



# Gendered health effects of cooking fuel technologies in southern Ghana

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## ABSTRACT

The introduction of clean cooking technologies in many developing countries ensures environmental quality and improved well-being through reduction in indoor air pollution. This study examines the adoption of cooking fuel technologies and its effect on health outcomes using panel data from two districts in the Greater Accra region of Ghana. The inverse probability weighting regression adjustment (IPWRA) approach was used to examine the effect of cooking fuel technologies on health outcomes. The empirical results show that factors such as tenancy, kitchen design, assets, gender, education, access to internet and tarred roads influence the adoption of cooking fuel technologies, including clean cooking fuels. The study finds that clean cooking fuels decrease female illness incidence but not male illness incidence, with large improvement for adults. The findings suggest that policies and programs aimed at promoting clean cooking fuel technologies can significantly improve well-being of females in developing countries.

## 1. Introduction

The energy sector has always held an important niche in the global development and policy spaces, and in recent times, its importance has received more attention due to the increasing call from governmental and non-governmental institutions for clean and sustainable energy resources. Interestingly, current policy frameworks favor a shift from using biomass and fossil energy sources to clean energy sources. For example, the Sustainable Development Goal (SDG) 7 is dedicated to delivering affordable and clean energy. The main driver of this policy shift is the general grim picture of the impact of unsustainable energy sources on the environment and human health. Available evidence suggests that using clean energy is associated with poverty reduction and overall economic development [1–4], reduction in child mortality rates, fuel-saving, reduced deforestation, decreased time-lost in gathering biomass fuels, as well as boosting maternal health [5,6]. On the other hand, it is estimated that energy contributes about 73 percent of all greenhouse gases (GHG) emissions due to human activities [7]; representing the main contributor to climate change and variability [7,8].

The use of energy for household cooking is the predominant energy demand in developing economies [9]. Thus, making the choice and adoption of cooking fuels an important policy area. Several reasons account for the prominence of cooking fuels to energy policy. First, the number of people involved in the use of cooking fuels is the largest in the

energy sector. Globally, around 2.8 billion people – representing a third of the global population, use polluting and unclean fuels for cooking [7]. Additionally, IEA [10] forecasts that by 2030, the population relying on “dirty” cooking energy may not reduce and this has negative consequences on the environment, and climate change and variability. Second, most traditional cooking fuels such as biomass or biofuel (especially fuelwood, charcoal, dung and agricultural residues), have negative effects on the environment. In recent times, the importance of addressing climate change and variability, and the realization of the negative consequences of human activities on the environment has drawn considerable attention to how “traditional and inefficient” cooking fuels could be replaced with clean and efficient energy sources. Besides, the generation and use of inefficient traditional cooking fuels are found to contribute to the deterioration of the environment. Foell et al. [5] indicated that the unsustainable harvesting of biomass/fuelwood and the accompanying “dirty” energy conversions from them poses environmental challenges such as deforestation, soil degradation and erosion. Similarly, the impact of black carbon emissions from burning biomass on climate change and variability has also been acknowledged in literature (see for example, [11,12]).

However, in recent times, another dimension of the use of traditional, unsustainable and inefficient cooking fuels that has received wide attention is the indoor air pollution and associated detrimental health impacts of these technologies. For example, the IEA [13]

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estimates that indoor exposure to air pollution from biomass kills close to 2.5 million people prematurely every year. Foell et al. [5] and Parikh [14] highlight the health challenges imposed by the drudgery and heavy physical burden associated with the gathering of traditional cooking fuels. Chronic obstructive pulmonary disease (COPD) kills many people and deaths related to chemically heart disease due to air pollution are relatively high [15]. Furthermore, IEA (2010) estimated that premature deaths caused by indoor use of biomass will overtake deaths from HIV/AIDS by 2030. Other studies find varying health consequences due to unclean energy sources such as stillbirth [16,17], worsened lung capacity [18], cervical cancer [19], asthma [20,21], tuberculosis [22,23], and low birth weight [17]. In most of these studies, the findings point to the disproportionate effects on women and children [5,24–26], indicating the relevance of gender dimension in global energy considerations [5].

Interestingly, the multi-dimensional negative impacts of traditional cooking technologies have facilitated the introduction of several clean cooking technology interventions in developing economies. For example, the United Nations' Sustainable Energy for All (SE4ALL), the Africa Clean Cooking Energy Solution (ACCES) and the Global Alliance for Clean Cookstoves (GACC) were initiated to encourage the use of clean energy (see Ref. [27]). There are also country-level initiatives to increase the use of clean cooking energy technologies. This is because these technologies can help to significantly reduce emissions (see Ref. [8,28]). Despite these clean energy initiatives, empirical studies on the impacts of cooking technologies on health outcomes in developing countries, particularly in Africa, are still evolving. Such a dearth of empirical studies poses a daunting challenge to implementing policies aimed at reducing unsustainable energy use. Moreover, Ghana has subscribed to other global and regional initiatives and has rolled out a free distribution of LPG stoves to poor and vulnerable households to reduce the dependence on solid biofuel and curtail the associated negative consequences [29]. These investments, coupled with regional and global commitments, provide the empirical basis to investigate the health impacts of household cooking fuel use. Nuances in country-level evidence in development economic literature provide a key justification for this present study.

This study makes four main contributions to the empirical literature on the effect of cooking fuel technologies on wellbeing in developing countries. First, the results contribute to the recent studies seeking to understand the effect of climate change adaptation and/or mitigation strategies on wellbeing, particularly the health component. Recently, there has been a renewed interest in understanding the choice of cooking fuels, which are major sources of indoor air pollution in developing countries, on health. Therefore, the results of this study contribute to the discussions on the Sustainable Development Goals (particularly, Goal 7) and the African Union's (AU) Agenda 2063. Although a number of prior literature have confirmed the health hazards of using solid fuels such as coal, firewood and other biomasses (see Ref. [16–23]), few studies have established the link from a development economics perspective in a developing country context, especially in Sub-Saharan Africa (SSA).

Second, employing treatment effect estimators to examine the effect of cooking fuel technologies on health outcomes is limited in the empirical literature (with few exceptions such as [30]). Treatment effect estimators have been shown to address selection bias and unobserved heterogeneity leading to robust empirical evidence (see for example, Wooldridge, 2010; Cattaneo, 2010; Drukker, 2015). Therefore, our results could be easily replicated in other developing countries with similar characteristics and observational data. Third, existing studies [14,31–33], mostly focused on women, children and middle-aged adults. The gendered dimension of the study (see also [30]) presents a more nuanced evidence of cooking fuel technologies on wellbeing in developing countries. Instead of estimating the effect on only women, who are usually at the forefront of using cooking fuel technologies in many developing countries, we also estimate the effects on male illness incidence. The gendered aspect is also relevant for the advancement of

the SDGs (particularly, Goal 5 on gender equality) and AU's Agenda 2063.

Fourth, studies examining the effect of cooking fuel technologies that employed panel datasets are limited in the literature as most studies relied on cross-sectional data. In the case of Ghana, which is the study's focus, prior studies have mainly focused on the determinants of choice and energy poverty [30,34–39]. Based on our knowledge, Twumasi et al. [30]'s study is one of the few studies analyzing the effect of cooking energy consumption on the health status of households. However, Twumasi et al. [30] employed cross-sectional data from only rural areas of Ghana with the share of healthy household members as a measure of health. This current study employed a 4-round panel data from two administrative districts in the Greater Accra region of Ghana and individual health status (i.e., the incidence of illness) as an indicator of health outcome. Using panel data, in this case, is more appropriate as the health effects of cooking fuel may take some time to be observed, and current disease patterns may be due to historical exposure to other individual and environmental factors (see for example [40]). This is an important addition to the empirical literature on the health effects of cooking fuel technologies in developing countries.

