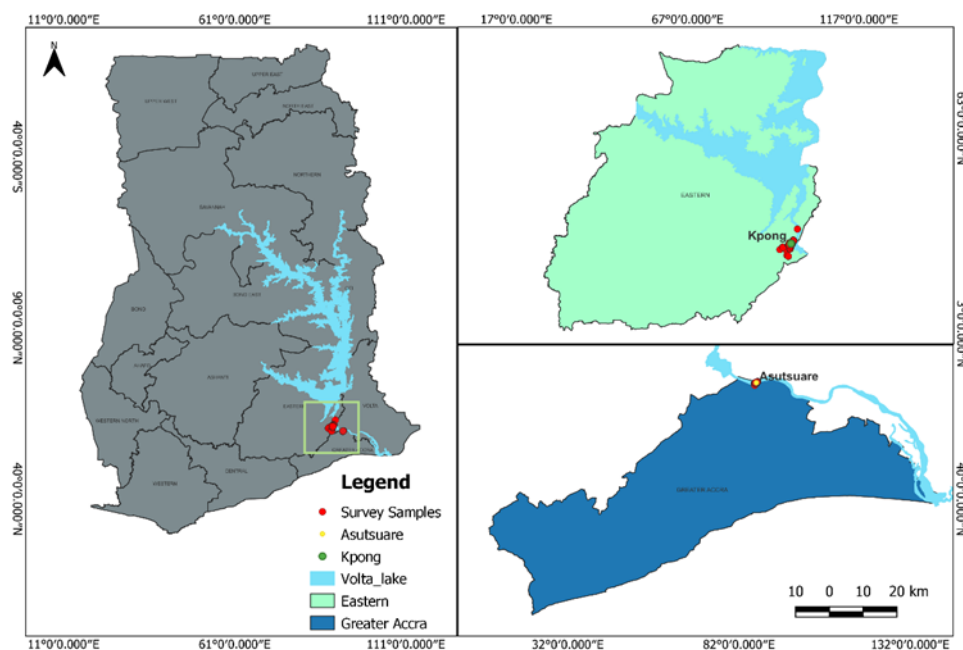
Figure 1. Map showing the Lower Volta and the study areas: Kpong in the Eastern and Asutuare in the Greater Accra regions respectively.

The Lower Volta Lake (LVL) extends from the Akosombo Dam in southeastern Ghana to the town of Yapei in the Central Gonja District, Northern Region of Ghana, some 400 kilometres (250 miles) to the north. The southern end of the LVL is home to Asutuare and Kpong. Aquatic weeds cover about 70% of the entire LV basin. Kpong and Asutuare areas, thus disrupting the water ecosystem, social, cultural, and economic activities, as well as the education of the girl child.

In 2018, the Volta River Authority and the School of Public Health at the University of Ghana launched the B4CcookingF with the goals of (i) managing invasive aquatic weeds through the production of biomass briquettes for cooking/heating and (ii) offering the communities an alternative fuel source and livelihood (i.e., biomass briquettes from aquatic weeds) to minimize the reliance on wood fuel. In 2019, we conducted a baseline census of all 22 communities in Kpong and Asuture towns. We identified 8,825 HHs, totaling 1907 compound houses. A " household" is a collective of individuals who share the same space, eat from the same pot, adhere to the same housekeeping practices, and receive care as a single unit. We used the term "compound house" to refer to HHs that share a common space. We restricted the B4CcookingF study to compound houses with a maximum of four households, to prevent air pollution from nearby HHs from contaminating the study houses. This restriction will enable us to supply briquettes to each HH in a compound house during the project's intervention period. Therefore, we considered 1104 of the 1907 compound houses that met the above requirement.

We estimated the sample size by considering the following factors: a 30% decrease in $PM_{2.5}$ levels from 850 g/m3 [39]; a 0.1 cluster effect; an intra-cluster correlation of 0.25; a 95% confidence interval; 5% type I error rate; 80% power; 359 variability; and a 15% rate of respondents who did not respond or dropped out. We determined the sample size for the RCT to be 210 for each group (420 overall) using a method described in [40]. In the current analysis, all 420 baseline participants were considered. Ethical approval for this study was obtained from the Ethics Review Committee, Ghana

Health Service through School of Public Health, University of Ghana and community leaders of Asutuare and Kpong township (GHS-ERC:015/03/21).

2.2. Data Collection

Trained field workers, led by a community representative, visited eligible HHs in each community and conducted survey interviews with primary cooks with a REDCap (Research Electronic Data Capture) device to gather data from participants using Android phones. Participants were interviewed with a slightly modified WHO questionnaire [41]. The online questionnaire is divided into six sections: HH characteristics, HH socioeconomic characteristics, water and sanitation, fuel storage for cooking, fuel devices for heating and lighting, and health outcomes. 2

2.2.1. Measures

Outcome Variables

The outcome variable was primary household fuel type / choice- the use of charcoal (yes, no), or wood fuel (yes, no), or LPG (yes, no) as a primary fuel. This was transformed into a nominal variable, where 0 was coded as wood fuel, 1 as charcoal and 2 as LPG. The use of wood fuel served as the base or reference category for the model.

