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Female labour force participation, power dynamics, and adoption of LPG for cooking in Ghana

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Received: 1 October 2024 / Accepted: 14 January 2025
Published online: 20 February 2025

Abstract
Cooking with solid fuels has been identified to pose health and environmental risks especially to women and children who bear the primary and heaviest burden of collecting firewood and cooking. While liquefied petroleum gas is recognized as a clean energy source that could alleviate the issues associated with solid fuels, empirical research has not extensively explored how women's involvement in the labour force and their power dynamics could promote the adoption of liquefied petroleum gas. This study addresses this gap by examining female labour force participation, power dynamics, and adoption of liquefied petroleum gas in Ghana using mixed-effect logistic regression model. The findings suggest that increasing women's participation in the labour market increases the likelihood of adoption of liquefied petroleum gas as a cooking fuel by 2.5 times. However, married women with limited decision-making power in their households are less likely to adopt liquefied petroleum gas as a cooking fuel. Policy should be geared towards empowering women by giving them employable skills through training.

Article Highlights

- Women who are in paid jobs use more clean cooking fuel than those who are not.
- Involving women in family decision making encourage the use of clean cooking fuel at home.
- Training women to acquire requisite skills will reduce their chances of using unclean fuel for cooking.

Keywords Labour force participation · Power dynamics · Women empowerment · Liquefied petroleum gas

1 Introduction

Although access to modern and efficient energy for cooking is recognized as a key global development target, about one-third of the world's population still lacks access to clean cooking technologies [1]. This inequity predominantly impacts women and children in developing nations, as they bear the primary and heaviest burden of collecting firewood, cooking, and managing domestic tasks. Compared to men, women, and children are more prone to accidents and physical injuries incurred during firewood collection and transportation [2]. Over the years, research has extensively established that household air pollution (HAP), resulting from the prolonged use of solid fuels contributes to environmental hazards,

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premature deaths, and various health issues including cardiovascular and respiratory diseases, and lung cancer [3–6]. These adverse impacts have inspired global commitments to accelerate the achievement of sustainable development goals 7 and 5, focused on ensuring access to affordable clean energy and empowerment for all women respectively [7]. However, sustained progress towards adopting clean cooking fuels such as liquefied petroleum gas (LPG) remains critically slow in lower and middle-income countries. Recent data from a national census in Ghana revealed that many households rely on wood (31.1%) and charcoal (23.2%) for primary cooking. Despite its wide availability, just about a third of households (36.9%) currently use LPG for primary cooking—often, with a higher concentration in urban (51.3%) than in rural areas (14.8%) [8].

The low uptake of LPG for cooking in Ghana is particularly concerning given that the fuel is widely available. About 70% of LPG supply in Ghana is imported by the Bulk Import Distribution and Export Companies (BIDECs). The rest is produced locally—by the Ghana National Gas Company (GNGC) and the Tema Oil Refinery (TOR). Government initiatives to encourage cooking with LPG began as early as 1989 and focused on distributing cylinders to households, food vendors, hospitals, and educational institutions. This resulted in significant growth in LPG consumption from 5,000 tonnes in 1990 to 34,000 tonnes in 1994 [9–11]. Over the last three decades, several government policy frameworks including the National Energy Policy, the Sustainable Energy for All Action Plan, and the Rural LPG Promotion Program have all emphasized improved access to clean energy, reduced deforestation, and environmental sustainability. These have helped to increase annual consumption of LPG to 317,000 tonnes. The 2017 policy initiative on LPG promotion aims to enhance LPG access for 50% of Ghanaians by 2030. This involves transitioning from the consumer-controlled cylinder (CCCM) model to a branded cylinder recirculation model (BCRM).

Although the new model has shown promising potential to expedite LPG adoption in nations such as India, Morocco, Turkey, Nicaragua and others [12, 13], a thorough analysis of the unique local and context-specific factors influencing household fuel selection is required to offer valuable insights for the transition. While previous research has extensively highlighted the role of technology [14, 15], socio-economic [16–22], and geographical factors [23] in household fuel choice, the specific impacts of women's paid employment and power dynamics on LPG adoption remain inadequately understood. This knowledge gap could be attributed to the limited attention to the subject as evidenced by past studies. For instance, [24] in a cross-sectional analysis of the determinants of household fuel choice in Guatemala focused on the correlations between fuel choice and factors such as household expenditure, fuel price, household size, and higher education. Other studies in Ghana including those [17, 19, 20, 25] have underscored the significance of income, access to infrastructure, location of households, energy supplies and social and demographic factors in LPG adoption.

This study addresses the current gap by examining the influence of female labour force participation and power dynamics on LPG adoption in Ghana. The paper differs from previous studies on energy choice in Ghana in two main ways. First, it uses panel data instead of cross-sectional data to address the problem of heteroscedasticity and track household behaviour over time. Secondly, the study employs a mixed-effect logistic regression model to account for heterogeneity in the sample. We argue that changes in women's involvement in decision-making affect household energy choices—and thus, households with increased women participation in the labour force, and increased decision-making power are more likely to choose LPG for clean cooking. We contribute to the policy discourse on inclusive growth and household fuel selection by investigating female labor force engagement, power dynamics, and LPG adoption, aligning with Sustainable Development Goals 5 and 7. The subsequent sections of this paper are structured as follows: Sect. 2 reviews existing studies on household fuel selection, Sect. 3 outlines the methodology and data used, Sect. 4 presents the results and discussion, and Sect. 5 offers concluding remarks along with policy recommendations.