The rest of the paper is structured as follows: in what follows in Section 2, we describe the cooking fuel technologies in Ghana. We then proceed to explain in Section 3 the methodology including data and the empirical strategy used to identify the effect of the cooking fuel technologies on health outcomes. Section 4 presents and discusses the empirical results. Section 5 concludes the study by indicating the policy implications and areas of future research.

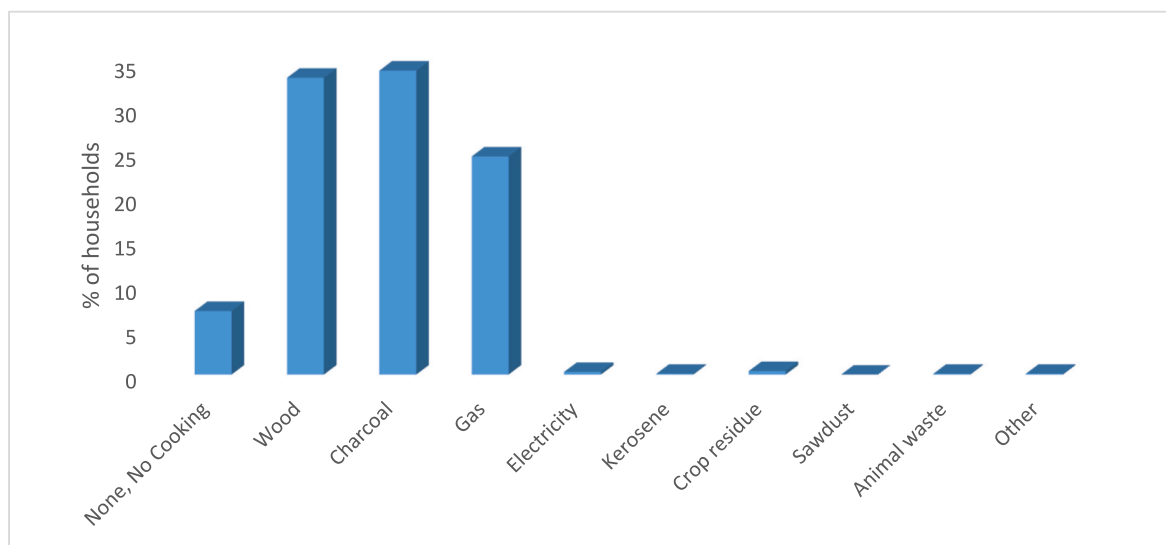
## 2. Cooking fuel technologies in Ghana

In Ghana, woodfuel (i.e., charcoal and wood) is the predominant source of household fuel energy for cooking [41]. According to the Energy Commission [42], biomass (especially woodfuel) contributed about 41 percent to the country's total primary energy in 2017 while consumption was projected at 2.83 million tons of oil equivalent. Fig. 1 presents a summary of the distribution of the main sources of cooking fuel.

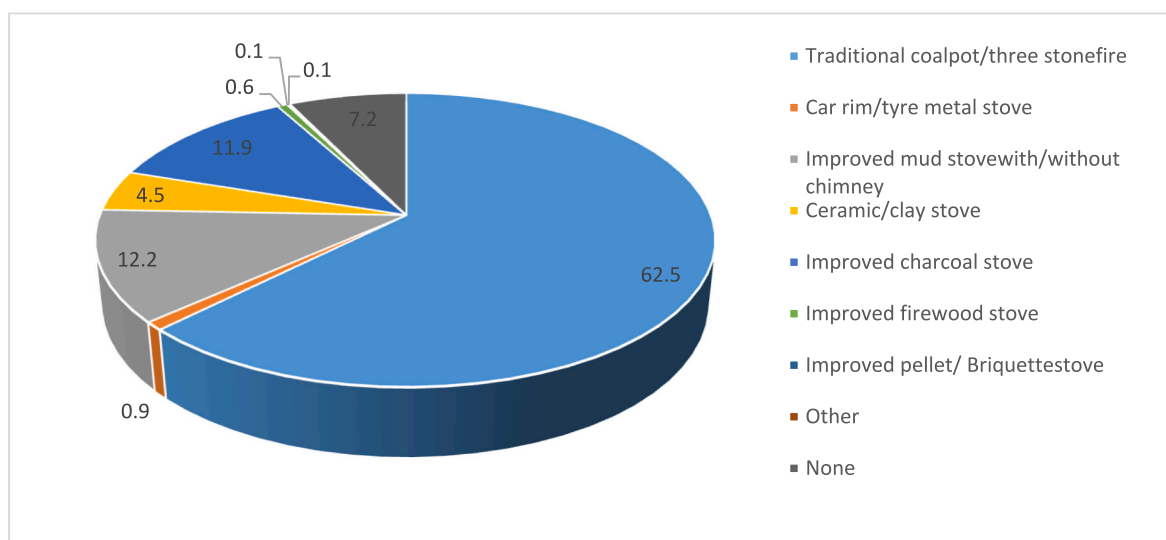
Charcoal is the main source of cooking fuel, accounting for about one-third (34.1%) of all fuel sources and closely followed by wood which accounts for 33.3 percent in 2017 [41]. This implies that wood and charcoal together account for nearly 68 percent of all fuel sources for cooking. In 2013, wood was the main source (41.3%), followed by charcoal (31.5%). Given that charcoal and wood are typical unclean and inefficient fuel sources, this observation should be a source of worry for policymakers and other stakeholders, as this can derail attempts of meeting the SDG 7 and other related goals. However, it quite encouraging that almost 25 percent of households use LPG, a leading clean energy source. The use of electricity is low and efforts to increase its use could improve the use of clean energy. This can be achieved through sustainable expansion and cost reduction in rural communities.

Considering cooking fuel use in urban and rural areas, the results show that firewood/wood is unsurprisingly predominant in rural Ghana, accounting for about 63 percent of cooking fuel use while charcoal and LPG are predominantly used (accounting for about 80 percent) in urban areas. The biomass cook-stove is the predominant cooking equipment employed by households in Ghana [41]. The distribution of the various cook-stove is presented in Fig. 2.

The most widely used cook-stoves are the traditional coal pot/three-stonefire place (62.5%), improved mud stoves with or without chimney (12.2%) and improved charcoal stoves (11.9%). However, various brands of improved cook-stoves are also in existence. For example, ceramic-lined charcoal stoves (e.g., Gyapa, Toyola and Holy Cook) and non-ceramic-lined charcoal stoves (e.g., Cookclean and Envirofit) are used extensively in urban areas [43]. Data from the GSS [41] indicate that the prominent place where cooking activities are undertaken in Ghana is outdoors (49.1%). Besides, few households undertake cooking



**Fig. 1.** Main sources of cooking fuel in Ghana. Source: Ghana Statistical Service [41].



**Fig. 2.** Cook-stoves used in Ghana. Source: Ghana Statistical Service [41].

activities in a separate dwelling (17.9%), verandas/roofed platforms with at least two open sides (17.9%), and dwelling not in sleeping area (13.7%).