Explanatory Variables

The explanatory variables are age (coded as <40, 41-64, >65), sex (coded as 0=male, 1=female), education (coded as 0=primary, 1=secondary, 2=tertiary), civil status (coded as 0=single, 1=married, 2=ever married), religion (coded as 0=Christian, 1=Muslim, 2=Agonist), ethnicity (coded as 1=Ga-Adangbe, 2=Ewe, 3=Akan, 4=others), age of household head (coded as 0=<40, 1=41-64, 2=>65), household head education (coded as 0=primary, 1=secondary, 2=tertiary), family size (coded as 0= <3, 1=3-5,2=>5), dwelling type (coded as 0=Urban, 1= Peri-urban), toilet facility type (coded as 0=improved, 1=unimproved), water source (coded as 0=improved, 1=unimproved), waste disposal method (coded as 0=burning, 1=indiscriminate disposal, 2=collection), wealth index (coded as 0=Lower class, 1= middle class, 2=upper class), and household average monthly income.

2.3. Data Analysis

Descriptive, bivariate and multivariate analyses were used to identify the predictors of cleaner cooking fuel choice. Descriptive statistics were used to report the frequency of the socio-demographic characteristics of participants (e.g., primary cook, household head and household characteristics) and cooking systems (e.g., stove and fuel usage, fuel usage by primary, secondary and tertiary fuel choice). This was followed by a bivariate analysis that assessed the relationship between household demographics by fuel type. Due to the nominal nature of the outcome variable, a multinomial logistic regression model was used to compute a multivariable model for the determinants of fuel choices. Multicollinearity was not an issue as all the model covariates had a variance inflation factor of less than 10 (The range of VIF from the model was 1.5 - 4.7) [42].

3. Results

3.1. Characteristics of Study Participants

Table 1 is a summary table of the characteristics of study participants. A descriptive analysis of the data shows that most of the participants were below 40 yrs (59.2%), females (93.5%), had primary education (79.0%), married (50.6%), belonged to the Christian religion (92.1%), and had a normal BMI (38.1%). Also, most of the household heads were above 65 yrs (94%) and were male (67.1%). The majority of the households (78.8%) were situated in peri-urban settings, with family sizes exceeding six (39.6%). Additionally, 96.1% had improved water sources, 80.2% had improved toilet facilities,

and 53.7% disposed of their waste indiscriminately. The households belonged to the lower-class wealth index, accounting for 67.8%.

Table 1. Primary cook, head of household, and household characteristics (n=420).

Study population characteristics	Frequency	Percent
Characteristics of primary cook		
Age		
Less than 40years	248	59.20
41 - 64years	160	38.20
65years and above	12	2.60
Sex of primary cook		
Male	27	6.40
Female	393	93.50
Educational level of primary cook		
Primary	331	79.00
Secondary	68	16.20
Tertiary	21	4.80
Civil status of primary cook		
Single	81	19.10
Married	212	50.60
Ever Married	127	30.30
Religion of primary cook		
Christian	386	92.10
Muslim	25	6.00
Agonist	9	1.90
Ethnicity of Primary Cook		
Ga-Adambge	83	19.80
Ewe	239	57.00
Akan	19	4.50
Others	79	18.60
BMI category	27.0 ±6.7	
Under weight (<18.5)	19	5.30
Normal (18.5- 24.9)	137	38.10
Over weight (25.0-29.9)	99	27.70
Obese (≥ 29,9)	103	28.90

Characteristics of household head		
Age of household head		
Less than or equal to 40years	8	1.70
41 - 64years	18	4.30
65 years and above	394	94.00
Sex of household head		
Male	282	67.10
Female	138	32.90
Educational level of household head		
Primary	296	70.60
Secondary	93	22.20
Tertiary	30	7.20
Characteristics of household		
Community type		
Peri urban	331	78.80
Rural	89	21.20
Size of family		
Less than 3	112	26.70
3-5	142	33.70
6 or more	166	39.60
Toilet facility type		
*Improved Toilet Facility	336	80.20
*Unimproved Toilet Facility	84	19.80
Water source		
^Improved Water Source	404	96.20
^Unimproved water Source	16	3.82
Waste disposal		
Burning	156	37.20
Indiscriminate Disposal	225	53.70
Collection.	36	8.60
Wealth index		
Lower class	284	67.80
Middle class	107	25.30

Upper class	29	6.90

[1] Note: Primary here refers to no education and primary, secondary is JHS and SHS. *Improved toilet facility refers to flush latrine/Water closet, ventilated improved. * Unimproved toilet facility refers to other pit latrines, open field, and others. ^Improved water source refers to pipe at home, public taps and treated sachet water. **^**Unimproved water source refers to stream/river, rainwater.