2 Empirical literature

Empirical studies on household fuel choice have focused on several determinants. Most of the studies focused on determinants such as household head characteristics, household income, type of household dwelling units, employment, educational attainment, and household size among others. For instance, in their investigation of household energy consumption patterns in Nepal, using the multiple discrete–continuous extreme value (MDCEV) model, [18] found that households with lower education levels and private house ownership tend to rely on firewood and kerosene for energy consumption. Conversely, households equipped with information and communication technology devices, as well as access to renewable energy sources, showed a preference for modern and cleaner fuels. In a related study, Pundo and Fraser [26] conducted an analysis of the factors influencing household fuel selection among firewood, charcoal, and kerosene in rural Kisumu. Utilizing data from the Kisumu household survey spanning the

period 2001, they identified several key determinants of fuel choice. These included the educational attainment of both spouses, the type of dwelling unit occupied by the husband, the primary type of food cooked, and the ownership status of the dwelling unit.

Additionally, several empirical investigations have demonstrated that household head characteristics play a significant role in determining fuel choice [16, 17, 27–29]. For instance, Zhang and Hassen [29] adopted a correlated random effect generalized ordered probit model and analyzed the determinants of household fuel choice in urban China. They used data from the eighth round of the household survey dataset and concluded that the gender of the household head, household size, education, fuel price, and household's economic status affect fuel choice in urban China. Earlier in 2014, Baiygunhi and Hassan [27] examined how the socio-economic characteristics of households affect the choice of cooking fuel in the Giwa Local Government area in Kaduna State, Nigeria, using multinomial logistics regression. They observed widespread fuel stacking in the surveyed areas. Furthermore, they identified the household head's age, level of education, type of dwelling unit, duration of food preparation, and firewood prices as the primary determinants of cooking fuel choice. Their analysis was based on cross-sectional data collected from 120 households in 2010/11. Similar findings that support these earlier results have been reported by Gyamfi and colleagues [16] using data from Amazonas in Brazil.

Using the household energy expenditure data of the Vietnam Living Standard Survey, [30] investigated energy transition, poverty, and inequality in Vietnam for the period 2014 to 2016. They reported that though most households have transitioned to modern energy, the extent of the transition depended on ethnicity, geographical location, and welfare group. Traditional fuel sources such as biomass and coal continue to be the dominant fuel used by the poor and ethnic minority groups. They recommended a national policy that reduces household energy costs.

The role of affordability in fuel choice has been extensively discussed in the literature. Income emerges as a critical determinant, indicating that higher household income contributes to improved economic well-being and a higher likelihood of adopting modern cooking methods [22, 24, 31]. Affordability is commonly assessed through fuel prices, with higher prices typically associated with lower adoption rates of modern fuels and technologies [32, 33]. Recognizing the importance of fuel and technology in influencing household fuel preferences, some studies have emphasized the impact of household decision-making regarding improved cookstoves on fuel and technology adoption [6, 34, 35].

Recent studies have highlighted the role of trust in local institutions and social capital in household fuel choice. Institutions shape how economic and political actors interact [36]. Therefore, the availability of trusted institutions determines whether consumers will have confidence in the institutions or not. Supply of modern cooking fuel such as LPG requires high sunk cost regarding infrastructure development. Thus, investors will require the government to show commitment and credibility [37]. This could only be achieved if there were strong institutions to provide checks and balances. Strong institutions will induce investment in modern cooking fuel infrastructure to ensure timely and consistent fuel supply, thereby making consumers rely on modern cooking fuel [38]. For instance, Soni and Chatterjee [38] use panel data of households in India to explore the enablers of the adoption of clean cooking technology and the sustained use of fuel. Based on the logistic regression model, they found a positive association between participation in community organizations and trust in local government with the adoption of stove technology and the adoption of LPG.

Women empowerment has been identified to influence household fuel choice. Women, who primarily undertake cooking responsibilities, invest considerable time, particularly when using solid fuels like charcoal and firewood. Studies have shown that women who are in employment tend to use clean or modern cooking fuel to cut the time allocated to cooking. In ref. [39] investigated the long-run relationship between clean cooking technology and female labour force participation in 45 sub-Saharan African countries from 2000 to 2017. They employed a two-step system generalized method of moments and found a positive association between clean cooking technology and female labour force participation. This suggests that clean cooking technology is likely to impact on female labour force participation.

In Ghana, several studies have been carried to understand the determinants of household fuel choice fuels [17, 19, 20, 25, 28]. In ref. [17], the authors examined the determinants of transition to clean energy in Ghana using the Ghana Living Standard Survey round 7. They employed a multinomial logistics regression model and found education, household dwelling type, household size, employment and income group as the main determinants of household energy choice in Ghana. In another study, Mensah and Adu [19] investigated the determinants of household fuel choice in Ghana using Ghana Living Standard Survey round five (GLSS V) data conducted in 2005/06. Through an ordered probit model, they found that income and access to suppliers were the key determinants of cooking fuel types in Ghana. Thus, they recommended intensification of the poverty reduction programme to increase the income of households. Similarly, Kwakwa et al. [28] employed logistic regression model to investigate the determinants of fuel choice by households in Ghana using data from 507 households in the tropical forest vegetation and the savanna vegetation zones. The authors established that income, education, family size and employment are the major determinants of household fuel choice.