### 3. Methodology and data

#### 3.1. Empirical strategy

In this study, we seek to address two main objectives: (1) to analyze the correlates of households' main cooking fuel adoption decisions, and (2) to examine the effects of cooking fuel technologies on gendered illness incidence. In analyzing the adoption decisions, this study assumes that households' choice of cooking fuel technologies is made up of clean sources (i.e., LPG or electricity<sup>1</sup>) and unclean sources (i.e., firewood and

charcoal) based on the satisfaction or net benefit to be derived from the use of each technology. The clean cooking technologies are assumed to consist of a package of less smoke/gas emissions, ease of use and durability in cooking the various food types. We assume that households decide on the cooking fuel technologies to adopt to maximize the net benefit or expected satisfaction to be derived from the technology as well as socio-economic characteristics.

Therefore, we model the adoption of cooking fuel technologies as a function of household characteristics including kitchen design indicators. Whilst this approach is convenient based on data availability, we do not consider household choice of multiple cooking fuels in the estimation strategy. In addition, the alternative cooking fuel technologies are assumed not to be affected by constraints on availability and investment cost and therefore, the decision involves only the choice of alternative sources.

Based on these assumptions, we can represent the *i*th household's expected benefit from the choice of alternative cooking fuel technologies *m* at time *t* as  $CFT_{imt}$ . The household will choose, for instance, LPG/

<sup>1</sup> In this study, we combined LPG/electricity in the empirical analysis due to limited samples in the data. In addition, the two cooking fuel sources fit into the classification of clean fuel.

electricity over firewood or charcoal if the expected satisfaction or net benefit of LPG/electricity is higher than that of firewood or charcoal. However, we do not observe the cooking fuel preferences of the households, except their socio-economic characteristics and the attributes of the various cooking fuel technologies. Therefore,  $CFT_{imt}^*$  which is a latent variable can be specified as a function of observed characteristics. The basic regression specification of the relationship between the latent variable, and household and community characteristics is expressed as follows:

$$CFT_{imt}^* = \beta_0 + \beta_1 X_{ijt} + \varepsilon_{ijt}, CFT_{imt} = 1 [CFT_{imt}^* > 0] \tag{1}$$

where  $CFT_{imt}$  is the dependent variable (dummy) which is measured as 1 if household  $i$  adopted clean cooking fuels (i.e., LPG/electricity) and 0 otherwise at time  $t$ ,  $\beta_s$  are the estimated coefficients and  $\varepsilon_{ijt}$  is the error term. Equation (1) is estimated using panel regressions such as random effects logit and correlated random effects (CRE) logit models. Our preferred CRE models address challenges related to unobserved heterogeneity (see [44–47] for additional discussion). In this study, we include the means of age of household head and household size (i.e., time variant variables) to estimate the CRE logit models (refer to Table 3, columns 3 and 4). In addition, the use of fixed effect (FE) models will be inappropriate for this study as the dependent variable (i.e., adoption of clean cooking fuel) is binary and there is not much variation in the choice of clean cooking fuels for the two survey waves (see for example, Greene, 2004). Therefore, equation (1) is estimated using a modified version as follows:

$$CFT_{imt}^* = \beta_0 + \beta_1 X_{ijt} + \beta_2 \bar{Z}_i + \varepsilon_{ijt}, CFT_{imt} = 1 [CFT_{imt}^* > 0] \tag{2}$$

where  $\bar{Z}_i$  represents the averages of the time-variant variables (i.e., age of household head and household size) with the corresponding coefficient  $\beta_2$ . The explanations for the rest of the variables in equation (2) are the same as in equation (1).

In addition, since there are three main sources of cooking fuel technologies (i.e., LPG/electricity, firewood and charcoal) in the data, we model the correlates of the choice of the alternative cooking fuel options based on a panel multinomial logit model as follows:

$$P(y_{it} = j) = \frac{e^{X_{it}\beta_j}}{e^{X_{it}\beta_1} + e^{X_{it}\beta_2} + \dots + e^{X_{it}\beta_j}} = Y_{it}^* = \beta_0 + \sum \beta_i X_{it} + U_{it} \tag{3}$$

Equation (3) shows the probability that option  $j$  (for instance, LPG/electricity) is chosen by a given household.

In estimating the effects of cooking fuel technologies on gendered health outcomes, the basic regression is specified as follows:

$$I_{ijt} = \alpha_0 + \alpha_1 CFT_{imt} + X_{ijt}\beta_0 + V_c + S_t + u_{ijt} \tag{4}$$

where  $I_{ijt}$  is the dependent variable captured as the illness incidence of individual  $i$  in household  $j$  in wave  $t$  (i.e., a dummy variable that takes the value of 1 if the individual experienced illness in the past four weeks and 0, otherwise);  $CFT_{it}$  is the main cooking fuel options such as clean cooking fuels (i.e., use of LPG or electricity), firewood and charcoal.<sup>2</sup>  $X_{ijt}$  represent the independent variables (i.e., individual and household characteristics) included in the regressions as controls. The descriptive statistics of all independent variables are reported in Table 1.  $S_t$  and  $V_c$  are wave and district dummies, respectively, and  $u_{ijt}$  is the error term. Robust standard errors are reported for all the regressions.

The estimated coefficient,  $\alpha_1$  represents the effects of cooking fuel technologies on gendered illness incidence. However, analyzing equation (4) using standard econometric techniques (for instance,

<sup>2</sup> Kerosene was used by only three households and therefore, it is dropped from the panel multinomial logit correlates of cooking fuel options. However, it is maintained in the logit correlates of clean cooking fuels and it is classified as part of the unclean cooking fuel.

**Table 1**  
Summary statistics of household socio-economic characteristics.

Variables	Baseline survey (April–May 2014)	Endline survey (May–June 2015)
	Mean (S.D)	Mean (S.D)
<i>Cooking Fuel Options</i>		
Household uses clean cooking fuel (i.e., either electricity or LPG)	0.050 (0.219)	0.048 (0.214)
Household uses LPG or electricity	0.050 (0.219)	0.048 (0.214)
Household uses charcoal	0.298 (0.458)	0.293 (0.455)
Household uses firewood/wood	0.651 (0.477)	0.659 (0.474)
<i>Kitchen Characteristics</i>		
Household cooks exclusively in a room	0.615 (0.485)	0.661 (0.474)
Household cooks outside or on compound	0.428 (0.495)	0.467 (0.499)
Kitchen has a window	0.505 (0.500)	0.643 (0.480)
<i>Household Characteristics</i>		
Household pays rent for dwelling	0.111 (0.314)	0.090 (0.287)
Natural log of household assets at baseline	8.534 (2.136)	8.353 (1.721)
Household undertakes irrigated agriculture	0.253 (0.435)	0.281 (0.450)
Male household head	0.743 (0.438)	0.723 (0.448)
Married household head	0.688 (0.464)	0.751 (0.433)
Household has access to internet	0.115 (0.319)	0.162 (0.369)
District of residence is urban	0.499 (0.500)	0.455 (0.499)
Age of household head	48.798 (12.436)	49.892 (12.412)
Household head has no formal education qualification	0.638 (0.481)	0.652 (0.477)
Household has basic education qualification	0.283 (0.451)	0.254 (0.436)
Household has secondary education qualification and beyond	0.079 (0.270)	0.094 (0.292)
Number of female children under 15 years	1.210 (1.074)	1.133 (1.095)
Household size	6.083 (2.540)	6.133 (2.536)
Household has off-farm income	0.567 (0.496)	0.637 (0.481)
Household energy expenditure (GHS)	182.709 (283.038)	325.340 (431.501)
Household per capita energy expenditure (GHS)	33.443 (50.439)	60.597 (87.437)
Market in the community of residence	0.113 (0.317)	0.101 (0.301)
Household has savings	0.865 (0.342)	0.863 (0.345)
Community has tarred road	0.129 (0.336)	0.085 (0.279)
Owner occupancy of household	0.765 (0.424)	0.776 (0.418)
<b>Observations (N)</b>	<b>505</b>	<b>437</b>

Notes: S.D. represents standard deviation. Number of observations for each variable is affected by missing data for that variable. Missing data for some of the baseline variables are replaced by sample means for those variables.