3.2. Bivariate Association Between Participant Characteristics and Fuel Type

Table 2 is a description of the bivariate association between participant characteristics and use of fuel type. The results from Table 2 shows that the sex of the participants was significantly associated with household fuel types (p=0.019). That is, the highest (64.6%) and lowest (15.0%) fuel types used by female participants were wood fuel and LPG respectively. The marital status of the participants was significantly associated to household fuel types (p=0.001). That is, the highest (61.5%) and lowest (10.3%) fuel types used by married participants were wood fuel and LPG respectively. The educational level of the participants was significantly associated to household fuel types (p<0.001). That is, the highest (69.8%) and lowest (11.2%) fuel types used by participants who had primary education were wood fuel and LPG respectively. The ethnicity of the participants was significantly associated to household fuel types (p=0.024). That is, the highest (58.7%) and lowest (17.5%) fuel types used by Ewe participants were wood fuel and LPG respectively.

The sex of the household head was significantly associated to household fuel types (p=0.016). That is, the highest (61.0%) and lowest (13.1%) fuel types used in houses with male household heads were wood fuel and LPG respectively. The educational level of the household head was significantly associated to household fuel types (p<0.001). That is, the highest (74.5%) and lowest (9.8%) fuel types used in houses with household heads having primary education were wood fuel and LPG respectively.

The income level of households was significantly associated to household fuel types (p=0.022). That is, the highest (61.4%) and lowest (15%) fuel types used in households with a monthly income of GHC 501-1000 were wood fuel and LPG respectively. The household ownership status was significantly associated to household fuel types (p=0.004). That is, the highest (64.0%) and lowest (8.6%) fuel types used by participants who live in rented houses were wood fuel and LPG respectively. Household dwelling type was significantly related to household fuel types (p=0.001). That is, the highest (75.0%) and lowest (8.3%) fuel types used by participants who live in houses occupied by multiple households were wood fuel and LPG respectively. Family size was significantly associated to household fuel types (p<0.001). That is, the highest (69.7%) and lowest (10.1%) fuel types used by participants whose family size was 4-6 were firewood and LPG respectively.

Table 2. Bivariate analysis of primary cook, household head and household characteristics by fuel types (n=420).

	Charcoal	Wood fuel	LPG	Chi-square	P-value
	N (%)	N (%)	N (%)		
Characteristics of Primary Cook					
Sex					
Male	12 (44.4)	13 (48.2)	2 (7.4)	8.7782	0.019[b**]
Female	80 (20.4)	254 (64.6)	59 (15.0)		
Age of primary cook					

Less than 40	4 (23.5)	10 (58.8)	3 (17.7)	11.1562	0.427[b]
41-64years	24 (25.0)	60 (62.5)	12 (12.5)		
65 years and above	7 (26.9)	14 (53.9)	5 (19.2)		
Civil Status					
Single	32 (15.5)	136 (65.7)	39 (18.8)	14.2701	0.001[a**]
Married	60 (28.2)	131 (61.5)	22 (10.3)		
BMI					
Underweight	4 (15.4)	16 (61.5)	6 (23.1)	9.146	0.204[b]
Normal BMI	27 (17.9)	99 (65.5)	25 (16.6)		
Overweight	31 (25.8)	70 (58.4)	19 (15.8)		
Obese	30 (24.4)	82 (66.7)	11 (8.9)		

Education level of primary cook

Primary	22 (19.0)	81 (69.8)	13 (11.2)	30.5222	<0.001[b]
Secondary	19 (33.9)	33 (59.0)	4 (7.1)		
Tertiary	8 (66.7)	3 (25.0)	1 (8.3)		

Religion of primary cook

Christianity	35 (30.2)	63 (54.3)	18 (15.5)	12.1612	0.075[b]
Muslim	52 (19.2)	178 (65.7)	41 (15.1)		
Agonist	3 (12.0)	21 (84.0)	1 (4.0)		

Ethnicity of primary cook

Ga Adagmbe	21 (16.3)	91 (70.5)	17 (13.2)	16.0099	0.024[b]
Ewe	57 (23.8)	141 (58.7)	42 (17.5)		
Akan	9 (40.9)	12 (54.5)	1 (4.6)		
Others	5 (17.2)	23 (79.3)	1 (3.5)		

Household Head Characteristics

Sex of household head

Male	73 (25.9)	172 (61.0)	37 (13.1)	9.2732	0.016[a]
Female	19 (13.8)	95 (68.8)	24 (17.4)		

Educational level of household head

Primary	16 (15.7)	76 (74.5)	10 (9.8)	59.3349	<0.001[b]
Secondary	27 (36.0)	43 (57.3)	5 (6.7)		
Tertiary	16 (57.1)	11 (39.3)	1 (3.6)		