From the review of the literature, no study has been carried out at the household level that investigates female labour force participation, power relations, and adoption of LPG fuel in Ghana. Therefore, this study seeks to bridge the gap in the empirical literature by contributing to the discourse on how female labour force participation and power relations affect the adoption of LPG.

3 Methodology

3.1 Theoretical framework and model specification

This study is premised on utility theory which stipulates that individuals have preferences, and their choices are influenced by their preferences. Based on this, we posit that energy consumers have a preference for various energy types and their choice of a specific energy type depends on their preferences. Let's assume that Z represents a set of feasible choices. Then we can model a consumer choice in which $Z \in \theta^n$ indicating that there are *n* different cooking fuel choices such as LPG, electricity, charcoal, wood fuel, and others. Also, we assume that $z \in Z$ then $z = (z_i, \ldots\ldots\ldots .., z_n)$. Where z represents cooking fuels.

The household utility function for cooking fuel choice is specified as:

$$W_{ij} = \beta_i Z_i + \mu_{ij} \tag{1}$$

where:

W_{ij} = the indirect utility of household *i* for cooking fuel *j*.

Z_i = vector of individual, household and other characteristics that could influence a household choice of cooking fuel.

β_i = vector of coefficients of explanatory variables which measures the average probability that a household chooses a particular fuel type.

μ_{ij} = stochastic component that captures the unobserved utility.

Following the theoretical framework, we specify mixed effects logistic regression model as:

$$logit\left(E\left(Y_{ij} = 1|X_i, b_i\right)\right) = log\left(\frac{Y_{ij}}{1 - Y_{ij}}\right) = B_i X_{1i} + B_2 X_{2i} + \cdots + B_n X_{ni} + Z_i b_i \tag{2}$$

where Y_{ij} denotes an *N*-dimension vector of LPG adoption (1 or 0) for the *ith*, $i = i, \ldots, N$ individual household at time $j, j = 1, \ldots .., n$. It measures the probability of adoption of LPG by a household. The X_i is an *N* x *n* matrix of factors that affect the adoption of LPG for *ith* household. B_i is $n \times 1$ vector of the fixed effects and they measure the effects of independent variables on adoption of LPG. Z_i is a *N* x *p* matrix for the *p* random effects, and b_i is an individual household-specific random effect and is assumed to be normally distributed, $b_i \sim N(0, \sigma_b^2)$.

The mixed effects logistic regression with the various covariance is stated as:

$$\begin{aligned} log\left(\frac{Y_{ij}}{1 - Y_{ij}}\right) =& \beta_0 + \beta_1 Mstatus_i + \beta_2 Agecat_i + \beta_3 Eduattain_i + \beta_5 Pdynamics_i \\ &+ \beta_7 logHHexpediture_i + \beta_8 FPE_i + \beta_9 Religion_i + \beta_{10} Ethnicity_i \\ &+ \beta_{11} Mstatus * FPE_i + \beta_{12} Pdyamics * FPE_i + \mu_{0i} + \varepsilon_{ij} \end{aligned} \tag{3}$$

Where μ_{0i} represents individual household-specific random effects and is assumed to be independently distributed as $\mu_{0i} \sim N(0, \sigma^2_{\mu_{0i}})$. *Mstatus* represents marital status of household head, *Agecat* represents age category of household head, *Eduattain* represents the educational attainment of household head, *Pdynamics* represents wives who can express their opinions on matters, *HHexpediture* represents annual household expenditure, *FPE* represents females in paid employment, *Religion* represents religion of household head, $Mstatus * FPE$ is an interaction variable measuring the interaction between marital status and female labour force participation, $Pdyamics * FPE$ is an interaction variable measuring the interaction between power dynamics and female labour force participation, β_0 represents the intercept and ε_{ij} represent the error term.

Table 1 Summary statistics of the variables for used in the analysis

Variables	Min	Max
Dependent variable		
LPG use (0 = No; 1 = Yes)	0	1
Independent variables		
Marital status of household head (1 = married; 2 = consensual union; 3 = separated; 4 = divorced; 5 = widow; 6 = never married; 7 = betrothed)	1	7
Ethnicity	1	7
Household head Age (1 = Youth; 2 = Adult; 3 = Aged)	1	3
Household head educational attainment (1 = None 2 = MSLC; 3 = BECE; 4 = SSCE; 5 = HND; 6 = Bachelor; 7 = Masters)	1	7
Power dynamics-opinion expression by wife (1 = Agree; 5 = Disagree)	1	5
Total annual household expenditure (Ghana Cedis)	30.4	66,100
FPE (1 = Yes: 0 = No)	0	1
Religion (1 = Christian; 2 = Muslim; 3 = Traditional; 4 = None)	1	4

3.2 Data and variable definitions

The study used Ghana's socio-economic household panel survey data developed by the Economic Growth Centre (EGC), Yale University, and the Institute of Statistical Social and Economic Research (ISSER), University of Ghana. The data is the first panel of household data on Ghana which follows individuals over time and provides details of both the natural and the built environment in which the individuals reside. The survey consists of three waves conducted in 2009/2010, 2013/2014 and 2017/2018. The data captures household information such as housing characteristics, individual consumption, household consumption, employment, health, migration, education, literacy, non-farm assets, non-farm enterprises, and cognitive assessment. The data consists of a nationally representative sample of 5009 households with 18,889 household members. Males constitute 47.6 percent while females constitute 52.4 percent of the sample. Table 1 shows the summary statistics of the variables used in the analysis.