**Table 2**  
Summary statistics of individual characteristics.

<i>Individual Characteristics</i>	Mean	S.D.
Age of individual	22.888	17.624
Male individual	0.495	0.500
Married individual	0.228	0.419
Individual has no formal educational qualification	0.817	0.386
Individual has basic educational qualification	0.127	0.333
Individual has secondary educational qualification and beyond	0.056	0.229
Individual illness incidence in the past 4 weeks	0.192	0.394
Illness incidence of males in the past 4 weeks	0.177	0.382
Illness incidence of females in the past 4 weeks	0.206	0.405
Illness incidence of adult females in the past 4 weeks	0.211	0.408
<b>Observations (N)</b>	<b>11,705</b>	<b>–</b>

Notes: Summary statistics are affected by missing data in each of the variables. The descriptive statistics are averages of four survey rounds. See also Okyere et al. [48].

**Table 3**  
Random effects estimates of Household's choice of clean cooking fuels.

Variables	Dependent variable: dummy for household uses clean cooking fuel (i.e. LPG/electricity).			
	(1)	(2)	(3)	(4)
	RE Logit	RE Logit	CRE Logit	CRE Logit
Household cooks exclusively in a room	0.615 (0.714)	0.873 (0.684)	0.593 (0.719)	0.855 (0.682)
Household pays rent for dwelling	1.284+ (0.811)		1.281+ (0.818)	
Household cooks outside or on compound	-0.243 (0.574)	-0.093 (0.580)	-0.280 (0.582)	-0.107 (0.578)
Kitchen has a window	1.402** (0.686)	1.393** (0.708)	1.435** (0.694)	1.417** (0.716)
Natural log of household assets	0.287+ (0.175)	0.411** (0.177)	0.285+ (0.178)	0.405** (0.180)
Household undertakes irrigated agriculture	-0.361 (0.520)	-0.478 (0.537)	-0.386 (0.525)	-0.497 (0.542)
Male household head	-2.013*** (0.682)	-2.029*** (0.678)	-2.046*** (0.687)	-2.051*** (0.683)
Married household head	0.590 (0.651)	0.581 (0.657)	0.611 (0.656)	0.604 (0.661)
Household has access to internet	2.756*** (0.582)	2.486*** (0.589)	2.746*** (0.585)	2.484*** (0.593)
District of residence is urban	0.499 (0.569)	0.542 (0.599)	0.503 (0.577)	0.540 (0.609)
Age of household head	-0.010 (0.030)	-0.004 (0.030)	0.067 (0.062)	0.054 (0.058)
Household head has basic education qualification	0.931+ (0.626)	0.928+ (0.582)	0.932+ (0.634)	0.929+ (0.588)
Household head has secondary education qualification and beyond	2.857*** (0.749)	2.716*** (0.696)	2.846*** (0.747)	2.710*** (0.695)
Number of female children under 15 years	-0.260 (0.347)	-0.302 (0.328)	-0.264 (0.340)	-0.312 (0.323)
Household size	-0.053 (0.135)	-0.037 (0.135)	0.003 (0.239)	-0.036 (0.250)
Household has off-farm income	-0.987+ (0.621)	-0.957+ (0.621)	-1.003+ (0.629)	-0.967+ (0.626)
Market in the community of residence	-0.682 (0.870)	-0.519 (0.844)	-0.635 (0.883)	-0.477 (0.848)
Household has savings	-0.387 (0.569)	-0.331 (0.567)	-0.418 (0.576)	-0.352 (0.574)
Community has tarred road at baseline	0.989* (0.602)	0.900+ (0.609)	1.031* (0.606)	0.927+ (0.613)
Owner occupancy of dwelling		-1.771*** (0.678)		-1.750*** (0.672)
Constant	-7.376*** (2.185)	-7.516*** (2.063)	-7.129*** (2.230)	-7.331*** (2.111)
Survey fixed effect	Yes	Yes	Yes	Yes
Average of time varying variables included	No	No	Yes	Yes
Observations (household-wave)	891	895	891	895
Number of households	499	499	499	499
Prob > Chi2	0.000	0.000	0.000	0.000

Notes: Robust standard errors in parentheses. \*\*\*p < 0.01, \*\*p < 0.05, \*p < 0.1, +p < 0.15. Average of time varying variables such as age of household head, and household size are included in the CRE estimates.

multivariate regression) could lead to inconsistent and biased estimates due to endogeneity issues. For instance, adoption of cooking fuel technologies is not random as it is influenced by several observed and unobserved characteristics. Therefore, failure to properly account for these sources of endogeneity could lead to upward bias of the estimates. Ideally, employing instrumental variables approach will be needed to address the potential estimation challenges already indicated.

However, obtaining valid instruments that satisfy the exclusion restriction criteria for the choice of cooking fuel technologies in this study context is challenging. Therefore, we employ the inverse probability weighting regression adjustment (IPWRA) method based on its doubly robust property to estimate the effects of cooking fuel options on gendered illness incidence (refer to Wooldridge, 2010; Cattaneo, 2010; Drukker, 2015; Tambo & Mockshell, 2018; Manda et al., 2018 [49–51]; [52] for the derivation and application of IPWRA in literature). Another advantage of using IPWRA method is its ability to estimate multivalued treatment effects for categorical treatment variables instead of other estimators (e.g., propensity score matching (PSM)) that are unique for only binary treatment variables. A limitation of the IPWRA method is that it is used for only cross-sectional data but not panel structure of the data. Therefore, our results are obtained by pooling the four survey rounds.

We estimate an average treatment effect on the treated (ATT) using the IPWRA method with a basic specification as follows:

$$ATT = E\{I_{CFIA} - I_{CFIN} | D_i = 1\}$$

$$= E(I_{CFIA} | D_i = 1) - E(I_{CFIN} | D_i = 1) \tag{5}$$

where  $E\{\cdot\}$  represents the expectation operator,  $I_{CFIA}$  indicates the potential illness incidence for households using clean cooking fuel (i.e., LPG/electricity),  $I_{CFIN}$  is the potential illness incidence for households not using clean cooking fuels (i.e., charcoal and firewood), and  $D_i$  is a binary treatment variable measured as 1 if household adopted clean cooking fuel and 0 otherwise.

We also estimate the effects of the choice of alternative main cooking fuels on gendered illness incidence based on multivalued treatment effects. As earlier discussed, the data contains three main sources of cooking fuels: 1 = LPG/electricity; 2 = Charcoal; and 3 = Firewood. We assume that the choice of different cooking fuel technologies could have differential effects on the gendered illness incidence. This analysis is undertaken based on the IPWRA estimator where the treatment model is specified using multinomial logit. As robustness checks for the IPWRA method, we also employ the inverse probability weighting (IPW) method due to its ability to estimate multivalued treatment effects. We also employed treatment effects using least absolute shrinkage and selection operator (LASSO) method-a doubly robust estimator relying on machine learning techniques in selecting important covariates ([53, 54]; [52]) as part of the sensitivity analyses. We rely on Stata version 17 ([52]) to estimate the panel multinomial logit models and the treatment effects.