Household Characteristics

Household average monthly income

Less or equal GHS 250-500	15 (15.0)	62 (62.0)	23 (23.0)	18.8999	0.022[b]
GHS 501-GHS 1000	37 (23.4)	97 (61.4)	24 (15.2)		
GHS 1001 and above	13 (36.1)	20 (55.6)	3 (8.3)		

House ownership

Sole Ownership	23 (18.8)	71 (58.2)	28 (23.0)	16.4935	0.004[a]
Family house	21 (17.1)	84 (68.3)	18 (14.6)		
Rented	48 (27.4)	112 (64.0)	15 (8.6)		

Dwelling

Single	20 (13.8)	9 (62.1)	35 (24.1)	23.2729	0.001[b]
Multiple	2 (16.7)	90 (75.0)	1 (8.3)		
Enclosed	11 (29.7)	24 (64.9)	2 (5.4)		

Size of family

Less than 3	37 (32.7)	65 (57.5)	11 (9.7)	29.9784	<0.001[a]
5-Mar	40 (20.2)	138 (69.7)	20 (10.1)		
6 or more	15 (13.8)	64 (58.7)	30 (27.5)		

* a=Pearson Chi-square Test, b=Fisher Exact Test, **p<0.05.

3.3. Predicting the Association Between Study Characteristics and Fuel Choice

Table 3 presents the results of the multinomial logistic regression estimate of household characteristics by fuel type. In this model, being ever married decreased the likelihood of using LPG (adjusted odds ratio (AOR) = 0.12, confidence interval (CI), 0.02 – 0.71) and charcoal (AOR: 0.18, 0.04-0.83) compared to wood fuel.   Household head having a tertiary education increases the likelihood of utilizing LPG (AOR: 11.66, 95%CI: 1.57,12.08). Having waste collected by a waste management

company increases the likelihood of using LPG (AOR: 8.95 ,95%CI: 1.20- 66.48). Having 6 or more family members in a household decreases the likelihood of using LPG (AOR: 0.18, 95%CI: 0.06-0.51). Relatively, rich households are more likely to use LPG (AOR: 3.65, 95%CI: 1.489.03) and charcoal (AOR: 11, 95%CI: 2.62-46.26).

Table 3. Multinomial logistic regression of household characteristics by fuel type (LPG and charcoal) having wood fuel as the reference (n=419).

Study population characteristics	LPG OR (95% CI)	P-value	Charcoal OR (95% CI)	P-value
Sex of primary cook				
Male	1.00		1.00	
Female	0.12 (0.01, 2.54)	0.175	0.35 (0.02, 5.70)	0.462
Age range of primary cook				
40years and less	1.00		1.00	
41 – 59years	0.69 (0.21, 2.22)	0.530	0.77 (0.30, 1.97)	0.581
60years and above	0.53 (0.05, 6.10)	0.610	0.67 (0.09, 5.22)	0.705
Marital status of primary cook				
Married	1.00		1.00	
Single	0.56 (0.13, 2.38)	0.436	0.62 (0.19, 1.99)	0.426
Ever married	0.12 (0.02, 0.71)	**0.020**	0.18 (0.04, 0.83)	**0.027**
Religion of primary cook				
Christian	1.00		1.00	
Moslem	0.25 (0.00, 112.20)	0.657	0.64 (0.00, 2.31)	0.883
Agnostic	0.96 (0.04, 21.84)	0.980	1.40 (0.09, 21.93)	0.810
Ethnicity of primary cook				
Ga Adamgbe	1.00		1.00	
Ewe	0.73 (0.18, 2.88)	0.648	0.43 (0.14, 1.30)	0.136
Krobo	0.19 (0.02, 1.62)	0.129	0.53 (0.10, 2.77)	0.451
Other	5.09 (0.01, 2084.02)	0.596	4.98 (0.01, 17.16)	0.590
Dwelling				
Single Occupancy	1.00		1,00	
Multiple Occupancy	2.06 (0.68, 6.20)	0.200	1.36 (0.55, 3.35)	0.505
Enclosed Dwelling	2.37 (0.36, 15.37)	0.367	1.64 (0.33, 8.08)	0.541
Educational level of primary cook				
Primary	1.00.		100.	
Secondary	1. 70 (0.54, 5.33)	0.363	2.11 (0.79, 5.56)	0.132
Tertiary	0.047 (0.00, 3.63)	0.168	0.012 (0.000, 1.033)	0.052
Relationship to household head				
Head of house	1..00		1.00	
Married to household head	0.70 (0.12, 4.10)	0.696	1.35 (0.28, 6.52)	0.711
Partner	0.39 (0.03, 5.88)	0.499	0.64 (0.07, 6.41)	0.708
Other relative	1.04 (0.04, 24.19)	0.982	0.97 (0.05, 17.61)	0.981
Age of household head				