3.3 Estimation technique

Exploratory data analysis was carried out to provide a detailed understanding of the data using tables and graphs. Further descriptive analysis was conducted to understand the trend of usage of cooking fuel and expenditure of cooking fuel over the period. Mixed effects logistic regression was estimated to examine the effect of female labour force participation, power dynamics, and adoption of LPG. Because the data consists of panels with repeated measurements, employing mixed-effects logistic regression estimation allows for modeling repeated measurements by incorporating a specific random effect into the model [40]. In this study, because the outcome variable consists of a repeated binary outcome of LPG use, we used the mixed effects logistic regression to model the log of odds of the outcome as a linear combination of the predictive variables as fixed effects and allowed the individual household-specific random effects to account for variations or heterogeneity in the sample.

4 Results and discussion

4.1 Descriptive statistics of the data

Table 2 presents the descriptive statistics of the data. Approximately 91 percent of the household members were identified as household heads,[1] while 4.5 percent were children and 3.0 percent were spouses of the household heads. Most of the household heads were males (57.5%) compared to females (42.5%). The data reveals that most household heads

[1] A household head is a member of the household who is recognized and acknowledged as head by the other household members either by virtue of his/her age or standing in the household as the main income earner or taking of key decisions [51].

Table 2 Descriptive Statistics. Source: Authors' computation using Ghana socio-economic panel data

	Percentage (%)	Number of observations
Household members		
Household head	90.52	15,591
Spouse	2.62	452
Child	4.45	767
Grand child	0.89	154
Parent/parent-in-law	0.19	32
Son/Daughter-in-law	0.05	8
Other relative	0.92	158
Adopted/Foster/Stepchild	0.30	51
House help	0.02	3
Non-relative	0.04	7
Gender household head		
Male	57.46	8959
Female	42.54	6632
Marital status household head		
Married	35.74	4682
Consensual union	5.61	735
Separated	1.53	200
Divorced	4.61	604
Widowed	5.07	664
Never married	47.36	6205
Betrothed	0.08	11
Ethnicity		
Akan	52.17	5773
Ga Adangbe	7.58	839
Ewe	16.32	1806
Guan	4.14	458
Gurma	6.33	700
Mole Dagbani	11.39	1260
Grusi	2.07	229
Age of household head		
Youth (15–35 years)	40.84	5350
Adult (35–60 years)	30.26	3965
Aged (above 60 years)	28.90	3786
Education of household head		
None	28.29	3704
MSLC	33.23	4351
BECE	22.63	2962
SSCE	9.82	1286
HND	1.79	235
Bachelors	3.58	468
Masters	0.66	86
Religion of household head		
Christian	88.40	11,580
Muslim	6.46	846
Tradition	2.21	290
None	2.93	383