### 3.2. Data

This study uses a rich panel data collected under the Agriculture-Water and Sanitation (AG-WATSAN) Nexus Project, Center for Development Research (ZEF), University of Bonn, Germany. The study was conducted in two districts in the Greater Accra region of Ghana. Based on the 2020 population and housing census, the Greater Accra region, where the nation's capital is located, has a population of 5.06 million (Ghana Statistical Service [55]). The region is located in southern belt and also shares boundary with the Gulf of Guinea (see Fig. 3). The details on research design and data collection techniques are shown in previous studies [49–51,48,56,57]. In summary, four rounds of data were collected between April–May 2014 to May–June 2015 from a random sample of 505 households in 16 communities in the Ga South municipal

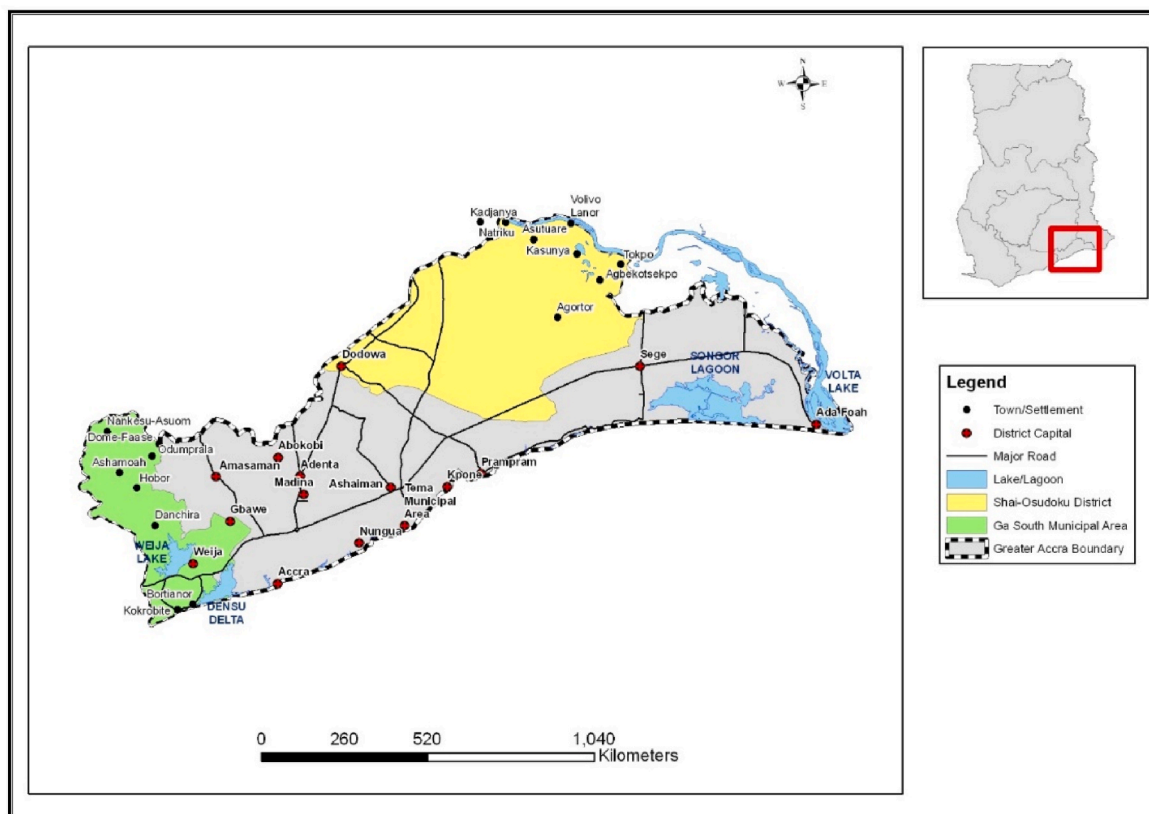


Fig. 3. Map of the study areas.

Source: [56].

and Shai-Osudoku district in the Greater Accra region of Ghana. The surveys interviewed the household heads or their spouses on agricultural production, water, sanitation and hygiene practices, energy sources, among other socio-economic characteristics.

The population of the study included households in multipurpose water systems and depending on unimproved water and sanitation in rural and peri-urban communities in the Greater Accra region. A multi-stage sampling approach was employed in the selection of the households. First, two districts (Ga South municipal and Shai-Osudoku district) were purposively chosen due to the availability of water resources used for multiple domestic and economic activities. The second stage involved a purposive selection of 16 communities in the two selected administrative districts. In the final stage, a random sample of 32 households from each community were selected; making a total of 512 households.

The household demographic and socio-economic characteristics include age, gender, marital status and educational level of the household head, household size, access to internet services, value of household assets, tenancy, number of female children below 15 years of age, and energy expenditure while kitchen variables include household has a room exclusively for cooking, whether household cooks outside or on the compound of the dwelling, and kitchen has a window. Interestingly, information on illness incidence were collected in the four rounds of the data collection whilst information on energy sources were collected in only two rounds of the survey (i.e., during baseline survey in April/May 2014 and endline survey in May/June 2015). Therefore, the panel regressions on the correlates of cooking fuel technologies rely on the baseline and endline survey data, collected within one-year period. We found that between the two survey rounds, there is not much variation in choices of cooking fuel technologies (refer to Table 1). Therefore, we explore this static choice of cooking fuel technologies in our data to estimate the treatment effects on illness incidence, where cooking fuel

technologies at the baseline was used as the treatment variable.

## 4. Results and discussion

### 4.1. Summary statistics

Table 1 reports the summary statistics of household socio-economic characteristics. There is low use of clean cooking fuel in the baseline and endline data, as about 5 percent of households used clean cooking energy (i.e., LPG and electricity). Adoption of clean cooking fuels reduced marginally by 0.2 percent between the endline and the baseline data. This trend is observed for other cooking fuel types, except the combined use of firewood and wood. Consistent with the pattern of the use of cooking fuel, majority of households (about 95%) rely on traditional fuel sources (charcoal, firewood and wood). This implies that the task of encouraging a shift from unclean cooking fuel sources to clean ones in rural and peri-urban Ghana is cut-out for government and other stakeholders. Given the link between the use of clean and modern fuel sources and the achievement of the SDGs, Ghana needs to double-up current efforts in meeting global frameworks.

Majority of households are led by males (about 74%) and with low educational attainment. Moreover, most households reside in rural areas and in areas with low infrastructure such as tarred road, market and internet. Energy expenditure increased between the two data points. However, the expenditure is low, especially the per capita energy expenditure. The rest of the summary statistics at the individual level are presented in Table 2.

Similar to the household head educational status, the level of education is generally low, as majority of the individuals (82%) have no formal education. The incidence of illness was about 19.2 percent in four survey rounds (refer to Section 3.2 for description of data). Relative to males, females (particularly, adults) were more likely to be sick in the

four weeks preceding the surveys.

#### 4.2. Correlates of cooking fuel technologies

The results of the determinants of cooking fuel technologies are reported in Table 3. Columns 1 and 2 report the random effect (RE) logit estimates, and columns 3 and 4 report the correlated random effects (CRE) logit estimates. Columns 1 and 3 report models where households payment for rent (i.e., tenant) variable is included in the RE and CRE estimates, while columns 2 and 4 includes 'owner occupancy of dwelling' variable (i.e., house ownership). There is no evidence that the inclusion or exclusion of these variables impose any differences in the direction of the estimates. The estimates show that the significant determinants are generally robust across the RE and CRE estimates. However, we focus discussions on the CRE estimates (i.e., columns 3 and 4) based on its ability to address unobserved heterogeneity. We find that window in a kitchen, male household head, access to internet, educational level, household assets, receipt of off-farm income, and access to tarred roads are key determinants of choice of clean cooking fuels in both the RE and CRE models.