40years and less	1.00		1.00	
41 – 59years	0.99 (0.03, 36.44)	0.995	15.00 (0.36, 62.07)	0.154
60years and above	0.74 (0.06, 8.56)	0.811	12.93 (0.79, 21.26)	0.073
Sex of household head				
Male	1.00		1.00.	
Female	0.85 (0.14, 5.29)	0.858	2.41 (0.52, 11.08)	0.260
Educational level of household head				
Primary	100.		100	
Secondary	2.38 (0.69, 8.11)	0.167	0.91 (0.34, 2.45)	0.853
Tertiary	11.66 (1.57,12.08)	**0.031**	12.76 (0.16, 97.09)	0.252
House ownership				
Sole Ownership	1.00		1.00	
Family house	1.12 (0.29, 4.30)	0.867	2.05 (0.71, 5.88)	0.183
Rented	1.51 (0.44, 5.19)	0.514	2.07 (0.74, 5.80)	0.164
Occupation of household head				
Trader	1.00.		1.00	
Farmer	0.22 (0.05, 1.04)	0.057	0.44 (0.13, 1.51)	0.191
Artisan	0.55 (0.10, 2.94)	0.482	0.61 (0.14, 2.63)	0.509
Employed	0.63 (0.01, 3.97)	0.622	0.96 (0.19, 4.98)	0.963
Unemployed	0.92 (0.18, 4.53)	0.920	0.50 (0.13, 1.96)	0.319
Household average monthly Income				
Ghc 250 or less	1.00		1.00	
Ghc 251 – 1000	0.84 (0.12, 5.87)	0.860	0.46 (0.11, 1.99)	0.300
Greater than or equal to Ghc 1001	3.18(0.29, 34.51)	0.341	2.64 (0.39, 17.89)	0.319
Reluctant	0.09 (0.00, 2.93)	0.177	0.36 (0.04, 3.58)	0.386
Waste disposal				
Burning	1.00		1.00	
Indiscriminate disposal	1.07 (0.38, 3.00)	0.894	1.14(0.49, 2.66)	0.768
Collection	8.95 (1.20, 66.48)	**0.032**	0.94 (0.16, 5.66)	0.947
Family size				
5members or less	1.00		1.00	
6 members or more	0.18 (0.06, 0.51)	**0.001**	0.48 (0.21, 1.09)	0.081
^Water sources				
Improved water source	1.00		1.00	
Unimproved water source	0.53 (0.07, 3.79)	0.524	0.17 (0.03, 0.98)	0.047
***Toilet facilities**				
Improved toilet facility	1.00		1.00	
Unimproved toilet facility	0.23(0.06,0.86)	0.028	0.46(0.17,1.25)	0.130
#Wealth Index				
Relatively poor household	1.00		1.00	

Relatively rich household	3.65 (1.48,9.03)	**0.005**	11(2.62,46.26)	**0.001**

[1] Note: Primary refers no education and primary, secondary is JHS and SHS. ^Improved water source refers to pipe at home, public taps and treated sachet water. **^**Unimproved water source refers to stream/river, rainwater. *Improved toilet facility refers to flush latrine/Water closet, ventilated improved * Unimproved toilet facility refers to other pit latrines, open field, and others. #Relatively poor household refers to lower class. #Relatively rich households refer to middle/upper class. Most of them are from the middle class.

4. Discussion

This study aimed to examine the determinants of cleaner cooking fuel choice among two riparian peri-urban communities in Ghana. Findings from this study show that most households used charcoal as their primary fuel (64.49%), followed by LPG (20.77%) and wood fuel (14.73%). A family size of 6 or more and having been previously married reduced the likelihood of using LPG as the primary fuel. Household heads with tertiary education increased the likelihood of utilizing LPG and having or being relatively rich, as indicated by the wealth tertile increased the likelihood of using LPG and charcoal compared to wood fuel as a primary fuel. Additionally, the majority of rich households with heads having tertiary education and having their waste collected by waste management companies increased the likelihood of using LPG. It is worth noting that although increasing wealth increased the likelihood of using cleaner fuel (LPG), this did not stop the wealthy from using dirty fuels such as charcoal more extensively. The findings from this study highlight the challenge of fuel stacking, where changes in behavior towards the use of only clean sources of fuel do not hold for most households.

This study has several strengths. First, data were derived from a baseline of a cluster randomized control trial, which randomly assigned households to the intervention and control arms. Thus, each household, or participant by inference, had an equal chance of recruitment into any of the arms. Second, a census was taken of all the communities to ensure representativeness, thus, reducing selection bias. Finally, this study employed a structured questionnaire on RedCapp using a slightly modified version of the WHO questionnaire as such information bias may not explain these findings. The WHO questionnaire for monitoring household energy use and SDG indicators has been used in several studies across the Africa region, an example is Parvizi et al., 2024.