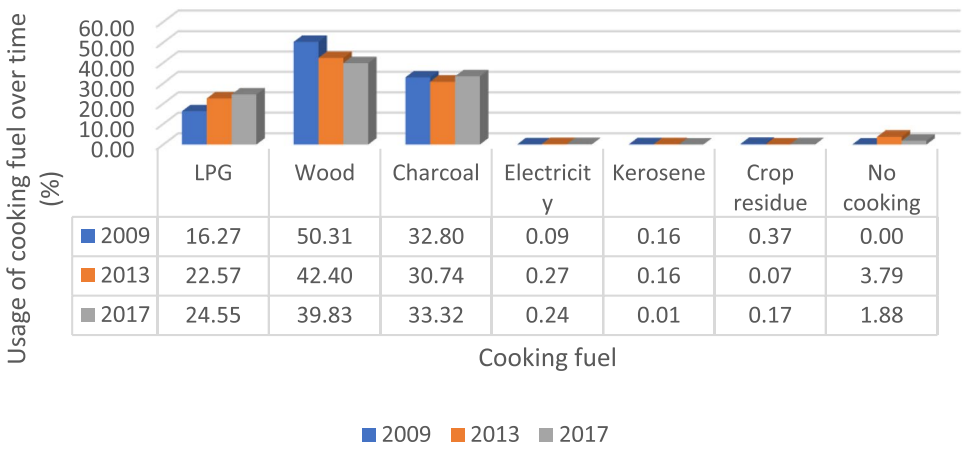

Fig. 1 Usage of cooking fuels from 2009 to 2017

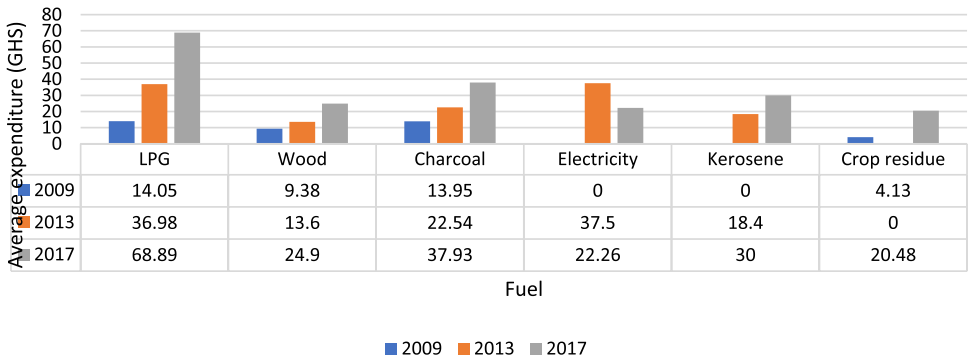

Fig. 2 Average expenditure on cooking fuel per month (GHS)

(47.4%) were unmarried, while 35.7 percent were married. Additionally, most household heads (40.8.%) were young adults, aged between 15 and 35 years. The educational background of the majority of household heads was middle school leaving certificates (MSLC), with over a quarter (33.2%) having no formal education. About 4.0 percent of household heads attained higher education levels, including bachelor's and master's degrees.

Figure 1 illustrates a notable decrease in the consumption of wood fuel for cooking from 50.3 percent to 39.8 percent between 2009 and 2017. However, consumption of charcoal recorded a marginal increase from 32.8 percent in 2009 to 33.3 percent in 2017. The decline in the use of wood fuel could be attributed to the effort by the government to promote the use of LPG. The government intensified its LPG promotion by introducing a rural LPG promotion program in 2013 and approved a national LPG promotion policy to provide policy backing for the LPG promotion. For instance, the use of LPG as primary cooking fuel increased from 16.3 percent in 2009 to 24.6 percent in 2017.

Further exploration of the data revealed that households consistently spent more on LPG compared to wood and charcoal across all periods. Specifically, in 2009, households' expenditure on LPG was approximately 50% higher than that on wood (refer to Fig. 2). This rose by 177% between 2013 and 2017. Despite being nearly equal to charcoal in 2009, households' expenditure on LPG surged to approximately 64% higher in 2013 and further escalated to 82% higher than charcoal by 2017. This could have accounted for the marginal increase in LPG usage by households in 2017. The government removed subsidies on LPG in 2015 which resulted in a higher price and consequently affected the demand for LPG between 2013 and 2017. According to the census data from the Ghana Statistical Service (GSS) released in 2021, LPG usage at the household level had increased to 36.9 percent and that of wood and charcoal has declined to 31.1 percent and 23.2 percent respectively [8].

Table 3 presents the analysis of household head characteristics and adoption of cooking fuel. The descriptive analysis revealed that heads of households tend to use more wood as cooking fuel compared to charcoal and LPG. While about 44 percent of household heads who are married use wood to cook, about 29 and 25 percent use charcoal and LPG respectively. This trend is similar for household heads who are in consensual union and those who are never married. However, the use of charcoal is higher for household heads who are divorced and separated. The use of clean fuel is very low (14%) for household heads who are separated compared to the other marital status categories. About 40 percent of household heads who use charcoal as cooking fuel are Christians and 33 and 24 percent use charcoal and LPG respectively. Muslims

Table 3 Household head characteristics and cooking fuel (%). Source: Authors' computation using Ghana socioeconomic panel data

Variables	No cooking	Wood	Charcoal	LPG	Electricity	Kerosene	Crop residue	Others	Total
Marital status									
Married	1.43	44.18	29.28	24.66	0.11	0.13	0.21	0.00	100
Consensual union	2.09	46.15	37.16	14.08	0.39	0.13	0.00	0.00	100
Separated	7.44	33.02	37.67	21.86	0.00	0.00	0.00	0.00	100
Divorced	4.48	31.39	43.20	20.48	0.00	0.30	0.00	0.15	100
Never married	2.55	40.44	33.45	23.12	0.28	0.06	0.10	0.01	100
Betrothed	0.00	18.18	81.82	0.00	0.00	0.00	0.00	0.00	100
Religion of household head									
Christian	2.05	40.38	33.10	24.05	0.21	0.11	0.09	0.01	100
Muslim	4.31	46.34	36.75	12.28	0.00	0.22	0.11	0.00	100
Traditional	0.33	71.66	15.31	10.10	0.00	0.00	2.61	0.00	100
None	6.50	53.75	29.00	10.00	0.25	0.00	0.25	0.25	100
Ethnicity									
Akan	2.10	38.54	36.81	22.20	0.25	0.02	0.00	0.00	100
Ga Adangbe	3.05	30.69	41.29	24.12	0.24	0.49	0.00	0.12	100
Ewe	1.69	49.55	28.71	19.89	0.17	0.00	0.00	0.00	100
Guan	3.11	54.22	34.44	8.22	0.00	0.00	0.00	0.00	100
Gurma	0.86	77.55	10.94	8.35	0.00	0.00	2.30	0.00	100
Mole Dagbani	4.02	52.29	30.28	13.01	0.00	0.00	0.04	0.00	100
Grusi	3.52	54.19	30.84	11.45	0.00	0.00	0.00	0.00	100
Age of household head									
Youth	3.10	38.60	32.61	25.21	0.27	0.07	0.12	0.02	100
Adult	1.97	41.92	32.61	23.00	0.18	0.09	0.22	0.00	100
Aged	1.45	46.11	33.43	18.58	0.10	0.19	0.12	0.02	100
Educational attainment of household head									
No education	1.42	59.37	28.52	9.97	0.30	0.03	0.38	0.00	100
MSLC	1.50	46.39	37.01	14.87	0.05	0.07	0.09	0.02	100
BECE	3.58	39.48	37.28	19.28	0.10	0.14	0.14	0.00	100
SSCE	5.32	29.60	32.46	32.06	0.40	0.08	0.00	0.08	100
HND	2.17	10.00	21.30	66.52	0.00	0.00	0.00	0.00	100
Bachelors	1.11	9.58	25.17	64.14	0.00	0.00	0.00	0.00	100
Masters	1.19	1.19	7.14	90.48	0.00	0.00	0.00	0.00	100
Women power dynamics									
Agree	0.59	41.18	34.50	23.41	0.13	0.09	0.09	0.00	100
Disagree	1.98	48.41	33.73	15.48	0.0	0.04	0.00	0.00	100
Female Labour force participation									
Female in paid employment	0.80	15.22	32.27	50.92	0.46	0.34	0.00	0.00	100
Female in unpaid employment	2.37	43.50	32.89	20.79	0.18	0.10	0.16	0.01	100
Observation	330	6057	4760	3216	28	16	22	2	14,431