Availability of kitchen window has a positive association with the choice of cooking fuel, implying that kitchen designs play a vital role in clean cooking fuel adoption in Southern Ghana. Male headed households are less likely to adopt clean cooking fuel. This result suggests that males do not invest in using clean cooking fuel, and this may be partly explained by the relative difference in cooking frequency between men and women. In patriarchal societies in many developing countries, cooking tends to be undertaken by women and therefore, male headed households compared to female headed households may be less willing to invest in clean cooking fuels. Additionally, the use of clean cooking fuel is financially demanding than traditional fuel, and since men usually do not cook in many rural communities in Southern Ghana, they find it prudent investing in low-cost traditional cooking fuel. This observation is consistent with the literature. For example, Rahut et al. [58] also found that relative to male-headed households, female-headed households adopt clean energy for lighting in SSA, explaining that females invest in these energy sources because they consider the health benefit. The results are also corroborated by several studies including Rao and Reddy [59], Rahut et al. [60], Behera et al. [61] and Rahut et al. [62].

Access to internet is positively associated with the choice of clean cooking fuel. This means that households with internet access are more likely to adopt clean cooking fuel. This finding is consistent with Acharya & Marhold [63], who found that the use of information and communication technology (ICT) systems is significantly associated with clean energy use. A possible explanation for this finding is that internet access provides the necessary information on the use and benefits of clean cooking fuel that stimulates adoption. This explanation is further corroborated by the evidence that households whose heads have at least secondary qualifications and those who have basic education qualifications have higher probabilities of adopting clean cooking fuel. These findings highlight the significance of information in the adoption of clean cooking fuel. The positive effect of education on the use of clean cooking fuel corroborates previous findings ([58,61,62,64]; [65]; [59, 66]). For example, Wassie et al. [64] observed that an increase in the educational level of household heads increases the likelihood of adopting modern and renewable energy for lighting in Ethiopia. Rahut et al. [58]'s study associates the positive effect of education on the use of clean energy with three things, including better awareness of the benefits of clean energy, more likelihood of educated people to have more income and the ability to afford these energy sources.

The results further show that household endowment, proxied by the household assets, positively determines adoption of clean cooking fuel. Using clean cooking fuel is relatively more expensive to using traditional fuel. Therefore, this evidence indicates that when household wealth increases, the household acquires the financial capacity to meet the cost

of using these clean fuels. This observation is consistent with the literature (see for example, [6,59–62,66,67]). Previous studies [59,61,66] observed that wealthy households are more likely to use clean energy sources such as LPG and electricity in India and South Asia. With increasing income, households make a shift away from traditional or dirty energy sources (e.g., dung and fuelwood) to the use of clean sources (e.g., LPG and electricity) [61]. However, the observation of earning off-farm income as a negative correlate to adoption of clean cooking fuels contradicts this earlier observation and this result is contrary to our apriori expectation. It is expected that access to off-farm income would boost household income that provides the ability to afford clean cooking fuels.

Interestingly, access to tarred roads increases the probability of adopting clean cooking fuel. This finding, together with the earlier evidence on the positive effect of access to internet, emphasizes the role of infrastructure in driving the use of clean cooking fuel. For example, good roads facilitate the provision and distribution of clean fuel (especially LPG), and reduces the cost of adopting these energy sources. This corroborates the findings of Wassie et al. [64] who observed that households having access to roads have higher likelihood of adopting clean lighting fuels in southern Ethiopia. Indeed, this study also partly confirms the evidence that grid lines usually follow road networks to facilitate maintenance and service delivery. It is also consistent with the observation of Ali et al. [68].

The results in Tables 4 and 5 corroborate the earlier evidence presented in Table 3. For example, households with access to internet, households in communities with tarred roads, households with heads having a better education, households with window in their kitchens, and households more endowed with assets have higher likelihood of choosing gas/electricity (clean cooking fuel) relative to firewood. Particularly, infrastructure (i.e., roads and internet) and education are important in shifting away from firewood to gas/electricity. Thus, knowledge and information provide key stimulus for the adoption of clean fuel. Similarly, the results reveal further insights. For example, in the adoption decision between charcoal and firewood (both unclean fuels), access to internet, communities with tarred roads, households with heads having a better education and off-farm income are more likely to choose charcoal relative to firewood. These findings are consistent with expectation. For instance, charcoal is relatively expensive than firewood, thus, households with more income can afford charcoal. Although charcoal and firewood are unclean fuels, charcoal is more refined than firewood in terms of smoke emission. Therefore, household with better information (i.e., education) are more informed about the desirability of charcoal relative to firewood.

Moreover, households that cook exclusively in rooms and have more household members are less likely to choose charcoal relative to firewood. In addition, households that are male headed are less likely to choose gas/electricity relative to firewood, which is consistent with the earlier findings.

#### 4.3. Gendered health effects of cooking fuel technologies

We undertake model diagnostics for the treatment effects estimates and the results show that the IPWRA estimator balances covariates used in analyzing the probability of choosing alternative cooking fuel technologies in Southern Ghana. For instance, the standardized means are close to zero and the variances are close to one. However, our Chi-Squared test of over-identification test for clean cooking technology was statistically significant at 1 percent. This is not surprising as the number of households relying on clean cooking fuels are extremely small in our sample. Interestingly, the diagnostics tests for the multivalued treatment effects satisfied the assumptions with considerable overlap of the propensity scores for the cooking fuel options. Therefore, our results should be interpreted with caution on the causal inference of health effects of cooking fuel technologies in the study context.

Table 6 reports the effects of cooking fuel technologies on illness,

**Table 4**  
Random effects multinomial logistic estimates of Household's choice of cooking fuel technologies.

Variables	(1)	(2)	(3)	(4)
	Gas/ Electricity	Charcoal	Gas/ Electricity	Charcoal
Household cooks exclusively in a room	-0.173 (0.783)	-1.730*** (0.371)	0.134 (0.696)	-1.546*** (0.362)
Household pays rent for dwelling	2.761*** (0.877)	2.431*** (0.531)		
Household cooks outside or on compound	-0.239 (0.643)	0.341 (0.293)	-0.075 (0.616)	0.373 (0.289)
Kitchen has a window	1.819** (0.759)	0.502 (0.374)	1.672** (0.744)	0.450 (0.362)
Natural log of household assets	0.233 (0.189)	-0.050 (0.087)	0.443** (0.189)	0.047 (0.090)
Household undertakes irrigated agriculture	-0.629 (0.597)	-0.333 (0.317)	-0.639 (0.587)	-0.108 (0.303)
Male household head	-1.944** (0.796)	0.449 (0.393)	-1.905** (0.750)	0.509 (0.384)
Married household head	0.563 (0.734)	-0.502 (0.366)	0.468 (0.726)	-0.409 (0.357)
Household has access to internet	3.584*** (0.629)	1.779*** (0.450)	3.158*** (0.596)	1.543*** (0.414)
District of residence is urban	0.535 (0.652)	-0.328 (0.375)	0.624 (0.642)	-0.306 (0.365)
Age of household head	-0.012 (0.033)	-0.019 (0.015)	-0.005 (0.032)	-0.015 (0.014)
Household head has basic education qualification	1.399** (0.702)	1.283*** (0.405)	1.400** (0.616)	1.251*** (0.388)
Household head has secondary education qualification and beyond	3.696*** (0.908)	1.267** (0.615)	3.373*** (0.793)	1.201** (0.593)
Number of female children under 15 years	-0.223 (0.399)	0.008 (0.180)	-0.314 (0.356)	-0.054 (0.174)
Household size	-0.126 (0.171)	-0.300*** (0.091)	-0.096 (0.158)	-0.255*** (0.089)
Household has off-farm income	-0.709 (0.689)	1.210*** (0.332)	-0.651 (0.664)	1.012*** (0.319)
Market in the community of residence	-0.938 (0.927)	-0.082 (0.486)	-0.468 (0.848)	0.084 (0.451)
Household has savings	-0.328 (0.637)	0.350 (0.441)	-0.269 (0.615)	0.345 (0.425)
Community has tarred road at baseline	2.597*** (0.787)	2.549*** (0.549)	2.337*** (0.751)	2.502*** (0.514)
Owner occupancy of dwelling			-2.905*** (0.676)	-2.094*** (0.417)
Constant	-6.807*** (2.325)	0.121 (1.038)	-6.487*** (2.159)	0.695 (1.039)
Survey fixed effect	Yes	Yes	Yes	Yes
Observations (household-wave)	889	889	893	893
Number of households	499	499	499	499
Prob > Chi2	0.000		0.000	