The study findings showed that most households used charcoal as their primary and secondary cooking fuel and LPG as their main tertiary fuel. This result is consistent with a study among urban households in Ghana, which established that most households rely largely on wood and charcoal and occasionally on LPG or electricity [43]. Also, relying on aggregate data using the GLSS, it was reported that wood fuels continue to be the most common energy source used for cooking by households in Ghana [44,49]. In Nigeria, a population-based research report suggests that almost 70% of households rely on biomass for cooking [45].

The novelty of this study lies in the findings that demographic factors such as higher educational level, having waste collected by waste management companies, and relatively rich households are the main determinants of LPG use. This is analogous to a study among households in Malawi, which showed that families choose one type of cooking fuel over another depending on the age of the household head, income, location and household head education status [48]. Another related study in Uganda showed that demographic characteristics such as level of education, age, and income influence a family's choice of cooking fuel [50]. Furthermore, corroborating studies conducted among households in China and Kenya found that family size, economic status, prices of fuel, gender and education are the determinants of household fuel choices in urban settings [46,47}. In sum, the extant literature has emphasized general household fuel choice and not cleaner sources of energy. Thus, this study shows that such factors may similarly influence the use of cleaner sources of energy, such as liquified petroleum gas.

5. Conclusions

The findings from this study highlight the need for important policy and programmatic changes aimed at increasing education on the use of cleaner fuels and resourcing households with the means to follow through with this education. Education should focus on enabling household heads to make fuel substitutions that will improve energy efficiency and have fewer negative effects on the environment, society, and people's health. Effective interventions should include the advancement of the Government of Ghana's efforts to raise the overall level of education, education on environmental risk factors, and support the most vulnerable transition out of poverty. This will contribute to a reduction in the use of charcoal from wood, which will indicate a reduction in the pressure that is placed on wood supplies and will help contribute towards mitigating deforestation. Furthermore, stakeholders and policies in the energy sector should advance and promote the use of renewable, clean technologies to reduce the impact on the ecosystem, reduce pollution, and meet household demand. This should include enhancing initiatives such as the National LPG Promotion Program and the Rural LPG Promotion Program, increasing subsidies for LPG, extending the LPG Cylinder Recirculation Model to rural regions, and addressing the issue of LPG supply bottlenecks [52].

Abbreviations

The following abbreviations are used in this manuscript:

B4CooingF	Briquette for cooking fuel
CO_2	Carbon dioxide
HH	Household
LPG	Liquified petroleum gas
LVL	Lower volta lake
REDCap	Research electronic device capture
WHO	World Health Organisation

References

1. World Health Organization. Household Air Pollution and Health. Geneva, Switzerland. Available online: http://www.who.int/mediacentre/factsheets/fs292/en/ (accessed on 20 December 2023).
2. Baiden, P.; Boateng, G.O; Dako-Gyeke, M.; Acolatse, C.K.; Peters, K.E. Examining the effects of household food insecurity on school absenteeism among Junior High School students: findings from the 2012 Ghana

global school-based student health survey, *African Geographical Review*,**2019,** http://doi.org/10.1080/19376812.2019.1627667.

3. Acharya, B.; Marhold, K. Determinants of household energy use and fuel switching behavior in Nepal. *Energy*, **2019** *169*, 1132–1138. http;//doi: 10.1016/j.energy.2018.12.109.

4. Rahut, D. B.; Das, S.; Groote, H.; Behera, B. Determinants of household energy use in Bhutan. *Energy*, **2014** *69*, 661–672. http;//doi: 10.1016/j.energy.2014.03.062.

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

6. Behera, B.; Ali, A. Household energy choice and c intensity: Empirical evidence from Bhutan. *Renewable and Sustainable Energy Reviews*, **2016**, *53*, 993–1009.

7. Liao, H.; Tang, X.; Wei, Y. M. Solid fuel use in rural China and its health effects. *Renewable and Sustainable Energy Reviews*, **2016**, *60*, 900–908.

8. Joshi, J.; & Bohara, A. K. Household preferences for cooking fuels and inter-fuel substitutions: Unlocking the modern fuels in the Nepalese household. *Energy Policy*, **2017**, *107*, 507–523.

9. Muller, C.; Yan, H. Household fuel use in developing countries: Review of theory and evidence. *Energy Economics*, **2018**, *70*, 429–439.

10. Meried, E. W. Rural household preferences in transition from traditional to renewable energy sources: the applicability of the energy ladder hypothesis in North Gondar Zone. *Heliyon*, **2021**,*7*(11), 08418.

11. Toole, R. The Energy Ladder: A Valid Model for Household Fuel Transitions in Sub-Saharan Africa? Master of Science in Urban and Environmental Policy and Planning and Economics http://hdl.handle.net/10427/012067 (accessed on 10 February 2020).