NB: The Pearson chi-squared test indicates significant differences in the use of cooking fuel across all the groups considered at 1% significant level

tend to use more wood and charcoal and less LPG compared to household heads who are Christians. Household heads who are traditionalists use more wood for cooking compared to Christians and Muslims. This is expected because most of the traditionalists are rural dwellers where wood fuel is abundant.

Furthermore, ethnicity influences the choice of household cooking fuel. Ga (24%) and Akan (22%) tribes tend to use more clean fuel compared to the other tribes. This is followed by the Ewe tribe, Mole Dagbani and Grusi tribes respectively. LPG adoption is low among Guan and Gurma tribes. Household heads in all age categories use more wood and charcoal compared to clean fuel (LPG). Among the age categories, youth (15–35 years) and adults (35–60 years) tend to

use cleaner fuel. We realized that the choice of cooking fuel by the household heads is greatly influenced by the educational attainment of the household head. From the data, it could be established that the adoption of LPG increases with higher educational attainment and decreases with low educational attainment. For instance, over 60 to 90 percent of household heads with higher educational attainment such as a diploma, bachelor's, and master's degree tend to adopt clean fuel compared to dirty fuel.

Furthermore, women in the workforce are more likely to use LPG than those who aren't. While 51% of working women use LPG for cooking, only 21% of women outside the workforce do. Additionally, women not in the labour force rely more on wood fuel (76%) compared to their working counterparts (47%).

4.2 Mixed effect logistic model estimation results and discussion

Table 4 presents the estimation results from the mixed effect logistic (MEL) model of the female labour force participation, power dynamics, and adoption of LPG. The coefficients are interpreted in terms of significant levels and odd ratios which indicate the extent of the effect. The results of MEL consist of fixed effects and the estimated variance component. The fixed effects are the odds ratios of the estimated variables. The estimated variance is 0.1 with a standard error of 0.1 is indicative of some level of variability in the sample. The model is highly significant compared to the ordinary logistic regression model with the likelihood ratio being highly significant. Additionally, the multicollinearity test shows that no two regressors are highly correlated as indicated by the variance inflation factor of 1.1 which is less than the rule of thumb of 10.

Our results suggest that being in a consensual union or separated reduces the likelihood of adoption of LPG by 0.6 and 0.3 times respectively compared to being married. On the other hand, household heads who are never married are 1.4 times more likely to adopt LPG than married household heads. The plausible explanation is that household heads who are not married may consider LPG to be convenient and easy to use. On the other hand, household heads who are widowed, and divorced do not significantly influence the adoption of LPG. Our findings suggest that religion does not have a significant effect on the choice of LPG as a cooking fuel by household heads. We found that ethnicity plays an important role in the adoption of LPG. Our results show that that being a Guan, Gurma and Mole Dagbani reduces the likelihood of adoption of LPG compared to being an Akan. A possible explanation is that the staple food prepared by the tribes of Gurma and Mole Dagbani requires the use of traditional stoves that utilize wood fuel. This could have contributed to the low adoption of LPG compared to the Akan tribe. This lends support to the fact that cultural and social norms play an important role in LPG adoption. The findings corroborate the findings by ref. [30] who established that minority ethnic groups tend to use biomass for cooking compared to the majority ethnic group.

Educational attainment increases the odds of a household's adoption of LPG. This is because higher education enhances the ability to earn higher income. Household heads with higher education such as masters increase the likelihood of adoption of LPG by 62 times compared to those who have no education. Likewise, having a higher national diploma education increases the likelihood of adoption of LPG by 10 times compared to those without education. Moreover, higher education enhances comprehension of clean fuel alternatives for cooking and the repercussions of utilizing unclean fuel sources. This finding lends support to the findings of the studies conducted by refs. [17, 19, 41]. For instance, ref. [17] find that household heads who have a basic, secondary, and tertiary education increase the adoption of LPG by 2.9, 6.3, and 14.3 times respectively.