Notes: Base model is firewood. Robust standard errors in parentheses, \*\*\*p < 0.01, \*\*p < 0.05, \*p < 0.1 and +p < 0.15.

**Table 5**  
Correlated random effects multinomial logistic estimates of Household's choice of cooking fuel technologies.

Variables	(1)	(2)	(3)	(4)
	Gas/ Electricity	Charcoal	Gas/ Electricity	Charcoal
Household cooks exclusively in a room	-0.275 (0.781)	-1.806*** (0.366)	0.076 (0.689)	-1.594*** (0.356)
Household pays rent for dwelling	2.796*** (0.886)	2.474*** (0.532)		
Household cooks outside or on compound	-0.284 (0.649)	0.332 (0.299)	-0.082 (0.607)	0.368 (0.291)
Kitchen has a window	1.926** (0.776)	0.550 (0.368)	1.744** (0.759)	0.484 (0.358)
Natural log of household assets	0.234 (0.193)	-0.048 (0.088)	0.440** (0.192)	0.048 (0.090)
Household undertakes irrigated agriculture	-0.658 (0.599)	-0.355 (0.319)	-0.658 (0.592)	-0.126 (0.303)
Male household head	-1.999** (0.810)	0.427 (0.401)	-1.937** (0.758)	0.498 (0.386)
Married household head	0.612 (0.744)	-0.486 (0.373)	0.508 (0.733)	-0.399 (0.360)
Household has access to internet	3.593*** (0.630)	1.796*** (0.460)	3.169*** (0.599)	1.552*** (0.420)
District of residence is urban	0.524 (0.668)	-0.342 (0.381)	0.608 (0.658)	-0.316 (0.367)
Age of household head	0.098 (0.067)	0.026 (0.046)	0.071 (0.060)	0.019 (0.042)
Household head has basic education qualification	1.427** (0.722)	1.314*** (0.414)	1.415** (0.625)	1.268*** (0.392)
Household head has secondary education qualification and beyond	3.693*** (0.910)	1.271** (0.619)	3.379*** (0.795)	1.217** (0.593)
Number of female children under 15 years	-0.235 (0.387)	0.006 (0.183)	-0.328 (0.347)	-0.053 (0.176)
Household size	0.056 (0.304)	-0.143 (0.201)	0.007 (0.307)	-0.097 (0.213)
Household has off-farm income	-0.729 (0.707)	1.201*** (0.336)	-0.662 (0.675)	0.996*** (0.321)
Market in the community of residence	-0.878 (0.949)	-0.030 (0.494)	-0.414 (0.857)	0.124 (0.455)
Household has savings	-0.357 (0.649)	0.351 (0.443)	-0.283 (0.623)	0.342 (0.422)
Community has tarred road at baseline	2.674*** (0.800)	2.592*** (0.559)	2.390*** (0.761)	2.536*** (0.519)
Owner occupancy of dwelling			-2.892*** (0.672)	-2.092*** (0.420)
Constant	-6.413*** (2.374)	0.460 (1.081)	-6.222*** (2.219)	0.966 (1.078)
Survey fixed effect	Yes	Yes	Yes	Yes
Average of time varying variables included	Yes	Yes	Yes	Yes
Observations (household-wave)	889	889	893	893
Number of households	499	499	499	499
Prob > Chi2	0.000		0.000	

Notes: Base model is firewood. Robust standard errors in parentheses, \*\*\*p < 0.01, \*\*p < 0.05, \*p < 0.1 and +p < 0.15.

**Table 6**  
Treatment effects of cooking fuel technologies on illness.

Clean cooking fuel	All individuals	Males	Females	Females at 14 years or above
<b>Panel A: Clean cooking fuel</b>	(1)	(2)	(3)	(4)
Panel A: Average treatment effect on the treated (ATET)				
Clean cooking fuel vs No clean cooking fuel	-0.024 (0.021)	0.012 (0.027)	-0.053* (0.031)	-0.086** (0.039)
Potential outcome means				
No clean cooking fuel	0.171*** (0.013)	0.131*** (0.014)	0.203*** (0.022)	0.224*** (0.032)
<b>Number of observations (N)</b>	<b>10,798</b>	<b>5389</b>	<b>5409</b>	<b>3600</b>
<b>Panel B: Cooking fuel options</b>				
Panel A: Average treatment effect on the treated (ATET)				
LPG/Electricity vs Firewood/wood	-0.034 (0.027)	-0.008 (0.041)	-0.055+ (0.036)	-0.080* (0.043)
Charcoal vs Firewood/wood	-0.013 (0.030)	-0.006 (0.045)	-0.005 (0.046)	0.054 (0.073)
Potential outcome means				
Firewood/wood	0.182*** (0.021)	0.152*** (0.033)	0.205*** (0.027)	0.218*** (0.034)
<b>Number of observations (N)</b>	<b>10,768</b>	<b>5371</b>	<b>5397</b>	<b>3588</b>

Notes: \*\*\*p < 0.01, \*\*p < 0.05, \*p < 0.1, +p < 0.15. Robust standard errors reported in parenthesis. Refer to Table 4 for detailed controls included in the models. Panel A models are specified using logit for outcome and treatment models. In Panel B, outcome model specified with Logit and treatment model specified with Multinomial Logit. Outcome model also include individual characteristics such as age, gender, marital status and educational level.

taking a gendered perspective. In panel A, there is no statistically significant effect of clean cooking fuel on illness for all individuals (i.e., column 1). However, considering the gender of household members provides evidence to indicate the health benefit of adopting clean cooking fuel. Though the gendered disaggregation shows no evidence of the health benefits of adopting clean cooking fuel for males, there is sufficient evidence for females. We find that females in households using clean cooking fuels are 5.3 percent less likely to be ill relative to their counterparts in households not using clean cooking fuel. The health benefit is even much higher (8.6%) for females who are at least 14 years old (i.e., adults). These findings are expected because cooking is one of the unpaid care activities that is strictly marked as a preserve of women, especially in developing countries. Since cooking is one of the most time-consuming responsibilities of women [69], it implies that women spend a considerable amount of time cooking daily to the extent that illnesses associated with using unclean cooking fuel would affect them more relative to men. The major transmission channel of the use of traditional cooking fuel is through indoor air pollution. The World Bank [70] noted that the traditional use of biomass causes indoor air pollution and imposes health hazard. Our findings concur with other studies on the effect of cooking fuels on women’s health [30,71,72]. For example, Agrawal [71] found that adult women who live in households that use biomass and solid fuels have a significantly higher risk of asthma compared to those who live in households that use cleaner fuels in India.