12. Karimu A., Mensah J.T., Adu G. Who Adopts LPG as the Main Cooking Fuel and Why? Empirical Evidence on Ghana Based on National Survey. World Dev. 2016; 85:43–57 doi: 10.1016/j.world dev.2016.05.004

13. Smith, K.R.; McCracken, J.P.; Thompson, L.; Edwards, R.; Shields, K.N.; Canuz, E.; Bruce, N. Personal child and mother carbon monoxide exposures and kitchen levels: Methods and results from a randomized trial of woodfired chimney cookstoves in Guatemala (RESPIRE). *J. Exp. Sci. Environ. Epidemiol*. **2010**, 20, 406–416.

14. *Dendup N., Arimura T.H. Information leverage: The adoption of clean cooking fuel in Bhutan. Energy Policy. 2018; 125:181–195. doi: 10.1016/j.enpol.2018.10.054.*

15. Ogwumike, F. O.; Ozughalu, U. M.; Abiona, G. A. Household energy use and determinants: Evidence from Nigeria. *International Journal of Energy Economics and Policy*, **2014**, *4*(2), 248–262.

16. Masera, O. R.; Navia, J. Fuel switching or multiple cooking fuels? Understanding inter-fuel substitution patterns in rural Mexican households. *Biomass and Bioenergy*, **1997**,*12*(5), 347-361.

17. Bonjour, S.; Adair-Rohani, H.; Wolf, J.; Bruce, N.G.; Mehta, S.; Prüss-Ustün, A.; Lahi, M.; Rehfuess, E.A.; Mishra, V.; Smith, K.R. Solid fuel use for household cooking: Country and regional estimates for 1980–2010. Environ. Health Perspect. 2013, 121, 784–790.

18. Twumasi M.A., Jiang Y., Ameyaw B., Danquah F.O., Acheampong M.O. The impact of credit accessibility on rural households clean cooking energy consumption: The case of Ghana. *Energy Rep*. 2020; 6:974–983. doi: 10.1016/j.egyr.2020.04.024.

19. McCarron A., Uny I., Caes L., Lucas S.E., Semple S., Ardrey J., Price H. Solid fuel users' perceptions of household solid fuel use in low- and middle-income countries: A scoping review. Environ. Int. 2020; 143:105991. doi: 10.1016/j.envint.**2020**.105991.

20. Nansaior, A.; Patanothai, A.; Rambo, A. T.; Simaraks, S. Climbing the energy ladder or diversifying energy sources? The continuing importance of household use of biomass energy in urbanizing communities in Northeast Thailand. *Biomass and Bioenergy*, **2011** *35*(10), 4180-4188.

21. Lam, N. L.; Smith, K. R.; Gauthier, A.; Bates, M. N. Kerosene: a review of household uses and their hazards in low-and middle-income countries. *Journal of Toxicology and Environmental Health, Part B*, **2012**, *15*(6), 396-432.

22. Goldemberg, J. Pesquisa e desenvolvimento na área de energia. *São Paulo em perspectiva*,2000, *14*, 91-97.

23. Heltberg, R. Household fuel and energy use in developing countries: A multi-country study. *The World Bank*, 2005, 1–87.

24.   Gould C.F., Schlesinger S.B., Molina E., Bejarano M.L., Valarezo A., Jack D.W. Household fuel mixes in peri-urban and rural Ecuador: Explaining the context of LPG, patterns of continued firewood use and the challenges of induction cooking. Energy Policy. 2020; 136:111053. doi: 10.1016/j.enpol.2019.111053.

25.   Van der Kroon, B.; Brouwer, R.; Van Beukering, P. J. The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. *Renewable and sustainable energy reviews*, **2013**, *20*, 504-513.

26.   Ma W., Zhou X., Renwick A. Impact of off-farm income on household energy expenditures in China: Implications for rural energy transition. Energy Policy. 2018; 127:248–258. doi: 10.1016/j.enpol.2018.12.016.

27.   WHO (2016). Clean Household Energy for Health, Sustainable Development, and Wellbeing of Women and children. In *WHO Guide*. Available online, http;//apps.who.int/iris/bitstream/10665/204717/1/9789241565233_eng.pdf?ua=1 (accessed on 6 December 2023).

28.   Sharma, D.; Ravindra, K.; Kaur, M.; Prinja, S.; Mor, S. Cost evaluation of different household fuels and identification of the barriers for the choice of clean cooking fuels in India. *Sustainable Cities and Society*, 2020, *52*, 101825.

29.   Gallagher, M.; Beard, M.; Clifford, M. J.; Watson, M. C. An evaluation of a biomass stove safety protocol used for testing household cookstoves, in low and middle-income countries. *Energy for Sustainable Development*, **2016**, *33*, 14–25.

30.   Ali, A.; Mottaleb, K. A.;Aryal, J. P. Wealth, education and cooking-fuel choices among rural households in Pakistan. *Energy Strategy Reviews*, **2019**,*24*, 236–243.

31.   Ndiritu, S. W.; Nyangena, W. Environmental goods collection and children's schooling: Evidence from Kenya. *Regional Environmental Change*, 2011, *11*(3), 531–542.