Young adults between the ages 15 and 35 are more likely to adopt LPG compared to adults and aged (above 60 years). Our results indicate that adults and the aged are less likely to adopt LPG. Adults and aged are 0.6 and 0.6 times less likely to adopt LPG. This could be explained that households with younger heads are more likely to adopt LPG compared to the aged. Thus, as individuals reach the mandatory retirement age of 60, their reduced income often leads them to opt for cheaper, albeit less clean, fuel sources [17]. Another plausible explanation could be that older household heads may have a preference for unclean fuel due to its availability and affordability. This finding is consistent with the findings of ref. [23] who established that the use of fuelwood by households could continue due to their developed loyalty and their desired preference for certain cooking methods. This aligns with the findings by ref. [19] who concluded that households with aged heads were unlikely to use clean and efficient fuel compared to households with younger heads.

The findings indicate that wives who cannot express their opinions in marriage are less inclined to adopt LPG, suggesting that disagreement regarding wives' capacity to voice their opinions correlates with lower LPG adoption likelihood. Their likelihood of adopting LPG reduces by 0.5 times compared to those who agree. This finding supports the goal of women's empowerment which emphasizes increasing the decision-making power of women [42]. The possible explanation is that when women have the power to express their opinion in decisions regarding the household introduction of

Table 4 Results of mixed-effect logistic model

Dependent variable			
LPG use			
Independent variables	Odds Ratio	95% Confidence Interval	
Intercept	0.012	0.005	0.030
Labour force participation			
Female in paid employment (FPE)	2.451***	1.658	1.628
Marital status			
Consensual union	0.556**	0.335	0.923
Separated	0.259*	0.059	1.134
Divorced	0.643	0.318	1.303
Widowed	1.076	0.588	1.971
Never married	1.441**	0.988	2.099
Interaction between marital status and female labour force participation			
Consensual union*FPE	1.060	0.286	3.923
Separated*FPE	3.433	0.360	32.727
Divorced*FPE	2.999	0.502	17.924
Widowed*FPE	0.434	0.074	2.554
Never married*FPE	0.528*	0.988	2.099
Religion			
Muslim	0.775	0.433	1.387
Traditional	1.521	0.491	4.715
None	0.493	0.167	1.453
Education			
MSLC	1.455**	1.045	2.025
BECE	1.735***	1.219	2.468
SSCE	3.067***	1.995	4.715
Higher national diploma (HND)	9.915***	4.494	21.875
Bachelors	14.927***	8.317	26.792
Masters	61.892***	9.651	396.879
Ethnicity			
Ga Adangbe	0.747	0.479	1.165
Ewe	0.849	0.050	1.303
Guan	0.069**	0.190	0.247
Gurma	0.253***	0.133	0.483
Mole Dagbani	0.495***	0.304	0.805
Grusi	0.668	0.297	1.502
Age groups			
Adult	0.633***	0.469	0.854
Aged	0.581*	0.384	0.879
Women power relation			
Disagree	0.469**	0.253	0.871
Power relation interaction*FPE	1.730	0.463	6.466
Household Expenditure	1.499***	1.352	1.660
Variance Component	0.078	0.013	0.475
LR test vs. logistic model: chibar2(01) = 6.10 Prob ≥ chibar2 = 0.007			

***,**,* represent 1%, 5% and 10% significant levels

energy, their decision will be geared towards adoption of LPG instead of unclean fuel to reduce the negative impact of unclean fuel on their health [3, 43]. Additionally, the increasing opportunity cost of household chores as measured by lost wages will motivate women to lessen the time allotted to cooking and invest it in the labour market. This is reflected in their decision to adopt clean fuels. This finding is consistent with the finding by ref. [44] who found that women who participate in household decision-making increase the probability of households adopting LPG.

Additionally, our results show that female labour force participation improves the adoption of LPG for cooking. Females who are in paid employment are more likely to adopt LPG than females who are not in paid employment. Females in paid employment are 2.5 likely to adopt LPG compared to those who are not. This could be attributed to the fact that women spend more productive time in cooking activities using different sources of fuel such as wood and charcoal. This significantly affects women's participation in the labour force and increases their chances of using unclean fuels such as wood and charcoal. Thus, the adoption of LPG tends to reduce time spent on cooking and thereby increase labour force participation [2]. This is consistent with findings by ref. [40] who found a long-term relationship between the adoption of clean cooking technology and female labour force participation. Cooking with dirty fuel has health implications which could affect an individual's productivity and economic input. For instance, cooking with wood and charcoal increases women's exposure to hazards relating to smoke and other health problems ref. [45] which tend to affect labour input and consequently impact on female labour supply ref. [46]. Additionally, the finding is consistent with a finding by ref. [47] who established that female labour force participation reduces households' use of biomass.