Switching to panel B, where the focus is to uncover the differential health effects of various cooking fuels, the evidence shows, albeit marginally, that adopting LPG/electricity (i.e., clean fuel) reduces the incidence of illness for only females. This result corroborates the evidence previously reported in panel A. However, there is no evidence that

the use of charcoal has any health benefit relative to using firewood/wood. This no-effect result can be attributed to the fact that charcoal and firewood/wood are both unclean energy fuel and have similar health consequences.

Could the results obtained from using a data with about 5 percent choice of clean cooking fuels overestimate the effect of clean cooking fuels on wellbeing? In this study context, it seems unlikely as the choice of cooking fuels was quite stable across the baseline and endline surveys, as shown in the descriptive statistics. Furthermore, we defined our treatment variable as the main cooking fuel and therefore, it is possible that the proportion may be much higher since households use multiple sources of cooking fuels simultaneously. Looking at the magnitude of the estimates, we can conclude that our results are at the lower bounds and therefore, the effects could be larger if we accounted for all potential users of clean cooking fuel. It is important to indicate that our definition based on main choice was premised on the fact that health gains from using clean cooking fuels could be negated by using “unclean or dirty” fuels. Therefore, relying on the main choice presents a more methodologically convenient way of examining the effect of cooking fuel technologies on health outcomes in Southern Ghana.

4.4. Sensitivity analyses

To provide for robustness check on the health effects in Table 6, the inverse probability weighting method (IPW) was also used to estimate the health effect of cooking technologies. The results are reported in Table 7. These estimates are similar to the IPWRA estimates, and thus imply that the earlier estimates are robust to alternative specification. For example, the evidence still shows that there are health benefits for all females and those aged 14 years and above, except that the probabilities are consistently higher in the IPW estimates.

However, the IPW estimates differ from the earlier estimates in two ways. First, the IPW estimates indicate health benefit for all the sample (i.e., regardless of gender) in the use of clean cooking fuel relative to no

**Table 7**  
IPW treatment effects of cooking fuel technologies on illness.

Clean cooking fuel	All individuals	Males	Females	Females at 14 years or above
<b>Panel A: Clean cooking fuel</b>	(1)	(2)	(3)	(4)
Panel A: Average treatment effect on the treated (ATET)				
Clean cooking fuel vs No clean cooking fuel	-0.030+ (0.021)	-0.001 (0.030)	-0.056* (0.030)	-0.093** (0.037)
Potential outcome means				
No clean cooking fuel	0.177*** (0.013)	0.144*** (0.017)	0.206*** (0.020)	0.231*** (0.029)
<b>Number of observations (N)</b>	<b>10,798</b>	<b>5389</b>	<b>5409</b>	<b>3600</b>
<b>Panel B: Cooking fuel options</b>				
Panel A: Average treatment effect on the treated (ATET)				
LPG/Electricity vs Firewood/wood	-0.041 (0.036)	-0.006 (0.040)	-0.083 (0.066)	-0.136 (0.103)
Charcoal vs Firewood/wood	-0.033 (0.035)	-0.018 (0.038)	-0.055 (0.067)	-0.064 (0.104)
Potential outcome means				
Firewood/wood	0.188*** (0.031)	0.150*** (0.031)	0.233*** (0.062)	0.274*** (0.100)
<b>Number of observations (N)</b>	<b>10,768</b>	<b>5371</b>	<b>5397</b>	<b>3588</b>

Notes: \*\*\*p < 0.01, \*\*p < 0.05, \*p < 0.1, +p < 0.15. Robust standard errors reported in parenthesis. Refer to Table 5 for detailed controls included in the models.

clean cooking fuel, at the 15 percent significance level (i.e.,  $p$ -value is closer to 10% level). Specifically, relative to not using clean cooking fuel, individuals in households using clean cooking fuels are 3 percent less likely to be ill. Second, the IPW estimates do not show any evidence of health benefits of using LPG/electricity relative to firewood/wood.

Finally, we also employed treatment effects using the least absolute shrinkage and selection operator (LASSO) method—a doubly robust estimator relying on machine learning techniques in selecting important covariates [53,54,52] to estimate the effect of clean cooking fuels on illness. The results (available upon request) are very similar to those obtained using the preferred IPWRA estimator.

## 5. Conclusion and policy implications

In this paper, the adoption of cooking fuel technologies and its effects on the health outcomes of households in the Greater Accra region of Ghana are analyzed using panel data. The study used the correlated random effect (CRE) logit and multinomial logit models to first estimate the determinants of cooking fuel technologies (i.e., LPG/electricity, charcoal and firewood) and then used the inverse probability weighting regression adjustment (IPWRA) estimator to examine the effect of cooking fuel technologies on health outcomes. Results from the CRE estimates indicate that household socio-economic characteristics such as tenancy, kitchen design, assets, gender, education, access to internet and tarred roads influence the adoption of cooking fuel technologies, including clean cooking fuels. Furthermore, the results from the IPWRA estimator show that clean cooking fuels decrease female illness incidence but not male illness incidence, with a large improvement for adults. A key implication of these findings is that policies and programs aimed at promoting clean cooking fuel technologies can significantly improve well-being of females in developing countries. Thus, such policies and programs should be deliberately targeted at women since they are at the forefront of decision-making on household cooking fuel needs and are most likely to be affected by the health effects of such fuels. Lastly, the government, through its relevant ministries, departments and agencies, needs to invest in constructing roads, extending the national grid, and boosting information and communication infrastructure to spur clean cooking fuel use. These infrastructures provide the foundation for the establishment, transport and delivery of clean cooking fuel facilities in Ghana.

This study has the following limitations which could be important for additional future studies. First, our sample may not be regionally or nationally representative of the choice of clean cooking fuels. Therefore, future studies using nationally representative panel data may shed additional light on the effect of cooking fuel technologies on health in developing countries. Second, our estimation strategies which have been shown in the literature to generate rigorous estimates from observational data may not comprehensively address all issues related to selection bias and unobserved heterogeneity. Therefore, we recommend additional studies employing randomized controlled trials (RCTs), instrumental variables (IV), and regression discontinuity design (RDD) to provide additional rigorous evidence on the topic. Lastly, other studies employing additional indicators on health and wellbeing could strengthen the evidence on the effect of cooking fuel technologies on health outcomes in developing countries.

However, it is important to note that our estimates using a 4-round panel data from Southern Ghana (which is uncommon in the study context) provide policy relevant evidence on the effects of cooking fuel technologies on health outcomes in developing countries. Similarly, our study employing observational data and several treatment effect estimators (i.e., rigorous econometric approaches) implies that similar studies could be undertaken in developing countries to expand the frontiers, particularly the external validity of the effect of cooking fuel technologies on wellbeing in developing countries.

## Declarations of interest

None.

## CRedit authorship contribution statement

**Charles Yaw Okyere:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Benjamin Musah Abu:** Conceptualization, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Collins Asante-Addo:** Conceptualization, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Theophilus Tweneboah Kodua:** Conceptualization, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing.

## Data availability

Data will be made available on request.

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