32.   World Energy Outlook 2022. www.iea/org/weo. Accessed on 15th December, 2025.

33.   World Energy Outlook 2019. www.iea.org/weo. Accessed on 7th January, 2022.

34.   Burwen, J.; Levine, D. I. A rapid assessment randomized-controlled trial of improved cookstoves in rural Ghana. *Energy for Sustainable Development*, **2012**, *16*(3), 328–338.

35.   Adeyemi, P. A.; Adereleye, A. Determinants of household choice of cooking energy in Ondo state, Nigeria. *Journal of Economics and Sustainable Development*, **2016**, *7*(9), 131-142.

36.   Jaiswal, V. B.; Meshram, P. U. Behavioral Change in Determinants of the Choice of Fuels amongst Rural Households after the Introduction of Clean Fuel Program: A District-Level Case Study. *Global Challenges*, **2021**, *5*(2), 2000004.

37.   Mperejekumana, P.; Li, H.; Wu, R.; Lu, J.; Tursunov, O.; Elshareef, H.; Dong, R. Determinants of household energy choice for cooking in Northern Sudan: A multinomial logit estimation. *International Journal of Environmental Research and Public Health*, **2021**, *18*(21), 11480.

38.   Endalew, M.; Belay, D. G.; Tsega, N. T.; Aragaw, F. M.; Gashaw, M.; Asratie, M. H. Household Solid Fuel Use and Associated Factors in Ethiopia: A Multilevel Analysis of Data From 2016 Ethiopian Demographic and Health Survey. *Environmental Health Insights*, **2022**, *16*, 11786302221095033.

39.   Quansah, R.; Semple, S.; Ochieng, C. A.; Juvekar, S.; Armah, F. A.; Luginaah, I.; Emina, J. Effectiveness of interventions to reduce household air pollution and/or improve health in homes using solid fuel in low-and-middle income countries: A systematic review and meta-analysis. *Environ Int*. **2017**, 103:73-90. doi: 10.1016/j.envint.2017.03.010.

40.   Rutterford, C.; Copas, A; Eldridge, S. Methods for sample size determination in cluster randomized trials. *Int J Epidemiol*. 2015, 44:1051-67.   doi: 10.1093/ije/dyv113.

41.   World Health Organization Questionnaire on Health Survey. 2019.(2_harmonized_household_energy_survey_questions long_roster_final_nov2019.pdf).   (accessed on 30 November 2019).

42.   Thompson, C. G.; Kim, R. S.; Aloe, A. M.; Becker, B. J. Extracting the variance inflation factor and other multicollinearity diagnostics from typical regression results. *Basic and Applied Social Psychology*,2017 *39*(2), 81–90 https://doi.org/10.1080/01973533.2016.1277529.

43.   Meng, T.; Florkowski, W.J.; Sarpong, D.B.; Chinnan, M.; Resurreccion, A.V.   Cooking fuel usage in sub-Saharan urban households, *Energies* **2021**, 14(15), 4629. https://doi.org/10.3390/en14154629

44. Kutortse, D.K. Residential energy demand elasticity in Ghana: an application of the quadratic almost ideal demand systems (QUAIDS) model. *Cogent Economics & Finance*, **2022** 10(1). https;//doi.org/10.1080/23322039.2022.2082670.

45. Ifegbesan, A.P.; Rampedi, I.T.; Annegarn, H. Nigerian households' cooking energy use, determinants of choice, and some implications for human health and environmental sustainability. *Habitat International, 2016, 55*, 17-24.

46. Zhang, X.-B.; Hassen, S. Household fuel choice in urban China: evidence from panel data. *Environment and Development Economics*, **2017**, *22*(4), 392–413. doi:10.1017/S1355770X17000092.

47. Waweru, D.; Mose, N. Fuel Choices in Urban Kenyan Households. *Journal of Economics and Sustainable Development.* **2022**, 2021. 10.7176/JESD/12-14-06.

48. Assa, M.; Maonga, B.; Gebremariam, G. Non-price determinants of household's choice of cooking energy in Malawi. *International Journal of Development and Sustainability*, **2015**, 4 (1).

49. Immurana, M.; Kisseih, K.; Yakubu, M.; Yusif, H. Financial inclusion and households' choice of solid waste disposal in Ghana. *BMC Public Health*. **2022**, 22. 10.1186/s12889-022-13512-2.

50. Katutsi, V.; Dickson, T.; Migisha, A. Drivers of Fuel Choice for Cooking among Uganda's Households. *Open Journal of Energy Efficiency*. **2020**, 9. 111-129. 10.4236/ojee.2020.93008.

51. Perros, T.; Allison, A.L.; Tomei, J. Behavioural factors that drive stacking with traditional cooking fuels using the COM-B model. *Nat Energy.* **2022** ,7. 886–898. https://doi.org/10.1038/s41560-022-01074-x