Further interaction of the female labour force participation variable with marital status revealed that female labour force participation could increase the bias of not adopting LPG by women who are never married and reduce the bias of married women of not adopting LPG. This is evidenced by a reduction in the likelihood of never-married household heads for adoption of LPG from 1.4 times to 0.5 times compared to married women. The plausible reason is that women who are never married and are in gainful employment may prefer to buy food from venders instead of cooking. The findings suggest that female labour force participation does not influence the power dynamic of married women on LPG adoption. The interaction variable for female labour force participation and power dynamics is insignificant.

Using household annual expenditure as a proxy for income, the analysis shows that higher expenditures reflect higher income levels. We found that households with higher incomes are 1.6 times more likely to adopt LPG compared to those with lower incomes. The average expenditure on LPG by households was GHS36 and GHS57 in 2013 and 2017 respectively while the minimum wage per month for the same period was GHS136 and GHS229 respectively. The share of household expenditure on LPG compared to the minimum wage was about 25%. This could explain why households with higher income were able to use LPG for cooking compared with poorer households. This aligns with the energy-ladder theory, which suggests that households tend to favor cleaner energy sources as their income increases or as they move into higher income brackets [17, 24, 27]. In ref. [17] concluded that households in the fourth- and fifth-income quintiles are 16.7 times and 33.7 times more likely to adopt clean energy compared to using wood and charcoal. Their finding was confirmed by a study conducted by refs. [19, 48] which established that non-poorer households adopt clean fuel over wood and charcoal as cooking fuel.

5 Conclusion and policy recommendations

This study examines how female labour force participation and power dynamics influence the adoption of LPG in Ghana, using a mixed-effects logistic regression model. The findings show that while household LPG usage has increased, the growth rate remains modest compared to the decline in wood and charcoal usage. High LPG costs, which are 1.8 to 2.7 times higher than charcoal and wood, may have hindered adoption despite government promotion efforts.

The findings also revealed that key factors influencing LPG adoption include marital status, education, household income, women's empowerment, and labour force participation. Married household heads are more likely to adopt LPG than those in consensual unions or separated. Policymakers should target these groups to improve adoption rates. Higher educational attainment also significantly increases LPG adoption, highlighting the importance of awareness campaigns. Particularly, the Integration of clean fuel education into primary, secondary, and vocational curricula could further promote adoption.

Women's empowerment and labour force participation play crucial roles in LPG adoption. Households where women can express their opinions are more likely to use LPG. Empowering women through national programs and vocational training can enhance their economic independence and decision-making, thereby increasing clean fuel adoption. Women in paid employment, who benefit from the convenience and health benefits of LPG, are also more likely to choose it. Providing women with employable skills through technical training can further this trend.

Overall, the climate implications of this study highlight an urgent need for government-led, smart policy interventions to displace solid fuel use and promote widespread use of LPG. This is particularly critical for Ghana, where illegal mining and heavy reliance on biomass fuel have significantly reduced the forest cover. For example, removing

all taxes on LPG could make it more affordable for low-income and rural households, thereby increasing its acceptability and appeal. Such a measure would not only help mitigate deforestation and reduce emissions from solid fuels, but also align with recent analyses of the climate related benefits of LPG use [49]. According to the World Liquid Gas Association [50], Ghana's plan to increase LPG access between 2020 and 2030 is estimated to save approximately 221 million trees and avert the equivalence of up to 9.30 million metric tonnes in CO_2 emissions.

Beyond promoting LPG, it is also crucial to recognize that the success of a sustainable climate intervention depends on providing diverse alternative fuel technologies and addressing socio-cultural factors that hinder transitions to cleaner energy solutions. Our findings revealed that enhancing paid employment opportunities for women and other forms of empowerment can significantly increase the adoption of clean cooking solutions. Recent initiatives such as the female-focused Science, Technology, Engineering and Mathematics (STEM) education and the Free Senior High School program, represent transformative policy transitions steps toward boosting women's economic and social empowerment in Ghana. However, efforts to achieve sustainable climate consumption choices would also require prioritizing women's participation in decision-making at all levels—household, community, subnational, regional and national. These socio-cultural changes and similar efforts are all critical to driving inclusive transitions to cleaner energy solutions—and ensuring long-term climate and societal benefits.

5.1 Limitations

Despite employing a rigorous methodology, this study has a major limitation. It primarily examines the aggregate experiences of women across diverse work contexts—due to the unavailability of data on specific work sectors. As a result, the analysis may not fully capture sector-specific work influences on women's experience, or their role as barriers or facilitators to LPG adoption.

For example, adoption of LPG may vary depending on the type of work women undertake. Women employed in the private sector may have different adoption patterns compared to those in the public sector, and these patterns could also vary between formal and informal sectors. Understanding these variations is crucial for designing effective policy interventions. Therefore, future research should explore how employment across various sectors influences LPG adoption for clean cooking, in order to provide more targeted insights for impactful policies.

Author contributions JW —conceptualization, analysis and written of report BOB—data cleaning, review of draft report, review of report SI—data gathering, analysis and review of report.

Data availability The data supporting this research can be accessed here. https://doi.org/10.7910/DVN/I2KJHT, Harvard Dataverse, V1, UNF:6:RxT0GYOVjMJ0 + UWer/3tkQ = = [fileUNF].

Declarations

Competing interests The authors declare no competing interests.

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